period is denoted n. The registration of the pattern position for each individual image combined with the independently known pattern variation over all sensing element (i.e. obtaining knowledge of the pattern configuration) and the recorded images allows for an efficient extraction of the correlation measure in each individual sensing element in the camera. For a light sensing element with label j, the n recorded light signals of that element are denoted $I_{1,j}$, ..., $I_{n,j}$. The correlation measure of that element, A_j, may be expressed as

$$A_j = \sum_{i=1}^{n} f_{i,j} I_{i,j}$$

Here the reference signal or weight function f is obtained from the knowledge of the pattern configuration. f has two indices i,j. The variation of f with the first index is derived from the knowledge of the pattern position during each image recording. The variation of f with the second index is derived from the knowledge of the pattern geometry which may be determined prior to the 3D scanning.

Preferably, but not necessarily, the reference signal f averages to zero over time, i.e. for all j we have

$$\sum_{i=1}^{n} f_{i,j} = 0$$

to suppress the DC part of the light variation or correlation measure. The focus position corresponding to the pattern being in focus on the object for a single sensor element in the camera will be given by an extremum value of the correlation measure of that sensor element when the focus position is varied over a range of values. The focus position may be varied in equal steps from one end of the scanning region to the other.

To obtain a sharp image of an object by means of a camera the object must be in focus and the optics of the camera and the object must be in a fixed spatial relationship during the exposure time of the image sensor of the camera. Applied to the present invention this should imply that the pattern and the focus should be varied in discrete steps to be able to fix the pattern and the focus for each image sampled in the camera, i.e. fixed during the exposure time of the sensor array. However, to increase the sensitivity of the image data the exposure time of the sensor array should be as high as the sensor frame rate permits. Thus, in the preferred embodiment of the invention images are recorded (sampled) in the camera while the pattern is continuously varying (e.g. by continuously rotating a pattern wheel) and the focus plane is continuously moved. This implies that the individual images will be slightly blurred since they are the result of a time-integration of the image while the pattern is varying and the focus plane is moved. This is something that one could expect to lead to deterioration of the data quality, but in practice the advantage of concurrent variation of the pattern and the focus plane is bigger than the drawback.

In another embodiment of the invention images are recorded (sampled) in the camera while the pattern is fixed and the focus plane is continuously moved, i.e. no movement of the pattern. This could be the case when the light source is a segmented light source, such as a segment LED that flashes in an appropriate fashion. In this embodiment the knowledge of the pattern is obtained by a combination of prior knowledge of the geometry of the individual segments on the segmented LED give rise to a variation across light sensing elements and the applied current to different segments of the LED at each recording.

In yet another embodiment of the invention images are recorded (sampled) in the camera while the pattern is continuously varying and the focus plane is fixed.

In yet another embodiment of the invention images are recorded (sampled) in the camera while the pattern and the focus plane are fixed.

The temporal correlation principle may be applied in general within image analysis. Thus, a further embodiment of the invention relates to a method for calculating the amplitude of a light intensity oscillation in at least one (photoelectric) light sensitive element, said light intensity oscillation generated by a periodically varying illumination pattern and said amplitude calculated in at least one pattern oscillation period, said method comprising the steps of:

- providing the following a predetermined number of sampling times during a pattern oscillation period:
  - o sampling the light sensitive element thereby providing the signal of said light sensitive element, and
  - o providing an angular position and/or a phase of the periodically varying illumination pattern for said sampling, and
- calculating said amplitude(s) by integrating the products of a predetermined periodic function and the signal of the corresponding light sensitive element over

said predetermined number of sampling times, wherein said periodic function is a function of the angular position and/or the phase of the periodically varying illumination pattern.

This may also be expressed as

$$A = \sum_i f(p_i) I_i$$

where A is the calculated amplitude or correlation measure, i is the index for each sampling, f is the periodic function, p_i is the angular position / phase of the illumination pattern for sampling i and I_i is the signal of the light sensitive element for sampling i. Preferably the periodic function averages to zero over a pattern oscillation period, i.e. $\sum_i f(p_i) = 0$.

To generalize the principle to a plurality of light sensitive elements, for example in a sensor array, the angular position / phase of the illumination pattern for a specific light sensitive element may consist of an angular position / phase associated with the illumination pattern plus a constant offset associated with the specific light sensitive element. Thereby the correlation measure or amplitude of the light oscillation in light sensitive element j may be expressed as

$$A_j = \sum_i f(\theta_j + p_i) I_{i,j} ,$$

where θ_j is the constant offset for light sensitive element j.

A periodically varying illumination pattern may be generated by a rotating wheel with an opaque mask comprising a plurality of radial spokes arranged in a symmetrical order. The angular position of the wheel will thereby correspond to the angular position of the pattern and this angular position may obtained by an encoder mounted on the rim of the wheel. The pattern variation across different sensor elements for different position of the pattern may be determined prior to the 3D scanning in a calibration routine. A combination of knowledge of this pattern variation and the pattern position constitutes knowledge of the pattern configuration. A period of this pattern may for example be the time between two spokes and the amplitude of a single or a plurality of light sensitive elements of this period may be calculated by sampling e.g. four times in this period.

A periodically varying illumination pattern may generated by a Ronchi ruling moving orthogonal to the lines and the position is measured by an encoder. This position corresponds to the angular position of the generated pattern. Alternatively, a checkerboard pattern could be used.

A periodically varying illumination pattern may generated by a one-dimensional array of LEDs that can be controlled line wise.

A varying illumination pattern may generated by a LCD or DLP based projector.

Optical correlation

The abovementioned correlation principle (temporal correlation) requires some sort of registering of the time varying pattern, e.g. knowledge of the pattern configuration at each light level recording in the camera. However, a correlation principle without this registering may be provided in another embodiment of the invention. This principle is termed "optical correlation".

In this embodiment of the invention an image of the pattern itself and an image of at least a part of the object being scanned with the pattern projected onto it is combined on the camera. I.e. the image on the camera is a superposition of the pattern itself and the object being probed with the pattern projected onto it. A different way of expressing this is that the image on the camera substantially is a multiplication of an image of the pattern projected onto the object with the pattern itself.

This may be provided in the following way. In a further embodiment of the invention the pattern generation means comprises a transparent pattern element with an opaque mask. The probe light is transmitted through the pattern element, preferably transmitted transversely through the pattern element. The light returned from the object being scanned is retransmitted the opposite way through said pattern element and imaged onto the camera. This is preferably done in a way where the image of the pattern illuminating the object and the image of the pattern itself are coinciding when both are imaged onto the camera. One particular example of a pattern is a rotating wheel with an opaque mask comprising a plurality of radial spokes arranged in a symmetrical order such that the pattern possesses rotational periodicity. In this embodiment there is a well-defined pattern oscillation period if the pattern is substantially rotated at a constant speed. We define the oscillation period as $2\pi/\omega$.

We note that in the described embodiment of the invention the illumination pattern is a pattern of light and darkness. A light sensing element in the camera with a signal proportional to the integrated light intensity during the camera integration time δt with label j, I_j is given by

$$h = Kj_{t}^{t+\delta t} \; T_j(t')S_j(t')df$$

Here K\s the proportionality constant of the sensor signal, t is the start of the camera integration time, T_j is the time-varying transmission of the part of the rotating pattern element imaged onto the/th light sensing element, and S_j is the time-varying light intensity of light returned from the scanned object and imaged onto the /th light sensing element. In the described embodiment T_j is the the step function substantially defined by $T_j(t) = 0$ for $\sin(\omega t+\phi_j) > 0$ and $T_j(t) = 1$ elsewhere. ϕ_S is a phase dependent on the position of the/th imaging sensor.

The signal on the light sensing element is a correlation measure of the pattern and the light returned from the object being scanned. The time-varying transmission takes the role of the reference signal and the time-varying light intensity of light returned from the scanned object takes the role of the input signal. The advantage of this embodiment of the invention is that a normal CCD or CMOS camera with intensity sensing elements may be used to record the correlation measure directly since this appears as an intensity on the sensing elements. Another way of expressing this is that the computation of the correlation measure takes place in the analog, optical domain instead of in an electronic domain such as an FPGA or a PC.

The focus position corresponding to the pattern being in focus on the object being scanned for a single sensor element in the camera will then be given by the maximum value of the correlation measure recorded with that sensor element when the focus position is varied over a range of values. The focus position may be varied in equal steps from one end of the scanning region to the other. One embodiment of the invention comprises means for recording and/or integrating and/or monitoring and/or storing each of a plurality of the sensor elements over a range of focus plane positions.

Preferably, the global maximum should be found. However, artifacts such as dirt on the optical system can result in false global maxima. Therefore, it can be advisable to look for local maxima in some cases.

Since the reference signal does not average to zero the correlation measure has a DC component. Since the DC part is not removed, there may exist a trend in DC signal over all focus element positions, and this trend can be dominating numerically. In this situation, the focus position may still be found by analysis of the correlation measure and/or one or more of its derivatives.

In a further embodiment of the invention the camera integration time is an integer number M of the pattern oscillation period, i.e. $\delta t = 2\pi M / \omega$. One advantage of this embodiment is that the magnitude of the correlation measure can be measured with a better signal-to-noise ratio in the presence of noise than if the camera integration time is not an integer number of the pattern oscillation period.

In another further embodiment of the invention the camera integration time is much longer than pattern oscillation period, i.e. $\delta t \gg 2\pi M / \omega$. Many times the pattern oscillation time would here mean e.g. camera integration time at least 10 times the oscillation time or more preferably such as at least 100 or 1000 times the oscillation time. One advantage of this embodiment is that there is no need for synchronization of camera integration time and pattern oscillation time since for very long camera integration times compared to the pattern oscillation time the recorded correlation measure is substantially independent of accurate synchronization.

Equivalent to the temporal correlation principle the optical correlation principle may be applied in general within image analysis. Thus, a further embodiment of the invention relates to a method for calculating the amplitude of a light intensity oscillation in at least one (photoelectric) light sensitive element, said light intensity oscillation generated by a superposition of a varying illumination pattern with itself, and said amplitude calculated by time integrating the signal from said at least one light sensitive element over a plurality of pattern oscillation periods.

Spatial correlation

The above mentioned correlation principles (temporal correlation and optical correlation) require the pattern to be varying in time. If the optical system and camera provides a lateral resolution which is at least two times what is needed for the scan of the object then it is possible to scan with a static pattern, i.e. a pattern which is not changing in time. This principle is termed "spatial correlation". The correlation measure is thus at least computed with sensor signals recorded at different sensor sites.

The lateral resolution of an optical system is to be understood as the ability of optical elements in the optical system, e.g. a lens system, to image spatial frequencies on the object being scanned up to a certain point. Modulation transfer curves of the optical system are typically used to describe imaging of spatial frequencies in an optical system. One could e.g. define the resolution of the optical system as the spatial frequency on the object being scanned where the modulation transfer curve has decreased to e.g. 50%. The resolution of the camera is a combined effect of the spacing of the individual camera sensor elements and the resolution of the optical system.

In the spatial correlation the correlation measure refers to a correlation between input signal and reference signal occurring in space rather than in time. Thus, in one embodiment of the invention the resolution of the measured 3D geometry is equal to the resolution of the camera. However, for the spatial correlation the resolution of the measured 3D geometry is lower than the resolution of the camera, such as at least 2 times lower, such as at least 3 times lower, such as at least 4 times lower, such as least 5 times lower, such as at least 10 times lower. The sensor element array is preferably divided into groups of sensor elements, preferably rectangular groups, such as square groups of sensor elements, preferably adjacent sensor elements. The resolution of the scan, i.e. the measured 3D geometry, will then be determined by the size of these groups of sensor elements. The oscillation in the light signal is provided within these groups of sensor elements, and the amplitude of the light oscillation may then be obtained by analyzing the groups of sensor elements. The division of the sensor element array into groups is preferably provided in the data processing stage, i.e. the division is not a physical division thereby possibly requiring a specially adapted sensor array. Thus, the division into groups is "virtual" even though the single pixel in a group is an actual physical pixel.

In one embodiment of the invention the pattern posseses translational periodicity along at least one spatial coordinate. In a further embodiment of the invention the spatially periodic pattern is aligned with the rows and/or the columns of the array of sensor elements. For example in the case of a static line pattern the rows or columns of the pixels in the camera may be parallel with the lines of the pattern. Or in the case of a static checkerboard pattern the row and columns of the checkerboard may be aligned with the rows and columns, respectively, of the pixels in the camera. By aligning is meant that the image of the pattern onto the camera is aligned with the "pattern" of the sensor element in the sensor array of the camera. Thus, a certain physical location and orientation of the pattern generation means and the camera requires a certain configuration of the optical components of the scanner for the pattern to be aligned with sensor array of the camera.

In a further embodiment of the invention at least one spatial period of the pattern corresponds to a group of sensor elements. In a further embodiment of the invention all groups of sensor elements contain the same number of elements and have the same shape. E.g. when the period of a checkerboard pattern corresponds to a square group of e.g. 2x2, 3x3, 4x4, 5x5, 6x6, 7x7, 8x8, 9x9, 10x1 0 or more pixels on the camera.

In yet another embodiment one or more edges of the pattern is aligned with and/or coincide with one or more edges of the array of sensor elements. For example a checkerboard pattern may be aligned with the camera pixels in such a way that the edges of the image of the checkerboard pattern onto the camera coincide with the edges of the pixels.

In spatial correlation independent knowledge of the pattern configuration allows for calculating the correlation measure at each group of light sensing. For a spatially periodic illumination this correlation measure can be computed without having to estimate the cosine and sinusoidal part of the light intensity oscillation. The knowledge of the pattern configuration may be obtained prior to the 3D scanning.

In a further embodiment of the invention the correlation measure, A_j, within a group of sensor elements with label /is determined by means of the following formula:

$$A_j = \sum_{i=1}^{n} f_{i,j} I_{i,j}$$

Where n is the number of sensor elements in a group of sensors, $f_j = (f_{1,j}, \ldots f_{n,j})$ is the reference signal vector obtained from knowledge of the pattern configuration, and $I_j = (I_{1,j}, \ldots I_{n,j})$ is input signal vector. For the case of sensors grouped in square regions with N sensors as square length then $n = N^2$.

Preferably, but not necessarily, the elements of the reference signal vector averages to zero over space, i.e. for all j we have

$$\sum_{i=1}^{n} f_{i,j} = 0$$

to suppress the DC part of the correlation measure. The focus position corresponding to the pattern being in focus on the object for a single group of sensor elements in the camera will be given by an extremum value of the correlation measure of that sensor element group when the focus position is varied over a range of values. The focus position may be varied in equal steps from one end of the scanning region to the other.

In the case of a static checkerboard pattern with edges aligned with the camera pixels and with the pixel groups having an even number of pixels such as 2x2, 4x4, 6x6, 8x8, 10x10, a natural choice of the reference vector f would be for its elements to assume the value 1 for the pixels that image a bright square of the checkerboard and -1 for the pixels that image a dark square of the checkerboard.

Equivalent to the other correlation principles the spatial correlation principle may be applied in general within image analysis. In particular in a situation where the resolution of the camera is higher than what is necessary in the final image. Thus, a further embodiment of the invention relates to a method for calculating the amplitude(s) of a light intensity oscillation in at least one group of light sensitive elements, said light intensity oscillation generated by a spatially varying static illumination pattern, said method comprising the steps of:

- providing the signal from each light sensitive element in said group of light sensitive elements, and
- calculating said amplitude(s) by integrating the products of a predetermined function and the signal from the corresponding light sensitive element over said group of light sensitive elements, wherein said predetermined function is a function reflecting the illumination pattern.

To generalize the principle to a plurality of light sensitive elements, for example in a sensor array, the correlation measure or amplitude of the light oscillation in group j may be expressed as

$$A_j = \sum_{i=1}^{n} f(i, j) I_{i,j} ,$$

where n is the number of sensor elements in group j, $I_{i,j}$ is the signal from the ith sensor element in group j and $f(i,j)$ is a predetermined function reflecting the pattern.

Compared to temporal correlation, spatial correlation has the advantage that no moving pattern is required. This implies that knowledge of the pattern configuration may be obtained prior to the 3D scanning. Conversely, the advantage of temporal correlation is its higher resolution, as no pixel grouping is required.

All correlation principles, when embodied with an image sensor that allows very high frame rates, enable 3D scanning of objects in motion with little motion blur. It also becomes possible to trace moving objects over time ("4D scanning"), with useful applications for example in machine vision and dynamic deformation measurement. Very high frame rates in this context are at least 500, but preferably at least 2000 frames per second.

Transforming correlation measure extrema to 3D world coordinates

Relating identified focus position(s) for camera sensor or camera sensor groups to 3D world coordinates may be done by ray tracing through the optical system. Before such ray tracing can be performed the parameters of the optical system need to be known. One embodiment of the invention comprises a calibration step to obtain such knowledge. A further embodiment of the invention comprises a calibration step in which images of an object of known geometry are recorded for a plurality of focus positions. Such an object may be a planar checkerboard pattern. Then, the scanner can be calibrated by generating simulated ray traced images of the calibration object and then adjusting optical system parameters as to minimize the difference between the simulated and recorded images.

In a further embodiment of the invention the calibration step requires recording of images for a plurality of focus positions for several different calibration objects and/or several different orientations and/or positions of one calibration object.

With knowledge of the parameters of the optical system, one can employ backward ray tracing technique to estimate the 2D -> 3D mapping. This requires that the scanner's optical system be known, preferably through calibration. The following steps can be performed:
1. From each pixel of the image (at the image sensor), trace a certain number of rays, starting from the image sensor and through the optical system (backward ray tracing).
2. From the rays that emit, calculate the focus point, the point where all these rays substantially intersect. This point represents the 3D coordinate of where a 2D pixel will be in focus, i.e., in yield the global maximum of light oscillation amplitude.
3. Generate a look up table for all the pixels with their corresponding 3D coordinates.
The above steps are repeated for a number of different focus lens positions covering the scanner's operation range.

Specular reflections

High spatial contrast of the in-focus pattern image on the object is often necessary to obtain a good signal to noise ratio of the correlation measure on the camera. This in turn may be necessary to obtain a good estimation of the focus position corresponding to an extremum in the correlation measure. This sufficient signal to noise ratio for successful scanning is often easily achieved in objects with a diffuse surface and negligible light penetration. For some objects, however, it is difficult to achieve high spatial contrast.

A difficult kind of object, for instance, is an object displaying multiple scattering of the incident light with a light diffusion length large compared to the smallest feature size of the spatial pattern imaged onto the object. A human tooth is an example of such an object. The human ear and ear canal are other examples. In case of intra oral scanning, the scanning should preferably be provided without spraying and/or drying the teeth to reduce the specular reflections and light penetration. Improved spatial contrast can be achieved by preferential imaging of the specular surface reflection from the object on the camera. Thus, one embodiment of the invention comprises means for preferential / selectively imaging of specular reflected light and/or diffusively reflected light. This may be provided if the scanner further comprises means for polarizing the probe light, for example by means of at least one polarizing beam splitter. A polarizing beam splitter may for instance be provided for forming an image of the object in the camera. This may be utilized to extinguish specular reflections, because if the incident light is linearly polarized a specular reflection from the object has the property that it preserves its polarization state

The scanner according to the invention may further comprise means for changing the polarization state of the probe light and/or the light reflected from the object. This can be provided by means of a retardation plate, preferably located in the optical path. In one embodiment of the invention the retardation plate is a quarter wave retardation plate. A linearly polarized light wave is transformed into a circularly polarized light wave upon passage of a quarter wave plate with an orientation of 45 degrees of its fast axis to the linear polarization direction. This may be utilized to enhance specular reflections because a specular reflection from the object has the property that it flips the helicity of a circularly polarized light wave, whereas light that is reflected by one or more scattering events becomes depolarized.

The field of view (scanning length)

In one embodiment of the invention the probe light is transmitted towards the object in a direction substantially parallel with the optical axis. However, for the scan head to be entered into a small space such as the oral cavity of a patient it is necessary that the tip of the scan head is sufficiently small. At the same time the light out of the scan head need to leave the scan head in a direction different from the optical axis. Thus, a further embodiment of the invention comprises means for directing the probe light and/or imaging an object in a direction different from the optical axis. This may be provided by means of at least one folding element, preferably located along the optical axis, for directing the probe light and/or imaging an object in a direction different from the optical axis. The folding element could be a light reflecting element such as a mirror or a prism. In one embodiment of the invention a 45 degree mirror is used as folding optics to direct the light path onto the object. Thereby the probe light is guided in a direction perpendicular to the optical axis. In this embodiment the height of the scan tip is at least as large as the scan length and preferably of approximately equal size.

One embodiment of the invention comprises at least two light sources, such as light sources with different wavelengths and/or different polarization. Preferably also control means for controlling said at least two light sources. Preferably this embodiment comprises means for combining and/or merging light from said at least two light sources. Preferably also means for separating light from said at least two light sources. If waveguide light sources are used they may be merged by waveguides. However, one or more diffusers may also be provided to merge light sources.

Separation and/or merging may be provided by at least one optical device which is partially light transmitting and partially light reflecting, said optical device preferably located along the optical axis, an optical device such as a coated mirror or coated plate. One embodiment comprises at least two of said optical devices, said optical devices preferably displaced along the optical axis. Preferably at least one of said optical devices transmits light at certain wavelengths and/or polarizations and reflects light at other wavelengths and/or polarizations.

One exemplary embodiment of the invention comprises at least a first and a second light source, said light sources having different wavelength and/or polarization, and wherein

a first optical device reflects light from said first light source in a direction different from the optical axis and transmits light from said second light source, and

a second optical device reflects light from said second light source in a direction different from the optical axis. Preferably said first and second optical devices reflect the probe light in parallel directions, preferably in a direction perpendicular to the optical axis, thereby imaging different parts of the object surface. Said different parts of the object surface may be at least partially overlapping.

Thus, for example light from a first and a second light source emitting light of different wavelengths (and/or polarizations) is merged together using a suitably coated plate that transmits the light from the first light source and reflects the light from the second light source. At the scan tip along the optical axis a first optical device (e.g. a suitably coated plate, dichroic filter) reflects the light from the first light source onto the object and transmits the light from the second light source to a second optical device (e.g. a mirror) at the end of the scan tip, i.e. further down the optical axis. During scanning the focus position is moved such that the light from the first light source is used to project an image of the pattern to a position below the first optical device while second light source is switched off. The 3D surface of the object in the region below the first optical device is recorded. Then the first light source is switched off and the second light source is switched on and the focus position is moved such that the light from the second light source is used to project an image of the pattern to a position below the second optical device. The 3D surface of the object in the region below the second optical device is recorded. The region covered with the light from the two light sources respectively may partially overlap.

In another embodiment of the invention the probe light is directed in a direction different from the optical axis by means of a curved fold mirror. This embodiment may comprise one or more optical elements, such as lenses, with surfaces that may be aspherical to provide corrected optical imaging.

A further embodiment of the invention comprises of at least one translation stage for translating mirror(s) along the optical axis. This allows for a scan tip with a smaller height than the scan length. A large scan length can be achieved by combining several scans with the mirror(s) in different positions along the optical axis.

In another embodiment of the invention the probe light is directed in a direction different from the optical axis by means of at least one grating that provides anamorphic magnification so that the image of the pattern on the object being scanned is stretched. The grating may be blazed. In this embodiment the light source needs to be monochromatic or semi-monochromatic.

The abovementioned embodiments suitable for increasing the scan length may comprise control means for providing a coordination of the light sources and the focus element.

Color scanning

One embodiment of the invention is only registering the surface topology (geometry) of the object being scanned. However, another embodiment of the invention is being adapted to obtain the color of the surface being scanned, i.e. capable of registering the color of the individual surface elements of the object being scanned together with the surface topology of the object being scanned. To obtain color information the light source needs to be white or to comprise at least three monochromatic light sources with colors distributed across the visible part of the electromagnetic spectrum.

To provide color information the array of sensor elements may be a color image sensor. The image sensor may accommodate a Bayer color filter scheme. However, other color image sensor types may be provided, such as a Foveon type color image sensor, wherein the image sensor provides color registration in each sensor element.

One embodiment of the invention comprises means selecting one color of the probe light at a time, i.e. selectively switching between different colors of the probe light, thereby illuminating the object with different colors. If a white light source is used then some kind of color filtering must be provided. Preferably comprising a plurality of color filters, such as red, green and blue color filters, and means for inserting said color filters singly in front of the white light source, thereby selecting a color of the probe light.

In one embodiment of the invention color filters are integrated in the pattern generation means, i.e. the pattern generation means comprises color filters, such as translucent and/or transparent parts that are substantially monochromatically colored. For example a pattern element such as a rotating wheel with an opaque mask and where the translucent / transparent parts are color filters. For example one third of the wheel is red, one third is green and one third is blue.

Probe light of different colors may also be provided by at least three monochromatic light sources, such as lasers or LED's, said light sources having wavelengths distributed across the visible part of the wavelength spectrum. This will in general also require means for merging said light sources. For example suitable coated plates. In the case of waveguide light sources, the merging may be provided by a waveguide element.

To handle the different colors of the probe light the optical system is preferably substantially achromatic.

One embodiment of the invention comprises means for switching between at least two colors, preferably three colors, such as red, green and blue, of the probe light for a focal plane position. I.e. for a single focal plane position it is possible to switch between different colors of the probe light. For example by switching on and off different monochromatic light sources (having one only light source turned on at a time) or by applying different color filters. Furthermore, the amplitude of the light signal of each of a plurality of the sensor elements may be determined for each color for each focal plane positions. I.e. for each focus position the color of the probe light may be switched. The embedded time varying pattern provides a single color oscillating light signal and the amplitude of the signal in each sensor element may be determined for that color. Switching to the next color the amplitude may be determined again. When the amplitude has been determined for all colors the focus position is changed and the process is repeated. The color of the surface being scanned may then be obtained by combining and/or weighing the color information from a plurality of the sensor elements. E.g. the color expressed as e.g. an RGB color coordinate of each surface element can be reconstructed by appropriate weighting of the amplitude signal for each color corresponding to the maximum amplitude. This technique may also be applied when a static pattern is provided where the color of at least a part of the pattern is varying in time.

To decrease the amount of data to be processed the color resolution of the imaging may be chosen to be less than the spatial resolution. The color information is then provided by data interpolation. Thus, in one embodiment of the invention the amplitude of the light signal of each of a plurality of the sensor elements is determined for each color for selected full color focal plane positions, and the amplitude of the light signal of each of a plurality of the sensor elements is determined for one color for each focal plane position. Then the color of the surface being scanned may be obtained by interpolating the color information from full color focal plane positions. Thus, for example the amplitude is registered for all colors at an interval of N focus positions; while one color is selected for determination of the amplitude at all focus positions. N is a number which could be e.g. 3, 5, or 10. This results in a color resolution which is less than the resolution of the surface topology. This technique may also be applied when a static pattern is provided where the color of at least a part of the pattern is varying in time.

Another embodiment of the invention does not register full color information and employs only two light sources with different colors. An example of this is a dental scanner that uses red and blue light to distinguish hard (tooth) tissue from soft (gum) tissue.

Impression scanning

One embodiment of the invention is adapted to impression scanning, such as scanning of dental impressions and/or ear canal impressions.

Small cavity scanner

Specific applications of the scanner according to the invention relates to scanning of cavities, in particular body cavities. Scanning in cavities may relate to scanning of objects in the cavity, such as scanning of teeth in a mouth. However, scanning of e.g. the ear relate to scanning of the inner surface of the cavity itself. In general scanning of a cavity, especially a small cavity, requires some kind of probe for the scanner. Thus, in one embodiment of the invention the point of emission of probe light and the point of accumulation of reflected light is located on a probe, said probe being adapted to be entered into a cavity, such as a body cavity.

In another embodiment of the invention the probe is adapted to scan at least a part of the surface of a cavity, such as an ear canal. The ability to scan at least a part of the external part of the ear and/or the ear canal and make a virtual or real model of the ear is essential in the design of modern custom-fitted hearing aid (e.g. ear shell or mold). Today, scanning of ears is performed in a two-step process where a silicone impression of the ear is taken first and the impression is subsequently scanned using an external scanner in a second step.

Thus, one embodiment of the invention comprises

- a housing accommodating the camera, pattern generation means, focus varying means and data processing means, and
- at least one probe accommodating a first optical system, preferably a substantially elongated probe.

Preferably, the point of emission of probe light and the point of accumulation of light returned from the scanned object is located on said probe. The optical system in the probe is for transmitting the probe light from the housing toward the object and also for transmitting and/or imaging light returned from the object back towards the housing where the camera is located. Thus, the optical system in the probe may comprise a system of lenses. In one embodiment of the invention probe may comprise at least one optical fibre and/or a fibre bundle for transmitting / transporting / guiding the probe light and/or the returned light from the object surface. In this case the optical fibre(s) may act as an optical relay system that merely transports light (i.e. probe light and returned light) inside the probe. In one embodiment of the invention the probe is endoscopic. The probe may be rigid or flexible. Use of optical fibre(s) in the probe may e.g. provide a flexible probe with a small diameter.

In one embodiment of the invention the light is transmitted to the object and imaged by means of only the optical system in the probe, the first optical system. However, in a further embodiment of the invention the housing may further comprise a second optical system.

In a further embodiment of the invention the probe is detachable from the housing. Then preferably a first point of emission of probe light and a first point of accumulation of returned light is located on the probe, and a second point of emission of probe light and a second point of accumulation of returned light is located on the housing. This may require optical systems in both the housing and the probe. Thus, a scan may be obtained with the probe attached to the housing. However, a scan may also be obtained with the probe detached from the housing, i.e. the housing may be a standalone scanner in itself. For example the probe may be adapted to be inserted into and scanning the inside of a cavity, whereas the housing may be adapted to scanning of exterior surfaces. The attachment of the probe may include mechanical and/or electrical transfer between the housing and the probe. For instance attaching the probe may provide an electrical signal to the control electronics in the housing that signals the current configuration of the device.

In one embodiment of the invention the probe light is directed toward the object in a direction substantially parallel with the optical axis and/or the longitudinal axis of the probe. In a further embodiment the probe comprises a posterior reflective element, such as a mirror, for directing the probe light in a direction different from the optical axis, preferably in a direction perpendicular to the optical axis. Applying to the abovementioned example with a stand-alone scanner housing with the probe detached, the probe light may exit the housing in a direction parallel with the optical axis of the optical system in the housing (i.e. the second optical system), whereas with the probe attached the probe light may be directed in a direction different than the optical axis of the optical system of the probe (i.e. the first optical system). Thereby the probe is better adapted to scanning a cavity.

In some embodiments of this invention, waste heat generated in the scanner is used to warm the probe such that no or less condensation occurs on the probe when the probe is inside the body cavity, e.g. the mouth. Waste heat can, e.g., be generated by the processing electronics, the light source, and/or the mechanism that moves the focus element.

In some embodiments of this invention, the scanner provides feedback to the user when the registration of subsequent scans to a larger model of the 3D surface fails. For example, the scanner could flash the light source.

Further, the probe may comprise means for rotating / spinning the reflective element, preferably around an axis substantially parallel with the optical axis and/or the longitudinal axis of the probe. Thereby the probe may be adapted to provide a scan 360° around the optical axis and/or the longitudinal axis of the probe, preferably without rotation of probe and/or scanner.

In a further embodiment of the invention a plurality of different probes matches the housing. Thereby different probes adapted to different environments, surfaces, cavities, etc. may be attached to the housing to account for different scanning situations. A specific example of this is when the scanner comprises a first probe being adapted to scan the interior part of a human ear and a second probe being adapted to scan the exterior part of said human ear. Instead of a second probe it may be the housing itself, i.e. with the probe detached, that is adapted to scan the exterior part of said human ear. I.e. the housing may be adapted to perform a 3D surface scan. In other words: the housing with the probe attached may be adapted to scan the interior part of a human ear and the housing with the probe detached may be adapted to scan the exterior part of said human ear. Preferably, means for merging and/or combining 3D data for the interior and exterior part of the ear provided, thereby providing a full 3D model of a human ear.

For handheld embodiments of this invention, a pistol-like design is ergonomic because the device rests comfortably inside the hand of the operator, with most of the mass resting on top of the hand and/or wrist. In such a design, it is advantageous to be able to orient the above-mentioned posterior reflective in multiple positions. For example, it could be possible to rotate a probe with the posterior reflective element, with or without the step of detaching it from the main body of the scanning device. Detachable probes may also be autoclavable, which is a definitely advantage for scanners applied in humans, e.g., as medical devices. For embodiments of this invention that realize a physically moving focus element by means of a motor, it is advantageous to place this motor inside a grip of the pistol-like shape.

Use of motion, gravity, and magnetic sensors

Handheld embodiments of the invention preferably include motion sensors such as accelerometers and/or gyros. . Preferably, these motion sensors are small like microelectromechanical systems (MEMS) motion sensors. The motion sensors should preferably measure all motion in 3D, i.e., both translations and rotations for the three principal coordinate axes. The benefits are:

A) Motion sensors can detect vibrations and/or shaking. Scans such affected can be either discarded or corrected by use of image stabilization techniques.

B) Motion sensors can help with stitching and/or registering partial scans to each other. This advantage is relevant when the field of view of the scanner is smaller than the object to be scanned. In this situation, the scanner is applied for small regions of the object (one at a time) that then are combined to obtain the full scan. In the ideal case, motion sensors can provide the required relative rigid-motion transformation between partial scans' local coordinates, because they measure the relative position of the scanning device in each partial scan. Motion sensors with limited accuracy can still provide a first guess for a software-based stitching/ registration of partial scans based on, e.g., the

Iterative Closest Point class of algorithms, resulting in reduced computation time.

C) Motion sensors can be used (also) as a remote control for the software that accompanies the invention. Such software, for example, can be used to visualize the acquired scan. With the scanner device now acting as a remote control, the user can, for example, rotate and/or pan the view (by moving the remote control in the same way as the object on the computer screen should "move"). Especially in clinical application, such dual use of the handheld scanner is preferable out of hygienic considerations, because the operator avoids contamination from alternative, hand-operated input devices (touch screen, mouse, keyboard, etc).

Even if it is too inaccurate to sense translational motion, a 3-axis accelerometer can provide the direction of gravity relative to the scanning device. Also a magnetometer can provide directional information relative to the scanning device, in this case from the earth's magnetic field. Therefore, such devices can help with stitching/registration and act as a remote control element.

The present invention relates to different aspects including the scanner device described above and in the following, and corresponding methods, devices, uses and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a method for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said method comprising the steps of:

- generating a probe light incorporating a spatial pattern,
- transmitting the probe light towards the object along the optical axis of an optical system, thereby illuminating at least a part of the object with said pattern,
- transmitting at least a part of the light returned from the object to the camera,
- varying the position of the focus plane of the pattern on the object while maintaining a fixed spatial relation of the scanner and the object,

- obtaining at least one image from said array of sensor elements,
- evaluating a correlation measure at each focus plane position between at least one image pixel and a weight function, where the weight function is determined based on information of the configuration of the spatial pattern;
- determining by analysis of the correlation measure the in-focus position(s) of:
    - each of a plurality of image pixels in the camera for said range of focus plane positions, or
    - each of a plurality of groups of image pixels in the camera for said range of focus planes, and
- transforming in-focus data into 3D real world coordinates.

Disclosed is also a computer program product comprising program code means for causing a data processing system to perform the method, when said program code means are executed on the data processing system.

Disclosed is also a computer program product, comprising a computer-readable medium having stored there on the program code means.

Another aspect of the invention relates to a scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:

- at least one camera accommodating an array of sensor elements,
- means for generating a probe light,
- means for transmitting the probe light towards the object thereby illuminating at least a part of the object,
- means for transmitting light returned from the object to the camera,
- means for varying the position of the focus plane on the object,
- means for obtaining at least one image from said array of sensor elements,
- means for:
    a) determining the in-focus position(s) of:
        - each of a plurality of the sensor elements for a range of focus plane positions, or

- each of a plurality of groups of the sensor elements for a range of focus plane positions, and

b) transforming in-focus data into 3D real world coordinates;

wherein the scanner further comprises counter-weight means for counter-balancing the means for varying the position of the focus plane.

Disclosed is also a method for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said method comprising the steps of:

- accommodating an array of sensor elements,
- generating a probe light,
- transmitting the probe light towards the object thereby illuminating at least a part of the object,
- transmitting light returned from the object to the camera,
- varying the position of the focus plane on the object,
- obtaining at least one image from said array of sensor elements,
- determining the in-focus position(s) of:
  - each of a plurality of the sensor elements for a range of focus plane positions, or
  - each of a plurality of groups of the sensor elements for a range of focus plane positions, and
- transforming in-focus data into 3D real world coordinates;

wherein the method further comprises counter-balancing the means for varying the position of the focus plane.

Another aspect of the invention relates to a handheld 3D scanner with a grip at an angle of more than 30 degrees from the scanner's main optical axis, for use in intraoral or in-ear scanning.

Brief description of the drawings

Fig. 1: A schematic presentation of a first example embodiment of the device according to the invention.

Fig. 2: A schematic presentation of a second example embodiment of the device according to the invention (optical correlation).

Fig. 3: Schematic presentations of example embodiments of patterns according to the invention.

Fig. 4: A schematic presentation of a first example embodiment of a flat scan tip with large scan length, using a plurality of (dichroic) mirrors and light sources.

[Fig. 5: - deleted --]

Fig. 6: A schematic presentation of a third example embodiment of a flat scan tip with a large scan length, using a curved mirror.

Fig. 7: A schematic presentation of a fourth example embodiment of a flat scan tip with large scan length, using a diffractive grating.

Fig. 8: A schematic presentation of an example embodiment of a mass-balanced focus lens scanner.

Fig. 9: A schematic presentation of an example embodiment of a device for simultaneous scanning of a surface shape and color.

Fig. 12: A schematic presentation of an example embodiment of a device for scanning the at least a part of the external part of the human ear and/or a part of the ear canal a human ear.

Fig. 13 (a) and (b): Schematics showing how a scanner embodiment can be used to both scan the outer and inner ear, respectively.

Fig. 14: Schematic of a scanner probe embodiment used to scan a narrow body cavity, such as a human ear.

Fig. 15: Examples of mirror configurations to be used with a scanner probe.

Fig. 16: A schematic representation of the reference signal values / weight values per pixel for a checkerboard pattern in an idealized optical system.

Fig. 17: Illustration of the process of generating a fused rererence signal, visualized as images.

Fig 18: Top: Example image with projected pattern showing on a human tooth. Bottom: The correlation measure for the series of focus lens positions at the group of pixels framed in the top part of the figure.

Fig. 19: Example fused correlation measure image of an intraoral scene.

Fig. 20: Example of a handheld intraoral scanner with a pistol-like grip and a removable tip.

It will be understood that the ray traces and lenses depicted in the figures are for purpose of illustration only, and depict optical paths generally in the discussed systems. The ray traces and lens shapes should not be understood to limit the scope of the invention in any sense including the magnitude, direction, or focus of light rays or bundles passing through various optical components, not withstanding any variations in number, direction, shape, position or size thereof, except as expressly indicated in the following detailed description of the exemplary embodiments illustrated in the drawings.

Detailed description of the drawings

A functional hand held 3D surface scanner should preferably have the following properties:

1) Telecentricity in the space of the object being scanned,
2) possibility to shift the focal plane while maintaining telecentricity and magnification
3) simple focusing scheme that involves tuning of optical components only in the handle of the device and not in the probe tip, and
4) a total size consistent with a hand held scanning device.

The scanner embodiment illustrated in **fig.** 1 is a hand-held scanner with all components inside the housing (head) 100. The scanner head comprises a tip which can be entered into a cavity, a light source **110,** optics 120 to collect the light from the light source, pattern generation means 130, a beam splitter 140, an image sensor and electronics 180, a lens system which transmits and images the light between the pattern, the object being scanned, and the image sensor (camera) 180. The light from the light source **110** travels back and forth through the optical system 150. During this passage the optical system images the pattern 130 onto the object being scanned 200 and further images the object being scanned onto the image sensor 181 . The lens system includes a focusing element 151 which can be adjusted to shift the focal imaging plane of the pattern on the probed object 200. One way to embody the focusing element is to physically move a single lens element back and forth along the optical axis. The device may include polarization optics 160. The device may include folding optics 170 which directs the light out of the device in a direction different to the optical axis of the lens system, e.g. in a direction perpendicular to the optical axis of the lens system. As a whole, the optical system provides an imaging of the pattern onto the object being probed and from the object being probed to the camera. One application of the device could be for determining the 3D structure of teeth in the oral cavity. Another application could be for determining the 3D shape of the ear canal and the external part of the ear.

The optical axis in fig. 1 is the axis defined by a straight line through the light source 110, optics 120 and the lenses in the optical system 150. This also corresponds to the longitudinal axis of the scanner illustrated in fig. 1. The optical path is the path of the light from the light source 110 to the object 220 and back to the camera 180. The optical path may change direction, e.g. by means of beam splitter 140 and folding optics 170.

The focus element is adjusted in such a way that the image of the pattern on the scanned object is shifted along the optical axis, preferably in equal steps from one end of the scanning region to the other. When the pattern is varied in time in a periodic fashion for a fixed focus position then the in-focus regions on the object will display an spatially varying pattern. The out-of-focus regions will display smaller or no contrast in the light variation. The 3D surface structure of the probed object is determined by finding the plane corresponding to an extremum in the correlation measure for each sensor in the camera's sensor array or each group of sensor in the camera's sensor array when recording the correlation measure for a range of different focus positions 300. Preferably one would move the focus position in equal steps from one end of the scanning region to the other.

Pattern generation

An embodiment of the pattern generation means is shown in fig. 3a: A transparent wheel with an opaque mask 133 in the form of spokes pointing radially from the wheel center. In this embodiment the pattern is time-varied by rotating the wheel with a motor 131 connected to the wheel with e.g. a drive shaft 132. The position of the pattern in time may be registered during rotation. This can be achieved by e.g. using a position encoder on the rim of the pattern 134 or obtaining the shaft position directly from motor 131 .

Fig. 3b illustrates another embodiment of the pattern generation means: A segmented light source 135, preferably a segmented LED. In this embodiment the LED surface is imaged onto the object under investigation. The individual LED segments 136 are turned on and off in a fashion to provide a known time-varying pattern on the object. The control electronics 137 of the time varying pattern is connected to the segmented light source via electrical wires 138. The pattern is thus integrated into the light source and a separate light source is not necessary.

Fig 3c illustrates a static pattern as applied in a spatial correlation embodiment of this invention. The checkerboard pattern shown is preferred because calculations for this regular pattern are easiest.

Temporal correlation

Fig. 1 is also an exemplary illustration of the temporal correlation wherein an image of the pattern on and/or in the object is formed on the camera. Each individual light sensing element in the camera sees a variation in the signal level corresponding to the variation of the illumination pattern on the object. The variation is periodic in the exemplary illustration. The light variation for each individual light sensing element will have a constant phase offset relative to the pattern position..

The correlation measure may be obtained by recording *n* images on the camera during at least one oscillation period. *n* is an integer number greater than one. The registration of the pattern position for each individual image combined with the phase offset values for each sensing element and the recorded images allows for an efficient extraction of the correlation measure in each individual sensing element in the camera using the following formula,

$$A_j = \sum_{i=1}^{n} f_{i,j} I_{i,j}$$

Here A_j is the estimated correlation measure of sensing element j, I_{1j}, ... I_{nj} are the n recorded signals from sensing element j, f_{1j}, ... f_{nj} are the n reference signal values obtained from the knowledge of the pattern configuration for each image recording. f has two indices i,j. The variation of f with the first index is derived from the knowledge of the pattern position during each image recording. The variation of f with the second index is derived from the knowledge of the pattern geometry which may be determined prior to the 3D scanning.

The focus position corresponding to the pattern being in focus on the object for a single sensor in the camera will be given by an extremum in the recorded correlation measure of that sensor when the focus position is varied over a range of values, preferably in equal steps from one end of the scanning region to the other.

Spatial correlation

In an example of the spatial correlation scheme, one image of the object with projected checkerboard pattern is recorded with as high resolution as allowed by the image sensor. The scheme in the spatial correlation in is then to analyze groups of pixels in the recorded image and extract the correlation measure in the pattern. An extremum in the obtained correlation measures indicates the in-focus position. For simplicity, one can use a checkerboard pattern with a period corresponding to $n = N \times N$ pixels on the sensor and then analyze the correlation measure within one period of the pattern (in the general case the pattern need not be quadratic $N \times N$). In the best case, it will be possible to align the pattern so that the checkerboard edges coincide with the pixel edges but the scanning principle does not rely upon this. Fig. 16 shows this for the case $n = A \times A = 16$. For a sensor with W x H = I 024 x 5 1 2 pixels, this would correspond to obtaining 256 x 128 correlation measure points from one image. Extraction of the correlation measure A_j within an $N \times N$ group of pixels with label / is given by

$$A_j = \sum_{i=1}^{\pi} f_{i,j} I_{i,j}$$

where $f_, = (U_j, \ldots f_{nj})$ is the reference signal vector obtained from knowledge of the pattern configuration, and $\boldsymbol{I}_j = (I_1 ,,,\ldots I_n J$ is input signal vector.

To suppress any DC part in the light we prefer that for all /that

$$0 = \sum_{i=1}^{n} f_{i,j}$$

For the situation depicted in fig. 16 for instance, $f_{i,j} = -1$ for the pixels corresponding to the dark parts of the pattern, and $f_{i,J} = +1$ otherwise. If the pattern edge was not aligned with the edges of the pixels, or if the optical system was not perfect (and thus in all practical applications), then $f_{i,J}$ would assume values between -1 and +1 for some /. A detailed description of how to determine the reference function is given later.

Optical correlation

An example of the optical correlation shown in fig. 2. In this embodiment an image is formed on the camera 180 which is a superposition of the pattern 130 with the probed object 200. In this embodiment the pattern is of a transmissive nature where light is transmitted through the pattern and the image of the pattern is projected onto the object and back again. In particular this involves retransmission of the light through the pattern in the opposite direction. An image of the pattern onto the camera is then formed with the aid of a beam splitter 140. The result of this arrangement is an image being formed on the camera which is a superposition of the pattern itself and the object being probed. A different way of expressing this is that the image on the camera is substantially a multiplication of an image of the pattern projected onto the object with the pattern itself.

The variation is periodic in the exemplary illustration. The correlation measure between the light variation on the object and the pattern for a given focus distance may be obtained by time integrating the camera signal over a large number of oscillation periods so that exact synchronization of pattern oscillation time and camera integration time is not important. The focus position corresponding to the pattern being in focus on the object for a single sensor in the camera will be given by the maximum recorded signal value of that sensor when the focus position is varied over a range of values, preferably in equal steps from one end of the scanning region to the other.

Finding the predetermined reference function

In the following, the process for computing the reference signal *f* is described for a spatial correlation embodiment of this invention, and depicted in a stylized way in Figure 17.

The process starts by recording a series of images of the checkerboard pattern as projected, e.g., on a flat surface, preferably oriented orthogonally to the optical axis of the scanner. The images are taken at different positions of the focusing element, in effect covering the entire travel range of said focus element. Preferably, the images are taken at equidistant locations.

As the focus plane generally is not a geometrical plane, different regions of the flat surface will be in focus in different images. Examples of three such images are shown in Figs 17a - 17c, where 1700 is an in-focus region. Note that in this stylized figure, transitions between regions in and out of focus, respectively, are exaggerated in order to demonstrate the principle more clearly. Also, in general there will be many more images than just the three used in this simple example.

In-focus regions within an image are found as those of maximum intensity variance (indicating maximum contrast) over the entire said series of images. The region to compute variance over need not be the same as the pixel group dimension used in spatial correlation, but should be large enough to contain the both dark and light regions of the pattern, and it must be the same for all images in the series.

Finally, a "fused image" (Fig 17d) is generated by combining all the in-focus regions of the series (17a - 17c). Note that in real applications, the fused image will generally not be a perfect checkerboard of black and white, but rather include intermediate gray values as caused by an imperfect optical system and a checkerboard that is not perfectly aligned with the camera sensors. An example of part of a real fused image is shown in fig 17e.

The pixel intensities within this image can be interpreted as a "weight image" with same dimensions as the original image of the pattern. In other words, the pixel values can be interpreted as the reference signal and the reference vector / set of weigth values $f_s = (f_{1j}, \dots f_{nj})$ for the n pixels in the pixel group with index j can be found from the pixel values.

For convenience in the implementation of the calculations, especially when carried out on an FPGA, the fused image can be sub-divided into pixel groups. The DC part of the signal can then be removed by subtracting the within-group intensity mean from each pixel intensity value. Furthermore, one can then normalize by dividing by the within-group standard deviation. The thus processed weight values are an alternative description of the reference signal..

Because of the periodic nature of the "fused image" and thus the "weight image", the latter can be compressed efficiently, thus minimizing memory requirements in the electronics that can implement the algorithm described here. For example, the PNG algorithm can be used for compression.

The "correlation image"

An "correlation" image is generated based on the "fused image" and the set of images recorded with the camera during a scan. For spatial correlation based on an $N \times N$ checkerboard pattern, recall that within-group correlation measure is

$$A_j = \sum_{i=1}^{N \times N} f_{i,j} I_{i,j},$$

where $f_j = (f_{1j}, \ldots f_{nj})$ are values from the fused image, and $I_j = (I_{1j}, \ldots I_{nj})$ are values from a recorded image on the camera. The pixel groupings used in any DC removal and possibly normalization that yielded the fused image are the same as in the above calculation. For each image recorded by the scanner during a sweep of the focusing element, there will thus be an array of (H/N) x (W/N) values of *A*. This array can be visualized as an image.

Fig. 18 (top section) shows one example correlation measure image, here of part of a human tooth and its edge. A pixel group of 6x6 pixels is marked by a square 1801 . For this example pixel group, the series of correlation measures *A* over all images within a sweep of the focusing element is shown in the chart in the bottom section of Fig 18 (cross hairs). The x-axis on the chart is the position of the focusing element, while the y-axis shows the magnitude of *A*. Running a simple Gaussian filter over the raw series results in a smoothed series (solid line). In the figure the focus element is in the position that gives optimal focus for the example group of pixels. This fact is both subjectively visible in the picture, but also determined quantitatively as the maximum of the series of *A*. The vertical line 1802 in the bottom section of Fig 18 indicates the location of the global extremum and thus the in-focus position. Note that in this example, the location of the maxima in the smoothed and the raw series, respectively, are visually indistinguishable. In principle, however, it is possible and also advantageous to find the maximum location from the smoothed series, as that can be between two lens positions and thus provide higher accuracy.

The array of values of *A* can be computed for every image recorded in a sweep of the focus element. Combining the global extrema (over all images) of *A* in all pixel groups in the same manner the fused image was combined, one can obtain a pseudo-image of dimension (H/N) x (W/N). This we call the "fused correlation image". An example of a fused correlation image of some teeth and gingiva is shown in Figure 19. As can be seen, it is useful for visualization purposes.

Increasing field of view

For the scan head to be entered into a small space such as the oral cavity of a patient it is necessary that the tip of the scan head is sufficiently small. At the same time the light out of the scan head need to leave the scan head in a direction different from the optical axis, e.g. at a direction perpendicular to the optical axis. In one embodiment of the invention a 45 degree mirror is used as folding optics 170 direct the light path onto the object. In this embodiment the height of the scan tip need to be at least as large as the scan length.

Another embodiment of the invention is shown in fig. 4. This embodiment of the invention allows for a scan tip with a smaller height (denoted *b* in the figure) than the scan length (denoted a in the figure). The light from two sources 110 and 111 emitting light of different colors/wavelengths is merged together using a suitably coated plate (e.g. a dichroic filter) 112 that transmit the light from 110 and reflects the light from 111. At the scan tip a suitably coated plate (e.g. a dichroic filter) 171 reflects the light from one source onto the object and transmits the light from the other source to a mirror at the end of the scan tip 172. During scanning the focus position is moved such that the light from 110 is used to project an image of the pattern to a position below 171 while 111 is switched off. The 3D surface of the object in the region below 171 is recorded. Then 110 is switched off and 111 is switched on and the focus position is moved such that the light from 111 is used to project an image of the pattern to a position below 172. The 3D surface of the object in the region below 172 is recorded. The region covered with the light from 110 and 111 respectively may partially overlap.

Another embodiment of the invention that allows for a scan tip with a smaller height (denoted *b* in the figure) than the scan length (denoted a in the figure) is shown in fig. 6. In this embodiment the fold optics 170 comprises a curved fold mirror 173 that may be supplemented with one or two lens elements 175 and 176 with surfaces that may be aspherical to provide corrected optical imaging.

Another embodiment of the invention that allows for a scan tip with a smaller height (denoted *b* in the figure) than the scan length (denoted a in the figure) is shown in fig.

7. In this embodiment the fold optics 170 comprises a grating 177 that provides anamorphic magnification so that the image of the pattern on the object being scanned is stretched. The grating may be blazed. The light source 110 needs to be monochromatic or semi-monochromatic in this embodiment.

Achieving high spatial contrast of pattern projected onto difficult objects

High spatial contrast of the in-focus pattern image on the object is necessary to obtain a high correlation measure signal based on the camera pictures. This in turn is necessary to obtain a good estimation of the focus position corresponding to the position of an extremum of the correlation measure. This necessary condition for successful scanning is easily achieved in objects with a diffuse surface and negligible light penetration. For some objects, however, it is difficult to achieve high spatial constrast, or more generally variation.

A difficult kind of object, for instance, is an object displaying multiple scattering with a light diffusion length large compared to the smallest feature size of the spatial pattern imaged onto the object. A human tooth is an example of such an object. The human ear and ear canal are other examples. Improved spatial variation in such objects can be achieved by preferential imaging of the specular surface reflection from the object on the camera. An embodiment of the invention applies polarization engineering shown in fig. 1. In this embodiment the beam splitter 140 is a polarizing beam splitter that transmits respectively reflects two orthogonal polarization states, e.g. S- and P-polarization states. The light transmitted through the lens system 150 is thus of a specific polarization state. Before leaving the device the polarization state is changed with a retardation plate 160. A preferred type of retardation plate is a quarter wave retardation plate. A linearly polarized light wave is transformed into a circularly polarized light wave upon passage of a quarter wave plate with an orientation 45 degrees of its fast axis to the linear polarization direction. A specular reflection from the object has the property that it flips the helicity of a circularly polarized light wave. Upon passage of the quarter wave retardation plate by the specularly reflected light the polarization state becomes orthogonal to the state incident on the object. For instance an S-polarization state propagating in the downstream direction toward the object will be returned as a P-polarization state. This implies that the specularly reflected light wave will be directed towards the image sensor 181 in the beam splitter 140. Light that enters into the object and is reflected by one or more scattering events becomes depolarized and one half of this light will be directed towards the image sensor 181 by the beam splitter 140.

Another kind of difficult object is an object with a shiny or metallic-looking surface. This is particularly true for a polished object or an object with a very smooth surface. A piece of jewelry is an example of such an object. Even very smooth and shiny objects, however, do display an amount of diffuse reflection. Improved spatial contrast in such objects can be achieved by preferential imaging of the diffuse surface reflection from the object on the camera. In this embodiment the beam splitter 140 is a polarizing beam splitter that transmits respectively reflects two orthogonal polarization states, e.g. S- and P-polarization states. The light transmitted through the lens system 150 is thus of a specific polarization state. A diffuse reflection from the object has the property that it loses its polarization. This implies that half of the diffusely reflected light wave will be directed towards the image sensor 181 in the beam splitter 140. Light that enters into the object and is reflected by specular polarization preserves its polarization state and thus none of it will be directed towards the image sensor 181 by the beam splitter 140.

Reducing shaking caused by focus element

During scanning the focus position is changed over a range of values, preferably provided by a focusing element 151 in the optical system 150. Fig. 8 illustrates an example of how to reduce shaking caused by the oscillating focus element. The focusing element is a lens element 152 that is mounted on a translation stage 153 and translated back and forth along the optical axis of said optical system with a mechanical mechanism 154 that includes a motor 155. During scanning the center of mass of the handheld device is shifted due to the physical movement of the lens element and holder. This results in an undesirable shaking of the handheld device during scanning. The situation is aggravated if the scan is fast, e.g. a scan time of less than one second. In one implementation of the invention the shifting of the center of mass is eliminated by moving a counter-weight 156 in a direction opposite to the lens element in such a way that the center of mass of the handheld device remains fixed. In the preferred implementation the focus lens and the counter-weight are mechanically connected and their opposite movement is driven by the same motor.

Color measurement

An embodiment of a color 3D scanner is shown in fig. 9. Three light sources **110, 111,** and **113** emit red, green, and blue light. The light sources are may be LEDs or lasers. The light is merged together to overlap or essentially overlap. This may be achieved by means of two appropriately coated plates **112** and 114. Plate **112** transmits the light from **110** and reflects the light from **111.** Plate **114** transmits the light from **110** and **111** and reflects the light from 113. The color measurement is performed as follows: For a given focus position the amplitude of the time-varying pattern projected onto the probed object is determined for each sensor element in the sensor **181** by one of the above mentioned methods for each of the light sources individually. In the preferred embodiment only one light source is switched on at the time, and the light sources are switched on after turn. In this embodiment the optical system **150** may be achromatic. After determining the amplitude for each light source the focus position is shifted to the next position and the process is repeated. The color expressed as e.g. an RGB color coordinate of each surface element can be reconstructed by appropriate weighting of the amplitude signal for each color corresponding the maximum amplitude.

One specific embodiment of the invention only registers the amplitude for all colors at an interval of P focus positions; while one color is selected for determination of the amplitude at all focus positions. P is a number which could be e.g. 3, 5, or 10. This results in a color resolution which is less than the resolution of the surface topology. Color of each surface element of the probed object is determined by interpolation between the focus positions where full color information is obtained. This is in analogy to the Bayer color scheme used in many color digital cameras. In this scheme the color resolution is also less than the spatial resolution and color information need to be interpolated.

A simpler embodiment of the 3D color scanner does not register full color information and employs only two light sources with different colors. An example of this is a dental scanner that uses red and blue light to distinguish hard (tooth) tissue from soft (gum) tissue.

Ear scanner embodiment

Figs. 12-1 5 schematically illustrate an embodiment of a time-varying structured light illumination-based scanner for direct scanning of human ears by scanning both the exterior (outer) and interior (inner) part of a human ear by use of a common scanner exterior handle and a detachable probe. This embodiment is advantageous in that it allows for non-intrusive scanning using a probe designed to be inserted into small cavities, such as a human ear. This is done in part by positioning the bulky and essential parts of the scanner, such as the scanner camera, light source, electronics and focusing optics outside the closely confined part of the ear canal.

The ability to scan the outer and inner part of human ears and make a virtual or real model of the ear is essential in the design of modern custom-fitted hearing aid (e.g. ear shell or mold). Today, scanning of ears is performed in a two-step process where a silicone impression of the ear is taken first and the impression is subsequently scanned using an external scanner in a second step. The process of making the impression suffers from several drawbacks which will shortly be described in the following. One major drawback comes from frequent poor quality impressions taken by qualified clinic professionals due to the preparation and techniques required. Inaccuracies may arise because the impression material is known to expand during hardening and that deformation and creation of fractures in the impression are often created when the impression is removed from the ear. Another drawback is related to health risks involved with taking the impression due to irritation and allergic responses, damage to the tympanic membrane and infections. Finally, the impression process is an uncomfortable experience for many patients, especially for young children, who often require impressions taken at regular intervals (e.g. every four months) to accommodate the changing dimensions of the ear canal. In short, these drawbacks can be overcome if it is possible to scan the outer and inner ear in a non-intrusive way and obtain a registration between the inner and outer ear surfaces.

The following is not restricted to ear scanning but can be used to scan any small bodily cavity. Fig. 12 is a schematic of an embodiment of such a scanner. The scanner consists of two main parts - a scanner exterior 1001 and a scanner probe 1002. The scanner exterior may be used without the probe to obtain a larger field-of-view needed e.g. to scan the exterior part of the ear 1102, or the first part of the ear canal up to the first bend. The large field-of-view of the scanner exterior is important to obtain good registration between individual sub-scans and high global accuracy. By attaching a scanner probe 1202 to the scanner exterior 1201 , the combined scanner allows for scanning of small and bent cavity surfaces, such as the interior part of an ear 1203. In

this way and using the same system, the combined scanner exterior and probe are able to both scan larger external areas along with smaller internal areas.
In fig. 12 the exterior part of the scanner embodiment 1001 consists of a diverging light source 1003 (laser, LED, Tungsten or another type) which is collimated using collimation optics 1004. The collimated light is used to illuminate a transparent object 1005 (e.g. glass) with an opaque pattern, e.g. fringes on it. The pattern is subsequently imaged onto the object to be scanned using a suitable optical system. The pattern is observed using a similar optical system and a camera 1006, where the latter is positioned outside the cavity. The 3D information is obtained from the 2D images by observing the light oscillation created by the movement of the pattern across the scan object as contained in the individual pixel amplitude.

To facilitate movement of the pattern, the fringe pattern 1005 is rotating in one embodiment. In another embodiment, the fringe pattern is positioned on a translating plate that moves in a plane perpendicular to the optical axis with a certain oscillation frequency. The light to and from the scan object is projected through a beam splitter arrangement 1007, which consists of a prism cube in one embodiment and in another embodiment consists of an angled plate or membrane. The beam splitter serves to transmit the source light further down the system, while at the same time guide the reflected light from the scan object back to the camera, which is positioned on an axis perpendicular to the axis of the light source and beam splitter.

To move the focus plane the scanner exterior includes focusing optics, which in one embodiment consists of a single movable lens 1008. The purpose of the focusing optics is to facilitate movement of the plane of focus for the whole imaging system in the required scanning range and along the optical axis. In one embodiment, the focusing optics of the scanner exterior 1101 includes an objective that can focus the light directly, without any use of additional optics, as shown in fig. 13a. In another embodiment, the scanner exterior is supplied with a wide-angle objective designed with a large field-of-view, e.g. sufficiently large for scanning the exterior part of a human ear 1102.

The optical part of the scanner probe consists of an endoscopic optical relay system 1009 followed by a probe objective 1010, both of which are of sufficiently small diameter to fit into the canal of a human ear. These optical systems may consist of both a plurality of optical fibers and lenses and serve to transport and focus the light from the scanner exterior onto the scan object 1014 (e.g. the interior surface of an ear), as well as to collimate and transport the reflected light from the scan object back to the scanner exterior. In one embodiment, the probe objective provides telecentric projection of the fringe pattern onto the scan object. Telecentric projection can significantly ease the data mapping of acquired 2D images to 3D images. In another embodiment, the chief rays (center ray of each ray bundle) from the probe objective are diverging (non-telecentric) to provide the camera with an angle-of-view larger than zero, as shown in fig. 13a.

The position of the focus plane is controlled by the focusing optics 1008 and can be moved in a range large enough to at least coincide with the scan surface 1014. A single sub-scan is obtained by collecting a number of 2D images at different positions of the focus plane and at different positions of the fringe pattern, as previously described. As the focus plane coincides with the scan surface at a single pixel position, the fringe pattern will be projected onto the surface point in-focus and with high contrast, thereby giving rise to a large variation, or amplitude, of the pixel value over time. For each pixel it is thus possible to identify individual settings of the focusing optics for which each pixel will be in-focus. By using knowledge of the optical system, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel basis.

In one embodiment, a mirror arrangement 1011 , consisting of a single reflective mirror, or prism, or an arrangement of mirrors, are located after the probe objective 1010. This arrangement serves to reflect the rays to a viewing direction different from that of the of the probe axis. Different example mirror arrangements are found in figs. 15a - 15d. In one particular embodiment, the angle between the mirror normal and the optical axis is approximately 45 degrees, thus providing a 90 degree view with respect to the probe axis - an arrangement ideal for looking round corners. A transparent window 1012 is positioned adjacent to the mirror and as part of the probe casing/shell, to allow the light to pass between the probe and the scan object, while keeping the optics clean from outside dirt particles.

To reduce the probe movement required by a scanner operator, the mirror arrangement may be rotated using a motor 1013. In one embodiment, the mirror arrangement rotates with constant velocity. By full rotation of a single mirror, it is in this way possible to scan with 360 degree coverage around the probe axis without physically moving the probe. In this case, the probe window 1012 is required to surround / go all around the probe to enable viewing in every angle. In another embodiment, the mirror rotates with a certain rotation oscillation frequency. In yet another embodiment, the mirror arrangement tilt with respect to the probe axis is varied with a certain oscillation frequency.

A particular embodiment uses a double mirror instead of a single mirror (figs. 15b and 15d). In a special case, the normal of the two mirrors are angled approx. 90 degrees with respect to each other. The use of a double mirror helps registration of the individual sub-scans, since information of two opposite surfaces in this way is obtained at the same time. Another benefit of using a double mirror is that only 180 degrees of mirror rotation is required to scan a full 360 degrees. A scanner solution employing double mirrors may therefore provide 360 degrees coverage in less time than single mirror configurations.

"Pistol-like" grip

Fig. 20 shows an embodiment of the scanner with a pistol-like grip 2001 . This form is particularly ergonomic. The scanner in Fig. 20 is designed for intra-oral scanning of teeth. The tip 2002.can be removed from the main body of the scanner and can be autoclaved. Furthermore, the tip can have two positions relative to the main body of the scanner, namely looking down (as in Fig 20) and looking up. Therefore, scanning the upper and the lower mouth of a patient is equally comfortable for the operator. Note that the scanner shown in Fig. 20 is an early prototype with several cables attached for testing purposes only.

Although some embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways within the scope of the subject matter defined in the following claims. In particular, it is to be understood that other embodiments may be utilised and structural and functional modifications may be made without departing from the scope of the present invention.

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

The features of the method described above and in the following may be implemented in software and carried out on a data processing system or other processing means caused by the execution of computer-executable instructions. The instructions may be program code means loaded in a memory, such as a RAM, from a storage medium or from another computer via a computer network. Alternatively, the described features may be implemented by hardwired circuitry instead of software or in combination with software.

Claims

1. A scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:
    - at least one camera accommodating an array of sensor elements,
    - means for generating a probe light incorporating a spatial pattern,
    - means for transmitting the probe light towards the object thereby illuminating at least a part of the object with said pattern in one or more configurations,
    - means for transmitting at least a part of the light returned from the object to the camera,
    - means for varying the position of the focus plane of the pattern on the object while maintaining a fixed spatial relation of the scanner and the object,
    - means for obtaining at least one image from said array of sensor elements,
    - means for evaluating a correlation measure at each focus plane position between at least one image pixel and a weight function, where the weight function is determined based on information of the configuration of the spatial pattern;
    - data processing means for:

        a) determining by analysis of the correlation measure the in-focus position(s) of:
        - each of a plurality of image pixels for a range of focus plane positions, or
        - each of a plurality of groups of image pixels for a range of focus plane positions, and

        b) transforming in-focus data into 3D real world coordinates.

2. A scanner according to claim 1, wherein the light returned from the object to the camera is light that is reflected and/or scattered and/or fluorescence light and/or phosphorescence light.

3. A scanner according to claims 1 or 2, wherein the means for evaluating a correlation measure is a data processing means.

4. A scanner according to claims 1 or 2, wherein the means for evaluating a correlation measure is an optical means.

5. A scanner according to any of the preceding claims, wherein the correlation measure is found mathematically substantially as an at least local extremum position of an optionally smoothed series of dot products computed for a plurality of said focus plane positions.

6. A scanner according to the previous claim, wherein each dot product is computed from a signal vector with more than one element representing sensor signals and a weight vector of same length as said signal vector of weights.

7. A scanner according to any of the preceding claims, wherein the pattern is varying in time.

8. A scanner according to the previous claim, wherein the time varying pattern is periodically varying in time.

9. A scanner according to any of the preceding claims, wherein the pattern is static.

10. A scanner according to any of the preceding claims, wherein the means for transmitting light returned from the object to the camera comprises means for imaging onto the camera said illuminated part of the object with said pattern.

11. A scanner according to any of the preceding claims, wherein the means for transmitting light returned from the object to the camera comprises means for imaging onto the camera the pattern itself and a superposition of light returned from the object to the camera such that the image on the camera substantially is a multiplication of said illuminated part of the object with said pattern and the pattern itself.

12. A scanner according to any of the preceding claims, wherein the embedded spatial structure of said pattern is varying in time.

13. A scanner according to any of the preceding claims, comprising at least one light source and pattern generation means.

14. A scanner according to the previous claim, wherein light from said probe light generating means is transmitted through said pattern generation means thereby generating the pattern.

15. A scanner according to any of claims 13 or 14, wherein said pattern generation means comprises a mask of transparent and opaque parts.

16. A scanner according to the previous claim, wherein said opaque parts absorb incident light.

17. A scanner according to any of the preceding claims, wherein said pattern possess translational and/or rotational periodicity.

18. A scanner according to any of the preceding claims, wherein said pattern illuminating the object is varying in time by translating and/or rotating said pattern.

19. A scanner according to any of claims 13-1 8, wherein light returned from the object is retransmitted through said pattern generating means before being imaged on said camera, preferably retransmitted in the opposite direction as the probe light.

20. A scanner according to any of the preceding claims, wherein the image of the pattern illuminating the object is coinciding with an image of the pattern itself.

21. A scanner according to any of the preceding claims, further comprising means for synchronizing exposure time of said sensor elements with pattern oscillation time.

22. A scanner according to any of the preceding claims, wherein exposure time of said sensor elements is an integer number of light oscillation cycles.

23. A scanner according to any of the preceding claims, wherein exposure time of said sensor elements is a large number of light oscillation cycles, such as at least 10 times the light oscillation cycle, such as at least 100 times the light oscillation cycle.

24. A scanner according to any of claims 13-23, wherein light from the light source is transmitted through the pattern generation means thereby generating the pattern.

25. A scanner according to any of the preceding claims, wherein the focus plane of the camera is adapted to be moved synchronously with the focus plane of the pattern.

26. A scanner according to any of the preceding claims, wherein the object is an anatomical object, such as an ear canal, or a dental object, such as teeth.

27. A scanner according to any of the preceding claims, comprising an optical system for transmitting the probe light towards the object and/or for imaging light returned from the object to the camera.

28. A scanner according to any of the preceding claims, further comprising at least one beam splitter located in the optical path.

29. A scanner according to any of the preceding claims, wherein an image of the object is formed in the camera by means of at least one beam splitter.

30. A scanner according to any of the preceding claims, wherein the pattern is transmitted towards the object along the same optical axis as reflected light transmitted from the object to the camera.

31. A scanner according to any of the preceding claims, wherein the optical system comprises a lens system.

32. A scanner according to any of the preceding claims, wherein one lens system transmits the pattern towards the object and images light returned from the object to the camera.

33. A scanner according to any of the preceding claims, wherein one lens system transmits the pattern towards the object and images the light returned from the object to the pattern generating means.

34. A scanner according to claims 31-33, wherein the lens system is telecentric or near telecentric.

35. A scanner according to any of the preceding claims, wherein the pattern is transmitted in the opposite direction of light imaged from the object to the camera.

36. A scanner according to any of the preceding claims, wherein the pattern is transmitted in the opposite direction of light imaged from the object to the pattern generating means.

37. A scanner according to any of the preceding claims, wherein the sensor signal is an integrated light intensity substantially reflected from the surface of the object.

38. A scanner according to any of the preceding claims, wherein the focus plane position is periodically varied with a predefined frequency.

39. A scanner according to the previous claim, wherein said frequency is at least 1 Hz, such as at least 2 Hz, 3, 4, 5, 6, 7, 8, 9 or at least 10 Hz, such as at least 20, 40, 60, 80 or at least 100 Hz.

40. A scanner according to any of the preceding claims, further comprising at least one focus element.

41. A scanner according to the previous claim, wherein the focus element is part of the lens system.

42. A scanner according to any of claims 40-41 further comprising means for adjusting and controlling the focus element.

43. A scanner according to any of claims 40-42, wherein the focus element is a single lens.

44. A scanner according to any of claims 40-43, further comprising a translation stage for adjusting the position of the focus element.

45. A scanner according to any of claims 40-44, wherein the focus element is translated back and forth along the optical axis.

46. A scanner according to any of claims 31-45, wherein the lens system is telecentric or near telecentric for all focus plane positions.

47. A scanner according to any of claims 40-46, further comprising focus gearing.

48. A scanner according to the previous claim, wherein the focus gearing is between 0.1 and 100, such as between 0.1 and 1, such as between 1 and 10, such as between 2 and 8, such as between 3 and 6, such as least 10, such as at least 20.

49. A scanner according to any of claims 40-48, further comprising means for reducing and/or eliminating the vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner.

50. A scanner according to any of claims 40-49, further comprising means for fixing and/or maintaining the centre of mass of the focus element adjustment system.

51. A scanner according to any of claims 40-50, further comprising means for reducing and/or eliminating the first order, second order, third order and/or higher order vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner.

52. . A scanner according to any of the preceding claims, further comprising a counter-weight to substantially counter-balance movement of the focus element.

53. A scanner according to the previous claim, further comprising means for translating the counter-weight opposite to movement of the focus element.

54. A scanner according to claims 52 or 53, wherein the counter-weight and the focus element are connected and driven by the same translation means.

55. A scanner according to any of claims 40-54, wherein the focus element is a liquid lens.

56. A scanner according to any of claims 13-55, wherein the pattern generation means comprises at least one translucent and/or transparent pattern element with an opaque mask.

57. A scanner according to any of the preceding claims, wherein the pattern is a static line pattern or a static checkerboard pattern.

58. A scanner according to claims 56 or 57, further comprising means for rotating and/or translating the pattern element.

59. A scanner according to any of claims 56-58, wherein said pattern element is a wheel.

60. A scanner according to any of claims 56-59, wherein said mask possesses rotational and/or translational periodicity.

61. A scanner according to any of claims 56-60, wherein said mask comprises a plurality of radial spokes, preferably arranged in a symmetrical order.

62. A scanner according to any of claims 56-61 , wherein the pattern element is located in the optical path.

63. A scanner according to any of claims 56-62, wherein light is transmitted through the pattern element, preferably transmitted transversely through the pattern element.

64. A scanner according to any of claims 56-63, wherein the time varying pattern is generated by rotating and/or translating the pattern element.

65. A scanner according to any of the preceding claims, comprising at least one segmented light source, such as a segmented LED.

66. A scanner according to the previous claim, wherein the pattern is generated by means of said segmented light source(s).

67. A scanner according to any of claims 65 or 66, wherein the time varying pattern is generated by switching on and off individual segments of the segmented light source(s).

68. A scanner according to any of the claims 7 to 67, further comprising means for synchronizing the time varying pattern oscillation with the integration time of a sensor element.

69. A scanner according to any of the claims 13 to 68, further comprising means for registering and/or monitoring the phase and/or the position and/or the angular position of the time varying pattern and/or the pattern generation means.

70. A scanner according to any of the claims 56 to 69, wherein the phase and/or the position and/or the angular position of the time varying pattern and/or the pattern element is registered by means of a position encoder on the pattern element.

71. A scanner according to any of the claims 7 to 70, further comprising means for sampling each of a plurality of the sensor elements a plurality of times during one pattern oscillation period, preferably sampled an integer number of times, such as sampling 2, 3, 4, 5, 6, 7 or 8 times during each pattern oscillation period, thereby determining the correlation measure using the formula,

$$A_j = \sum_{i=1}^{n} f_{i,j} I_{i,j}$$

where n is the number of times sampled, A_j is the estimated correlation measure of sensing element j, $f_{1,j}, \ldots, f_{nj}$ are the values of the weight function based on information of the configuration of the spatial pattern at each of the times sampled, and $I_{1,j}, \ldots, I_{nj}$ are the recorded sensor signals at each of the times sampled.

72. A scanner according to any of the preceding claims, wherein at least a part of the object surface is imaged in the camera.

73. A scanner according to any of the preceding claims, wherein a superposition of the pattern with at least a part of the object surface is imaged in the camera.

74. A scanner according to any of the claims 13 to 73, wherein light reflected from the object is retransmitted through the pattern generating means before entering the camera, preferably retransmitted in the opposite direction.

75. A scanner according to any of the claims 7 to 74, further comprising means for recording each of a plurality of the sensor elements over a plurality of pattern oscillation periods, such as up to 2, 5, 10, 20, 50, 100, 250, 500, 1000, 5000 or up to 10000 pattern oscillation periods.

76. A scanner according to the previous claim, further comprising means for determining the maximum signal value of each of a plurality of the sensor elements over a range of focus plane positions.

77. A scanner according to any of the preceding claims, wherein the resolution of the measured 3D geometry is equal to the resolution of the camera.

78. A scanner according to any of the preceding claims, wherein the resolution of the measured 3D geometry is lower than the resolution of the camera, such as at least 2 times lower, such as at least 3 times lower, such as at least 4 times lower, such as least 5 times lower.

79. A scanner according to any of the preceding claims, wherein the sensor element array is divided into groups of sensor elements, preferably rectangular groups, such as square groups of sensor elements, preferably adjacent sensor elements.

80. A scanner according to any of the preceding claims, wherein the image of the pattern, such as a line pattern or a checkerboard pattern, is aligned with the rows and/or the columns of the array of sensor elements.

81. A scanner according to any of the preceding claims, wherein at least one spatial period of the pattern corresponds to a group of sensor elements.

82. A scanner according to any of the preceding claims, wherein one or more edges of the pattern is aligned with and/or coincide with one or more edges of the array of sensor elements.

83. A scanner according to any of the preceding claims, wherein the correlation measure within a group of sensor elements is determined by means of the following formula: $A_j = \sum f_{=1} f_{tj} \; I_{tj}$, where A_j is the correlation measure of the group of sensor elements with label j, n is the number of sensor elements in the group, $f_1 J, \ldots, f_{nj}$ are the values of the weight function based on information of the configuration of the spatial pattern, and $I_1 J, \ldots, I_{nj}$ are the recorded sensor signals at each of the sensor elements in the group.

84. A scanner according to the previous claim, wherein integration of the weight function over a group of sensor elements is zero, i.e. $0 = \sum f_{=1} f_{i,j}$, for the group with label j, thereby suppressing the DC part of the correlation measure.

85. A scanner according to any of the preceding claims, further comprising means for selective imaging of specularly and/or diffusively reflected light.

86. A scanner according to any of the preceding claims, further comprising means for polarizing the probe light, such as a polarizing element.

87. A scanner according to any of the preceding claims, further comprising at least one polarizing beam splitter.

88. A scanner according to any of the preceding claims, wherein an image of the object is formed in the camera by means of at least one polarizing beam splitter.

89. A scanner according to any of the preceding claims, further comprising means for changing the polarization state of the probe light and/or the light reflected from the object.

90. A scanner according to any of the preceding claims, further comprising a retardation plate and a linearly polarizing element, located in the optical path, a retardation plate such as a quarter wave retardation plate.

91. A scanner according to any of the preceding claims, further comprising at least one light reflecting element, preferably located along the optical axis, for directing the probe light and/or imaging an object in a direction different from the optical axis, a light reflecting element such as a mirror.

92. A scanner according to the previous claim, further comprising means for increasing the extension of the scanned surface in the direction of the optical axis.

93. A scanner according to any of the preceding claims, comprising at least two light sources, such as light sources with different wavelengths and/or different polarization.

94. A scanner according to the previous claim, further comprising control means for controlling said at least two light sources.

95. A scanner according to any of claims 93 or 94, further comprising means for combining and/or merging light from the at least two light sources, such as light sources with different wavelengths and/or different polarization states.

96. A scanner according to any of claims 93 to 95, further comprising means for separating light from at least two light sources, such as light sources with different wavelengths and/or different polarization states.

97. A scanner according to any of the preceding claims, further comprising at least one optical device which is partially light transmitting and partially light reflecting, said optical device preferably located along the optical axis, an optical device such as a coated mirror or coated plate.

98. A scanner according to the previous claim, comprising at least two of said optical devices, said optical devices preferably displaced along the optical axis.

99. A scanner according to claim 97 or 98, wherein at least one of said optical devices transmits light at certain wavelengths and/or polarizations and reflects light at other wavelengths and/or polarizations.

100. A scanner according to any of claims 97 to 99, comprising at least a first and a second light source, said light sources having different wavelength and/or polarization, and wherein

a first optical device located along the optical path reflects light from said first light source in a direction different from the optical axis and transmits light from said second light source, and

a second optical device located further down the optical path reflects light from said second light source in a direction different from the optical axis.

101. A scanner according to the previous claim, wherein said first and second optical devices reflect the probe light in parallel directions, preferably in a direction perpendicular to the optical axis, thereby imaging different parts of the object surface.

102. A scanner according to the previous claim, wherein said different parts of the object surface are at least partially overlapping.

103. A scanner according to any of claims 93 to 102, comprising control means for providing a coordination of the light sources and the focus element.

104. A scanner according to any of the preceding claims, further comprising at least one curved fold mirror for directing the probe light and/or imaging an object in a direction different from the optical axis, such as in a direction perpendicular to the optical axis.

105. A scanner according to the previous claim, further comprising one or more optical elements, such as lenses, with surfaces that may be aspherical to provide corrected optical imaging.

106. A scanner according to any of the preceding claims, further comprising at least one grating for directing the probe light and/or imaging an object in a direction different from the optical axis, such as in a direction perpendicular to the optical axis.

107. A scanner according to the previous claim, wherein the grating provides anamorphic magnification, whereby the image of the pattern on the object being scanned is stretched.

108. A scanner according to claims 106 or 107, wherein the grating is blazed.

109. A scanner according to any of the preceding claims, wherein the point of emission of probe light and the point of accumulation of reflected light being located on a probe, said probe being adapted to be entered into a cavity, such as a body cavity.

110. A scanner according to the previous claim, wherein the probe is adapted to scan one or more objects in a cavity, such as teeth in a mouth.

111. A scanner according to claim 109, wherein the probe is adapted to scan at least a part of the surface of a cavity, such as an ear canal.

112. A scanner according to any of the preceding claims, comprising:

a) a housing accommodating the camera, pattern generation means, focus varying means and data processing means, and
b) at least one probe accommodating a first optical system.

113. A scanner according to the previous claim, wherein the housing comprises a second optical system.

114. A scanner according to any of claims 112 or 113, wherein the probe is endoscopic.

115. A scanner according to any of claims 112 to 114, wherein the probe comprises at least one optical fibre and/or a fibre bundle for transmitting the probe light and/or the reflected light from the object surface.

116. A scanner according to any of claims 112 to 115, wherein the probe is detachable from the housing.

117. A scanner according to any of claims 112 to 116, wherein the probe is rigid or flexible.

118. A scanner according to any of claims 112 to 117, wherein the point of emission of probe light and the point of accumulation of reflected light is located on the probe.

119. A scanner according to any of claims 112 to 118, wherein
a first point of emission of probe light and a first point of accumulation of reflected light is located on the probe, and
a second point of emission of probe light and a second point of accumulation of reflected light is located on the housing.

120. A scanner according to any of claims 112 to 119, wherein the probe light is directed toward the object in a direction substantially parallel with the optical axis and/or the longitudinal axis of the probe.

121. A scanner according to any of claims 112 to 120, wherein the probe comprises a posterior reflective element, such as a mirror, or prism, for directing the probe light in a direction different from the optical axis, preferably in a direction perpendicular to the probe axis.

122. A scanner according to the previous claim, further comprising means for rotating the reflective element, preferably around an axis substantially parallel with the optical axis.

123. A scanner according to any of claims 112 to 122, wherein the probe is adapted to provide scan 360° around the optical axis and/or the longitudinal axis of the probe, preferably without rotation of probe and/or scanner.

124. A scanner according to any of claims 112 to 123, wherein a plurality of different probes matches the housing.

125. A scanner according to any of claims 112 to 124, comprising a first probe being adapted to scan the interior part of a human ear and a second probe being adapted to scan the exterior part of said human ear.

126. A scanner according to any of claims 112 to 125, wherein the housing is adapted to perform a 3D surface scan.

127. A scanner according to any of claims 112 to 126, wherein the housing with the probe attached is adapted to scan the interior part of a human ear and the housing with the probe detached is adapted to scan the exterior part of said human ear.

128. A scanner according to any of claims 112 to 127, further comprising means for merging and/or combining 3D data for the interior and exterior part of the ear, thereby providing a full 3D model of a human ear.

129. A scanner according to any of the preceding claims, being adapted to impression scanning, such as scanning of dental impressions and/or ear channel

impressions.

130. A scanner according to any of the preceding claims, being adapted to intraoral scanning, i.e. direct scanning of teeth and surrounding soft-tissue in the oral cavity.

131. A scanner according to any of the preceding claims, being adapted for dental applications, such as scanning of dental impressions, gypsum models, wax bites, dental prosthetics and abutments.

132. A scanner according to any of the preceding claims, being adapted to scanning of the 3D structure of skin in dermatological or cosmetological applications.

133. A scanner according to any of the preceding claims, being adapted to scanning of jewelry or wax models of whole jewelry or part of jewelry.

134. A scanner according to any of the preceding claims, being adapted to scanning and/or quality control of industrial parts

135. A scanner according to any of the preceding claims, being adapted to provide time resolved 3D scanning, such as time resolved 3D scanning of moving industrial parts.

136. A scanner according to any of the preceding claims, wherein the scanner is adapted to be handheld, and where the scanner comprises one or more built-in motion sensors that yield data for combining at least two partial scans to a 3D model of the surface of an object, where the motion sensor data potentially is used as a first guess for an optimal combination found by software.

137. A scanner according to any of the preceding claims, wherein the scanner is adapted to be handheld and where the scanner comprises one or more built-in motion sensors which yield data for interacting with the user interface of some software related to the scanning process.

138. A method for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said method comprising the steps of:

- generating a probe light incorporating a spatial pattern,
- transmitting the probe light towards the object along the optical axis of an optical system, thereby illuminating at least a part of the object with said pattern,
- transmitting at least a part of the light returned from the object to the camera,
- varying the position of the focus plane of the pattern on the object while maintaining a fixed spatial relation of the scanner and the object,
- obtaining at least one image from said array of sensor elements,
- evaluating a correlation measure at each focus plane position between at least one image pixel and a weight function, where the weight function is determined based on information of the configuration of the spatial pattern;
- determining by analysis of the correlation measure the in-focus position(s) of:
    - each of a plurality of image pixels in the camera for said range of focus plane positions, or
    - each of a plurality of groups of image pixels in the camera for said range of focus planes, and
- transforming in-focus data into 3D real world coordinates.

139. A computer program product comprising program code means for causing a data processing system to perform the method of the preceding claim, when said program code means are executed on the data processing system.

140. A computer program product according to the previous claim, comprising a computer-readable medium having stored thereon the program code means.

141 . A scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:

- at least one camera accommodating an array of sensor elements,
- means for generating a probe light,
- means for transmitting the probe light towards the object thereby illuminating at least a part of the object,
- means for transmitting light returned from the object to the camera,
- means for varying the position of the focus plane on the object,
- means for obtaining at least one image from said array of sensor elements,
- means for:
  - a) determining the in-focus position(s) of:
    - each of a plurality of the sensor elements for a range of focus plane positions, or
    - each of a plurality of groups of the sensor elements for a range of focus plane positions, and
  - b) transforming in-focus data into 3D real world coordinates;

wherein the scanner further comprises counter-weight means for counter-balancing the means for varying the position of the focus plane.

142. A method for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said method comprising the steps of:

- accommodating an array of sensor elements,
- generating a probe light,
- transmitting the probe light towards the object thereby illuminating at least a part of the object,
- transmitting light returned from the object to the camera,
- varying the position of the focus plane on the object,
- obtaining at least one image from said array of sensor elements,
- determining the in-focus position(s) of:

- each of a plurality of the sensor elements for a range of focus plane positions, or
- each of a plurality of groups of the sensor elements for a range of focus plane positions, and

- transforming in-focus data into 3D real world coordinates;

wherein the method further comprises counter-balancing the means for varying the position of the focus plane.

143. A handheld 3D scanner with a grip at an angle of more than 30 degrees from the scanner's main optical axis, for use in intraoral or in-ear scanning.

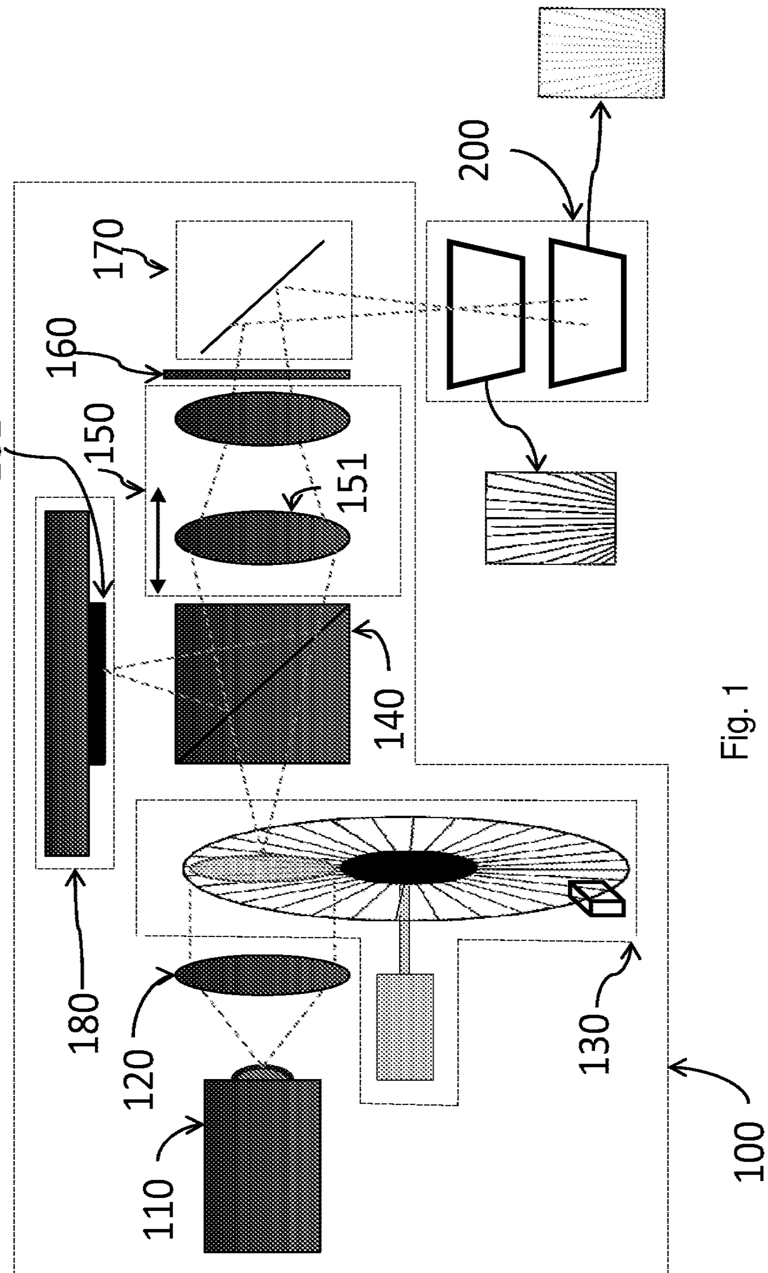

Fig. 1

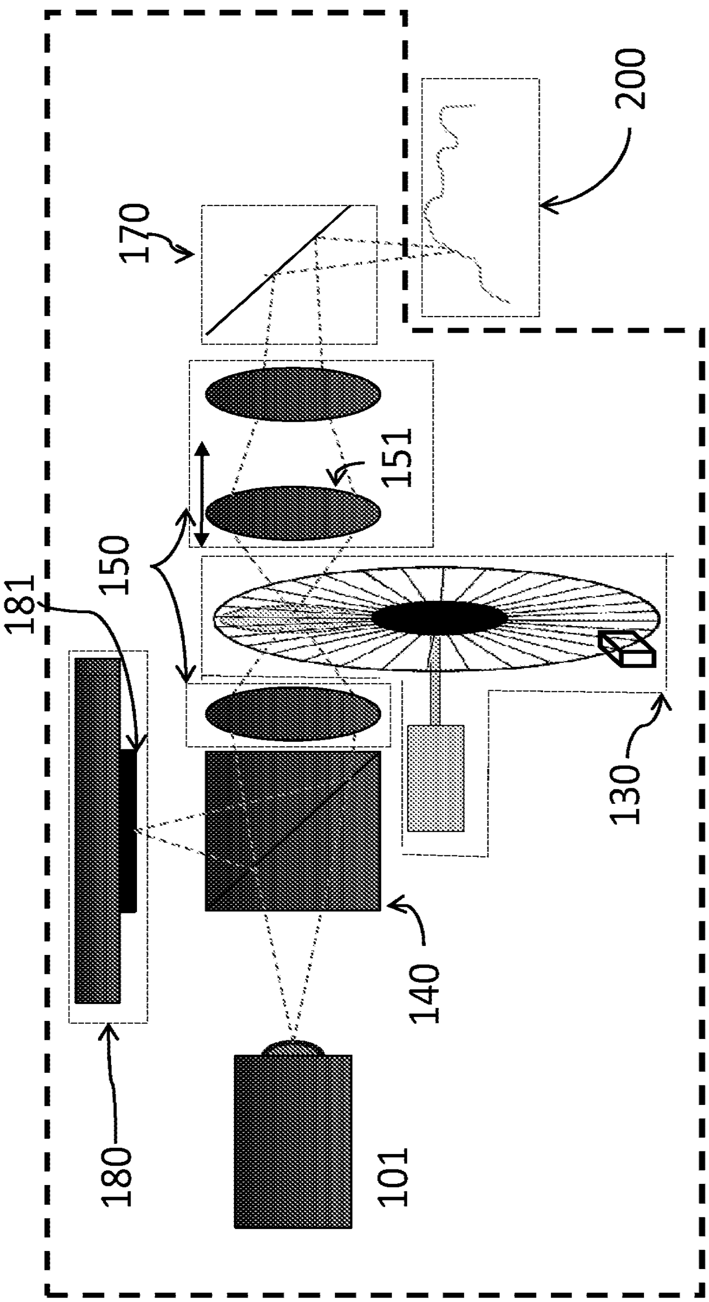

Fig. 2

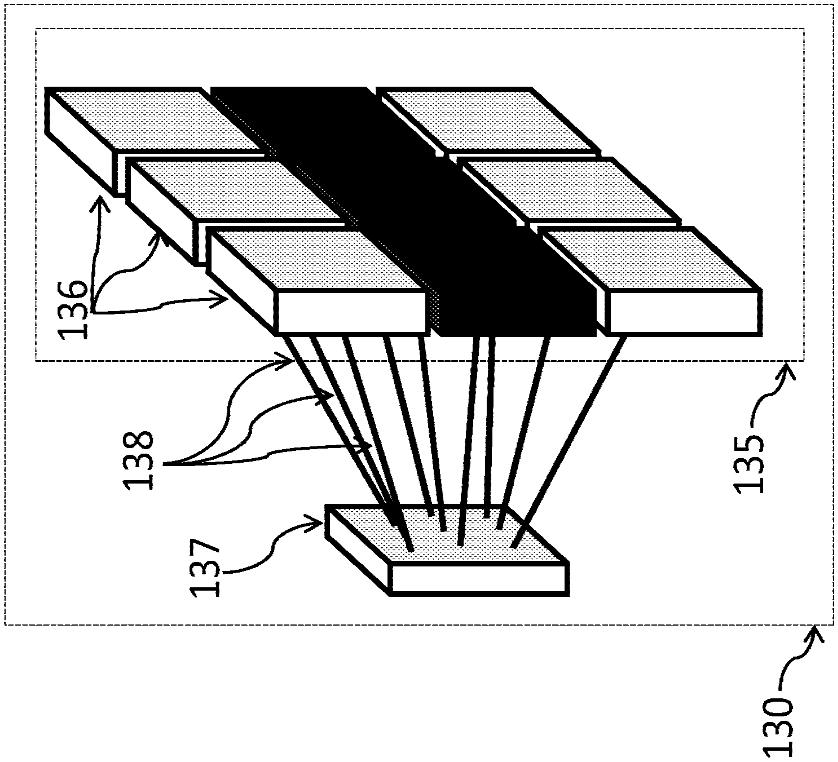

Fig. 3b

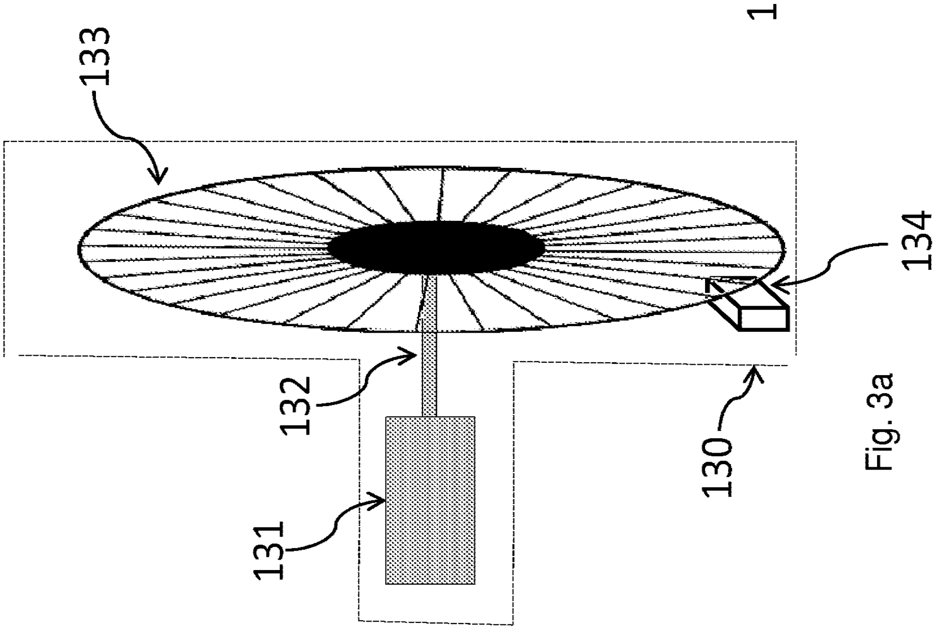

Fig. 3a

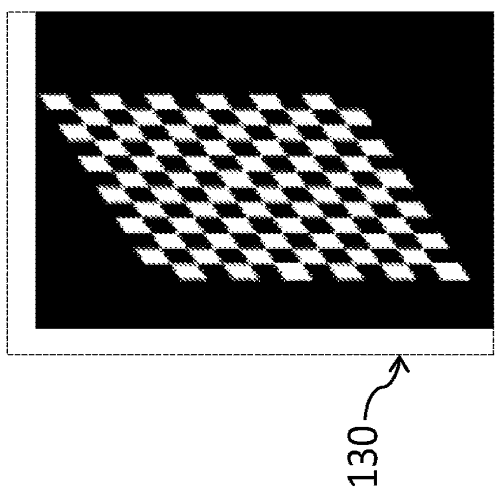

Fig. 3c

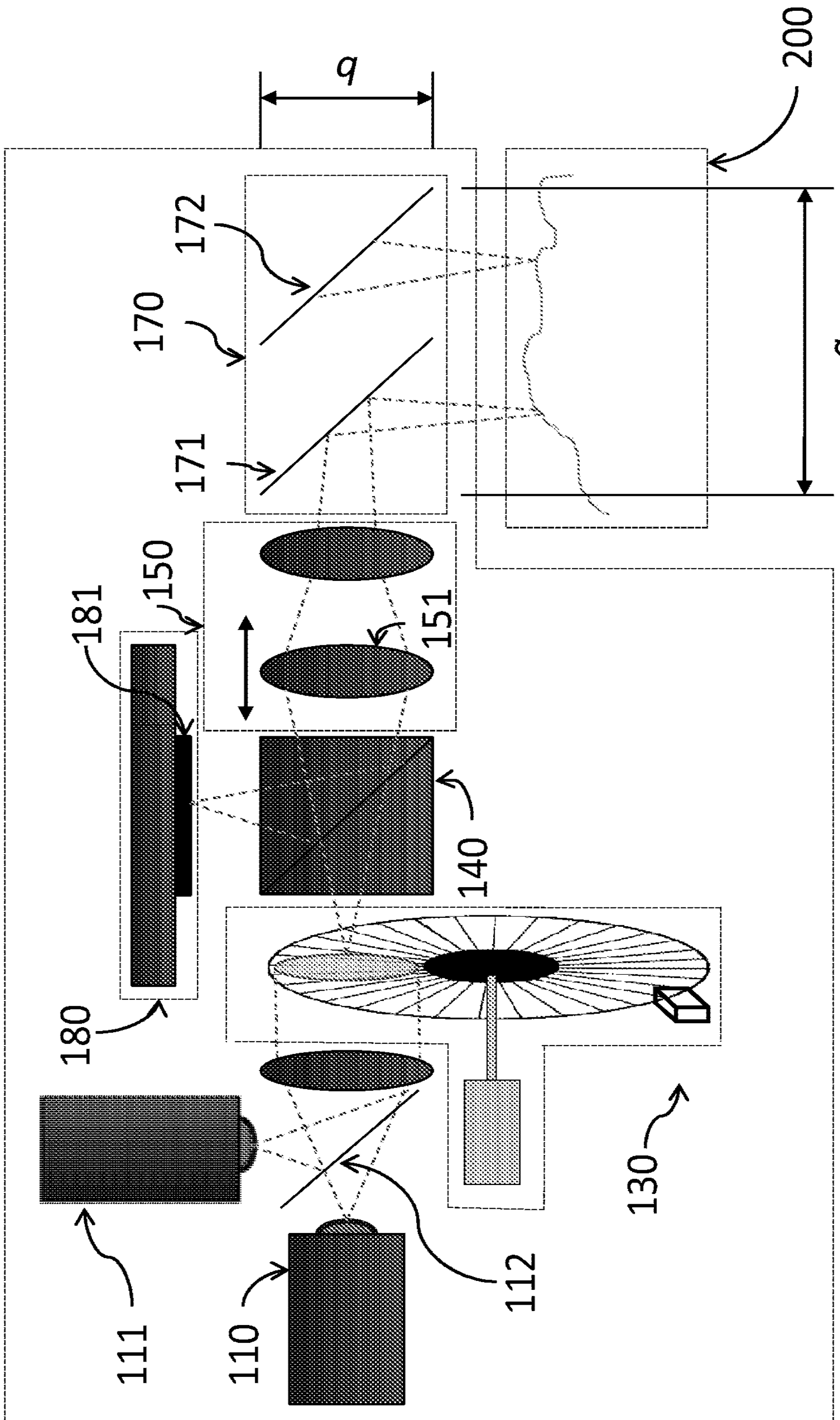

Fig. 4

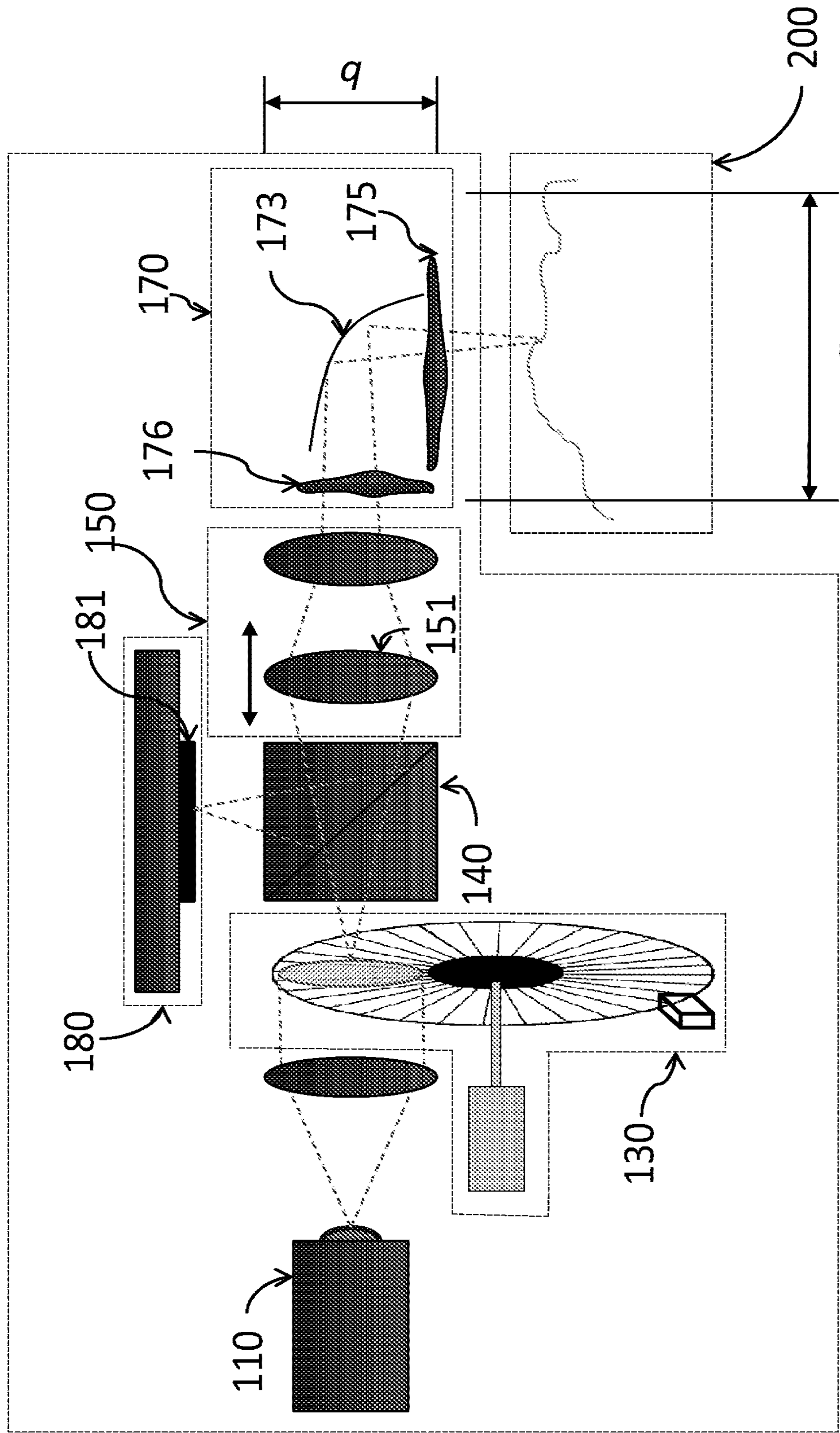

Fig. 6

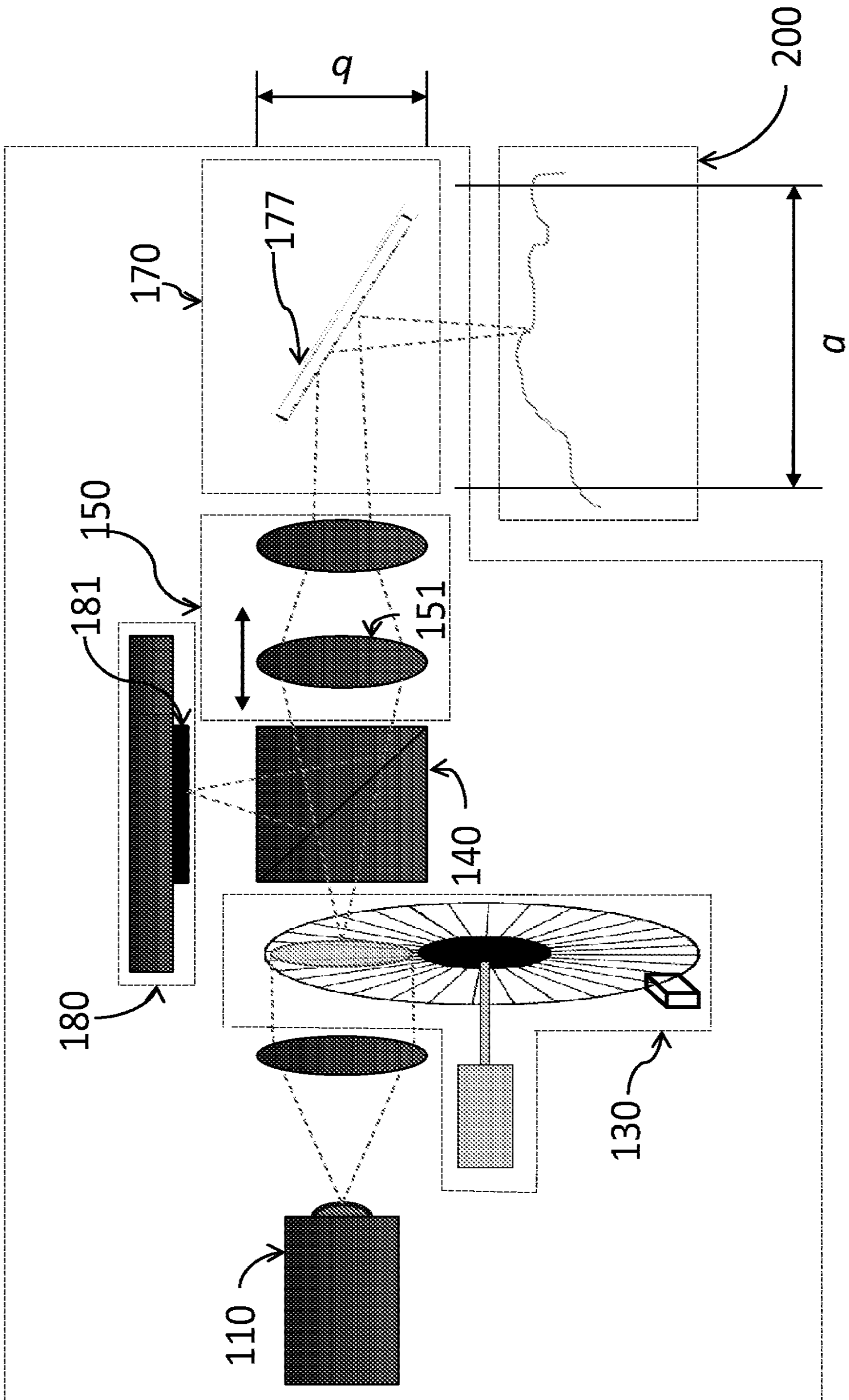

Fig. 7

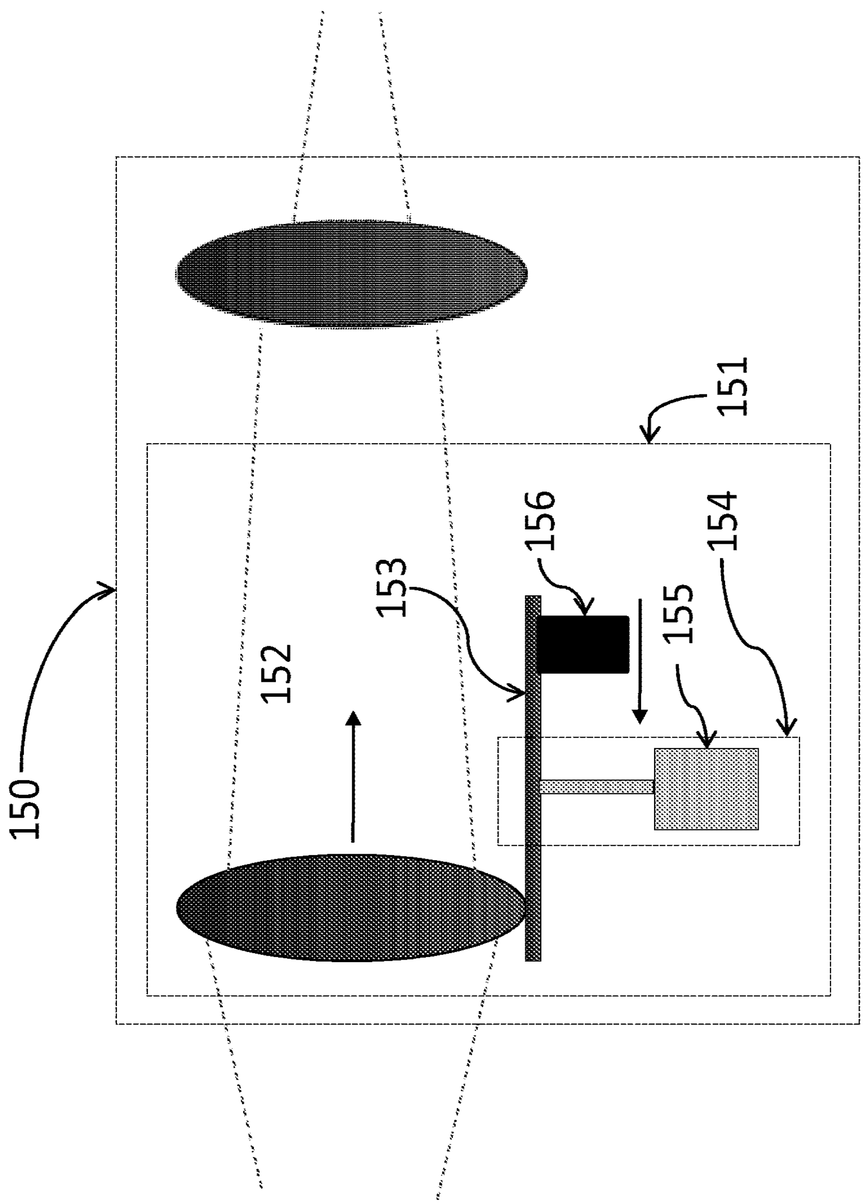

Fig. 8

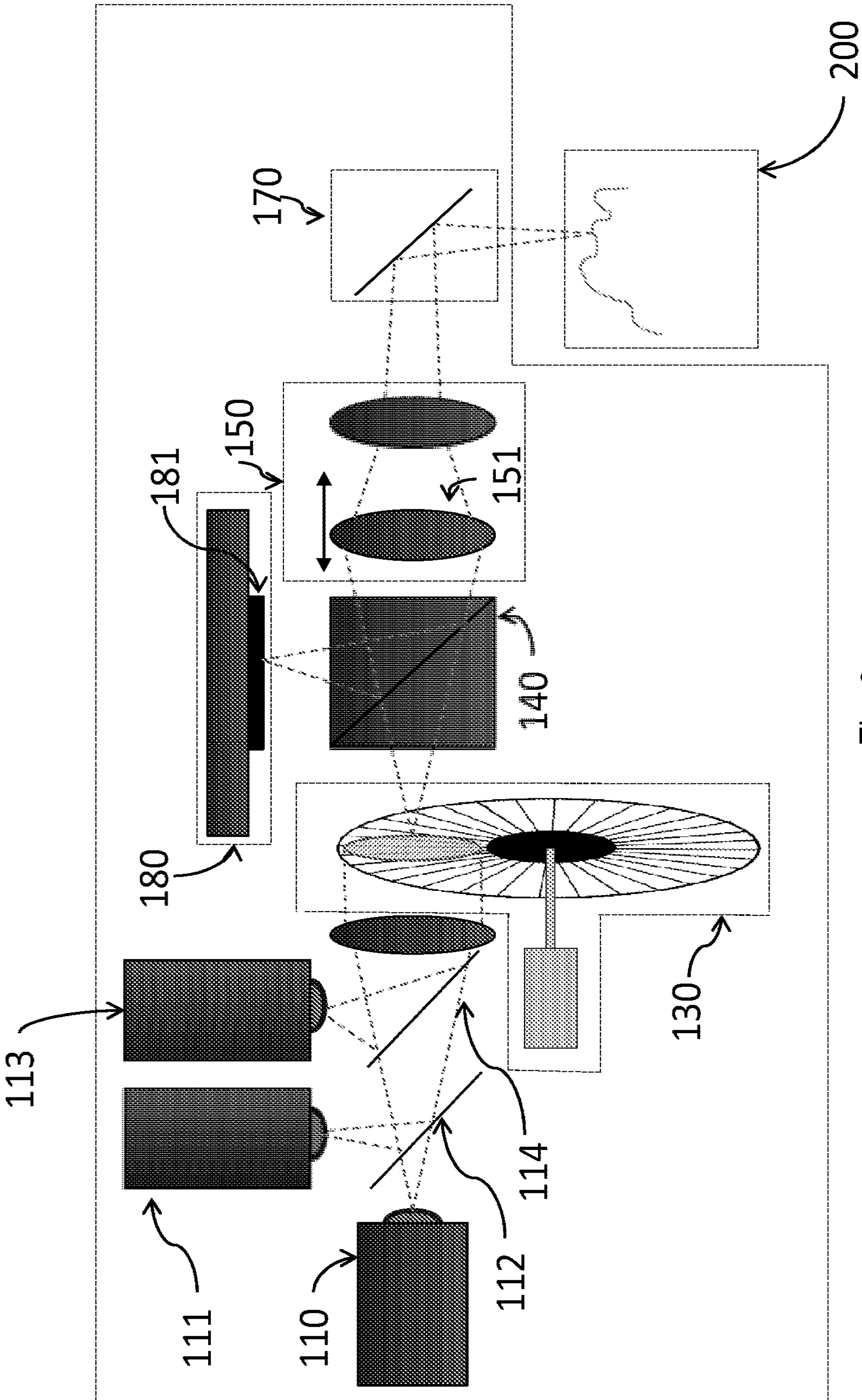

Fig. 9

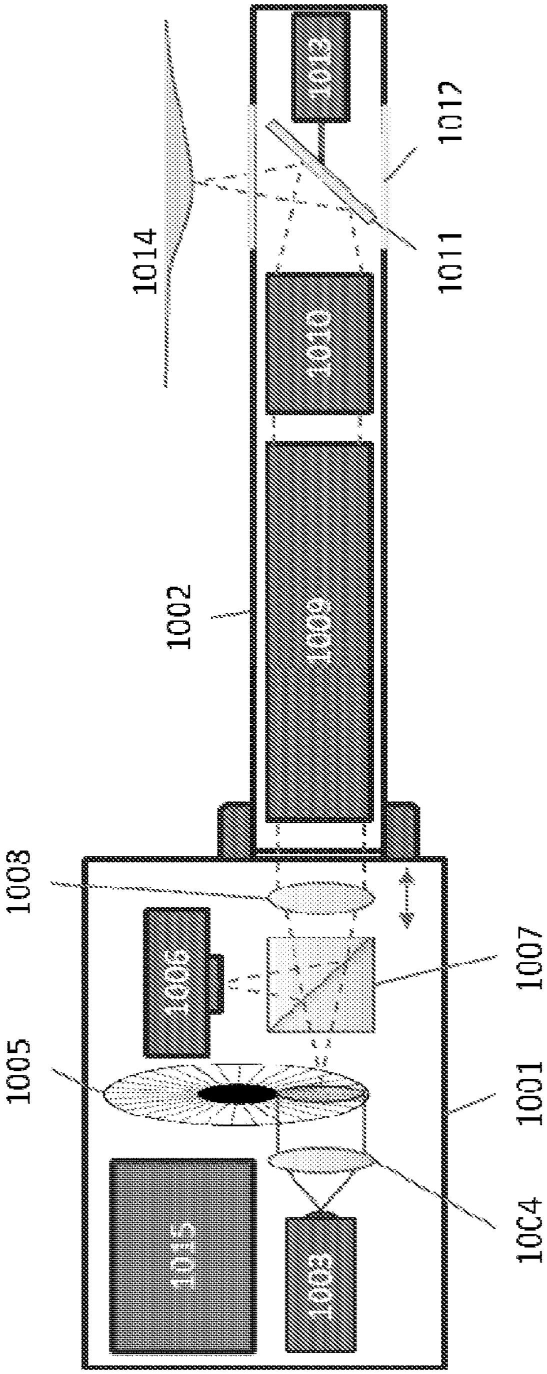
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Fig. 12

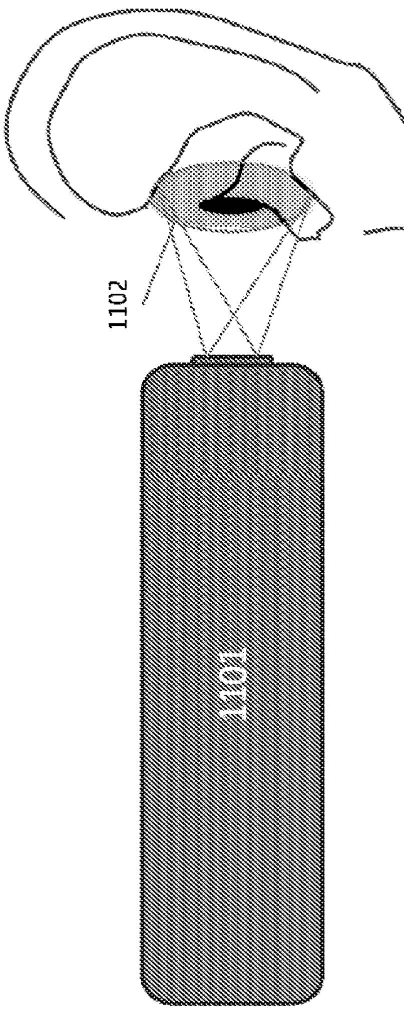

Fig. 13a

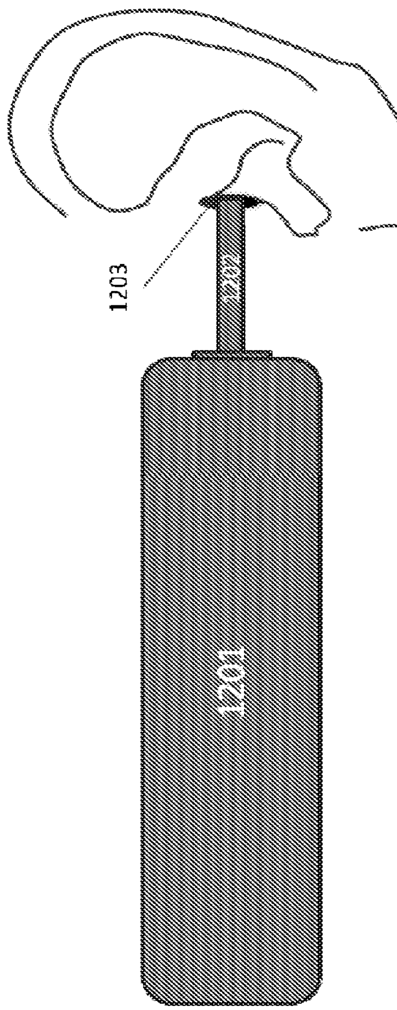

Fig. 13b

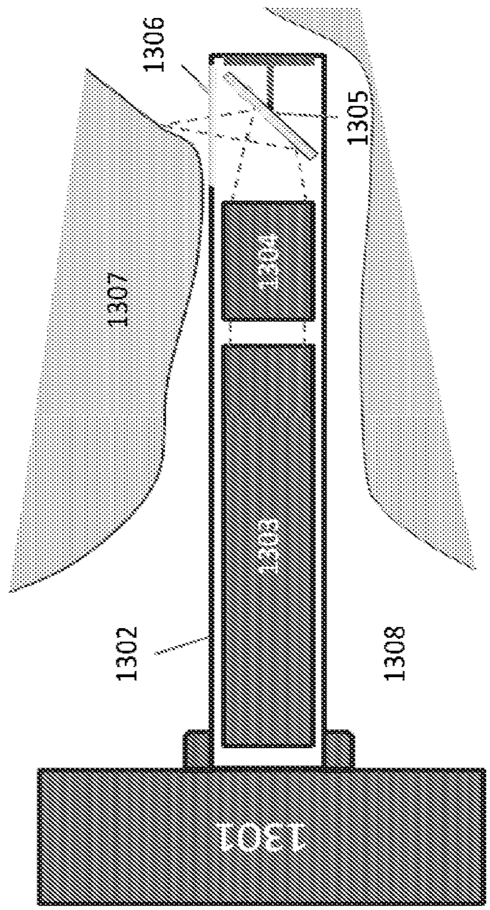

Fig. 14

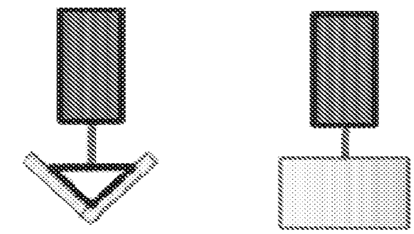

Fig. 15d

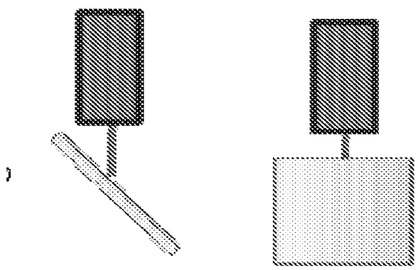

Fig. 15c

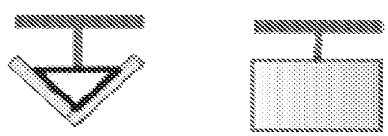

Fig. 15b

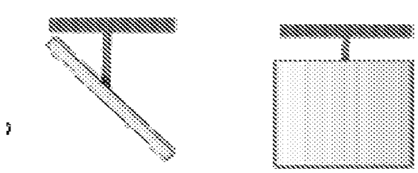

Fig. 15a

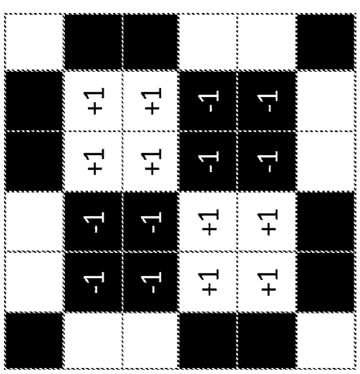

Fig. 16

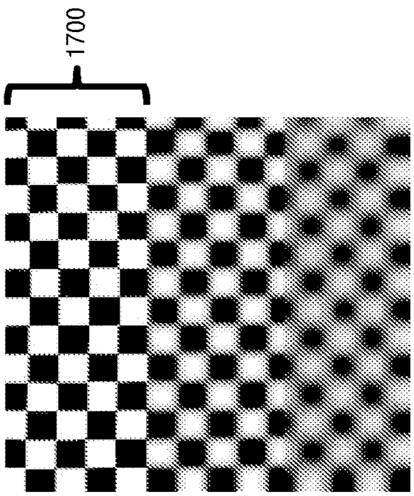

Fig. 17c

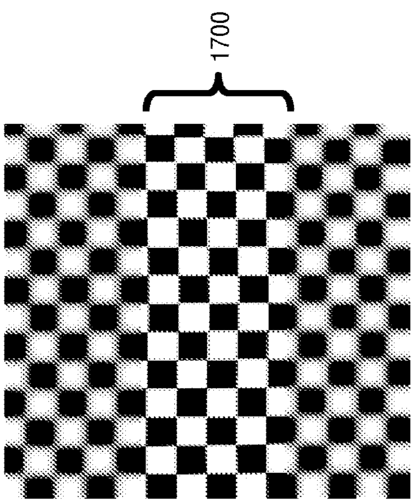

Fig. 17b

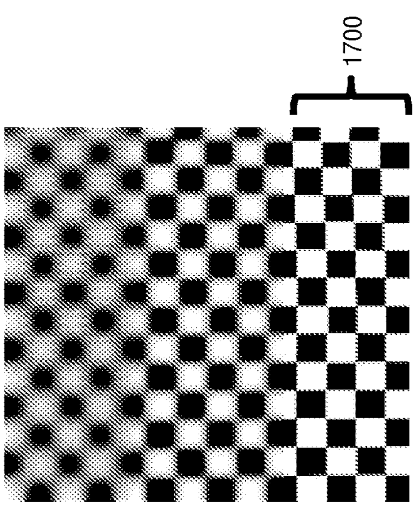

Fig. 17a

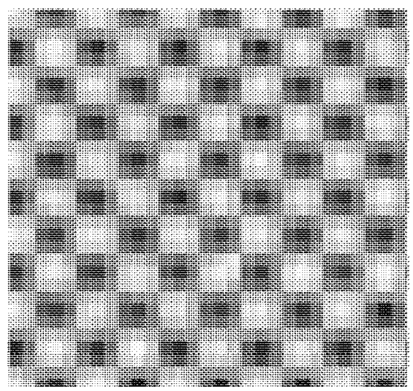

Fig. 17e

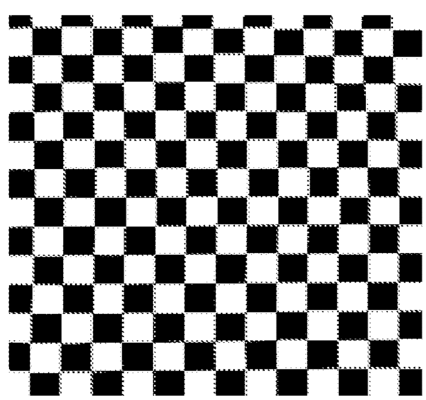

Fig. 17d

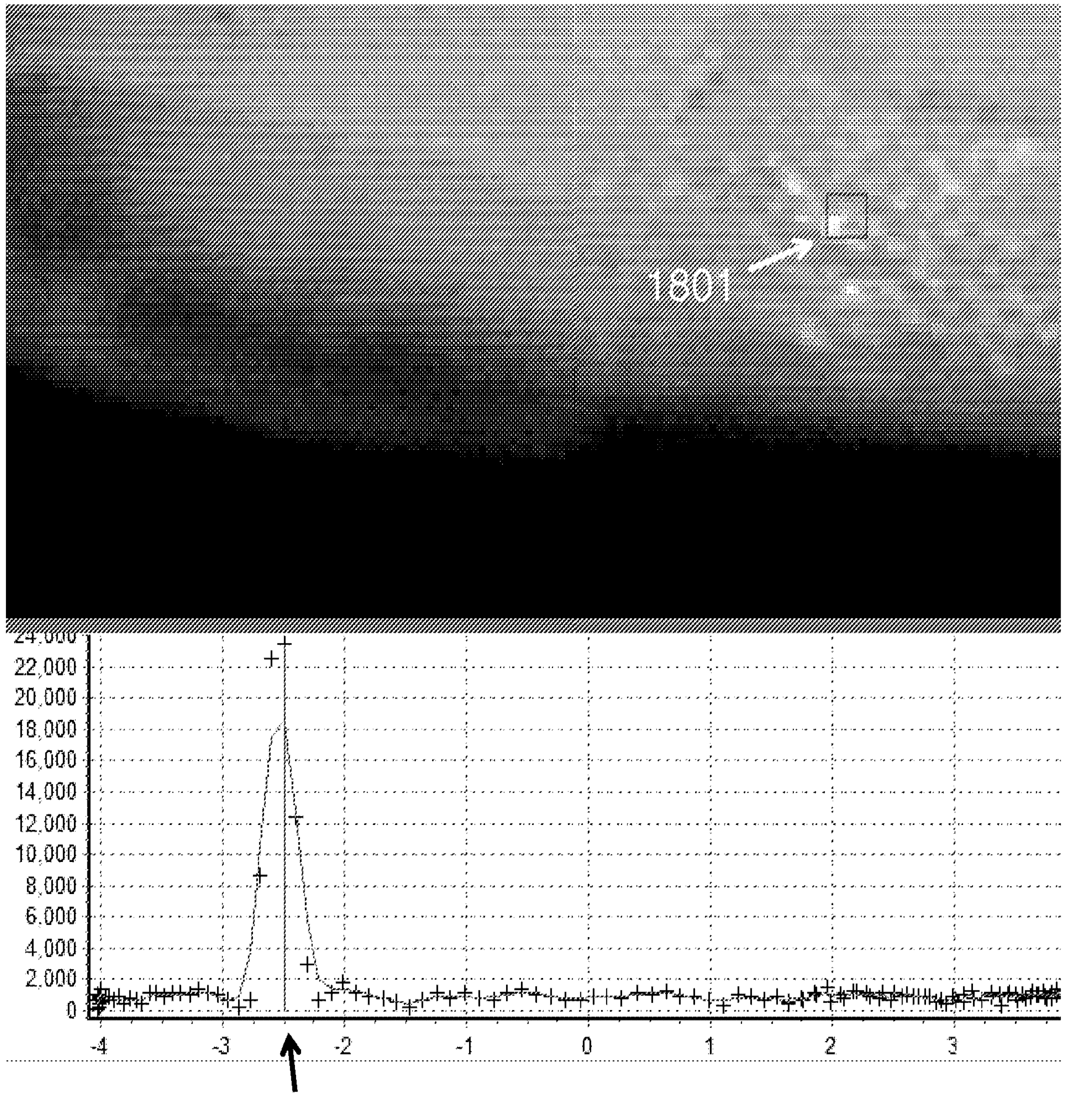
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Fig. 18

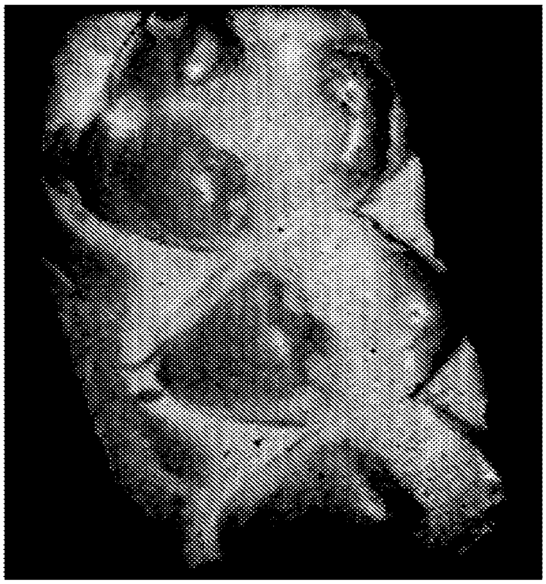

Fig. 19

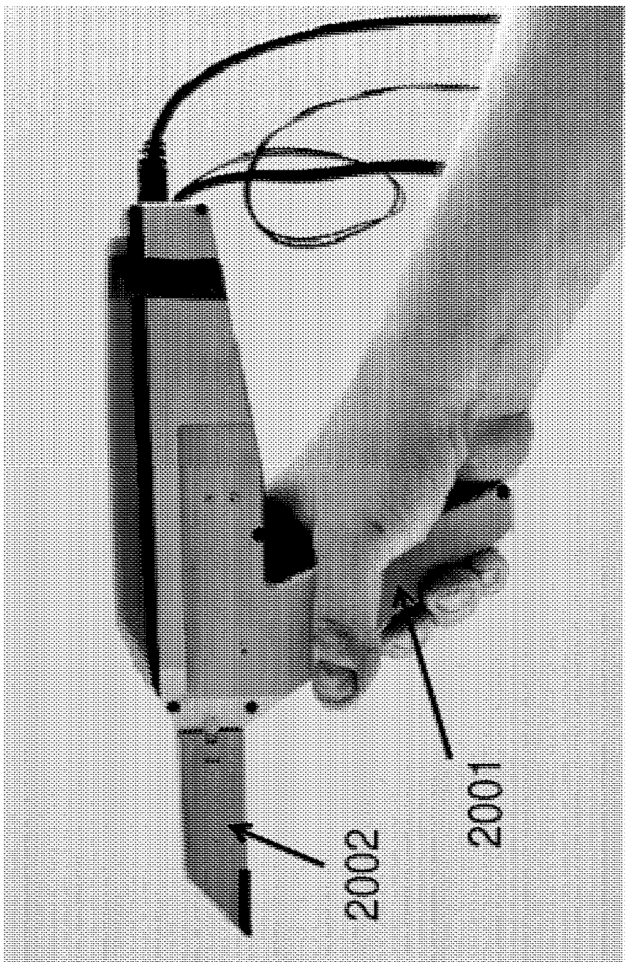

Fig. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2010/050148

A. CLASSIFICATION,OF SUBJECT MATTER
INV. A61B5/107
ADD.

According lo International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and where practical search terms used)

EPO-Internal

C. DCXUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
X A	US 4 575 805 A (MOERMANN WERNER H [CH] ET AL) 11 March 1986 (1986-03-11) column 2, line 23 - line 52 column 3, line 50 - line 68; figure 5	143 1
A	US 2007/194214 A1 (PFEIFFER JOACHIM [DE]) 23 August 2007 (2007-08-23) paragraphs [0001], [0002], [0045], [0051], [0056], [0057], [0075]	1
A	US 2003/096210 A1 (RUBBERT RUDGER [DE] ET AL RUBBERT RUEDGER [DE] ET AL) 22 May 2003 (2003-05-22) paragraphs [0066], [0067]	1

-/--

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents

"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2010	06/10/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office P B 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel (+31-70) 340-2040, Fax (+31-70) 340-3016	Hunt, Brynley

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2010/050148

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/158665 A1 (BABAYOFF NOAM [IL] ET AL) 20 July 2006 (2006-07-20) paragraphs [0035] - [0037], [0047]; figures Ia, 3	1,138, 141,142
A	US 2005/283065 A1 (BABAYOFF NOAM [IL]) 22 December 2005 (2005-12-22) the whole document	1,138, 141,142

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/DK2010/050148

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 4575805	A	11-03-1986	NONE			
US 2007194214	A1	23-08-2007	AT	373834	T	15-10-2007
			CN	1934481	A	21-03-2007
			DE	102004014048	A1	20-10-2005
			EP	1728115	A1	06-12-2006
			WO	2005091046	A1	29-09-2005
			JP	2007529731	T	25-10-2007
US 2003096210	A1	22-05-2003	US	2006079981	A1	13-04-2006
			US	2009291417	A1	26-11-2009
us 2006158665	A1	20-07-2006	NONE			
US 2005283065	A1	22-12-2005	AT	406850	T	15-09-2008
			AT	383817	T	15-02-2008
			DE	602005004332	T2	08-01-2009
			EP	1607064	A2	21-12-2005
			EP	1607041	A2	21-12-2005

Forni PCT/ISA/21 0 (patent family annex) (Apnl 2005)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 October 2011 (06.10.2011)

PCT

(10) International Publication Number
WO 2011/120526 A1

(51) International Patent Classification:
A61B 1/227 (2006.01) *A61B 5/107* (2006.01)
A61B 1/06 (2006.01) *G01B 11/25* (2006.01)

(21) International Application Number:
PCT/DK2011/050103

(22) International Filing Date:
30 March 2011 (30.03.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/318,882 30 March 2010 (30.03.2010) US
PA 2010 00264 30 March 2010 (30.03.2010) DK

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(74) **Agent**: **HØIBERG A/S**; St. Kongensgade 59 A, DK-1264 Copenhagen K (DK).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: SCANNING OF CAVITIES WITH RESTRICTED ACCESSIBILITY

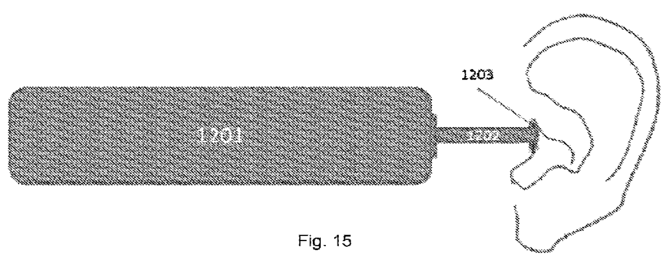


Fig. 15

(57) **Abstract**: Disclosed is a method and a scanner system for scanning interior surfaces, where the method comprises: - providing a probe shaped scanner having an axis, where the probe shaped scanner comprises: • at least one light source configured to create and project structured light, and • at least one camera configured to record 2D images; - entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object; - creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object; - recording a series of 2D images of the reflection of the pattern from the interior surface using said camera; - combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and - providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created. The scanner system may comprise a probe shaped scanner, a data conversion device and a data processing device, optionally all integrated in one device. (fig.15 should be published)

WO 2011/120526 A1

Scanning of cavities with restricted accessibility

The invention relates to the creation of high precision three-dimensional replicas of real objects. The invention specifically concerns the three-dimensional scanning of interior surfaces or cavities of limited dimensions or with restricted accessibility. Furthermore, the invention relates in particular to scanning the human ear and ear canal.

Systems for three-dimensional optical scanning are well known in the prior art. They typically comprise one or more light sources projecting a structured light pattern on the object to be scanned, one or more cameras and data processing equipment to convert the recorded image coordinates to three dimensional coordinates using state of the art software. Usually, only a part of the object is scanned in a single scan. To create a full scan the object, camera and light source need to be move relative to each other.

Accuracy and precision are of utmost importance in many applications, e.g. when the scan data is used to model an object that must fit precisely into another part. Such applications are e.g. devices for the ear canal such as hearing aids, dental implants and other prostheses for the body. For hearing aid shells, sub-millimeter precision is required lest the shell cause irritation, acoustic feedback and possibly infection to the epidermis of the ear canal. For dental implants the precision requirement is even greater, since a human being can detect differences less than 1/10 of a millimeter when biting. Therefore systematic or random errors in the calibration and/or performance of scanners for these uses can be serious. This has hitherto limited the use of scanning in the modeling of such implants and shells.

Disclosed is a method for scanning interior surfaces, where the method comprises:

- providing a probe shaped scanner having an axis, where the probe shaped scanner comprises:

  - at least one light source configured to create and project structured light, and
  - at least one camera configured to record 2D images;

- entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object;

- creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object;

- recording a series of 2D images of the reflection of the pattern from the interior surface using said camera;

- combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and

- providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created.

The method may in particular be suitable for scanning partly obstructed interior surfaces, where visual access to part of the interior surface is blocked due to e.g. impurities and/or due to the geometrical form of the interior surface where e.g. bends may prevent visual access to a part of the interior surface.

The method may also be applicable to the scanning of interior surfaces where visual access is provided over the entire scanned surface.

In some embodiments, the method comprises:

- providing that the camera comprises a plurality of sensor elements or a plurality of groups of sensor elements;

- varying the focus plane of the pattern over a range of focus plane positions while maintaining a substantially fixed spatial relation of the camera and said interior surface,

where the combining of 2D images comprises determining by analysis of said 2D images the in-focus position(s) of the focus plane for:

a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or

b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes,

and where said 3D real world coordinates are from said in-focus positions.

Disclosed is a scanner system for three-dimensional scanning of interior surfaces, said scanner comprising:

- a probe shape scanner configured to be entered into a cavity, said probe shaped scanner comprising

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object, where said light source emits light from a point of emission; and
- at least one camera, adapted to record 2D images of the pattern, where the camera accumulates light at a point of accumulation;

- a data conversion device adapted to convert 2D images into 3D real world coordinates,

- a data processing device configured to create surface information for areas of the surface, where image scanning is not complete.

Disclosed is a method for scanning interior surfaces comprising the

- entering a probe shaped scanner having an axis into a cavity,
- creating and projecting structured light from a light source on the probe producing a pattern on an interior surface of an object, and at a camera of the probe, recording 2D images of the pattern reflected from the interior surface, thereby performing a scan around the axis of the probe,
- determining 2D coordinates of the images of the pattern,
- combining a series of images to obtain 3D real world coordinates of the interior surface, and
- processing data such that surface information from areas of the surface, where image scanning is not complete, is created.

Consequently, it is an advantage that surface information can be obtained for e.g. areas where there are no 2D images recorded, due to e.g. holes of surface information, by e.g. using kinds of data other than image data.

In some embodiments, the data that are provided and processed to create surface information, are obtained from the recorded 2D images.

In some embodiments, the probe shaped scanner has an axis and where a scan around the axis is performed.

In the context of the present invention, the phrase “hole in the surface information” may relate to a part of the surface where data is lacking. Such a lack of data may e.g. occur when visual access to the interior surface is blocked. The holes may also be referred to as occluded holes when caused by an object that blocks the visual access to the interior surface of the object

Furthermore it is an advantage that surface information can be obtained even if the surface in e.g. the ear is not clean, such that 2D images do not correctly show the recorded surface, e.g., if there are foreign objects, such as ear wax in the ear covering parts of the surface, or if there are other foreign objects such as hair, scars or animals in the ear diminishing the quality of the scanning. Thus foreign object may be hair, ear wax, small animals such as insects, eggs from insects, pearls, sand, dirt, pimples, scars etc.

Consequently, it may be an advantage that prior to scanning, the patient's ear need not be rinsed to remove foreign objects such as cerumen or ear wax. Hereby the patient does not need to visit a doctor to have his/her ear rinsed. In some cases it may be advantageous to apply a diffusively reflecting material to the surface of the ear canal if the appearance is too glossy.
Both the ear canal and the external part of the ear, called the pinna, may be scanned.

It is an advantage that one scan can be performed in less than 1 minute.

The axis of the scanner may be the longitudinal axis of the scanner and/or the optical axis of the scanner. The optical axis of the scanner may be defined by the optical axis of the camera or the optical axis of the light source

It is an advantage to scan the ear and the ear canal directly with a scanner, instead of providing an impression of the ear canal, and then scanning the impression. The silicone used when making an impression expands the ear and may thus not give a correct impression.

It is a further advantage with regard to ear scanning that the improved fit of the hearing aid shells according to the present invention compared to prior art hearing aid shells means that the frequent problem of acoustic feedback in hearing aids is minimized.

Furthermore it is an advantage that the direct scanning of the ear significantly reduces the production cost of hearing aids, since the impressions used today are rendered superfluous. Obviating the impression removes the handling and mailing cost and cuts down the production time and improves flexibility.

Thus it is an advantage that the method allows for easy scanning of interior surfaces of objects which cannot be scanned with high precision using prior art scanning methods.

Preferably the method is carried out with a scanner according to the invention.

According to one aspect the invention relates to a method for 3D modeling and production comprising obtaining 3D real world coordinates of an interior surface of a cavity provided using the method according to the invention, and creating a piece adapted to fit into the cavity.
Thereby, the steps for manufacturing the piece are reduced to the absolute minimum and an essentially perfect fit of the piece can be obtained. The interior surface may be scanned a number of times, such as under different conditions affecting the geometry of the interior surface. Thereby the variations in the dimensions of the interior surface can be recorded. This is very cumbersome using the prior art techniques.

Once the data are recorded the piece may be manufactured using any automatic manufacturing technique such as milling. More preferably the modeling technique comprises 3Dimensional printing, stereo lithography, selective laser sintering, laminated object modeling, inkjet modeling, fused deposition modeling, or nano-printing. A common feature of these techniques is that only the required amount of material is used and that it is easier to produce complex models such as devices for the ear and/or ear canal and/or dental implants.

The devices for the ear may comprise a hearing aid, a mobile phone, a loud speaker, noise protection, a microphone, communication devices, a tinnitus masker or a tinnitus masking device such as the ones described in US 5,325,872 and WO 91/17638.

In some embodiments holes in the surface information are registered.
When holes in the surface information of the physical object are registered, other ways of determining the surface or the contour of the surface at these areas can be applied such that all areas will be covered, imaged, detected, or interpolated in one way or the other for acquiring surface information.

In some embodiments holes in the surface information are closed by fitting to higher-order mathematical surfaces, such as second-order, third--order, fourth-order etc.
The information from neighbour areas etc can be used to infer the contour at holes. Thus the artificial hole closing may be performed by fitting parametric surface such as spline surface or higher-order mathematical surfaces.

In some embodiments holes in the surface information are closed by using information about where there exists no surface.
If complete image data are missing from a region of the ear canal, then knowledge about the ear anatomy indicating that there exists no surface in said particular part of the region can be used to determine where the surface then should be arranged or interpolated. Thus the surface should not be in an area where it is positively detected that there is no surface. Thus it is an advantage to exclude a volume from scans or 2D images where it is certain that there exists no surface.

In some embodiments holes in the surface information are closed by combing image data with data other than image data.

It is an advantage to combine image data with other types of data, e.g. data from other sources or sensors than the image sensor or camera, such as data from a touch sensor, such that the image data can be verified, assisted or supported by the other data.

In some embodiments holes in the surface information are closed by using other data than image data.
It is an advantage to use data from other sources or sensors than the camera providing the image data, if there exist no image data covering an area of the surface.

In some embodiments the surface model obtained from the scan is processed, for example smoothed. Processing can remove noise and outliers in the raw scan data.

In some embodiments other data than image data comprises color, interference, angle of reflected light, and/or data from one or more other sensors than the camera.

In some embodiments the one or more other sensors comprise touch sensor, contact sensor, sonic sensor, and/or temperature sensor.

In some embodiments a part of the data of surface information of the left ear is used as a part of the data of surface information for the right ear, if there are parts of the right ear where surface information has not been acquired, and vice versa.
It is an advantage to use corresponding scan data from one ear to the other ear, because of symmetry between a person’s two ears.

A part of the data of surface information of the left ear may be used for verifying data obtained from one the right ear even though no data are missing for that ear, and vice versa.

In some embodiments holes or missing areas in a scan are inferred or interpolated based on previous scans of the person's ear. It is an advantage because especially children with hearing loss require refitted hearing aids frequently as they grow, but the shape of their ear canal may not change as rapidly as its size.

In some embodiments foreign objects in the ear canal are identified.

In some embodiments identifying foreign objects comprises detecting reflections from the foreign object.
It is an advantage because foreign objects such as hair may reflect light very well, and thus the reflections from hair and other foreign objects may be distinct from reflections from skin in the ear.

In some embodiments a foreign object is identified by analyzing the difference in the reflected light from the skin and the foreign object, respectively.
The difference in the reflected light may be the difference in contrast of the reflected light.

In some embodiments a foreign object is identified if it has an overall higher or lower reflectivity than the skin.

In some embodiments the foreign object is identified if there is a sudden change in reflectivity at the boundary between the foreign object and the skin.

In some embodiments the foreign object is identified by means of a combination of its overall higher or lower reflectivity than the skin and the sudden change in reflectivity at the boundary between the foreign object and the skin.

It is an advantage to detect the foreign object by its different reflectivity, because it allows monochromatic or near-monochromatic light to be used. Thus detection of the contrast is better according to the present method than described in prior art US7529577B, which discloses "analyzing the output with respect to spectral composition of the light received at the light sensitive element and identifying foreign object based on the spectral composition of the received light", see claim 1. According to the present method a monochromatic or near-monochromatic light may be used.

In some embodiments the method comprises using monochromatic light to illuminate the surface for analyzing reflected light.
The light or illumination may alternatively be semi-monochromatic or light having more wavelengths.

In some embodiments the method comprises identifying foreign objects by correlating surface data with the 3D position of the specific data.
It is an advantage because the places in the ear where hair and ear wax are typically present may be known in advance. Likewise the places in the ear where hair or ear wax seldom or never are present may also be known in advance. Thus by correlating the predefined knowledge about typical places for hair and ear wax, respectively, with the actual scan, it is possible to either rule out that a foreign object can be hair or ear wax, or possible to determine with a high probability that a detected foreign object is hair or ear wax.

In some embodiments detecting hair comprises having predefined information in the system about where hair normally is arranged in the ear.

It is an advantage because if inconclusive data is obtained from a place in the ear, and this place typically contains hair, then the inconclusive data is likely to stem from hair.

In some embodiments foreign objects in the ear are filtered out from the images of the ear.
It is an advantage that the ear shall not be cleansed and rinsed before scanning the ear, because foreign object such as ear wax is filtered out from the images.

In some embodiments foreign objects are presented to the operator on a display.

In some embodiments the operator can assist in detecting foreign objects by reacting to the data presented on the display. This may be by pointing toward foreign objects or by pointing toward borders between the foreign objects and the skin.

In some embodiments the foreign objects are colored in a different color on the display than the rest of the surface on the image.

In some embodiments detecting hair comprises detecting and deleting single points on the images.
It is an advantage because hair may appear as single points on the images, because a hair is normally not thick enough to provide a real image of it.

In some embodiments detecting hair comprises detecting the root of the hair in the skin.
It is an advantage to detect the root of a hair, because it ends in an enlargement, the hair bulb, which is whiter in color and softer in texture than the shaft, and is lodged in a follicular involution called the hair follicle in the

epidermis layer of the skin, and therefore it may be easier to detect the root of a hair than the hair itself, because the skin is different at the point where a hair is growing out.

In some embodiments detecting hair comprises detecting the thickness of the hair.
It is an advantage because hereby it can be determined whether a hair is so thick that it may influence the measurements or whether the hair is thin enough to be disregarded.

In some embodiments detecting hair comprises detecting the movement of hair when the probe touches the hair.

In some embodiments the method comprises determining whether scar tissue is fresh or old, when detecting a foreign object in the form of scar tissue,
It is an advantage because if the scar is fresh, the scar should heal before the ear scanned and a hearing device is applied in the ear.
On the other hand if the scar is old, then a hearing device can be fitted by avoiding that the hearing device applies pressure on the scar, which will be uncomfortable for the user.

The light source may be configured to create and project structured light such that a pattern is produced on a surface exposed to light from the light source.

In some embodiments color filters are applied to the light source.
It is an advantage to use color filters such as red, green and blue, since hereby different colors to be emitted to the surface can be produced using only a single light source.

In some embodiments the light source is adapted to emit different colors.

It is an advantage since the different colors can be used to detect different objects or features of the surface. The wavelengths of the different colors may be close to each other to obtain a good result.

In some embodiments the light source emits multi-colored light.
It is an advantage to use multi-colored light in combination with the patterned light, e.g. chessboard pattern, because each period or region in the pattern can be analysed for each different color.

Furthermore, it is an advantage to use multi-colored light in combination with a pattern with differently colored periods or regions because each period or region in the pattern can be analyzed for each different color without analyzing the spectral composition of the light reflected from the surface.

In some embodiments the light source emits monochromatic or near-monochromatic light but switches between different colors in time. It is an advantage to use light varying in color over a period of time because the pattern can be analyzed for each different color without analyzing the spectral composition of the light reflected from the surface.

In some embodiments the size of regions of the emitted light pattern is 20x20 mm.

In some embodiments the size of the regions of the emitted light pattern is 10x10 mm.

It is an advantage to use a pattern which is two times smaller, since hereby there are four squares within one area instead of one square within the same area, and hereby a better resolution can be achieved.

In some embodiments light with different polarisation is used, such that light with different polarisations is projected onto the interior surface of the object.

In some embodiments the polarization state of the emitted and/or the detected light is controlled.
It is an advantage to control the polarization because hereby skin and in particular hair, which has a high degree of specular reflection, can be distinguished from surfaces with a low degree of specular reflection. Surfaces with a high degree of specular reflection reflect light with a specific relationship between the polarization of the incident and reflected light. In this way surfaces with high degree of specular reflection may be distinguished from surfaces with low degree of specular reflection.

The polarization of reflected light may be controlled by means of e.g. a linear polarization filter or quarter wave plate or filter, which can be added and/or removed from the light path and/or rotated in the light path.

In some embodiments the light source is a laser and light from said laser is guided to impinge on the surface in a small spot.

In some embodiments there is more than one light source in the probe shaped scanner and the different light sources are alternately turned on and turned off.

In some embodiments the light source emits infrared light.

It is an advantage because it may be possible to see right through hair using infrared light.

In some embodiments the optical resolution of the scanner is 100 µm.

It is an advantage to have such a high resolution since hereby as many details of the surface as possible can be resolved. Alternatively, the resolution of the scanner may be 200 μm.

In some embodiments the method comprises detecting the hardness under the skin in different parts of the ear canal.
It is an advantage because a soft part of the ear canal is likely to be tissue, and a hard part of the ear canal is likely to be bone, and if the hearing device has a very tight fit in the ear canal where there is bone, it may be very unpleasant for the user. On the other hand, the hearing device can have a tight fit where there is soft tissue under the skin in the ear canal. So by detecting where there is soft tissue and hard bone in the ear canal, the hearing device can be made to fit very comfortably in the user's ear.

In some embodiments light with different wavelengths is used to detect the hardness under the skin in the ear canal.
It is an advantage because the different layers of skin, bone, tissue etc has different properties regarding absorption and/or scattering for different light wavelengths.

In some embodiments the light used for scanning comprises one or more narrow laser beams co-propagating with a broader light beam. The co-propagating laser beams may be light that is reflected and/or refracted from a prism or a beam-combining element. It is an advantage because the narrow laser beams may be of a different color than the broader light beam. The light from the narrow laser beams reflected from the surface may be used to determine the amount of absorption and/or scattering in the tissue in the regions where the narrow beams impinge. A region of large absorption may result in reflection of a small amount of light compared to a region of small absorption. A region of large scattering may result in reflection of a considerably broadened beam compared to a region of small sub-surface scattering. Soft or hard tissue in the ear may differ in the amount of light absorption and/or scattering. Thus this may be used to identify soft or hard regions in the ear.

In some embodiments the hardness under the skin is evaluated by detecting the reflected pattern of light, calculating the size of the regions of the pattern, and comparing this size with the regular or emitted size of the regions of the pattern.

In some embodiments the scanner comprises guide means adapted to assist the operator in holding the scanner in the correct distance and/or position relative to the ear.
The distance may be relative to an external part of the ear, the pinna, or relative to a part of the ear canal.

In some embodiments the guide means comprises two laser beams, and when the two laser beams are crossing each other at a point on the ear, the distance between scanner and ear is correct for scanning.
The point on the ear may a point on the external part of the ear.

In some embodiments the guide means comprises a first and a second set of two laser beams, and when the first set of laser beams are crossing each other at a first point on the ear, the distance between scanner and ear is correct for scanning of a first region of the ear, and when the second set of laser beams are crossing each other at a second point on the ear the distance between the scanner and ear is correct for scanning of a second region of the ear.
The points on the ear may be one point or two different points on the external part of the ear. The first and the second point may indicate the distance the scanner probe should be moved in/out of the ear.

The two sets of two laser beams may be of different color.

In some embodiments the ear is scanned in a first configuration where the mouth is closed, and in a second configuration, where the mouth is open. It is an advantage because then the two extreme configurations of the jaw and mouth and thereby the ear are recorded.

Thus with regard to ear scanning it is possible to record a number of scans of one ear, and ask the patient to deliberately vary the size of the ear canal by swallowing, yawning, chewing, and drinking. In this way a series of scans of the ear canal can be recorded and the magnitude of the variation of the patient's ear canal can be detected.

In some embodiments the image data of the first and the second configurations are merged into one image by means of CAD. Thus it is possible to superimpose the scans on one another to create a combined image or model, which will fit the patient's ear under all conditions. Such a model is naturally made as a combination of or a compromise between the different sizes of the ear canal.

In some embodiments a touch sensor is arranged in connection with the scanner, such that the touch sensor is adapted to register contact with the skin.

In some embodiments the touch sensor comprises a tactile component at the probe tip. It is an advantage to also perform a touch or contact measurement to thereby obtain a double check of the real time image detection, and to acquire further data which can be used to obtain a complete scan of the ear canal.

In some embodiments the touch sensor is a capacitive sensor.

In some embodiments the direction of the ear canal towards the ear drum is determined by means of image data and/or one or more other data.
It is an advantage because when the direction of the ear canal towards the ear drum is known, the speaker or transceiver in a hearing aid can be arranged such that it points directly towards the ear drum, whereby the user of the hearing aid will receive the sounds directly at the ear drum, whereby the sound quality is improved for the user.

In some embodiments a motion sensor is arranged in connection with the scanner, such that the motion sensor is adapted to perform a motion measurement of the scanner.
It is an advantage also to perform motion measurement, since this can be used in registration.

In some embodiments an orientation sensor is arranged in connection with the scanner, such that the orientation sensor is adapted to perform an orientation measurement of the scanner.

In some embodiments the scanner comprises a number of marks in its cover, such that an operator can visually determine how far the scanner must be moved into the ear canal.
It is an advantage because when the scanner is moved into an ear canal, the operator may not be able to see the tip of the scanner. When the operator can see the marks of the scanner cover, he thereby has a guide to how far the scanner is moved into the ear, and when it should not be moved any further into the ear, in order not to be touching the ear drum. The marks may e.g. be three lines arranged with a distance from each other on the scanner cover.

In some embodiments a user interface of the scanner is adapted to direct the operator to insert the probe a certain distance into the ear canal.

It is an advantage since it may be used in registration.

In some embodiments a user interface of the scanner is adapted to direct the operator to move the probe a certain distance in any three-dimensional direction.
It is an advantage since it may be used in registration.

In some embodiments the shape of the probe prevents it from reaching the ear drum. It is an advantage because the ear drum or tympanic membrane is very sensitive. For example, the probe can have a conical longitudinal cross section, or a bulge.

In some embodiments a camera, such as a second camera or a video camera, is arranged in relation to the scanner such that it is configured to record images, from where the position of the scanner relative to the ear is adapted to be determined.
It is an advantage to record the scanner position relative to the ear by means of a regular camera capturing photographs or by means of a video camera.

In some embodiments the method comprises the steps of:
- varying the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the camera and the surface,
- determining the in-focus position(s) of:
a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or
b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes, and
transforming in-focus data into 3D real world coordinates.

One object of the invention is to provide a scanner which may be integrated in a manageable housing, such as a handheld housing. One object of the invention is to discriminate out-of-focus information. One object of the invention is to provide a fast scanning time.

The focus scanning may be achieved by a scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:

- means for generating a probe light incorporating a pattern,
- at least one camera accommodating an array of sensor elements,
- means for transmitting the probe light towards the object thereby illuminating at least a part of the object with said pattern,
- means for imaging light reflected from the object to the camera,
- means for varying the position of the focus plane of the pattern on the object while maintaining a fixed spatial relation of the scanner and the object, and
- data processing means for:
    a) determining the in-focus position(s) of:
        - each of a plurality of the sensor elements for a range of focus plane positions, or
        - each of a plurality of groups of the sensor elements for a range of focus plane positions, and
    b) transforming in-focus data into 3D real world coordinates.

The method and apparatus relating to focus scanning is for providing a 3D surface registration of objects using light as a non-contact probing agent. The light is provided in the form of an illumination pattern to provide a light oscillation on the object. The variation / oscillation in the pattern may be spatial, e.g. a static checkerboard pattern, and/or it may be time varying, for example by moving a pattern across the object being scanned.

Focus scanning provides for a variation of the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the scanner and the object. It does not mean that the scan must be provided with a fixed spatial relation of the scanner and the object, but merely that the focus plane can be varied (scanned) with a fixed spatial relation of the scanner and the object. This provides for a hand held scanner solution based on focus scanning.

Some embodiments comprises a first optical system, such as an arrangement of lenses, for transmitting the probe light towards the object and a second optical system for imaging light reflected from the object to the camera. In some embodiments only one optical system images the pattern onto the object and images the object, or at least a part of the object, onto the camera, e.g. along the same optical axis, however along opposite optical paths.

In some embodiments an optical system provides a confocal imaging of the pattern onto the object being probed and from the object being probed to the camera. The focus plane may be adjusted in such a way that the image of the pattern on the probed object is shifted along the optical axis, e.g. in equal steps from one end of the scanning region to the other. The probe light incorporating the pattern provides a pattern of light and darkness on the object. Specifically, when the pattern is varied in time for a fixed focus plane then the in-focus regions on the object will display an oscillating pattern of light and darkness. The out-of-focus regions will display smaller or no contrast in the light oscillations.

When a time varying pattern is applied a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane and at different instances of the pattern. As the focus plane coincides with the scan surface at a single pixel position, the pattern will be projected onto the surface point in-focus and with high contrast, thereby giving rise to a large variation, or amplitude, of the pixel value over time. For each pixel it is thus possible to identify individual settings of the focusing plane for which each pixel will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel basis.

Thus, in one embodiment the focus position is calculated by determining the light oscillation amplitude for each of a plurality of sensor elements for a range of focus planes.

For a static pattern a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane. As the focus plane coincides with the scan surface, the pattern will be projected onto the surface point in-focus and with high contrast. The high contrast gives rise to a large spatial variation of the static pattern on the surface of the object, thereby providing a large variation, or amplitude, of the pixel values over a group of adjacent pixels. For each group of pixels it is thus possible to identify individual settings of the focusing plane for which each group of pixels will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel group basis.

Thus, in one embodiment the focus position is calculated by determining the light oscillation amplitude for each of a plurality of groups of the sensor elements for a range of focus planes.

The 2D to 3D conversion of the image data can be performed in a number of ways known in the art. I.e. the 3D surface structure of the probed object can be determined by finding the plane corresponding to the maximum light oscillation amplitude for each sensor element, or for each group of sensor elements, in the camera's sensor array when recording the light amplitude for a range of different focus planes. Preferably, the focus plane is adjusted in equal steps from one end of the scanning region to the other. Preferably the focus plane can be moved in a range large enough to at least coincide with the surface of the object being scanned.

Handheld embodiments of the invention preferably include motion sensors such as accelerometers and/or gyros. Preferably, these micro electro mechanical systems (MEMS) should measure all motion in 3D, i.e., both translations and rotations for the three principal coordinate axes. The benefits are:

A) Motion sensors can detect vibrations and/or shaking. Scans such affected can be either discarded or corrected by use of image stabilization techniques.
B) Motion sensors can help with stitching/ registering partial scans to each other. This advantage is relevant when the field of view of the scanner is smaller than the object to be scanned. In this situation, the scanner is applied for small regions of the object (one at a time) that then are combined to obtain the full scan. In the ideal case, motion sensors can provide the required relative rigid-motion transformation between partial scans' local coordinates, because they measure the relative position of the scanning device in each partial scan. Motion sensors with limited accuracy can still provide a first guess for a software-based stitching/ registration of partial scans based on, e.g., the Iterative Closest Point class of algorithms, resulting in reduced computation time.
C) Motion sensors can be used (also) as a remote control for the software that accompanies the invention. Such software, for example, can be used to visualize the acquired scan. With the scanner device now acting as a remote control, the user can, for example, rotate

and/or pan the view (by moving the remote control in the same way as the object on the computer screen should "move"). Especially in clinical application, such dual use of the handheld scanner is preferable out of hygienic considerations, because the operator avoids contamination from alternative, hand-operated input devices (touch screen, mouse, keyboard, etc).

The present invention relates to different aspects including the method described above and in the following, and corresponding apparatus, methods, devices, uses and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a scanner for three-dimensional scanning of interior surfaces, comprising:

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object,
- at least one camera, adapted to record 2D images of the pattern,
- data processing means adapted to convert 2D image information into 3D real world coordinates,
- the point of emission of light as well as the point of accumulation of reflected light for the camera being located on a probe having an axis,
- the at least one light source and the at least one camera being adapted to perform a scan around the axis,
- the probe being adapted to be entered into a cavity, and

wherein the scanner comprises:

- means for processing data such that surface information from areas of the surface, where image scanning is not complete, is created.

The probe of the scanner may be either rigid of flexible.

This scanner has the advantage that it may be able to cover the whole circumference without moving the scanner thus being able to scan the whole inner surface of an object. With this layout it is possible to scan interior surfaces such as the ear canal, tubes, pipes and bores with non-contact scanning and obtain high precision scan data of the whole interior surface of the object.

Furthermore, the dimensions of the scanner can be very small thus allowing scanning and 3D mapping of interior surfaces with small cross section, which are inaccessible to prior art scanners.

It is an advantage that the scanner is equipped with a position sensor, which allows the relative position and orientation of the scanner and the object to be determined for successive scans. This greatly facilitates the combination of data from successive scans and makes it possible to combine these with much higher precision irrespective of the position and orientation of the scanner during scanning.

The compact layout of the scanner allows for easy scanning of interior surfaces of objects of extremely small size. The ease of operation of the scanners according to the invention means that practitioners without experience in scanning can easily perform the scanning operations, which is required especially in the case of scanning of body cavities and scanning for archaeological purposes.

In some embodiments, the probe shaped scanner has an axis and the at least one light source and the at least one camera are adapted to perform a scan around the axis

In some embodiments, the data conversion device and said probe shaped scanner are integrated in one device.
In some embodiments, the data conversion device is part of a separate unit, such as part of a personal computer connected to the probe shaped scanner.

In some embodiments, the said data processing device and said probe shaped scanner are integrated in one device.
In some embodiments, the data processing device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

In some embodiments, the data processing device and said data conversion device are comprised in one integrated conversion and processing device. The integrated conversion and processing device and the probe shaped scanner may be integrated in one device

In some embodiments, the scanner system comprises a nontransitory computer readable medium having one or more computer instructions stored thereon, where said computer instructions comprises instructions for conversion of 2D images and/or for processing data.

Disclosed is a hearing aid device obtained by from a 3D model of the interior surface of an ear, where said 3D model is obtained by the method according to the invention and/or by the scanner according to the invention.

Disclosed is a nontransitory computer readable medium storing thereon a computer program, where said computer program is configured for causing computer-assisted scanning of partly obstructed interior surfaces.

Disclosed is a computer program product comprising program code means for causing a data processing system to perform the method described above when said program code means are executed on the data processing system, and a computer program product comprising a computer-readable medium having stored there on the program code means.

Brief description of the drawings

The above and/or additional objects, features and advantages of the present invention, will be further elucidated by the following illustrative and non-limiting detailed description of embodiments of the present invention, with reference to the appended drawings, wherein:

Figure 1 illustrates an embodiment of the interior surface scanner according to the invention.

Figure 2 shows a cross section of an embodiment of the interior surface scanner according to the invention.

Figure 3 illustrates another embodiment of the interior surface scanner with a mirror in front of the camera.

Figure 4 shows a cross section of another embodiment of the interior surface scanner with a mirror in front of the camera.

Figure 5 shows how a structured light pattern is projected onto the interior surface. In this case the pattern is a single cone. This pattern is then reflected from the surface into the camera.

Figure 6 illustrates an example of the use of mirrors and/or prisms. A structured light pattern is reflected in a mirror before being projected onto the interior surface. In this case the pattern is a single cone. This pattern is then reflected from the surface into a mirror that reflects the pattern into the camera.

Figure 7 shows a cross section of a model of the interior surface scanner according to the invention. Note that the camera has been moved out of the probe and a lens system is used to guide the image to the camera.

Figure 8 shows a cross section of a model of the interior surface scanner according to the invention. Note that the camera has been moved out of the probe and optical fibres are used to guide the image to the camera.

Figure 9 illustrates different positions sensors, which can be applied within the invention.

Figure 10 shows an embodiment of a hollow calibration object used for calibration of the camera and light sources. Note the symmetric 3D object feature curves on the object, which are utilised in the calibration.

Figure 11 shows a schematic sketch of a scanner according to the invention adapted for scanning of the ear and ear canal.

Figure 12 shows a schematic sketch of another embodiment of the scanner for the ear and ear canal.

Figure 13 shows a scan of an ear and an ear canal seen from two different views.

Figure 14 illustrates an embodiment of the scanner being able to scan the surface lying behind the end of the probe.

Fig. 15 shows an example of a scanner with a probe in an ear.

Fig. 16 shows an example of scanner with an extra camera mounted.

Fig. 17 shows examples of laser beams for guiding the position and orientation of the scanner.

In the following description, reference is made to the accompanying figures, which show by way of illustration how the invention may be practiced.

Figure 1 to Figure 4 illustrates two embodiments of the invention. The first part 101 of the scanner is the probe, which is inserted into the cavity. The second part 102 is a handle. The scanner in Figure 1 and Figure 2 comprises a cover 103, a scan button 104, a disposable cover 105, light guides 201, a light source 202, a position sensor 203, optics and mirrors and/or prisms 204, a camera 205 and a protector/collision detector 206. A rotating mirror and/or prism with a micro motor 301 is also added to the component list in the embodiment shown in Figure 3 and Figure 4. As illustrated in Figure 5, the scanner works by projecting a structured light pattern 501 onto the interior surface of the object 502. The camera 503 acquires images of the reflection 504 of the light pattern from the surface. By locating the light pattern in the images, the corresponding 3D surface positions can be reconstructed applying well-known projective geometry. The scanner only scans limited parts of the surface at each position and usually it has to be moved around handheld or automatically to scan the full interior surface.

The light is generated by one or more light sources such as lasers, variable output-powered laser, light emitting diodes (LED), halogen spots or other spotlights and travels through the light guides such as optical fibers. In some applications it might be relevant to use monochromatic, coherent or polarized light. At the end of the light guides optics and mirrors and/or prisms may create the desired pattern. Examples of optics are filters, lenses or prisms. An alternative to the use of light guides is to place the light source near the tip of the scanner. Note that the projection of light, even lasers, onto the surface does not damage the surface.

The light sources for some applications preferably are as small as possible to minimize the dimensions of the scanner. It is thus contemplated that the light source may have a cross section perpendicular to the direction of emitted light of less than 5 mm^2, preferably less than 4 mm^2, for example less than 3 mm^2, such as less than 2 mm^2, for example less than 1 mm^2, such as less than 0.5 mm^2, for example less than 0.25 mm^2.

The scanner may work with only one light source, but for many purposes it is advantageous to have several such as at least two light sources, such as at least three light sources, for example at least four light sources, such as at least five light sources, such as at least six light sources, for example at least seven light sources, such as at least eight light sources, for example at least ten light sources, such as at least twelve light sources, for example at least sixteen light sources, such as at least twenty light sources.

Depending on the desired pattern one, two, three or more optics and one, two, three, four or more mirror and/or prisms are required. The structured light pattern may be a number of rays forming a grid of spots on the surface consisting of one, two, three, four or more rows of points, one, two, three or more cones of light forming contours on the surface, one, two, three of more planes of light forming contours on the surface, one, two, three of more thick planes of light forming thick contours on the surface, a number of rectangular shaped rays forming a distorted checker board pattern on the surface or more complex shapes.

Thus, when projecting a pattern of rays, pattern may comprise at least 10 rays, such as at least 25 rays, for example at least 100 rays, such as at least 1000 rays, for example at least 10,000 rays, such as at least 100,000 rays, for example at least 1,000,000 rays.

Figure 5 illustrates how a single light cone 501 is projected onto the object surface 502 using optics 503. Figure 6 shows how the emission angle of the light cone can be increased significantly by reflecting the emitted light 601 into a cone mirror and/or prism 602 after the optics 603. Any type of mirrors such as coplanar mirrors and cone mirrors can be used to reflect the light. Applying mirrors and/or prisms make it possible to change the emission direction invariant of the orientation of the light guides. The light pattern can also be moved over the surface without moving the actual scanner by rotating and/or tilting the mirrors and/or prisms. The rotation and/or tilting of the mirrors and/or prisms may be carried out by a motor.

Preferably the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe are chosen to give an angle between incident light on the object and light reflected from the object of approximately 20-30 degrees. An example of this embodiment is illustrated in figure 6.

Occlusion effects represent a problem for some types of scanning of interior surfaces. Some of these can be overcome by selecting a direction of emission and recording of light with respect to the axis of the scanner, which ensures that light is projected on and recorded from all parts of the interior surfaces. One embodiment of the scanner is designed, wherein the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe are chosen to give a scan of the surface lying ahead of the end of the probe. An example of such a scanner is shown in Figure 5. Alternatively the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe may be chosen to give a scan of the surface lying approximately around the end of the probe. An example of this is shown in figure 6. Alternatively, the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe may be chosen to give a scan of the surface lying behind the end of the probe. Figure 14 illustrates an example of such a scanner. These alternative embodiments may be obtained with one scanner by tilting mirrors and/or prisms.

The light source intensities are preferably varied depending on the surface and color of the object to be scanned. Preferably the intensity should be determined automatically using automatic light source intensity calibration.

The intensity calibration may be performed by inserting the scanner into the object and calculate a number of histograms from the acquired images. First a histogram is calculated with the light source turned off. A second histogram is the calculated when the light source is turned on with an arbitrary intensity. The first histogram is then subtracted from the second to remove the background intensity. The intensity is then adjusted until the requested quantile corresponds to a predefined intensity. The background could also be removed by subtracting the image corresponding to the light source turned off from the image with light. The histogram used to determine the intensity could then be calculated from this difference image.

The images are acquired by the one or more cameras. Preferably the cameras comprise a lens and a sensor array such as a CCD or CMOS chip. Usually the camera also comprises a filter placed in front of the sensor array. The effect of the filter is that only light with approximately the desired wavelength passes the filter. This makes it feasible to separate different light sources in the scanner and remove most of the background light. Alternatively, the camera may be color sensitive.

The scanner may comprise just one camera or comprise several such as at least 2 cameras, such as at least 3 cameras, for example at least 4 cameras, such as at least 6 cameras, for example at least 7 cameras, such as at least 8 cameras, for example at least 10 cameras, such as at least 12 cameras, for example at least 16 cameras, such as at least 20 cameras.

Preferably the cameras are arranged such that reflected light is recorded from different directions covering the 360 degrees around the probe, as seen in Figures 11 and 12, right side.

Preferably the camera part of the scanner is as small as possible. The size of commercially available cameras is reduced almost every year, and it is estimated that the lower limit for camera size and pixel size have not been reached at all yet. Irrespective of the future development within this area, any camera smaller than the cameras presently available will be suitable for use in the present invention. Therefore the light detecting component of the camera may have a cross section in a direction perpendicular to the direction of incident light of less than 10 mm^2, such as less than 9 mm^2, for example less than 8 mm^2, such as less than 7 mm^2, for example less than 6 mm^2, such as less than 5 mm^2, for example less than 4 mm^2, such as less than 3 mm^2, for example less than 1 mm^2, such as less than 0.5 mm^2, for example less than 0.25 mm^2, such as less than 0.1 mm^2, for example less than 0.01 mm^2.

The number of pixels of the camera is a question of the size of the camera, depending on the size of the pixels, the computing power used for processing the results of the scans and the cost of the camera. No upper limit for the number of pixels can be set, since precision is increased whenever the number of pixels is increased. Accordingly, the camera may comprise an array of at least 125x125 pixels, more preferably at least 250x250 pixels, more preferably more than 500x500 pixels, more preferably more than 1000x1000 pixels, such as more than 2000x2000 pixels, for example more than 4000x4000 pixels, such as more than 8000x8000 pixels, for example more than 10,000x10,000 pixels, such as more than 25,000x25,000 pixels, for example more than 50,000x50,000 pixels, such as more than 100,000x100,000 pixels, for example more than 250,000x250,000 pixels, such as more than 500,000x500,000 pixels, for example more than 1,000,000x1,000,000 pixels. Similarly, the pixel size may be the smallest available on the market, for example wherein a cross section of a pixel is less than 100 micrometres, such as less than 50 micrometres, for example less than 25 micrometres, such as less than 20 micrometres, for example less than 15 micrometres, such as less than 10 micrometres, for example less than 7.5 micrometres, such as less than 5 micrometres, for example less than 2.5 micrometres, such as less than 2 micrometres, for example less than 1.5 micrometres, such as less than 1 micrometres, for example less than 0.5 μ, such as less than 0.25 micrometres, for example less than 0.1 micrometres, such as less than 0.01 micrometres.

The light pattern may be reflected from the surface directly into the camera or into one or more light reflecting means such as mirrors or prisms before ending up in the camera. In the embodiment of the scanner in Figure 1 no mirrors are applied, since the scanner only needs to "look" forward with respect to the camera, i.e. the direction of the view is always parallel with the optical axis of the camera. Figure 5 illustrates the simple emission of the light pattern 501 and its reflections 504 from the object surface 502 into the camera 505 without the use of mirrors. Figure 5 is a simplified illustration of the principle used in the scanner in Figure 1.

Applying one or more mirrors and/or prisms for reflecting the light into the camera gives full freedom to select the direction of the view invariant of the orientation of the camera. Figure 6 illustrates how the emitted light pattern 601 is reflected using a cone mirror and/or prism 602 before it hits the object surface 605. The reflected light 604 is likewise reflected into a mirror and/or prism 606 before entering the camera 607. Figure 6 is a simplified illustration of the principle used in the scanner in Figure 3. Static mirrors such as coplanar or cone mirrors can be applied directly in the invention. Static mirrors have the advantage of being simple and mechanically stable.

In the embodiment of the scanner shown in Figure 3 the mirror and/or prism in front of the camera is coplanar, circular and able to rotate. The advantage of a rotating mirror and/or prism compared to a static mirror and/or prism, such as a cone mirror and/or prism, is that the image resolution and the field of view of the camera are significantly increased. Indeed resolution and field of view are seriously limited due to the small dimensions of the scanner, which directly affect the accuracy and flexibility. Tilting the mirror and/or prism further increases the accuracy and flexibility. In practice, the same mirror and/or prism can be used to generate the light pattern and reflecting the light into the camera. However, applying different mirrors and/or prisms for light and cameras, as presented in Figure 3, increase the flexibility of the scanner especially with respect to direction of view, depth of field and point reconstruction quality.

In the case of very small dimensions of the cavity and/or high requirements for accuracy it is infeasible to place the camera on the head of the scanner. The problem is solved by moving the cameras out of the probe. The image/light is then directed into the cameras by the use of light guides such as a lens system or optical fibres. An embodiment of the invention where a lens system 701 and optical fibres 801 are used as light guides are illustrated in Figure 7 and Figure 8, respectively. The lens system might be similar to the lens systems used in periscopes and endoscopes. At the moment the lens system is superior to optical fibres with respect to smallest dimensions and image quality. The disadvantage of the lens system is that it requires the probe be rigid, whereas the optical fibres are fully flexible, i.e. the probe can be flexible.

The objective of the position sensor is to determine the relative position and orientation of the probe head with respect to the object to be scanned. Knowing this position is extremely advantageous in combining the individual scans when the scanner or object is moved. Errors in the position measures will directly affect the quality of the scan. In the case of non-fixed objects such as the ear canal of humans are scanned, it is extremely advantageous to measure the position with respect to the object, e.g. the ear canal, and not to a fixed coordinate system, since the object might move during the scanning.

The position sensor is only used to combine the individual scans. The position sensor can be rendered superfluous by a registration of the individual scans. The output of the registration is the relative position of the scans. Knowing the relative positions of the scans makes it straightforward to combine the scans. For the registration to be successful the interior surface needs to contain a proper number of distinct features, which is not always the case.

The position sensor can be a magnetic sensor as shown in Figure 9, where the receiver 902 usually is in the scanner and the transmitter 903 is secured to the object 901, e.g. the head of a human. Magnetic sensors have the advantage of not suffering for occlusion problems. Alternative sensors might be optical or sonic sensors. Figure 9 illustrates an optical sensor where markers 904 are placed on the object and a sensor 905 on the scanner.

Likewise Figure 9 illustrates a sonic sensor, where an emitter 906 is placed on the object and a detector 907 is placed on the scanner. Both optical and sonic sensors suffer from occlusion problems, but their cost is often lower and the precision superior to those of magnetic sensors. In the case of a fixed object or an object, which can be fixed, a mechanical position sensor becomes attractive. As illustrated in Figure 9 these sensors usually consist of a number of joints 908 connected by encoders. Many mechanical sensors are highly accurate, but they tend to be bulky or cumbersome to use.

In general, the position needs to be determined with respect to the head of the scanner. More precisely, the position of the focal point of the camera has to be determined when the camera is placed on the probe head. In the case where light guides are used in front of the camera, the position should correspond to the tip of the guides. With a rigid design of the scanner cover as in Figure 1 to Figure 4 the position sensor can be placed anywhere on the scanner, since the relative distance between the scan head and the position sensor is constant. With a flexible design of the probe the position sensor needs to be placed on the scan head, e.g. at the front as on the scanner in Figure 11 and Figure 12.

In the design of the scanner show in Figure 1 and Figure 3 only the probe 101 is supposed to move into the cavity. The main objective of the design has been to minimize the width of this part, since it determines the minimal size of the cavity, which can be scanned. In general the width of the probe can be varied freely down to approximately 0.1 mm, e.g. the width can be 30, 20, 15, 10, 8, 6, 5, 4, 3, 2, 1 or 0.1 mm. However the final design is a trade-off between size, accuracy and mechanical stability. In general the application determines the desirable design.

In the case of scanning the human ear canal the width of the part is requested to be below 4 mm. Figure 3 shows a scanner designed for scanning ear canals, where the width of the probe is 3.5 mm. The length of the probe can also be varied freely down to approximately 5 mm, e.g. the length can be 20, 35, 50, 100, 200, 300 or 500 mm. The length of the probe shown in Figure 1 and Figure 3 is 55 mm.

The rest of the scanner's cover is basically a handle. For optimal handling this part should preferably be 10-30 mm width and 100-150 mm long. The dimension can however be varied freely. As in Figure 1 and Figure 3 the width of the handle may be extended to make room for the components, e.g. the position sensor. The dimensions of this extension should however be minimized if the objective is to create the smallest and lightest scanner. The width and length of the extension shown in Figure 1 and Figure 3 is 40 mm and 30 mm, respectively. Note that larger light sources such as halogen spots may be moved to the extension.

In another embodiment of the scanner it is possible to rotate the probe around its axis. The advantage of this design compared to only rotating the mirrors and/or prisms as in Figure 3 is that the motor can be placed in the handle. Likewise another embodiment comprises a linear drive, which is able to translate the probe along its axis. The scanner can also be mounted on a robot, or another device, which is able to position the scanner with any orientation and position within its workspace.

The choice of material for the cover depends on the actual application, especially whether the probe needs to be rigid or flexible. Preferably the cover should be produced in stainless steel or from a material selected from a group consisting of alloy, aluminum, a plastic polymer, Kevlar (R), ceramics or carbon.

In some application it might be necessary to protect the components such as cameras, mirrors and/or prisms and lenses against dust and other dirt. In practice this is done by inserting a window of transparent material such as glass or a plastic polymer in the holes in front of the relevant components.

Other features in the preferred embodiment are a protector/collision detector, a scan button, and a disposable scanner cover. The protector consists of soft material such as rubber, silicone or a plastic polymer and ensures that the tip of the probe and the surface are not damaged in the case of a collision. In the case of scanning an ear canal it is crucial that the scanner does not damage the eardrum. In the case of very fragile surfaces, a collision detector adapted to measure the distance from the tip of the scanner to the bottom of the interior surface is added to the protector. When surfaces are scanned for which the scanner is subject to hygiene requirements, a disposable cover is desirable to minimize the need for cleaning. The disposable cover will usually only cover the probe or parts of it, but can be fit to the specific requirements. The scan button is used to start and stop the scan operation.

The acquired images may be analyzed real-time in a digital signal processor or microprocessor, which is placed in the scanner handle or in a separate processing box. The first step in the analysis of an image may be to detect the light pattern in the image using a standard tracking algorithm. When the light pattern is known, potentially with sub-pixel precision, the corresponding 3D coordinates can be reconstructed using well-known projective geometry. A precise reconstruction of the 3D coordinates requires a very high quality of the camera and light calibration. The next step may be to combine the 3D coordinates from different images acquired at the same or at different positions. The merging may simply be performed by combining the individual points sets positioned with respect to their relative position. Finally the points may be triangulated using a standard triangulation algorithm to form the final surface of the 3D model. The 3D model may then be transferred over a network to the destination for further use.

The scanner according to the invention is especially adapted for scanning interior surfaces, such as body cavities and other interior surfaces with narrow openings, into which light from an external scanner cannot enter due to occlusion effects.

It is thus envisaged that the scanner is advantageous for scanning body cavities such as the internal surfaces of the ear, nose, mouth, teeth, stomach, lungs, alveoli, throat, rectum, vagina, veins, blood vessels, urinary tract. Scanning of teeth can be used in connection with correction of teeth and manufacture of dental implants. Scanning the blood vessels may be useful in connection with surgery. Scanning the vagina can be used in connection with pregnancy and delivery and also for measuring and modeling an individually adapted diaphragm. Figure 13 shows a scan of the interior surface of an ear and an ear canal 1301.

The scanner can also be used for industrial purposes such as for scanning internal surfaces of engines, fuel canals, bore, internal thread, pipes, tubes and containers. In this way the exact dimensions, such as volume and/or cross section and/or location of features, of the devices can be measured. When using a scanner with a position sensor, this can be done more precisely than with any of the known scanners. Furthermore, the present scanners are not sensitive to small deviations in the orientation of the axis of the scanner with respect to the axis of the object being scanned.

Another use is for archaeological purposes such as for scanning internal surfaces of jars, skulls and other archaeological items.

Furthermore, the scanners are very useful in industrial design especially in connection with computer assisted 3D modeling.

A possibility according to the invention is to scan the ear canal directly. This can be done by building the components of the scanner into an apparatus, which can be inserted into the ear of the patient. Embodiments of this scanner are shown in Figure 11. Preferably, the light source, e.g. the laser, and the camera are located outside the ear. The laser light can be carried into the scanner by light guides 201, and similarly, the reflected signals can be carried to a camera by another light guide 801. The scanner also consists of a position sensor 203, which measures the relative position of the scanner with respect to the object. During the scan, the scanner preferably rests on the edge of the ear canal, most preferably in those places where bones are closest to the skin surface. This is in order to obtain the highest stability and is very important, since the scanner itself works with an accuracy of less than 0.05 mm. The length of the ear canal can be scanned by moving the scanner in or out and record a series of overlapping images of the ear canal. The scanner may comprise only one laser source and one camera as the one shown in the left of Figure 11. In that case the scanner has to rotate while the camera records images. The scanner may comprise multiple laser sources such as four as shown in the scanner in the right part of Figure 11. The presence of multiple laser sources and cameras removes the need for rotation of the scanner in the ear canal. In the laser scanner disclosed in Figure 11, the laser source or sources project a ray of laser light on the surface of the ear canal.

Another type of ear canal laser scanner is shown in Figure 12. Here the laser light is projected as laser sheets producing a laser contour on the surface of the ear canal. Thereby, more rapid scanning can be performed compared to the above laser scanner. In the scanner shown in the right part of Figure 12, four laser sheets and four cameras are present. Thereby the laser sheets cover the whole circumference and rotation of the scanner is not required.

The same types of variation of the ear canal scanner can be used as in other cases of three-dimensional scanners according to this invention. Thus, the scanner may comprise at least two cameras, such as 4 cameras, such as for example 6 cameras. Likewise, there may be several laser sources such as for example 2 lasers creating laser sheets with an offset of 180 degrees, such as 3 laser sheets with an offset of 120 degrees, or 4 laser sheets with an offset of 90 degrees.

Currently hearing aids are created in a silicon mould, made with an ear impression.

It is possible to scan and create very detailed and accurate copies of ear impressions with the developed system as described in 3Shape's prior art document "Method for modeling customized earpieces" with publication number WO02071794 published in 2002.

Apart from hearing aids, other devices could also be inserted into a shell made to fit the ear canal of an individual. Such devices that could advantageously be incorporated into a shell manufactured according to the disclosed method include mobile phones, communication devices, loud speakers, tinnitus masking devices, or devices recording vibrations in the skull and transforming these into an audio signal.

Devices that may be incorporated into a shell in the ear also comprise devices related to Man Machine Interface (MMI) products, such as custom made ear microphone or receivers that enable reliable and clear communication even in the noisiest environments, or products related to wireless internet applications.

Speech not only creates sound waves, it also generates vibrations within the skull of the speaker. These vibrations can be picked up in the ear, but they may be picked up other places too, but by far the most convenient method is to do it in the ear. In one piece, a device thus may comprise a microphone to pick up the speech of the person wearing it, and a loudspeaker to transmit the speech of the communication partner. It is important that such devices are made to fit the ear.

Devices based on detection of vibration instead of sound can be used in the noisiest environments, since they only pick up the speech of the wearer and they allow for quiet communication, since the speaker can speak with a low voice when needed. The devices allow for completely hand-free communication.

Such a device is naturally also devoid of any kind of acoustic feedback if manufactured using the present invention.

The precision of the light sources and cameras is very high today and so is that of the software developed to detect the intersection of the light sheet with the object and to convert the two-dimensional data to three-dimensional coordinates. Therefore differences in precision and hence improvement of the precision primarily resides in the calibration of the systems. Recall that precision is of utmost importance in many applications.

To obtain the highest precision both the light pattern and the camera need to be calibrated. Preferably the calibration should be performed using a calibration object with symmetrical 3D object feature curves and the corresponding methods as described below and in 3Shape's prior art document "Method for modeling customized earpieces" with publication number WO02071794 published in 2002. The main advantage of this type of calibration objects is that the light pattern can be calibrated independently of the calibration of the camera. An embodiment of the hollow calibration object used for calibration of the scanner is shown in Figure 10. Note the symmetric 3D object feature curves 1001 on the calibration object, which are utilized in the calibration.

Preferably, a light pattern is projected onto the calibration object to produce 2D image feature curves in the acquired images.

When preferred, the image feature curves may be determined using the Hough transformation, filter search, max intensity, threshold, center of gravity, derivatives or other procedures.

The image feature coordinates are found as the intersection between image feature curves. These intersections could be seen in the images as corners or sharp edges of the image feature curves. The image feature coordinates may be found as the intersection between the image feature curves such as the intersection between two n^{th} order curves, as the intersection between two first order curves, as the intersection between two second order curves, as the intersection between two third order curves, as the intersection between a fist order curve and a second order curve, as the intersection between a first order curve and a third order curve, or as the intersection between a second order curve and a third order curve or as the intersection between any other possible combination of curves.

Preferably, the calibration method comprises plotting of a mathematical combination of image feature points or features derived from these points against the angle of rotation or the translation of the calibration object. By plotting this function and optionally estimating a mathematical function describing the relationship between the function of an image coordinate and the angle of rotation or the translation, estimation of the light parameters and angle or rotation and/or translation becomes especially precise. The method may comprise determination of the mean plane of symmetry in the plot.

The mean plane of symmetry can be determined by calculating the mean angle of rotation / mean translation for pairs of image feature points having the same value in the mathematical combination. Doing this produces multiple estimates for the encoder offset and light pattern displacement allowing also for the estimate of the laser sheet angle.

Light pattern calibration may also comprise selecting symmetric points, plotting of the rotation angle and/or the translation for the first point against the difference in the rotation angle and/or the translation between the two symmetric points, deriving a mathematical formula for the plotted lines and estimating the light pattern parameters.

Alternatively, mathematical formulas can be derived for the curves that appear in some of the plots of the mathematical combination as a function of the angle of rotation or the translation. Given these curves and the corresponding formulas, the encoder offset, the light pattern displacement, and the light pattern angle can be estimated.

Preferably, light pattern coordinates of the 3D object feature curves are estimated corresponding to a discrete number of values of angle of rotation and/or translations. These values should preferably cover the whole circumference and/or length of the calibration object.

2D coordinates of the 3D object feature curves corresponding to a discrete number of values of angle or rotation and/or translation may be calculated from mathematical functions determining the 3D object feature curves. In order to determine the calibration parameters such as camera position, camera orientation, and camera optic parameters, pairs of 2D light pattern coordinates are compared to calculated 2D coordinates for a discrete number of values of angle or rotation and/or translation. This comparison preferably comprises using the Tsai or the Heikkilae algorithm. The advantage of the Tsai and the Heikkilae algorithms in this context is that they provide rapid and precise estimation of the calibration parameters such as radial lens distortion.

Alternative methods for calibration comprise direct linear transformation and direct non-linear matrix transformation optionally in combination with an optimization procedure such as least squares to minimize the error. In these cases initial calibration parameters may be estimated to facilitate the convergence of the parameters during optimization.

To improve calibration, precision outliers may be excluded from the calibration. Outliers can e.g. be identified in the plot of the mathematical combination of image feature coordinates against the angle of rotation / the translation or by back projection of coordinates after an initial calibration.

Two percent of the feature points deviating most from the back-projected 2D image feature curves may be excluded from the calibration or at least 3 percent, such as at least 5 percent, for example at least 10 percent, for example at least 12 percent, such as at least 15 percent for example at least 20, preferably at least 25 percent, for example at least 30 percent, more preferably at least 33 percent may be excluded to improve calibration precision.

In order to cover the whole circumference of the calibration object the discrete number of values for angle of rotation / translation may be at least 100, preferably at least 240, for example at least 500, such as at least 750, for example at least 1000, such as at least 1200, for example at least 1500, such as at least 1800, for example at least 2000, such as at least 2400, for example at least 3000, for example at least 3600, such as at least 4200. The higher the discrete number of values of angle of rotation / translation, the higher the calibration precision.

The highest calibration precision is obtained when using a rigid setup, which comprises mounting the calibration object onto mounting means.

Fig. 15 shows an example of a scanner with a probe in an ear.

The scanner 1201 comprises a probe 1202, where the tip of the probe 1202 is shown to be partly inserted in the ear canal of a patient. Light 1203 is emitted from the probe tip of the scanner 1201 in order to scan the ear and/or the ear canal.

Fig. 16 shows an example of scanner with an extra camera mounted.
The scanner 1601 is arranged such that the ear 1604 and/or ear canal of a patient can be scanned. The scanner 1601 comprises a probe 1602, which

comprises a probe tip 1605 from where light 1603 is emitted from the scanner.

The scanner 1601 is shown with a cut-off section such that the components inside the scanner 1601 can be viewed. The scanner comprises a light source 1606 which emits light 1603, a pattern 1607 which produces structured light from the light source 1606, a beam splitter (not shown), optical lenses 1608, and a camera or image sensor 1609 for capturing optical images. On the external portion of the scanner 1601 a camera 1610 is arranged, which is adapted to record images, for example as still photographs or video. The field of view 1611 of the camera 1610 is shown to be in the direction of the probe tip, such that the camera 1610 records images of, for example, the external part of the ear 1604. These recordings may be used as reference images for detecting the position and/or orientation of the scanner for example for coupling the scanned 2D images to a 3D position, and from this the position of the scanner 1601 relative to the ear 1604 is adapted to be determined.

Fig. 17 shows examples of laser beams for guiding the position and orientation of the scanner.

Both fig. 17a) and fig. 17b) shows the scanner 1601 and the ear 1604.

In fig. 17a) two laser beams 1613 from two light sources 1612 arranged on the external part of the scanner 1601 guide the scanner operator (not shown) to hold the scanner 1601 in the correct distance from the ear 1604 for scanning. The laser beams 1613 cross each other at a point 1614, and for example when this point 1614 is at the external surface of the ear, then the scanner 1601 is in the correct distance from the ear 1604.

In fig. 17b) two sets of two laser beams 1613, 1616 from two sets of light sources 1612, 1615, respectively, guide the scanner operator (not shown) to hold the scanner 1601 in the correct distance from the ear 1604 for scanning. The two sets of light sources 1612, 1615 are arranged on the external part of the scanner 1601. The two laser beams 1613 cross each other at a first point 1614, and the two other laser beams 1616 cross each other at a second point 1617. When for example the first point 1614 is at the external surface of the ear, then the scanner 1601 is in a correct first distance from the ear 1604, and when for example the second point 1617 is at the external surface of the ear, then the scanner 1601 is in a correct second distance from the ear 1604. The first distance may be the distance in which a first set of scanning images are made, and afterwards the scanner 1601 may be moved into the ear to the second distance to capture a second set of scanning images or vice versa such that the scanner 1601 is first arranged at the second distance to capture images and then the scanner is moved out of the ear to the first distance to capture images there.

Although some embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways within the scope of the subject matter defined in the following claims. In particular, it is to be understood that other embodiments may be utilised and structural and functional modifications may be made without departing from the scope of the present invention.

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

The features of the method described above and in the following may be implemented in software and carried out on a data processing system or other processing means caused by the execution of computer-executable instructions. The instructions may be program code means loaded in a memory, such as a RAM, from a storage medium or from another computer via a computer network. Alternatively, the described features may be implemented by hardwired circuitry instead of software or in combination with software.

References

1. [1] TSai, R. Y., "A versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses", IEEE Journal of Robotics and Automation, pages 323-344, Vol. RA-3, No. 4, August 1987.
2. [2] Heikkilae, J, "Geometric Camera Calibration Using Circular Control Points", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No. 10, pp. 1066-1077, Oct 2000

Claims:

1. A method for scanning partly obstructed interior surfaces, where the method comprises:

- providing a probe shaped scanner having an axis, where the probe shaped scanner comprises:

  - at least one light source configured to create and project structured light, and
  - at least one camera configured to record 2D images;

- entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object;

- creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object;

- recording a series of 2D images of the reflection of the pattern from the interior surface using said camera;

- combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and

- providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created.

2. The method for scanning according to the preceding claim, wherein the method comprises:

- providing that the camera comprises a plurality of sensor elements or a plurality of groups of sensor elements;

- varying the focus plane of the pattern over a range of focus plane positions while maintaining a substantially fixed spatial relation of the camera and said interior surface,

where the combining of 2D images comprises determining by analysis of said 2D images the in-focus position(s) of the focus plane for:

a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or

b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes,

and where said 3D real world coordinates are from said in-focus positions.

3. The method for scanning according to any of the preceding claims, wherein holes in the surface information are registered.

4. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by fitting to higher order mathematical surfaces, such as second order, third orders, fourth order etc.

5. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by using information about where there exists no surface.

6. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by combining image data with other data than image data.

7. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by using other data than image data.

8. The method for scanning according to any of the preceding claims, wherein other data than image data comprises color, interference, angle of reflected light, and/or data from one or more other sensors than the camera.

9. The method for scanning according to any of the preceding claims, wherein the one or more other sensors comprise a touch sensor, contact sensor, sonic sensor, and/or temperature sensor.

10. The method for scanning according to any of the preceding claims, wherein part of the data of surface information of the left ear is used as a part of the data of surface information for the right ear, if there are parts of the right ear where surface information has not been acquired, and vice versa.

11. The method for scanning according to any of the preceding claims, wherein holes in a scan are inferred or interpolated based on previous scans of the person's ear.

12. The method for scanning according to any of the preceding claims, wherein foreign objects in the ear canal are identified.

13. The method for scanning according to any of the preceding claims, wherein identifying foreign objects comprises detecting reflections from the foreign object.

14. The method for scanning according to any of the preceding claims, wherein a foreign object is identified by analyzing the difference in the reflected light from the skin and the foreign object, respectively.

15. The method for scanning according to any of the preceding claims, wherein the method comprises using monochromatic light to illuminate the surface for analyzing reflected light.

16. The method for scanning according to any of the preceding claims, wherein the method comprises identifying foreign objects by correlating surface data with the 3D position of the specific data.

17. The method for scanning according to any of the preceding claims, wherein foreign objects in the ear are filtered out from the images of the ear.

18. The method for scanning according to any of the preceding claims, wherein foreign objects are presented to the operator on a display.

19. The method for scanning according to any of the preceding claims, wherein the foreign objects are coloured in a different colour on the display than the rest of the surface on the image.

20. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting and deleting single points on the images.

21. The method for scanning according to any of the preceding claims, wherein detecting hair comprises having predefined information in the system about where hair normally grows in the ear.

22. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the root of the hair in the skin.

23. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the thickness of the hair.

24. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the movement of hair when the probe touches the hair.

25. The method for scanning according to any of the preceding claims, wherein determining whether scar tissue is fresh or old, when detecting a foreign object in the form of scar tissue.

26. The method for scanning according to any of the preceding claims, wherein color filters are applied to the light source.

27. The method for scanning according to any of the preceding claims, wherein the light source is adapted to emit different colors.

28. The method for scanning according to any of the preceding claims, wherein the light source emits multi-colored light.

29. The method according to any of the preceding claims, wherein the light source emits monochromatic or near-monochromatic light but switches between different colors in time.

30. The method for scanning according to any of the preceding claims, wherein the size of regions of the emitted light pattern is 20x20 mm.

31. The method for scanning according to any of the preceding claims, wherein the size of the regions of the emitted light pattern is 10x10 mm.

32. The method for scanning according to any of the preceding claims, wherein light with different polarization is used.

33. The method for scanning according to any of the preceding claims, wherein the polarization state of the emitted and/or the detected light is controlled.

34. The method for scanning according to any of the preceding claims, wherein the light source is a laser and light from said laser is guided to impinge on the surface in a small spot.

35. The method for scanning according to any of the preceding claims, wherein there is more than one light source in the probe shaped scanner and the different light sources are alternately turned on and turned off.

36. The method for scanning according to any of the preceding claims, wherein the light source emits infrared light.

37. The method for scanning according to any of the preceding claims, wherein the optical resolution of the scanner is 100 μm or higher.

38. The method for scanning according to any of the preceding claims, wherein the method comprises detecting the hardness under the skin in different parts of the ear canal.

39. The method for scanning according to any of the preceding claims, wherein light with different wavelengths is used to detect the hardness under the skin in the ear canal.

40. The method for scanning according to any of the preceding claims, wherein the light used for scanning comprises one or more narrow laser beams co-propagating with a broader light beam.

41. The method for scanning according to any of the preceding claims, wherein the hardness under the skin is evaluated by detecting the reflected pattern of light, calculating the size of the regions of the pattern, and comparing this size with the regular size.

42. The method for scanning according to any of the preceding claims, wherein the scanner comprises guide means adapted to assist the operator in holding the scanner in the correct distance and/or position relative to the ear.

43. The method for scanning according to any of the preceding claims, wherein the guide means is two laser beams, and when the two laser beams are crossing each other at a point on the ear, the distance between scanner and ear being correct for scanning.

44. The method for scanning according to any of the preceding claims, wherein the guide means comprises a first and a second set of two laser beams, and when the first set of laser beams are crossing each other at a first point on the ear, the distance between scanner and ear is correct for scanning of a first region of the ear, and when the second set of laser beams are crossing each other at a second point on the ear the distance between the scanner and ear is correct for scanning of a second region of the ear.

45. The method for scanning according to any of the preceding claims, wherein the ear is scanned in a first configuration where the mouth is closed, and in a second configuration, where the mouth is open.

46. The method for scanning according to any of the preceding claims, wherein the image data of the first and the second configurations are merged into one image by means of CAD.

47. The method for scanning according to any of the preceding claims, wherein a touch sensor is arranged in connection with the scanner, such that the touch sensor is adapted to register contact with the skin.

48. The method for scanning according to any of the preceding claims, wherein the touch sensor comprises a tactile component at the probe tip.

49. The method for scanning according to any of the preceding claims, wherein the touch sensor is a capacitive sensor.

50. The method for scanning according to any of the preceding claims, wherein the direction of the ear canal towards the ear drum is determined by means of image data and/or one or more other data.

51. The method for scanning according to any of the preceding claims, wherein a motion sensor is arranged in connection with the scanner, such that the motion sensor is adapted to perform a motion measurement of the scanner.

52. The method for scanning according to any of the preceding claims, wherein an orientation sensor is arranged in connection with the scanner, such that the orientation sensor is adapted to perform an orientation measurement of the scanner.

53. The method for scanning according to any of the preceding claims, wherein the scanner comprises a number of marks in its cover, such that an operator can visually determine how far the scanner must be moved into the ear canal.

54. The method for scanning according to any of the preceding claims, wherein a user interface of the scanner is adapted to direct the operator to insert the probe a certain distance into the ear canal.

55. The method for scanning according to any of the preceding claims, wherein a user interface of the scanner is adapted to direct the operator to move the probe a certain distance in any three-dimensional direction.

56. The method for scanning according to any of the preceding claims, wherein the shape of the probe prevents it from reaching the ear drum.

57. The method for scanning according to any of the preceding claims, wherein a camera, such as a second camera or a video camera, is arranged in relation to the scanner such that it is configured to record images, from where the position of the scanner relative to the ear is adapted to be determined.

58. The method according to any of the preceding claims, comprising determining the relative position and orientation of the scanner during successive scans with at least one sensor.

59. The method according to any of the preceding claims, where the data that are provided and processed to create surface information, are obtained from the recorded 2D images.

60. The method according to any of the preceding claims, where the probe shaped scanner has an axis and where a scan around the axis is performed.

61. A scanner system for three-dimensional scanning of interior surfaces, said scanner comprising:

- a probe shape scanner configured to be entered into a cavity, said probe shaped scanner comprising

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object, where said light source emits light from a point of emission; and
- at least one camera, adapted to record 2D images of the pattern, where the camera accumulates light at a point of accumulation;

- a data conversion device adapted to convert 2D images into 3D real world coordinates,

- a data processing device configured to create surface information for areas of the surface, where image scanning is not complete.

62. The scanner system according to claim 61, wherein the probe shaped scanner has an axis and the at least one light source and the at least one camera are adapted to perform a scan around the axis

63. The scanner system according to claim 61 or 62, wherein said data conversion device and said probe shaped scanner are integrated in one device.

64. The scanner system according to claim 61 or 62, wherein said data conversion device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

65. The scanner system according to any of claims 61 to 64, wherein said data processing device and said probe shaped scanner are integrated in one device.

66. The scanner system according to any of claims 61 to 64, wherein said data processing device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

67. The scanner system according to any of claims 61 to 66, wherein said data processing device and said data conversion device are comprised in one integrated conversion and processing device, where this integrated conversion and processing device and the probe shaped scanner may be integrated in one device.

68. The scanner system according to any of claims 61 to 67, where the system comprises a nontransitory computer readable medium having one or more computer instructions stored thereon, where said computer instructions comprises instructions for conversion of 2D images into 3D real world coordinates and/or for processing data.

69. A hearing aid device obtained by from a 3D model of the interior surface of an ear, where said 3D model is obtained by the method according to any of claims 1-60 or by the scanner according to any of claims 61-67.

70. A computer program product comprising program code means for causing a data processing system to perform the method of any one of claims 1-60, when said program code means are executed on the data processing system.

71. A computer program product according to claim 70, comprising a computer-readable medium having stored thereon the program code means.

71. A nontransitory computer readable medium storing thereon a computer program, where said computer program is configured for causing computer-assisted scanning of partly obstructed interior surfaces.

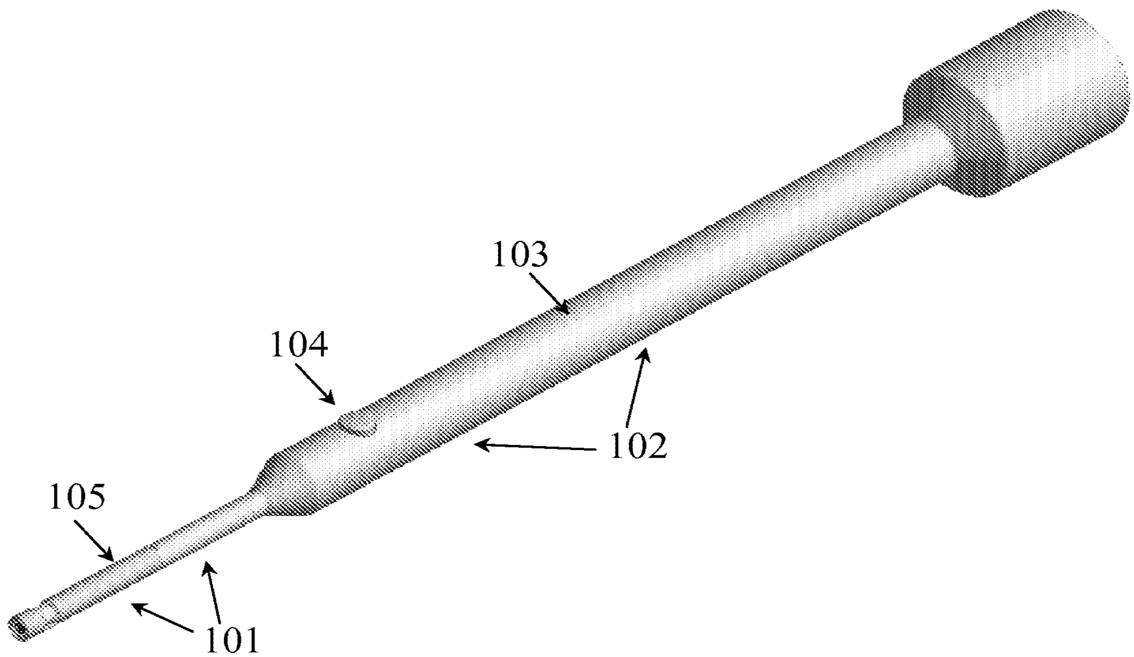


Figure 1

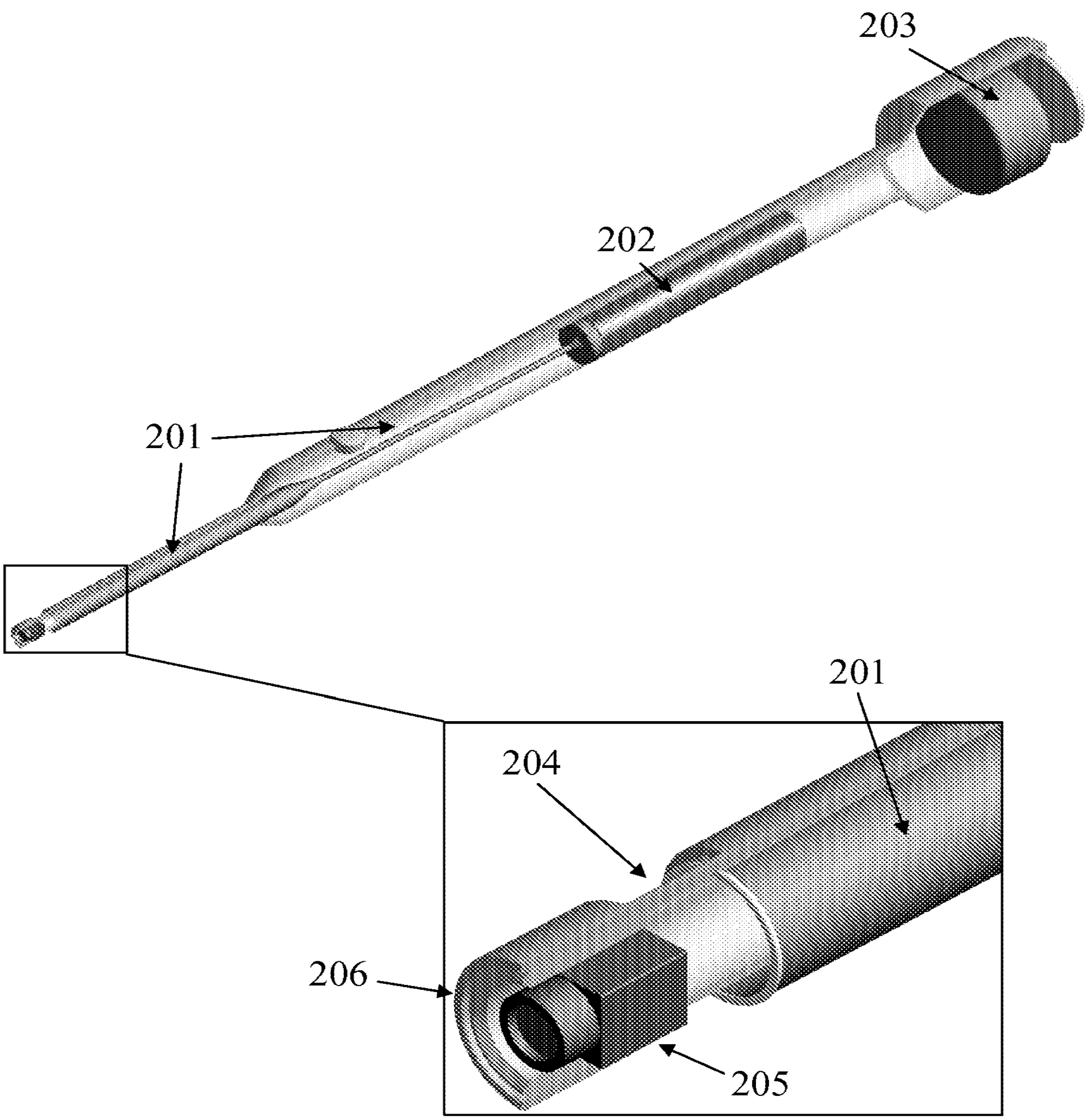


Figure 2

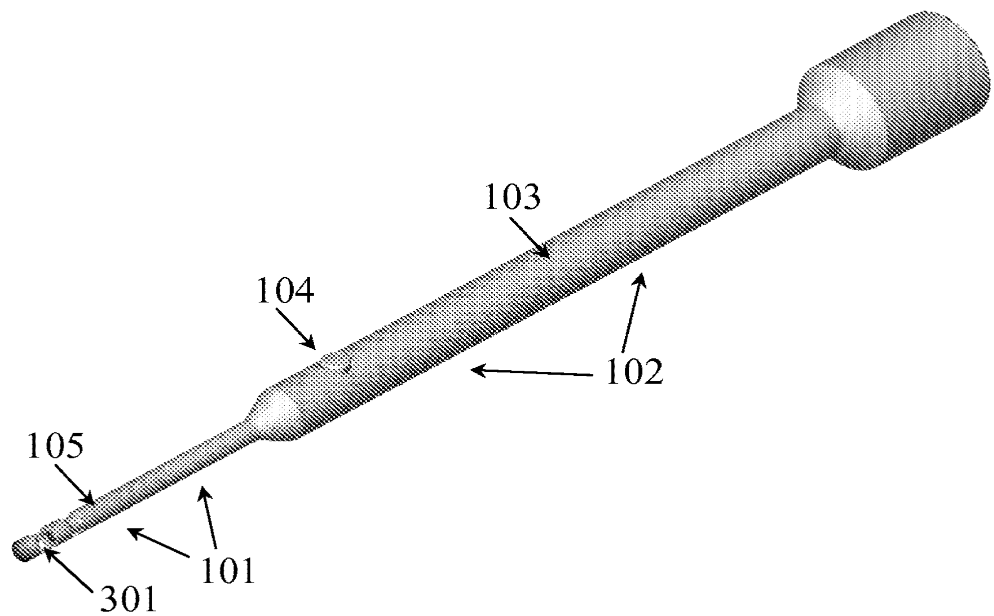


Figure 3

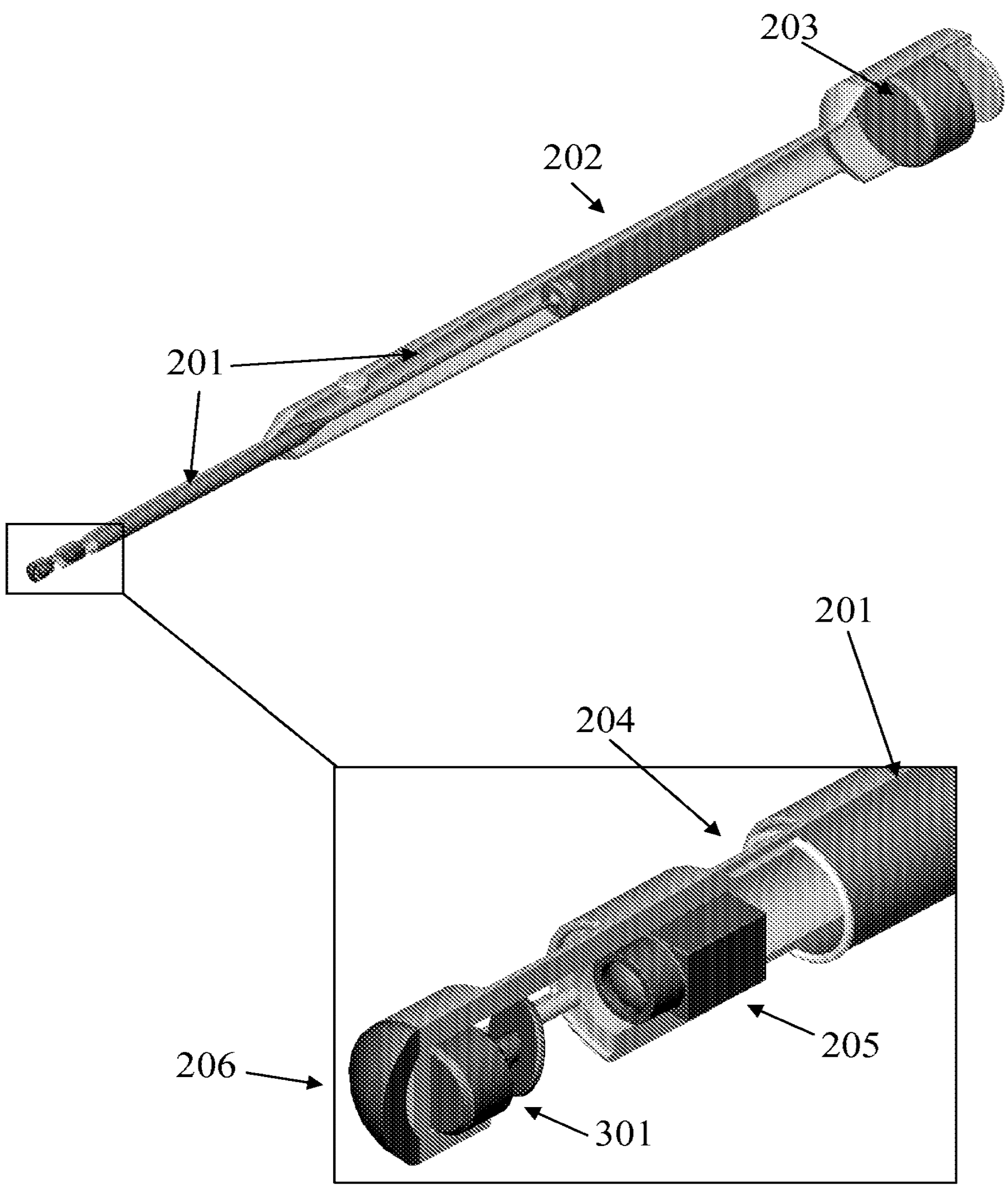


Figure 4

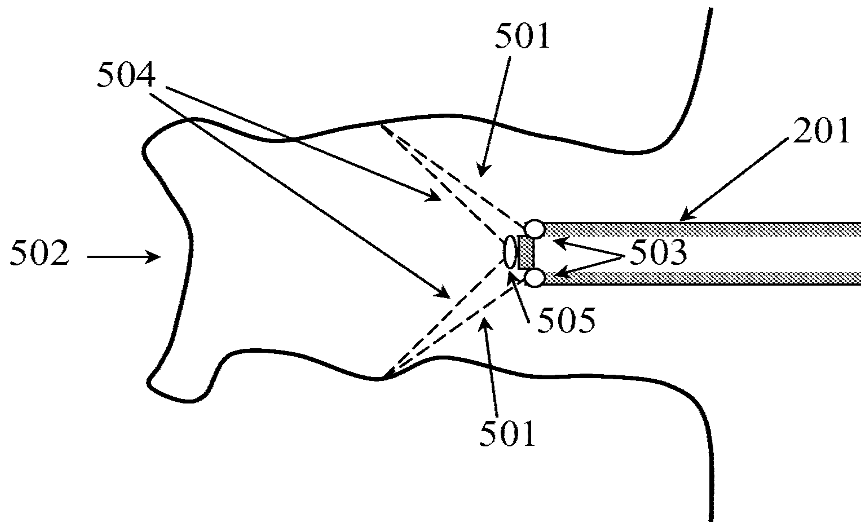


Figure 5

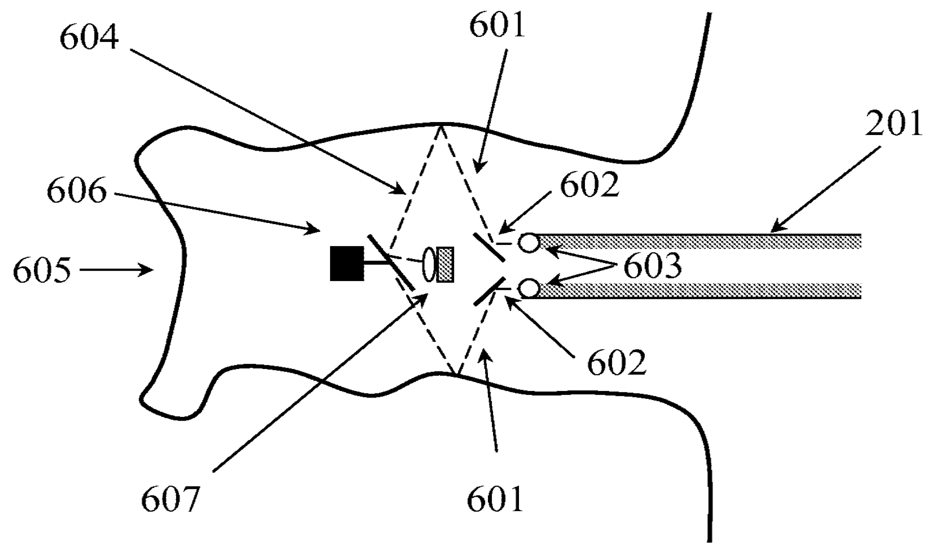


Figure 6

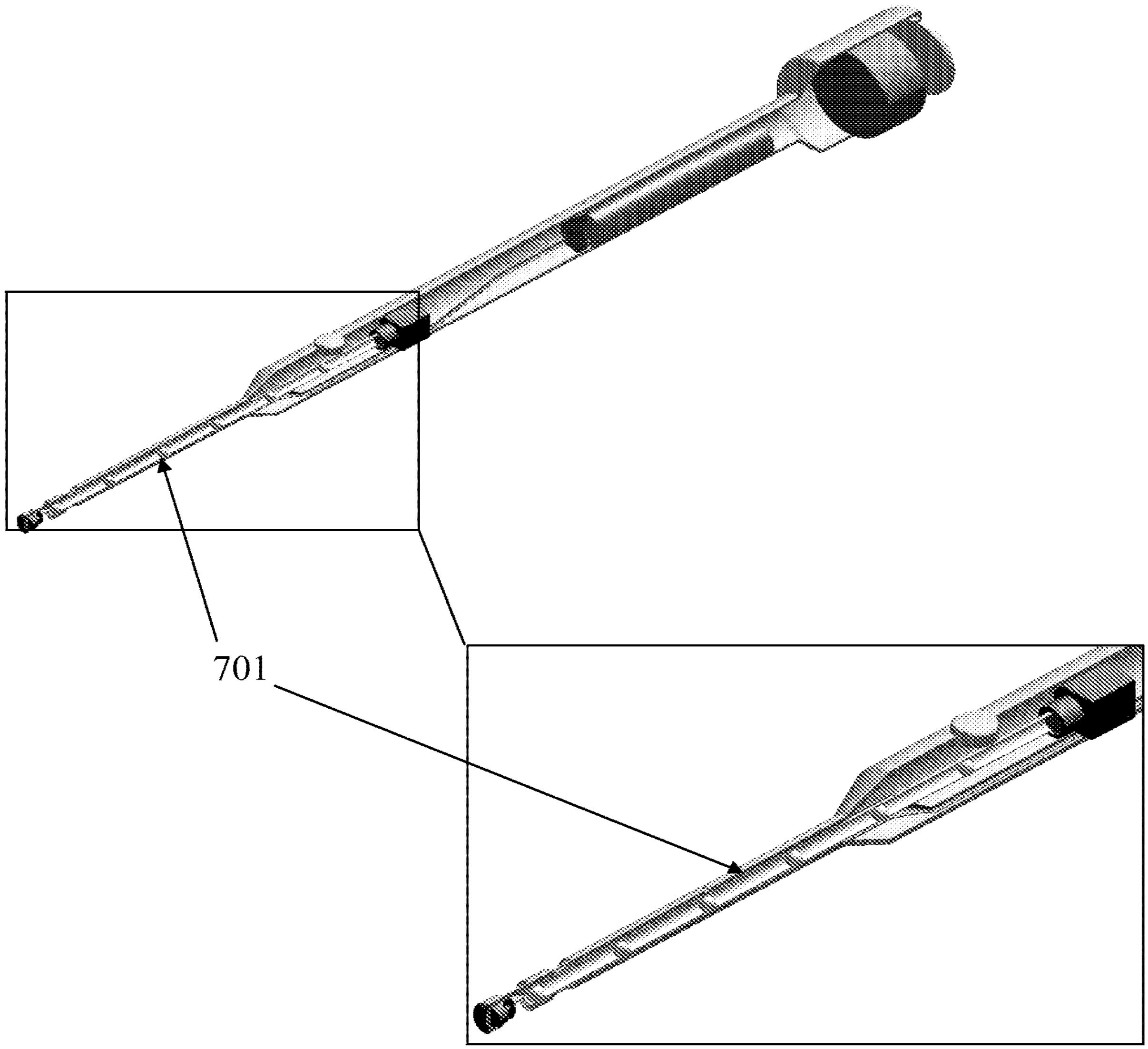


Figure 7

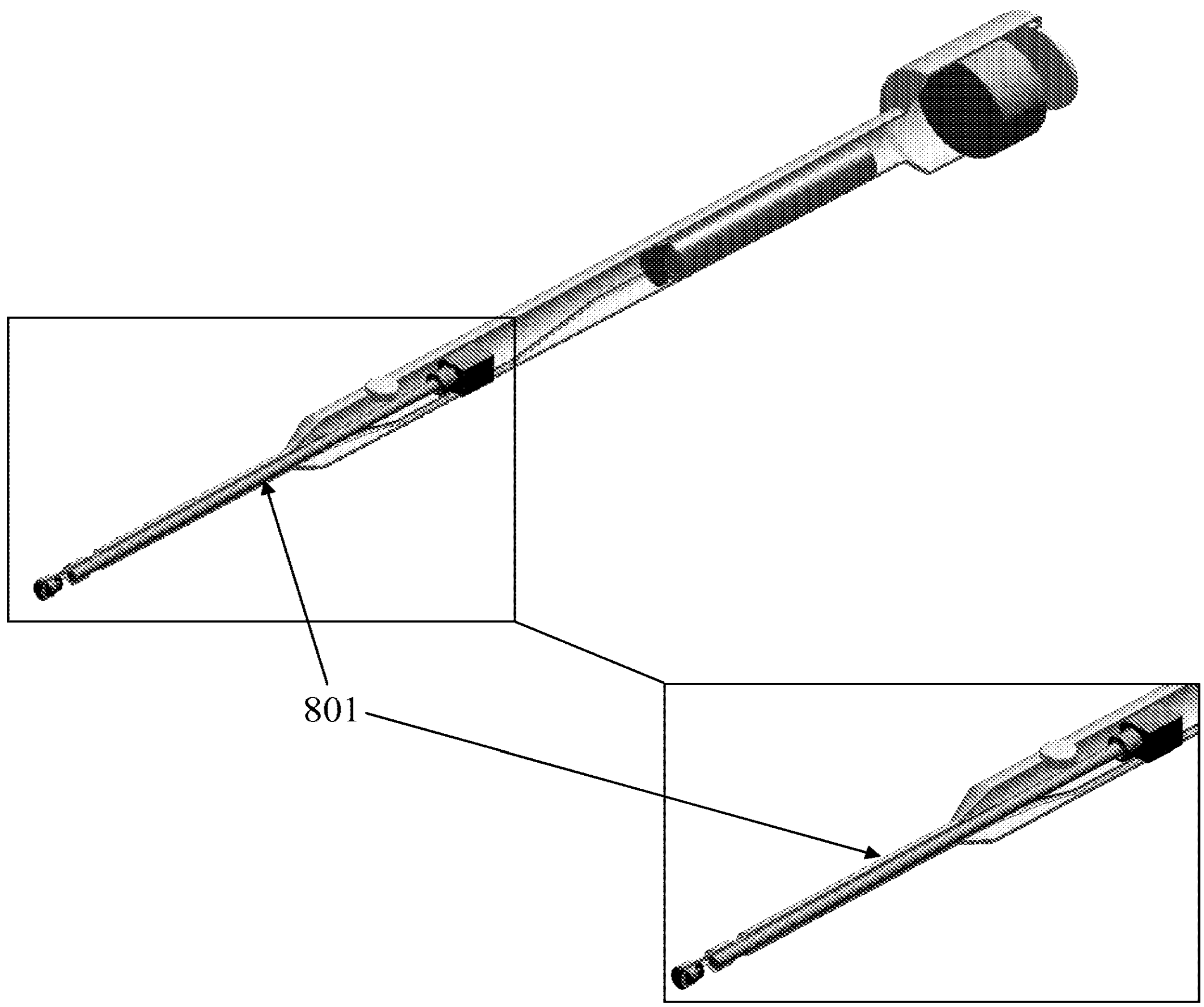


Figure 8

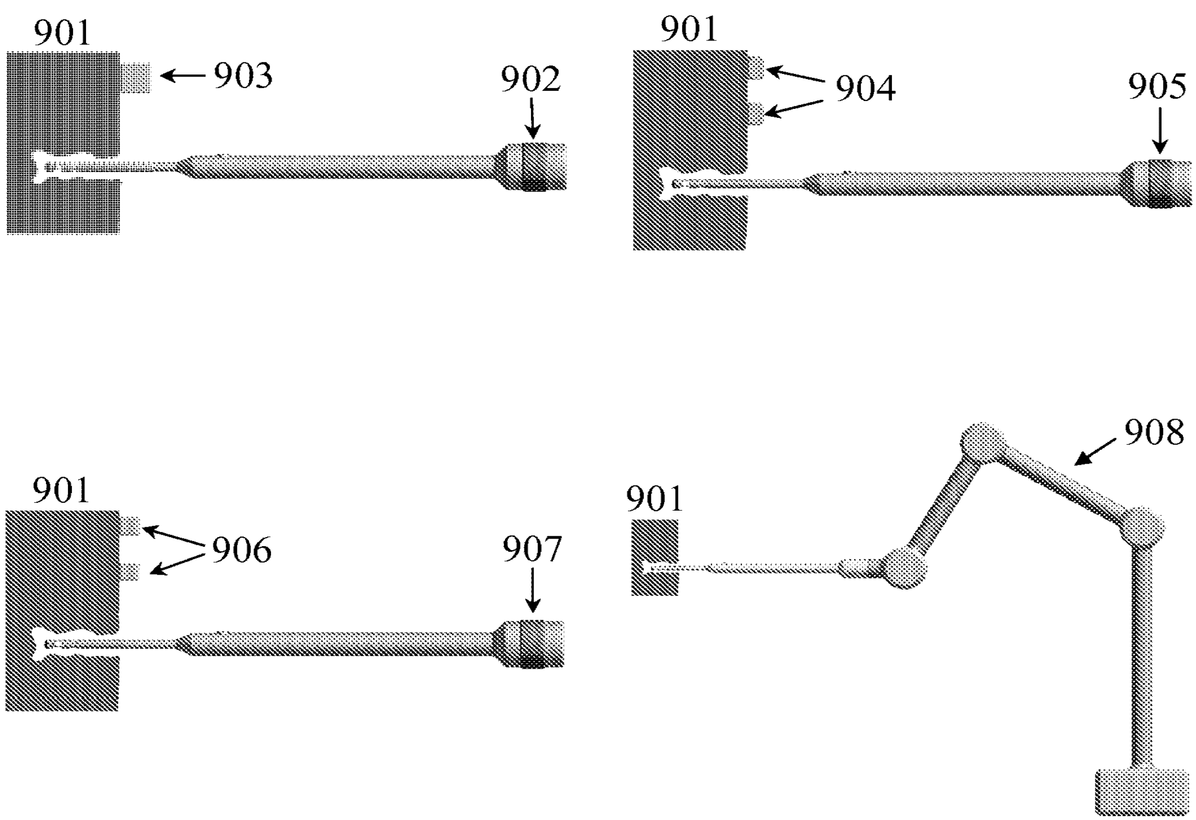


Figure 9

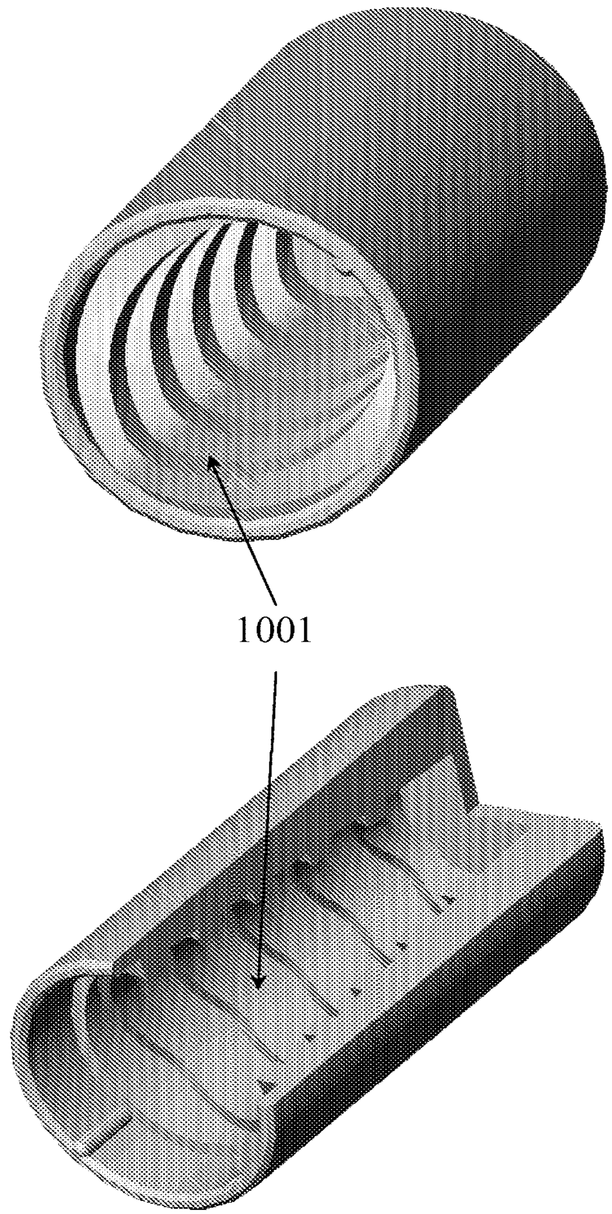


Figure 10

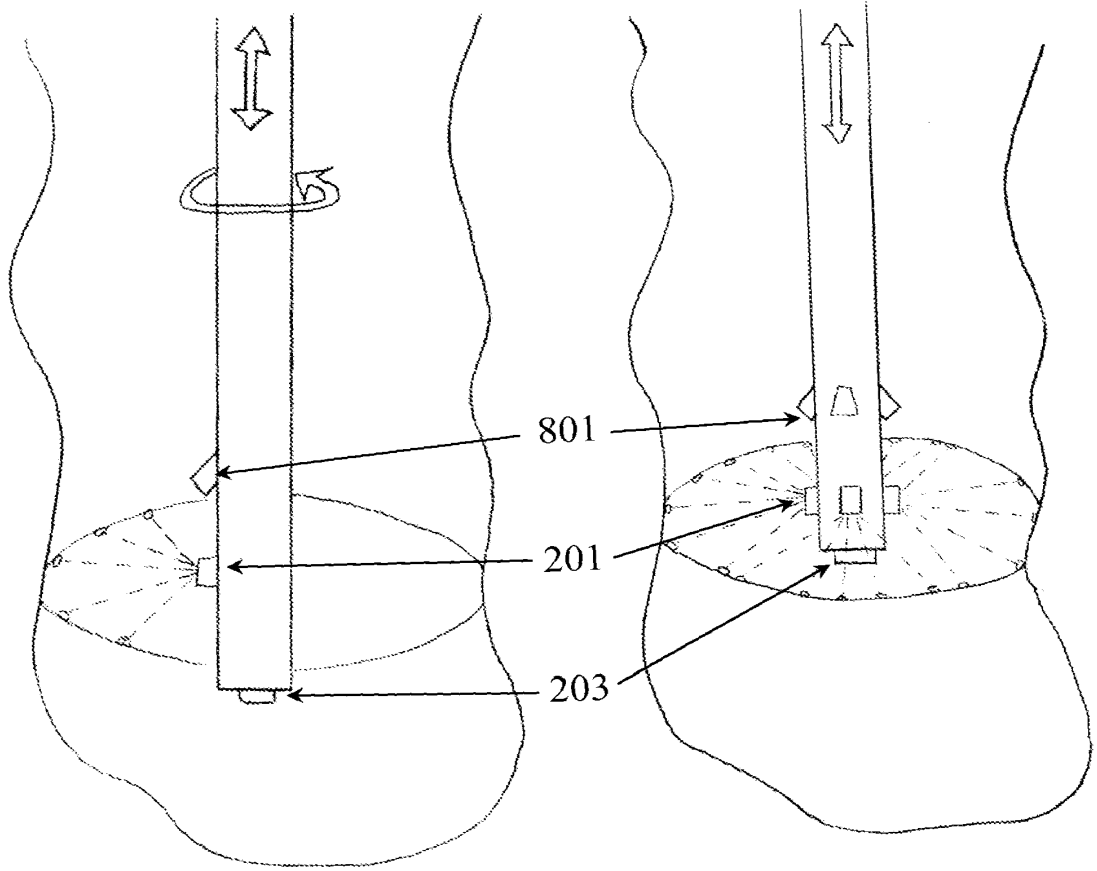


Figure 11

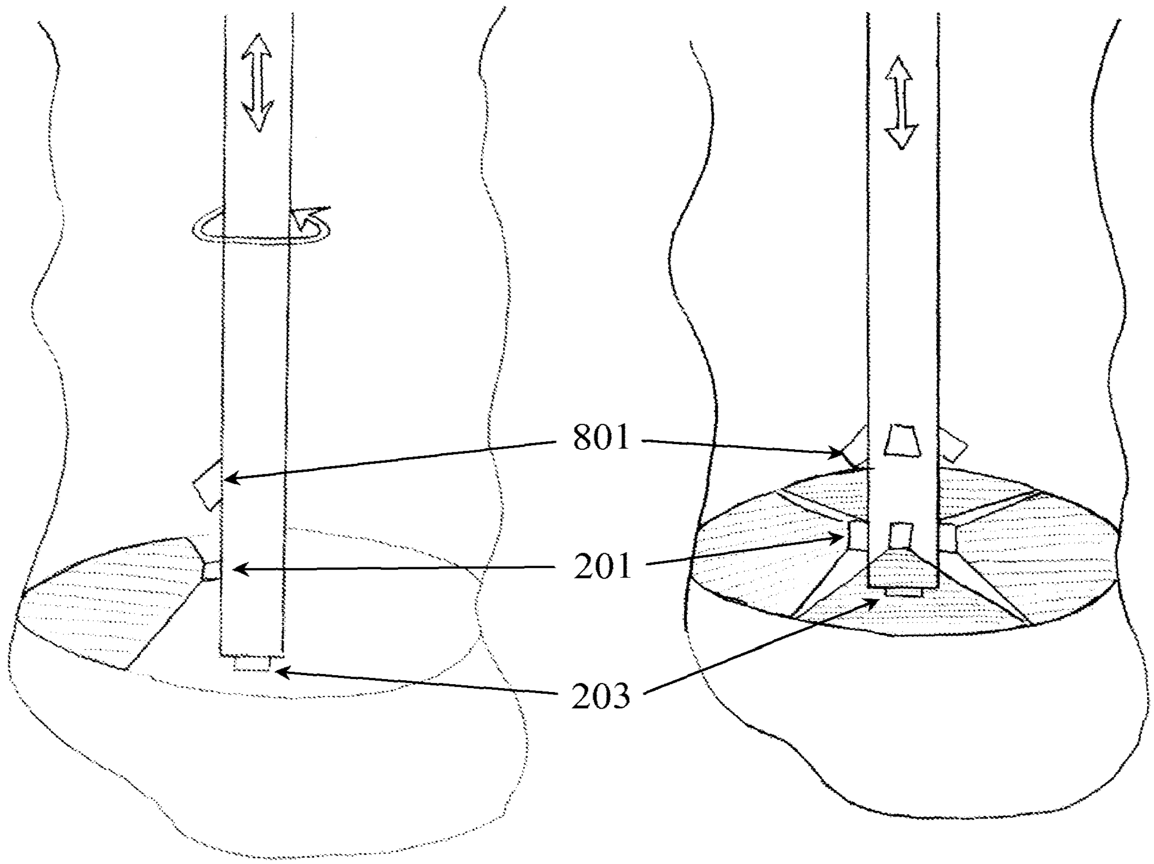


Figure 12

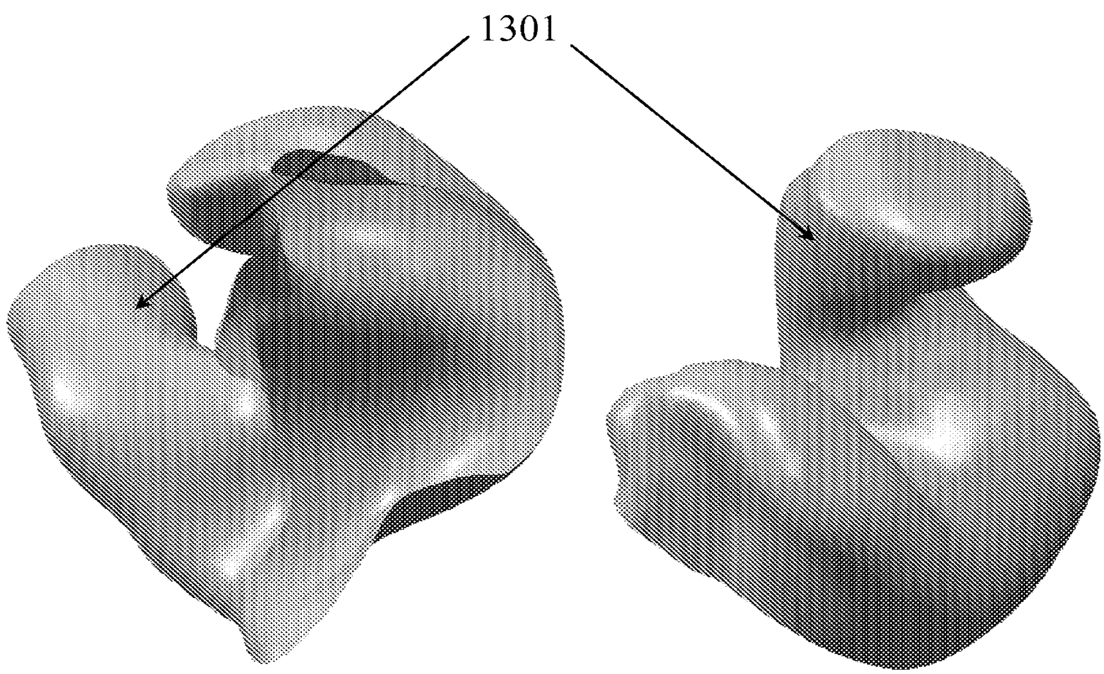


Figure 13

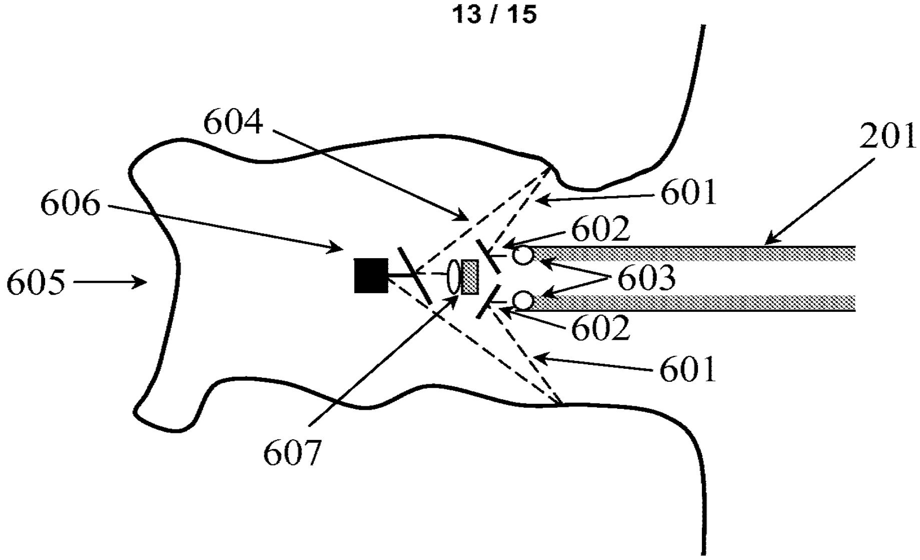


Figure 14

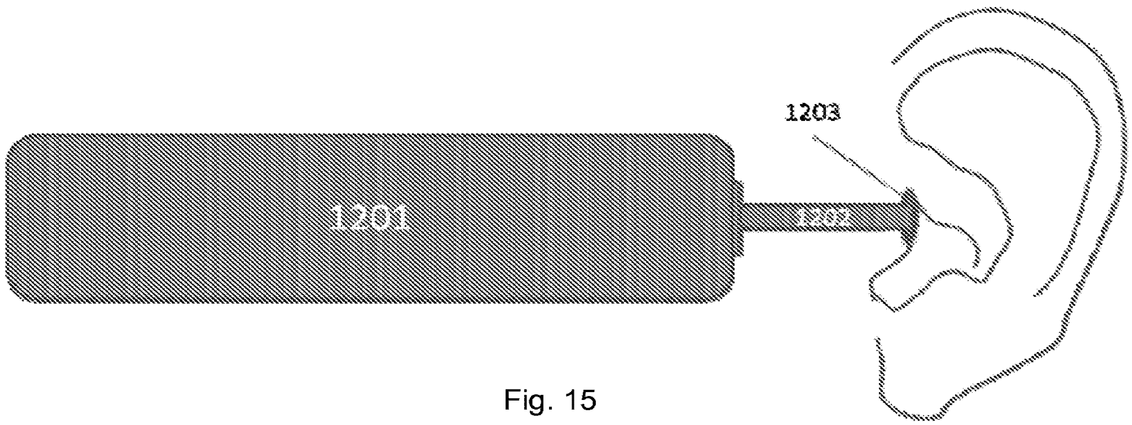
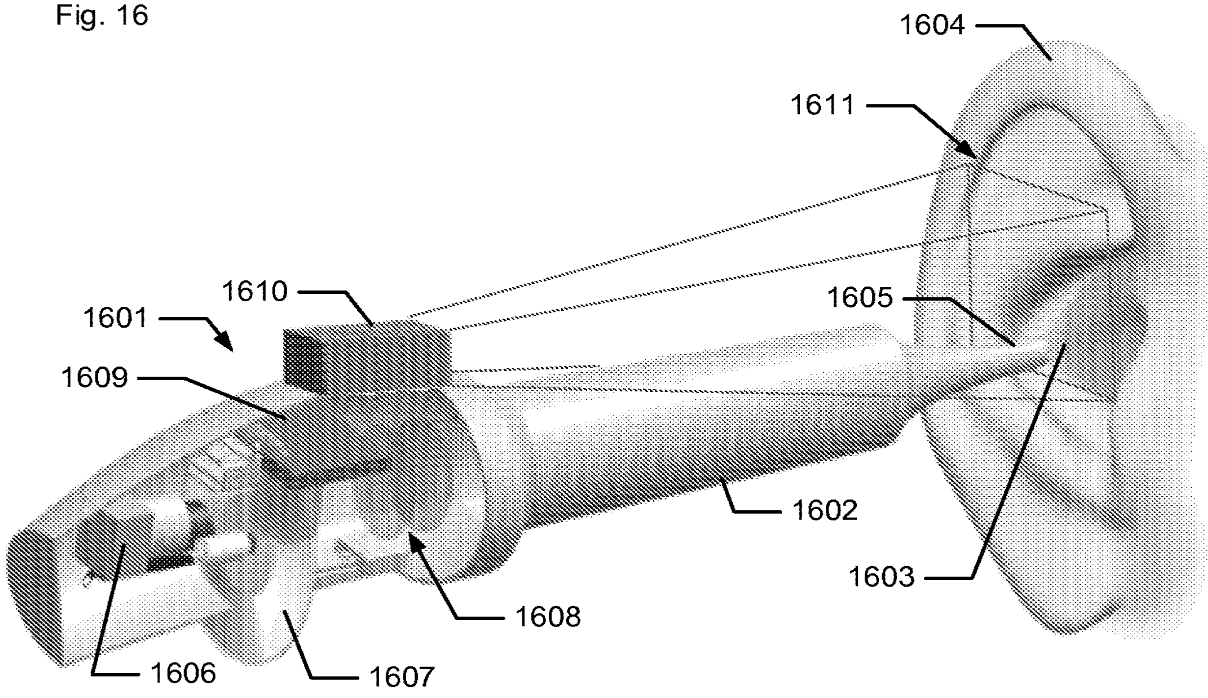

1201
1202
1203

Fig. 15

Fig. 16


1604
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1606
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Fig. 17a)

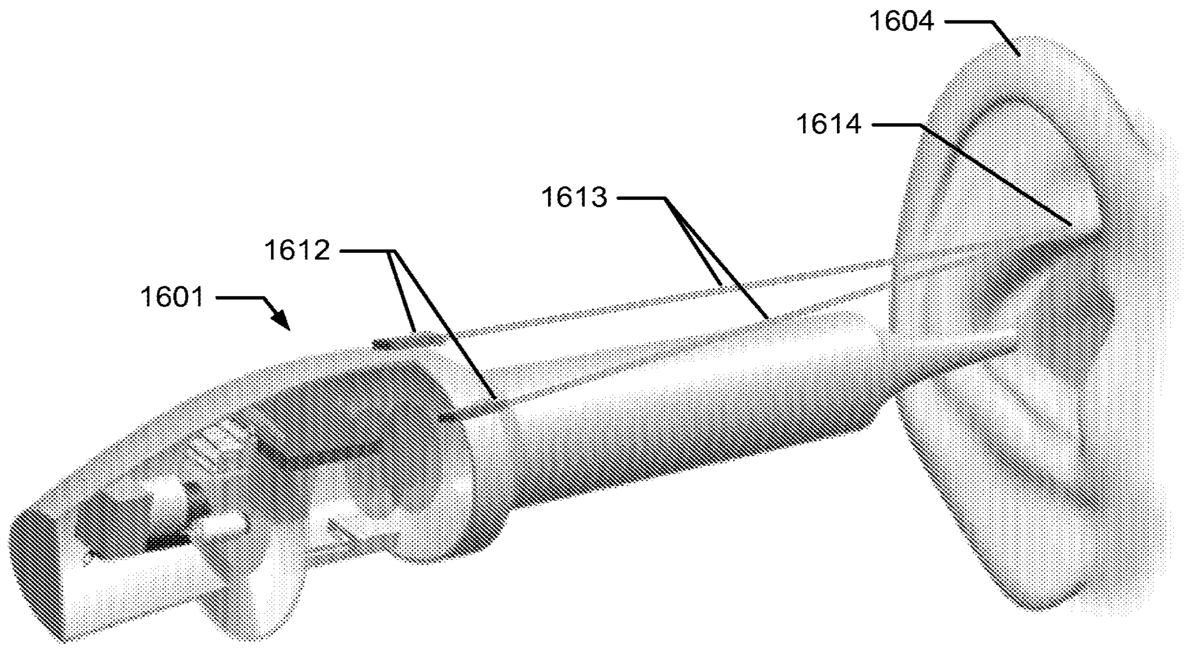
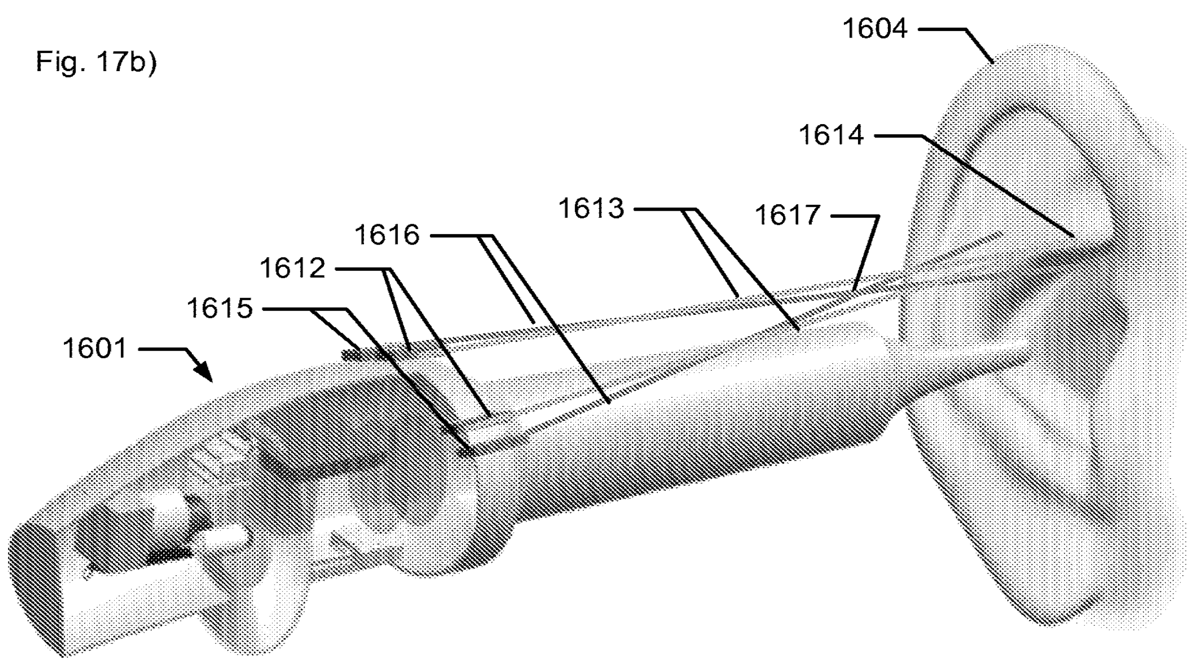


Fig. 17b)



INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

A. CLASSIFICATION OF SUBJECT MATTER
A61B1/227 (2006.01), A61B1/06 (2006.01), A61B5/107 (2006.01), G01B11/25 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC, ECLA: A61B, G01B.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, TXTE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 0216865 A2 (3SHAPE) 28. February 2002.	1-9, 37, 42, 45-49, 60-61, 69-71.
A		10-36, 38-41, 43-44, 50-59.
X	WO 02071794 A1 (3SHAPE) 12. September 2002.	1, 3-23, 26-37, 42,53-56, 60-61, 69-71.
A		2, 24-25, 38-41, 42-52, 57-59.
X	WO 0216867 A1 (3SHAPE) 28. February 2002.	1, 11-23, 26-35, 37, 42, 45, 60-61, 69-71.
A		2-10, 24-25, 36, 38-41, 43-44.
X,P	WO 2010145669 A1 (3SHAPE) 23. December 2010.	1-2, 60-61

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10/05/2011	20/06/2011

Name and mailing address of the ISA/	Authorized officer
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Facsimile No.	Telephone No. +45 43 50 81 24

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
There are at least 3 unrelated inventions (See explanation on extra sheet):

A: Claims 1-60, 69-71. A method for scanning partly obstructed interior surfaces for creating a 3D model and a hearing aid device obtained using this method and a computer program product executing the method.

B: Claims 61-68. A scanner system for carrying out three dimensional scanning of interior surfaces.

C: Claim 72 (numbered 71 in the application). A nontransitory computer readable medium storing a computer program for causing scanning of partly obstructed interior surfaces.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-61, 69-71

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/DK2011/050103

Patent document cited in search report	Publication date	Patent family member(s)	publication date
WO0216865 A2	20020228	US2003164952 A1 20030904 US7625335 B2 20091201 ES2327212T T3 20091027 EP1314000 A1 20030528 WO0216865 A3 20020620 WO0216867 A1 20020228 DK1314000T T3 20090817 AU8381201 A 20020304 AU8176101 A 20020304 AT431541T T 20090515	
WO02071794 A1	20020912	US2004107080 A1 20040603 EP1368986 A1 20031210	
WO0216867 A1	20020228	US2003164952 A1 20030904 US7625335 B2 20091201 ES2327212T T3 20091027 EP1314000 A1 20030528 WO0216865 A2 20020228 DK1314000T T3 20090817 AU8381201 A 20020304 AU8176101 A 20020304 AT431541T T 20090515	
WO2010145669 A1	20101223	NONE	

Form PCT/ISA/210 (patent family annex) (July 2009)

(Continuation of box III)

There are at least 3 unrelated inventions:

A: Claims 1-60, 69-71. A method for scanning partly obstructed interior surfaces for creating a 3D model and a hearing aid device obtained using this method and a computer program product executing the method.

B: Claims 61-68. A scanner system for carrying out three dimensional scanning of interior surfaces.

C: Claim 72 (numbered 71 in the application). A nontransitory computer readable medium storing a computer program for causing scanning of partly obstructed interior surfaces.

From the document WO 0216865 A2 (3SHAPE) 28. February 2002 (hereinafter denoted D1) it is known to make a direct scan of the ear canal of an individual in order to establish three dimensional model of the dimensions of the ear canal (see page 17, lines 5-13 and page 58, line 16 to page 59 line 29). The scanner system used for the method may comprise a probe shaped scanner (figures 3 1-35) having an axis, where the scanner further comprises a light source to create and project structured light (se page 59, line 15-16) and a camera recording 2D images of the reflected pattern from the interior surface. Series of the 2D images are used for obtaining 3D plots of the interior surface. Further, from D1 it is known to fill in "holes" in information by interpolation. Therefore, the method of claim 1 and the apparatus of claim 61 are both known from D1.

Hereinafter, claim 2 and claim 62 do not share any inventive feature beyond what is known from D1 because claim 2 is related to a method where the scanner system is varying the focus plane of the pattern while claim 62 relates to a scanner being able to perform a scan around its axis.

Accordingly, there is no inventive concept binding the to claims together and unity can not be acknowledged between inventions A and B.

Invention C does not in anyway relate to invention A because it merely discloses a nontransitory computer readable medium without defining any computer program steps/algorithms for carrying out the method disclosed in claim 1.

Accordingly, unity can not be acknowledged between invention A and C.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 August 2004 (05.08.2004)

PCT

(10) International Publication Number
WO 2004/066615 A1

(51) International Patent Classification[7]: H04N 5/225, 7/14, H04M 1/725, H04N 5/232, H04M 1/247

(21) International Application Number: PCT/EP2003/000607

(22) International Filing Date: 22 January 2003 (22.01.2003)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (*for all designated States except US*): **NOKIA CORPORATION** [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI).

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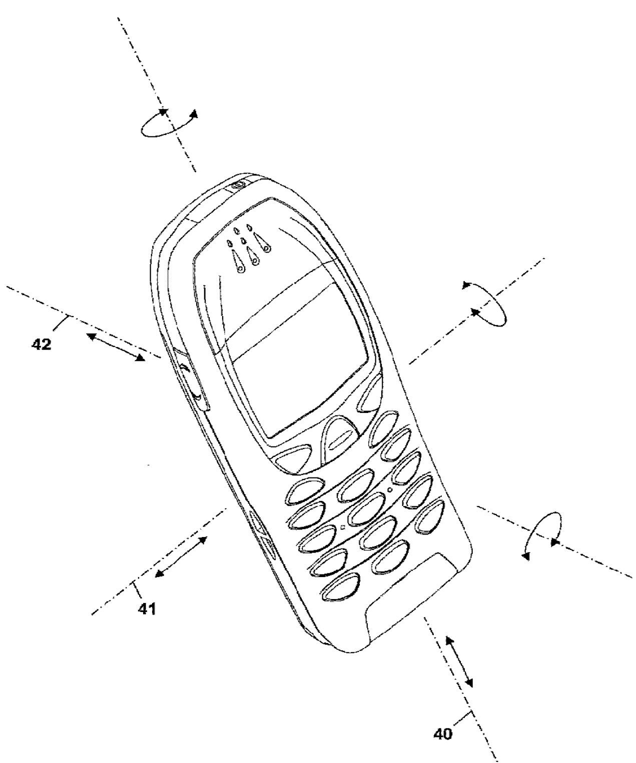
(81) Designated States (*national*): AE, AG, AL, AM, AT (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK (utility model), SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),

[Continued on next page]

(54) Title: IMAGE CONTROL



(57) Abstract: The present invention relates to the field of hand-held devices that are equipped wit a processor and a digital camera for capturing motion video or still images. Images captured by the camera are used to determine motion of the hand-held device. A resulting motion signal is used as input to a user interface. Displayed images can be scrolled, zoomed or rotated by moving the hand-held device. The motion signal can also be used as input for a graphical user interface to move a cursor or other object of the graphical user interface over the display. The invention relates further to a hand-held device provided with means for sensing motion, a display, a keypad with at least a first- and a second key, and a graphical user interface with objects and a cursor. The hand-held device also comprises means for transforming the sensed motion of the handheld device into a signal suitable for moving the cursor over the display.

WO 2004/066615 A1

Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

IMAGE CONTROL

The present invention relates to the field of hand-held devices that are equipped with a processor and a digital camera for capturing motion video or still images, in particular such devices that further comprise a display for displaying images or a graphical or character based user interface.

BACKGROUND ART

Hand-held devices provided with digital image capturing equipment, digital processing power and high resolution displays are becoming increasingly more common in a wide variety of uses.

For example, small mobile phones are recently being equipped with digital cameras and relatively small high resolution LCD screens. Hand-held computers commonly called "personal digital assistants" (PDA) are also available and are typically equipped with small high resolution display screens and have slots for receiving e.g. a digital camera. Similarly, communicators having both cellular communication and computer capabilities are available, typically having small display screens and an inbuilt or detachable digital camera. These small, hand-held devices do not, and cannot, conveniently have conventional input devices, such as a computer mouse and other control keys. Therefore, conventional personal computer interfaces, which also have their own drawbacks, are not suited for these small hand-held devices.

As a result, there are significant limitations on using such small hand-held devices in both obtaining output, e.g. viewing data on the display screen, and in inputting

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commands, e.g. changing the area viewed on the display screen or controlling the performance of a particular parameter associated with the device. Further, given the limited area available, not only on the display screen but also on the entire device, adding additional control keys, etc., is both difficult and burdensome to a user requiring two hand operation of the device.

US 6466198 discloses a system and method for view navigation and magnification of the display of hand-held devices in response to the orientation changes along only two axes of rotation as measured by sensors inside the devices. The view navigation system can be engaged and controlled by simultaneously pressing switches on both sides of the hand-held device. Miniature sensors like accelerometers, tilt sensors, or magneto-resistive direction sensors sense the orientation changes. These miniature sensors are presently not typically standard equipment for hand-held devices. Thus, such sensors add cost, use precious space and add weight.

The present invention is directed toward overcoming one or more of the above-identified problems.

DISCLOSURE OF THE INVENTION

On this background, it is an object of the present invention to provide a hand-held device of the kind referred to initially, which allows user input with the same hand that holds the device, without requiring the dedicated sensatory equipment used by prior art hand-held devices.

This object is achieved in accordance with claim 1, by providing a hand-held device comprising a processor, a digital camera for capturing motion video or still images, and means for transforming a signal from the camera into a motion signal indicative of the motion of the hand-held device.

Thus, by using a sensor that is available to start with in many hand-held devices -- namely a digital camera -- for a secondary use, namely creating a motion signal indicative of the motion of the hand-held device, a hand-held device with motion sensing is provided in a economical and reliable manner.

The hand-held device may further comprise a user interface in which motion of the hand-held device is - through the motion signal derived thereof - used as a user input.

The hand-held may further comprise a display, preferably a display suitable for displaying captured images.

Motion of a given type of the hand-held device can be used to manipulate images shown at least in part on the display, preferably by moving the images in a manner substantially corresponding to the movement of the hand-held device.

Different types of motion the hand-held device can e.g. be used to move, and/or zoom, and/or expand/collapse and/or rotate images displayed on the display.

Motion substantially parallel to the plane of the display of the hand-held device can be used to scroll an image displayed on the display. Motion substantially perpendicular to the plane of the display can be used to zoom an image displayed on the display. Rotational motion of the hand-held device can be used to rotate an image displayed on the display.

The images that are manipulated can e.g. be images that were previously captured by the camera.

The movement of image can be inverted with respect to motion of the hand-held device, since some users may prefer this.

The user interface may comprise a graphical user interface and motion of the hand-held device can be used as an input to the graphical user interface.

Motion of the hand-held device can be used to manipulate an object displayed by the graphical user interface, preferably by moving the object in a manner substantially corresponding to the motion or to the inverted motion of the hand-held device, whereby the object displayed by the graphical user interface can be an icon, a dialogue box, a window, a menu or a pointer.

Motion of a given type of the hand-held device can be used to move, and/or zoom, and/or expand/collapse and/or rotate objects displayed by the graphical user interface.

Motion substantially parallel to the plane of the display of the hand-held device can be used to scroll an object displayed by the graphical user interface. Motion substantially perpendicular to the plane of the display can be used to zoom an object displayed by the graphical user interface. Rotational motion of the hand-held device can be used to rotate an object displayed by the graphical user interface.

The digital camera can be an inbuilt camera or can be a detachable camera. The camera may be movable relative to the hand-held device.

The means for transforming a signal from the camera into a motion signal preferably derives the motion signal from changes between succeeding images captured by the camera.

The camera can be equipped with an autofocus system, whereby the focusing setting of the autofocus system can be used for detecting movement in the camera direction.

The hand-held device may further comprise at least one key. The functionality of a motion type can be dependent on the state of the at least one key.

Rotational motion of the hand-held device about an axis substantially perpendicular to the display may be used to cause an inverse rotational movement of the image or graphical user interface object relative to the display, preferably in a manner such that the image or object is static with respect to the fixed coordinate system in which the hand-held device is situated.

The motion signal can be used to adjust device settings, such as sound settings, keypad settings and display settings.

The hand-held device may further comprise a keypad with at least a first and a second key and the graphical user interface comprising a cursor, whereby motion of the hand-held device can be used to position the cursor over an object of the graphical user interface and primary functions associated with the object concerned can be activated by pressing the first key and secondary functions associated with the object of the concerned can be activated by pressing the second key.

The functionality of the first key can be associated with selection and activation of objects of the graphical user interface, and the functionality of the second key can be associated with calling up a context-sensitive menu.

The selection of the object concerned can be performed by pressing and releasing the first key. Activation of the object concerned can be performed by pressing and releasing the first key twice in rapid succession. Moving or resizing of the object concerned can be performed by holding down the first key while moving the hand-held device to move the cursor.

The first key and the second key can be softkeys, whereby the current functionality of the softkeys is shown in the display, preferably in dedicated fields of the display.

The first key can be placed below the display on the left side of the latter, preferably proximate to lower edge of the display, and the second key can be placed below the display on the right side of the latter, preferably proximate to lower edge of the display.

It is another object of the present invention to provide an improved method for proving user input to hand-held devices. This object is achieved by providing a method for creating user input for a hand-held device that has a processor, a user interface and a digital camera for capturing motion video or still images comprising the steps of:

determining motion of the hand-held device from the camera signal;

using the determined motion of the hand-held device as an input for the user interface.

It is yet another object of the present invention to provide a use of a digital camera of a hand-held device that has a processor to produce a motion signal indicative of motion of the hand-held device.

A further object of the invention is to provide a hand-held device with an improved graphical user interface. This object is achieved by providing a hand-held device comprising a processor, means for sensing motion of the hand-held device, a display, a keypad with at least a first- and a second key, a graphical user interface with objects and a cursor, and means for transforming the sensed motion of the handheld device into a signal suitable for moving the cursor over the display.

By controlling the position of a cursor through motion of the handheld device it becomes possible to provide a user-friendly cursor controlled graphical user interface for hand-held devices.

Preferably, motion of the hand-held device is used to position the cursor over objects of the graphical user interface and primary functions associated with the object concerned are activated by pressing the first key and secondary functions associated with the object concerned are activated by pressing the second key.

The functionality of the first key can be associated with selection and activation of objects of the graphical user interface, and the functionality of the second key can be preferably associated with calling up a context-sensitive menu.

Selection of the object concerned is preferably performed by pressing and releasing the first key, and activation of the object concerned is preferably performed by pressing and releasing the first key twice in rapid succession.

Moving or resizing of the object concerned can be performed by holding down the first key while moving the hand-held device to move the cursor and the object concerned in unison therewith.

The first key and the second key can be softkeys, whereby the current functionality of the softkeys is shown in the display, preferably in dedicated fields of the display.

The first key can be placed below the display on the left side of the latter, preferably proximate to lower edge of the display, and the second key can be placed below the display on the right side of the latter, preferably proximate to lower edge of the display.

The means for transforming motion of the handheld device into a signal suitable for moving the cursor over the display may further comprise a tilt sensor and/or an image capturing device and/or an accelerometer.

The hand-held device according may further comprise means to transform a signal from the image capturing device, i.e. camera and/or tilt sensor and/or accelerometer into a position signal for the cursor.

The means for transforming a signal from the camera into a motion signal preferably derives the motion signal from changes between succeeding images, or parts of succeeding images captured by the camera.

The camera may have an autofocus system, whereby the focusing setting of the autofocus system is used for detecting movement in the camera direction.

The graphical user interface may include one or more of the following object types: icons, dialogue boxes, windows, menus, pointers.

Further objects, features, advantages and properties of the hand-held device, method for proving user input and use of a digital camera in a hand-held device according to the invention will become apparent from the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following detailed portion of the present description, the invention will be explained in more detail with reference to the exemplary embodiments shown in the drawings, in which:

Fig. 1 illustrates a preferred embodiment of a hand-held device according to the invention,
Fig. 2 shows a block diagram of the hand-held device of the embodiment of Fig. 1,
Fig. 3 indicates the axes of movement and rotation along which the hand-held device is moved and rotated in order to create user input in accordance with the present invention,
Figs. 3.1 to 3.7 illustrate the use of the present invention for zooming, scrolling and rotating images shown on the display,
Figs. 3.8 to 3.10 illustrate the use of the present invention for user input to a graphical user interface to scroll a table in a window and to resize a window,
Figs. 3.11 to 3.13 illustrate the use of the present invention for scrolling a magnifying window over the display,

Figs. 3.14 and 3.15 illustrate the use of the present invention for moving a part of an image by cutting an pasting,

Fig. 3.16 illustrates the use of the present invention with a text editing application,

Fig. 3.17 illustrates the use of the present invention with an application for entering musical notes in a stave,

Fig. 3.18 illustrates the use of the present invention with a labyrinth game

Fig. 3.19 illustrates the use of the present invention for controlling a video game,

Fig. 3.20 illustrates the use of the present invention with an application for controlling the sound settings of a music player funtion,

Fig. 4 outlines a software flow diagram for zooming, scrolling and rotating images shown on the display, and

Figs. 5 and 6 show an alternative preferred embodiment of a hand-held device according to the invention.

DETAILED DESCRIPTION

This invention allows hand-held communication or computing devices with a relatively small display to receive user input by moving or rotating the device. In particular with devices having a display, the invention allows convenient navigation of a large stored virtual display or of objects in a graphical user interface. Such devices may include PDA devices, camcorders, digital photo cameras, digital binoculars (solid-state stereoscopic imaging system incorporated for viewing and digitally recording magnified stereo images), mobile hand-held terminals, advanced pagers, mobile telephones, and communicators.

According to a preferred embodiment, the hand-held device is a hand portable phone, preferably a cellular/mobile phone.

Fig. 1 shows a mobile phone according to the invention, and it will be seen that the phone, which is generally designated by 1, comprises a user interface having a keypad 2, a display 3, an on/off button 4 , a speaker 5 (only the openings are shown), and a microphone 6 (only the opening is shown). The phone 1 according to the preferred embodiment is adapted for communication via a cellular network, such as the GSM 900/1800 MHz network.

The keypad 7 has a first group of keys 8 as alphanumeric keys, by means of which the user can enter a telephone number, write a text message (SMS), write a name (associated with the phone number), etc. Each of the twelve alphanumeric keys 8 is provided with a figure "0-9" or a sign "#" or "*", respectively. In alpha mode each key is associated with a number of letters and special signs used in the text editing.

The keypad 7 additionally comprises two softkeys 9, two call handling keys 12, and an arrow key 10. The function of the softkeys depends on the state of the phone and the navigation in the menu can be performed by using the navigation-key. The present function of the softkeys 9 is shown in separate fields in the display 3, just above keys 9. The two call handling keys 12 are used for establishing a call or a conference call, terminating a call or rejecting an incoming call. This key layout is characteristic for e.g. the Nokia 6210™ phone.

The arrow key 10 is an up/down key which can be used for cursor movement and scrolling and is placed centrally on the front surface of the phone between the display 3 and the group of alphanumeric keys 7. A battery pack 14 is mounted on the back of the phone and supplies electrical power for the electronic components of the mobile phone.

The phone has a flat display 3 that is typically made of a LCD with optional back lighting, such as a TFT matrix capable of displaying color images.

The phone is equipped with a digital camera 35 of which only the lens 36 is visible in Fig. 1. The camera is arranged at the rear of the phone above the battery pack 14. The camera direction is therefore substantially perpendicular to the rear surface of the phone 1. Just under the camera an infrared port 38 for IrDA communication is provided (only window of the port is shown). The camera may alternatively have a rotatable connection to the phone (not shown), to allow adjustment of the camera direction relative to the housing of the phone.

Fig. 2 schematically shows the most important parts of a preferred embodiment of the phone, in the form of a block diagram. A processor 18 controls the communication with the network via the transmitter/receiver circuit 19 and an internal antenna 20. A microphone 6 transforms the user's speech into analogue signals, the analogue signals formed thereby are A/D converted in an A/D converter (not shown) before the speech is encoded in a digital signal processing unit 14 (DSP). The encoded speech signal is transferred to the processor 18, which i.e. supports the GSM terminal software. The processor 18 also forms the interface to the peripheral units of the apparatus, including a RAM memory 17a and a Flash ROM memory 17b, a SIM card 16, and the keypad 2 (as well as data, power supply, etc.). The digital signal-processing unit 14 speech-decodes the signal, which is transferred from the processor 18 to the earpiece 5 via a D/A converter (not shown). The processor communicates in two directions with the IrDA port 38 (infrared port) that allows data communication with other devices that are equipped with such a port, such a PC's, laptops, personal digital assistants (PDA) and other mobile phones. The phone may further be equipped with a short range RF transmitter receiver (not shown), e.g. according to the Bluetooth standard, for data transmission with other devices as mentioned for IR data communication.

The processor 18 also forms the interface for the display controller 31. The image controller 31 receives the image files from the processor 18 and renders images for showing on the display 3.

A camera controller 37 is also connected to the processor 18 and controls the digital camera 35. The camera controller 37 sets the resolution, the refresh rate, the focus, and zoom factor of the camera 35. The camera controller 37 sets the focus automatically through any of the well-known auto focus techniques available. The output signal of the camera 35 is connected to the processor 18.

When the camera is used to detect motion of the hand-held device, the camera controller 37 automatically selects the appropriate resolution and refresh rate, so that the refresh rate is high enough to derive a smooth motion signal from the changes in the succeeding images. For motion detection it is not usually necessary to use the complete image captured by the digital camera. The software can pick out a particular section of the image for the motion detection so that the amount of data that has to be processed is reduced. These two measures (low resolution and using a section of the image) allow higher sampling rates and reduced power consumption because of lower data processing power demands.

Some surfaces in the camera view may not be particularly suited for detecting motion, e.g. because of a uniform surface, or because the distance to the objects in the camera view is too large to determine changes in distance accurately. Such problems may be solved (in the embodiment with the adjustable camera direction) by directing the camera to another available object with sufficient texture, such as the user. The camera direction is thus reversed compared to the "normal" direction. The motion signal derived from the camera signal is therefore automatically inversed when the camera is directed to the user.

The camera 35 is a conventional digital camera and therefore not all the features of the camera 35 are shown. The image sensor of the digital camera can be any of the known configurations for solid-state image sensors, such as frame transfer, interline transfer CCDs, or diode arrays.

Standard CCD devices are sensitive to both visual light and near infrared light. Conventional digital cameras for capturing images with visual light are therefore provided with an infrared filter for preventing influences of infrared light on the captured image. The mobile phone 1 is also provided with an infrared filter (not shown). The infrared filter can be moved out of the path of the light into the camera for capturing infrared images. The IrDA port 38 can be set to irradiate continuously to function as a light source for the camera 35 when it is in the infrared mode. Thus, the camera 35 can be used when there is little or no ambient light. The use of an IrDA port as a light source for a digital camera and the details of a device to move the infrared filter in and out of the camera path as well adjustments to the auto focus system are disclosed in US patent application with serial nr. 10/029,968, hereby incorporated by reference.

The lens 36 is preferably a fixed focal length lens with movable lens group to allow auto focus, however, lens 36 could be any type of lens providing for adjustment to focus on different parts of the image received, as will be understood to those skilled in the art.

The characteristics of visible light and near infrared light with respect to focusing are slightly different. Therefore, the auto focus system has two settings; a first setting for capturing images with visual light and a second setting for infrared light.

Standard software for processing, storing and recalling pictures captured with visual light and captured with infrared light is installed on the phone 1. This software may as such be conventional and commercially available. The software is also able to control the refresh rate of the images shown on the display.

Optionally, the phone 1 may also comprise one or two tilt sensors 39 which determine the direction and magnitude of the displacement relative to vertical using the planetary gravitational field. Such sensors could be any of well known types such as those operating with an encoding disk on a freely rotatable shaft connected to a weight, or of the type that uses sphere provided with an asymmetrical weight that floats in a liquid. Alternatively the tilt sensor could by of the gyroscopic type. The signals of the camera the tilt sensors can be combined for generating the motion signal.

The phone 1 in accordance with e preferred embodiment employs two operational modes associated with the use of motion of the phone to generate user input, which throughout this document are referred to as navigation mode and fixed mode. When set to the navigation mode, motion of the phone 1 is used as input, and when displaying an image, the display view is automatically scrolled, zoomed and rotated to follow movements of the holding hand. The navigation mode is activated by pressing the left softkey 9 "Navigate". Thus, the navigation mode is activated and the functionality of the left softkey 9 changes to "Fixed". When set back to the fixed mode by pressing the left softkey "Fixed" again, the display view becomes stationary and no longer follows the movements of the hand.

Fig. 3 indicates the relative axes of orientation along which the phone 1 is rotated or translated in order to navigate an image on the display 3. Throughout this document, axis 40 will be referred to as the Y-axis, and motion of the phone in the direction of the Y-axis is in a preferred embodiment used to scroll images in the Y-direction. Similarly, axis 41 will be referred to as the X-axis and motion of the phone in the direction of the X-axis is in a preferred embodiment used to scroll images in the X-direction. Motion in the camera direction measured along the Z-axis 42 is in a preferred embodiment used to control the zoom factor of the images shown on the display 3. Rotation about the Z-axis is used to rotate images shown on the display 3. Though these are the preferred functions assigned with movements along the X- ,Y- and Z-axes, any other functionality can be assigned to movement in the direction of these axes or to rotational movement about these axes.

While the scrolling, zooming, and rotation of the display follows the movements of the device, the rate of scrolling/zooming/rotation as well as the amount of scrolling/zooming/rotation need not follow the exact amount of change in position, and can be inverted. As will be discussed below, the control software of the present invention can smooth the movements of the phone to provide a convenient effect on the display.

Figs. 3.1 to 3.13 show an overview of the operation of the phone 1 to scroll, zoom and rotate images.

With reference to Fig. 3.1, a high resolution image of a holiday snapshot comprising a lake, a bridge and a mountain peak stored in the RAM 17a is shown for viewing on the display 3. The display 3 is too small to show the entire image with sufficient size to appreciate all the details in the image conveniently. The user presses the left softkey 9 "Navigate" to enter the navigation mode. The phone activates the navigation mode and changes the label above the left softkey 9 to "Fixed". In Fig. 3.2, the navigation process is started when the operator's hand moves the phone 1 along the Z- axis 42 in the direction of arrow 42′ for magnifying the view so that the display 3 shows the central portion of the image with the bridge in an enlarged manner (Fig. 3.3). By moving the phone along the Y-axis 40 in the direction of arrow 40′ the display 3 scrolls the images upwards and the mountain peak above the bridge can be viewed (Fig. 3.5).

In Fig. 3.6 the holiday snapshot is shown in a portrait orientation and can only be properly viewed with the phone in a horizontal position. The user wishes to view the image with the phone in an upright position so that the image will be displayed in a landscape position with respect to the display 3. The user presses the left softkey 9 "Navigate" to activate the navigation mode and rotates the phone a half turn anticlockwise (Fig. 3.7). The movement of the phone 1 creates a series of changing images captured by the camera 35 from which the software on the phone derives a motion signal. Upon detection the rotational movement about the Z-axis the software on the phone rotates the displayed image in the opposite direction, and when the user has completed a half anticlockwise turn the software has rotated the image a half turn clockwise, and the user can conveniently view the image with the phone in an upright position. The image is thus static with respect to the fixed coordinate system in which the phone 1 device is situated.

The settings for the responses to motion of the phone 1 can thus be set in way in which the user perceives the view as that of a static image over which a magnifying window (the display 3) is moved.

Fig. 3.8 shows a display 3 of the phone in a mode in which a graphical user interface is used to command the device. A window 70 containing a scrollable table is displayed on the display 3. Scroll bars 71 and 72 are shown to the right and at the bottom of the table, respectively. A cursor 73 can be moved over the display by moving the phone in the direction of the X- and Y-axes. The left softkey 9 "Left-click" has the same functionality as the left mouse button as known from many windows based graphical user interfaces, namely to select a primary function associated with an object marked by the cursor 73. By clicking, double clicking or holding the left softkey 9 down. The right softkey 9 "Right-click" also has the same functionality as the right mouse button as known from many windows based graphical user interfaces, namely to select secondary functions associated with an object marked by the cursor 73. It is possible to assign the "Left click" and "Right click" to other keys of the phone, but using a similar layout as for the keys of a computer mouse may facilitate user acceptance.

Example 1: The user wishes to scroll the table to the right to view column E. By holding the left softkey 9 "Left-click" pressed and moving the phone to the right along the X-axis the table is scrolled by dragging it with the cursor to the right as shown in Fig. 3.9.

Example 2: The user wishes to resize the window 70. After placing the cursor 73 on the upper bar of the window 70 and while holding the left softkey 9 "Left-click" movement of the phone 1 in the direction of the Z-axis resizes the window 70. Moving the phone towards the user enlarges the window as shown in Fig. 3.10 and moving away from the user reduces the size of the window (not shown).

Example 3: The user wishes to move a part of an image in an image editing program. The part of the image to be moved is marked with a sizable box 65. Holding the left softkey 9 "Left-click" down and moving the mouse by rotating the phone about the X- and Y-axis resizes the box (Fig. 3.14). After sizing the box 65 the left softkey 9 is released and the cursor 73 can be moved freely. The box can be dragged and dropped to the desired position by placing the cursor 71 in the box 65 and holding the left softkey 9 "Left-click" down whilst rotating the phone about the Y- and/or X-axis until the box has moved to the desired position. By releasing the left softkey 9 the boxed is dropped and the cursor 73 can move freely again. Thus, the part of the image in the box is cut from the original position and pasted to the new position.

In the same or manner any object e.g. text in a text editor program, or numbers/text in a spreadsheet can be marked, resized, dragged and dropped "click and drag" with the left softkey.

The most common "gestures" performed by moving the phone and pressing the softkeys are:

- point (to place the cursor over an object of the graphical user interface),
- left-click (to press and release the left softkey) to select the object which the cursor is placed,
- double-click (to press and release a softkey twice in rapid succession) to activate the object that the cursor is placed over,
- right-click (to press and release the right softkey) to call up a context-sensitive menu, and
- drag (to hold down the left softkey while moving the phone to move the cursor) to move or resize objects.

Figs. 3.11 to 3.13 show another method of manipulation magnified portion of an image. Fig. 3.11 shows the display 3 with an image of a several advanced type mobile phones. A magnifying window 103 enlarges a portion of the image to allow the user a view with both a good overview and the possibility to view detail in a selected portion of the image. The magnifying window 103 can be moved over the display 3 by holding down the left softkey 9 "Navigate" whilst moving the phone in the direction of arrow 41' and/or arrow 40' (Fig. 3.12) to place the magnifying window at the desired position (Fig 3.13). The magnifying factor of the magnifying window can be changed by moving the phone 1 in the direction of the Z-axis (not shown).

Fig 3.16 shows another example of the use of the present intention in the form of an application for entering text. In the upper part of the display shows a string of characters already entered. A set of characters that can be entered, in this example the alphabet, is displayed below the upper part of the display. Other character sets could comprise a number set or special signs set, etc.

The functionality of the left softkey 9 "Type" and the right softkey 9 "Options" is shown in the lower part of the display. One of the characters of the character set is marked by bold print. By rotating the phone about the Y-axis 40 the marking moves left or right. By rotating the phone about the X-axis 41 the marking moves up and down. The marked character is added to the string of characters by pressing the left softkey 9 "Type".

By pressing the right softkey "Options" a scrollable list of selectable menu items is displayed (not shown) comprising: "Clear last character", "Clear screen", "Number character set", "Symbol character set", and "Exit", one of the menu items being marked by inverse print. The list can be scrolled by rotating the phone about the Z-axis 41, and the marked menu item is selected by pressing the left softkey 9 "Select".

Fig 3.17 shows another example of the use of the present invention in the form of an application for entering musical notes in a stave 69. A cursor 73 (shape changed to a cross for this application) is used to indicate the position where a note is to be entered. By rotating the phone about the Y-axis 40 the cursor can be moved left an right. By rotating the phone about the X-axis 41 the cursor can move up and down.

The cursor is placed above the position in the stave at which a note is to be entered, higher tones are placed higher up in the stave and lower tones are placed lower in the stave. A tone is entered by pressing the left softkey 9 "Type". After typing a note the application prompts for entering the length of the note by displaying the text "Length? 1=1 2=½ 4=¼ 8=$^{1}/_{8}$" between the stave and the labels for the softkeys. The note length is entered by pressing the alphanumeric key with the value associated with the desired note length.

By pressing the right softkey "Options" a scrollable list of selectable menu items is displayed (not shown) comprising: "Clear last note", "Clear stave", "Enter special notes", and "Exit", one of the menu items being marked by inverse print. The list can be scrolled by rotating the phone about the X-axis 41, and the marked menu item is selected by pressing the left softkey 9 "Select".

Fig. 3.18 shows another example of the use of the present invention in the form of an application simulating a labyrinth game. The player (user of the hand-held device) endeavors to guide a virtual ball 59 through a virtual labyrinth formed by virtual walls 57 on a virtual playing surface past a plurality of virtual openings 58 though which the virtual ball 59 may drop.

The application simulates the effect caused by gravity that tilting a real playing surface out of the horizontal plane has on a real ball, e.g. the virtual ball starts rolling to the lower side of the display 3 when the latter is tilted out of the horizontal plane. Also the effect of gravity on a real ball passing over a real opening is simulated by the application, e.g. the virtual ball drops through the virtual opening when it passes over a virtual opening.

At the start of the game, the display is held horizontally, or any other orientation that the user deems suitable as reference orientation to calibrate the virtual "horizontal" position of the display. The movement of the virtual ball over the virtual playing surface is controlled by moving the phone out of- and back into the horizontal plane by rotating it rotating about the Y-axis 40 and/or the X-axis. The rotational movements are detected from the changes between the succeeding images captured by the camera and translated into changes in speed and rolling direction of the virtual ball.

Fig 3.19 shows another example of the use of the present invention in the form of an application for controlling another computer game, in this example a car racing simulation. The player (user of the hand-held device) endeavors to "drive" a car around a racing circuit as fast as possible. The application allows the player to control the steering breaking and giving gas functions. The imaginary view on the racing circuit is the main content of the display, but is not shown on Fig. 3.19. The display further shows a steering wheel and rearview mirrors. A race is started by double clicking the left softkey 9 "Action". The control settings for speed and directions are calibrated and set to zero for the present position and orientation of the phone 1. After an audible start signal the driver is supposed to attempt to follow the displayed racing circuit. The "car" is steered by rotating the phone about the z-axis 42. Rotating the phone clockwise out of the calibrated position about the Z-axis makes the "car" turn right. Rotating the phone further out of the calibrated orientation, make the "car" turn sharper and vice versa. Similarly, rotating the phone anti-clockwise about the Z-axis out of the calibrated position makes the "car" turn left. The speed of the "car" is controlled by tilting the phone 1 about the X-axis 41. Rotating the phone 1 out of the calibrated position in one direction is used to give "gas". Rotating the phone 1 further out of the calibrated orientation increases the amount of "gas", and vice versa. The amount of breaking applied to the car is similarly controlled by rotating the phone 1 out of the calibrated position in the opposite direction. The user may select which direction of rotation about the X-axis is used to give "gas", whereby the breaking direction is always the opposite. Other computer games that can be controlled in a similar manner but using more axes of motion/control include motor bike racing, and helicopter flying. For motorbike racing the factor balance can be included in relation to motion about one of the axes, to produce a very realistic experience, with e.g. steering bar rotation connected to rotation about the Z-axis, giving gas and breaking connected to rotation about the X-axis and balance connected to translative motion along the X-axis. For enhancing the games the capacity of the mobile phone to generate sound via the loudspeaker, in particular a hands-free loudspeaker is used to simulate e.g. motor, and/or propeller sound. The vibrator function (not shown) of the mobile phone can be used to give feedback in connection with shocks and crashes.

Fig 3.20 shows another example of the use of the present invention in the form of an application for controlling the sound setting of a music player function of the phone. The application allows a user to control volume, bass and treble. The application shows a volume button, a bass button and a treble button on the display 3. The button that is to be manipulated is be marked by a higher line thickness (as shown for the "Volume" button in Fig. 3.20). The marking can be moved to other buttons by rotating the phone about the Y-axis 40. The marked button is manipulated by holding the left softkey 9 "Control" down while rotating the phone about the Z-axis 42. Clockwise rotation of the phone results in an increased setting of the parameter concerned, anticlockwise rotation of the phone results in a decreased setting of the parameter concerned. The application ends by pressing the right softkey 9 "Exit". Alternatively, the display shows slide control knobs for each of the parameters to be controlled (not shown). The knob that is to be manipulated is be marked by a higher line thickness. The marking can be moved to other knobs by rotating the phone about the Y-axis 40. The marked knob is manipulated by holding the left softkey 9 "Control" down while moving the phone in the direction of the Z-axis 42. Moving the phone in the direction in which the display 3 is facing increases the parameter setting concerned, moving the phone in the opposite direction results in a decreased setting of the parameter concerned.

Another example of the use of the present invention is in connection with another terminal such as a PC (not shown). The motion signal of the phone is transmitted to the PC to control the movement of an object. The object could be a 3-D object displayed on a screen connected to the PC, whereby orientation changes of the phone are used to change the orientation of the displayed object. The orientation of the object on the screen can be completely synchronized with the orientation of the phone. After an initial calibration of the relative positions, e.g. when the phone is upright, the displayed object is also upright. For e.g. presenting a product, the product can be shown as an object on a large screen. To change the orientation of the object the user changes the orientation of the phone by rotating it, and the PC rotates the displayed object in the same way in response to the signal that it receives from the phone.

Another example of using the phone with another terminal, i.e. a workstation or a PC is for moving through an imaginary 3-D space displayed on a screen by e.g. a CAD program. The movements of the phone in the real 3-D world are incorporated in the signal that is sent to the workstation and the PC or workstation translates the signal to movements of the viewing position in the "3-D space" displayed on the screen. Changes in the orientation of the phone are also incorporated in the signal that is sent to the workstation and translated to changes of the viewing direction in the "3-D space" displayed on the screen. Thus the user can "walk" through an imaginary room by walking around in the real world whilst holding or carrying the phone, and change the viewing direction by pointing the phone in the desired viewing direction. To facilitate this manner of use, the invention could be incorporated in a smaller device that is integrated in a helmet or mounted to another kind of headgear, so that viewing direction can be changed by the user turning his/her head in the desired direction of view.

This manner of controlling the viewing position and the viewing direction can equally well be used for computer games and any other software applications that display a virtual 3-D space on a screen, i.e. to move through and observe a room, or any other place created in a virtual world. Another example of a use of this manner of controlling is game application that guides, i.e. instructs a user to follow a virtual path and checks through the motion signal if the user really travels this path. Such games could be used by a group of users with interactive mobile phones in a suitable open space such as a sports ground.

Fig. 4 outlines the software flow diagram for the manipulation of an image as described with reference to Figs. 3.1 to 3.7. The flow from start 80 to end 98 is performed several times a second in a standard polling process of the processor 18. At the initialization step at block 82, the current view settings are marked. The label above the left softkey 9 is set to "Navigation" in block 84. The status of the left softkey 9 is checked in block 86. If the left softkey 9 is pressed, the system is set to the navigation mode in block 88 and the label above the left softkey is changed to "Fixed".

At block 90 the camera image and auto focus settings are acquired, stored and compared to the previous readings. If a change in image or in auto focus setting is detected at block 92, the program derives the movement of the phone 1 from the changes in block 94 and computes the new view settings i.e. zoom factor, rotation angle and portion of the image to be displayed. It also instructs the display controller 31 to refresh the display 3 to show the new view and it saves the present camera image as the basis for comparison in the next iteration of the process.

In block 96 the status of the left softkey 9 is checked and if it is pressed the process ends at block 98 until the program is polled again. If the check for the left softkey 9 is negative, the program goes to step 90 and the above process repeats itself.

The program can be set with different response curves for computing the new view setting in response to changes in camera image and/or auto focus setting at block 94. Fine or coarse modes of response can be set by the operator or can be changed dynamically during the time the system is in the navigation mode. With fine response, the display view changes at a relatively slow rate in response to the movements of the phone. With coarse response, the display view changes rapidly in response to the movements of the phone. The response can also be inverted to adapt to user preferences.

The functionality associated with a given type of motion of the phone 1 can be set. Thus, the user can e.g. set the program such that the cursor 73 can be moved up and down by rotation about the X- axis and can be moved left and right by rotation about the Z-axis. Given types of motion of the phone 1 can be associated with functionality that does not relate to the display 3, such as sound settings (e.g. volume and balance) and display settings (e.g. brightness, color balance and contrast).

Figs. 5 and 6 show an alternative preferred embodiment of a hand-held device according to the invention in the form of a communicator 101. The communicator 101 is basically built up in the same way as the mobile phone 1 though with a larger display 103 and a larger keyboard 107. A camera 135 (only lens 136 is shown) is mounted in the back/bottom of the communicator and has the same functionality as the camera in the phone 1. The internal hardware is also build up in the same way as the phone 1, but with increased processing power and a larger memory. Movements of the communicator 101 in the direction of or about the X-axis 141, the Y-axis 140 and Z-axis 142 have the same functionality as in the phone 1.

Although the present invention has been described in detail for purpose of illustration, it is understood that such detail is solely for that purpose, and variations can be made therein by those skilled in the art without departing from the scope of the invention.

Thus, while the preferred embodiments of the devices and methods have been described in reference to the environment in which they were developed, they are merely illustrative of the principles of the inventions. Other embodiments and configurations may be devised without departing from the scope of the appended claims.

CLAIMS:

1. A hand-held device comprising a processor, a digital camera for capturing motion video or still images, and means for transforming a signal from the camera into a motion signal indicative of the motion of the hand-held device.

2. A hand-held device according to claim 1, further comprising a user interface in which motion of the hand-held device is - through the motion signal derived thereof - used as a user input.

3. A hand-held device according to claim 1 or 2, further comprising a display suitable for displaying captured images.

4. A hand-held device according to claim 3, in which motion of a given type of the hand-held device is used to manipulate images shown at least in part on the display, preferably by moving the images in a manner substantially corresponding to the movement of the hand-held device.

5. A hand-held device according to claim 4, in which a given type of motion the hand-held device is used to move, and/or zoom, and/or expand/collapse and/or rotate images displayed on the display.

6. A hand-held device according to claim 5, in which motion substantially parallel to the plane of the display of the hand-held device is used to scroll an image displayed on the display, and/or motion substantially perpendicular to the plane of the display is used to zoom an image displayed on the display and/or rotational motion of the hand-held device is used to rotate an image displayed on the display.

7. A hand-held device according to any of claims 4 to 6, in which the images are images previously captured by the camera.

8. A hand-held device according to any of claims 4 to 7, in which movement of image is inverted with respect to motion of the hand-held device.

9. A hand-held device according to any of claims 2 to 8, in which the user interface comprises a graphical user interface, and wherein motion of the hand-held device is used as an input to the graphical user interface.

10. A hand-held device according to claim 9, in which motion of the hand-held device is used to manipulate an object displayed by the graphical user interface, preferably by moving the object in a manner substantially corresponding to the motion or to the inverted motion of the hand-held device, whereby the object displayed by the graphical user interface can be, an icon, a dialogue box, a window, a menu or a pointer.

11. A hand-held device according to claim 9, in which motion of a given type of the hand-held device is used to move, and/or zoom, and/or expand/collapse and/or rotate objects displayed by the graphical user interface.

12. A hand-held device according to claim 11, in which motion substantially parallel to the plane of the display of the hand-held device is used to scroll an object displayed by the graphical user interface, and/or motion substantially perpendicular to the plane of the display is used to zoom an object displayed by the graphical user interface and/or rotational motion of the hand-held device

is used to rotate an object displayed by the graphical user interface.

13. A hand-held device according to any of claims 2 to 12, in which the digital camera is detachable.

14. A hand-held device according to any of claims 2 to 13, in which the digital camera is movable relative to the hand-held device.

15. A hand-held device according to any of claims 2 to 14, in which the means for transforming a signal from the camera into a motion signal derives the motion signal from changes between succeeding images, or parts of succeeding images captured by the camera.

16. A hand-held device according to any of claims 2 to 15, in which the camera has an autofocus system, whereby the focusing setting of the autofocus system is used for detecting movement in the camera direction.

17. A hand-held device according to any of claims 2 to 16, further comprising at least one key, wherein the functionality of a motion type is dependent on the state of the at least one key.

18. A hand-held device according to any of claims 2 to 17, in which rotational motion of the hand-held device about an axis substantially perpendicular to the display results in an inverse rotational movement of the image or graphical user interface object relative to the display, preferably in a manner such that the image or object is static with respect to the fixed coordinate system in which the hand-held device is situated.

19. A hand-held device according to any of claims 2 to 18, in which the motion signal is used to adjust device settings, the device settings preferably comprising sound settings and display settings.

20. A hand-held device according to any of claims 9 to 19, further comprising a keypad with at least a first- and a second key and the graphical user interface comprises a cursor, whereby motion of the hand-held device is used to position the cursor over an object of the graphical user interface and primary functions associated with the object concerned are activated by pressing the first key and secondary functions associated with the object of the concerned are activated by pressing the second key.

21. A hand-held device according to claim 20, in which the functionality of the first key is associated with selection and activation of objects of the graphical user interface, and in which the functionality of the second key is preferably associated with calling up a context-sensitive menu.

22. A hand-held device according to claim 21, in which selection of the object concerned is performed by pressing and releasing the first key, and activation of the object concerned is preferably performed by pressing and releasing the first key twice in rapid succession.

23. A hand-held device according to claim 21 or 22, in which moving or resizing of the object concerned is performed by holding down the first key while moving the hand-held device to move the cursor.

24. A hand-held device according to any of claims 20 to 23, in which the first key and the second key are softkeys whereby the current functionality of the softkeys is

shown in the display, preferably in dedicated fields of the display.

25. A hand-held device according to claim 24, in which the first key is placed below the display on the left side of the latter, preferably proximate to lower edge of the display, and the second key is placed below the display on the right side of the latter, preferably proximate to lower edge of the display.

26. A hand-held device according to any of claims 1 to 25, further comprising at least one gravity based tilt sensor, and whereby the signal from the at least one tilt sensor is used in combination with the signal from the camera for creating the motion signal.

27. A hand-held device according to claim 26, wherein a tilt sensor is associated with the X-axis and/or a tilt sensor is associated with the Z-axis.

28. A hand-held device according to claim 27, wherein the signal form the at least one tilt sensor is used to determine the absolute orientation of the handheld device relative to the direction of the gravitational pull.

29. A hand-held device according to any of claims 1 to 28, further comprising means for sending the motion signal to another terminal via cable, infrared waves or radio frequency waves.

30. A system comprising a hand-held device according to claim 29 and a terminal capable of displaying imaginary three-dimensional objects on a two-dimensional screen, said terminal comprising means to change the orientation of the displayed object in response to signals received from the handheld device, whereby orientation changes of

the hand-held device are translated to corresponding orientation changes of the displayed object.

31. A system according to claim 30, in which position changes of the handheld device are translated to position changes of the displayed object.

32. A system comprising a hand-held device according to claim 29 and a terminal capable of displaying an imaginary three-dimensional space on a two-dimensional screen, said terminal comprising means to change the viewing position in the imaginary three-dimensional space in response to signals received from the handheld device, whereby positional changes of the hand-held device are translated to corresponding changes in the viewing position.

33. A system according to claim 30, in which orientation changes of the handheld device are translated into corresponding changes in the viewing direction in the imaginary three-dimensional space.

34. A method for creating user input for a hand-held device that has a processor, a user interface and a digital camera for capturing motion video or still images comprising the steps of:

determining motion of the hand-held device from the camera signal;

using the determined motion of the hand-held device as an input for the user interface.

35. Use of a digital camera for capturing motion video or still images of a hand-held device that has a processor to produce a motion signal indicative of motion of the hand-held device.

36. A hand-held device comprising a processor, means for sensing motion of the hand-held device, a display, a keypad with at least a first- and a second key, a graphical user interface with objects and a cursor, and means for transforming the sensed motion of the handheld device into a signal suitable for moving the cursor over the display.

37. A hand-held device according to claim 36, in which motion of the hand-held device is used to position the cursor over an object of the graphical user interface and primary functions associated with the object concerned are activated by pressing the first key and secondary functions associated with the object concerned are activated by pressing the second key.

38. A hand-held device according to claim 37, in which the functionality of the first key is associated with selection and activation of objects of the graphical user interface, and in which the functionality of the second key is preferably associated with calling up a context-sensitive menu.

39. A hand-held device according to claim 38, in which selection of the object concerned is performed by pressing and releasing the first key, and activation of the object concerned is preferably performed by pressing and releasing the first key twice in rapid succession.

40. A hand-held device according to claim 38 or 39, in which moving or resizing of the object concerned is performed by holding down the first key while moving the hand-held device to move the cursor and the object concerned in unison therewith.

41. A hand-held device according to any of claims 36 to 40, in which the first key and the second key are softkeys whereby the current functionality of the softkeys is shown in the display, preferably in dedicated fields of the display.

42. A hand-held device according to claim 41, in which the first key is placed below the display on the left side of the latter, preferably proximate to lower edge of the display, and the second key is placed below the display on the right side of the latter, preferably proximate to lower edge of the display.

43. A hand-held device according to any of claims 36 to 42, in which said means for transforming motion of the handheld device into a signal suitable for moving the cursor over the display comprises a tilt sensor and/or an image capturing device and/or an accelerometer.

44. A hand-held device according to claim 43, in which said image capturing device is a motion video or still image digital camera.

45. A hand-held device according to any of claims 36 to 44, further comprising means to transform a signal from the camera and/or tilt sensor and/or accelerometer into a position signal for the cursor.

46. A hand-held device according to claim 45, in which said means for transforming a signal from the camera into a motion signal derives the motion signal from changes between succeeding images, or parts of succeeding images captured by the camera.

47. A hand-held device according to any of claims 44 to 46, in which the camera has an autofocus system, whereby

the focusing setting of the autofocus system is used for detecting movement in the camera direction.

48. A hand-held device according to any of claims 36 to 47, in which the graphical user interface includes one or more of the following object types: icons, dialogue boxes, windows, menus, pointers.

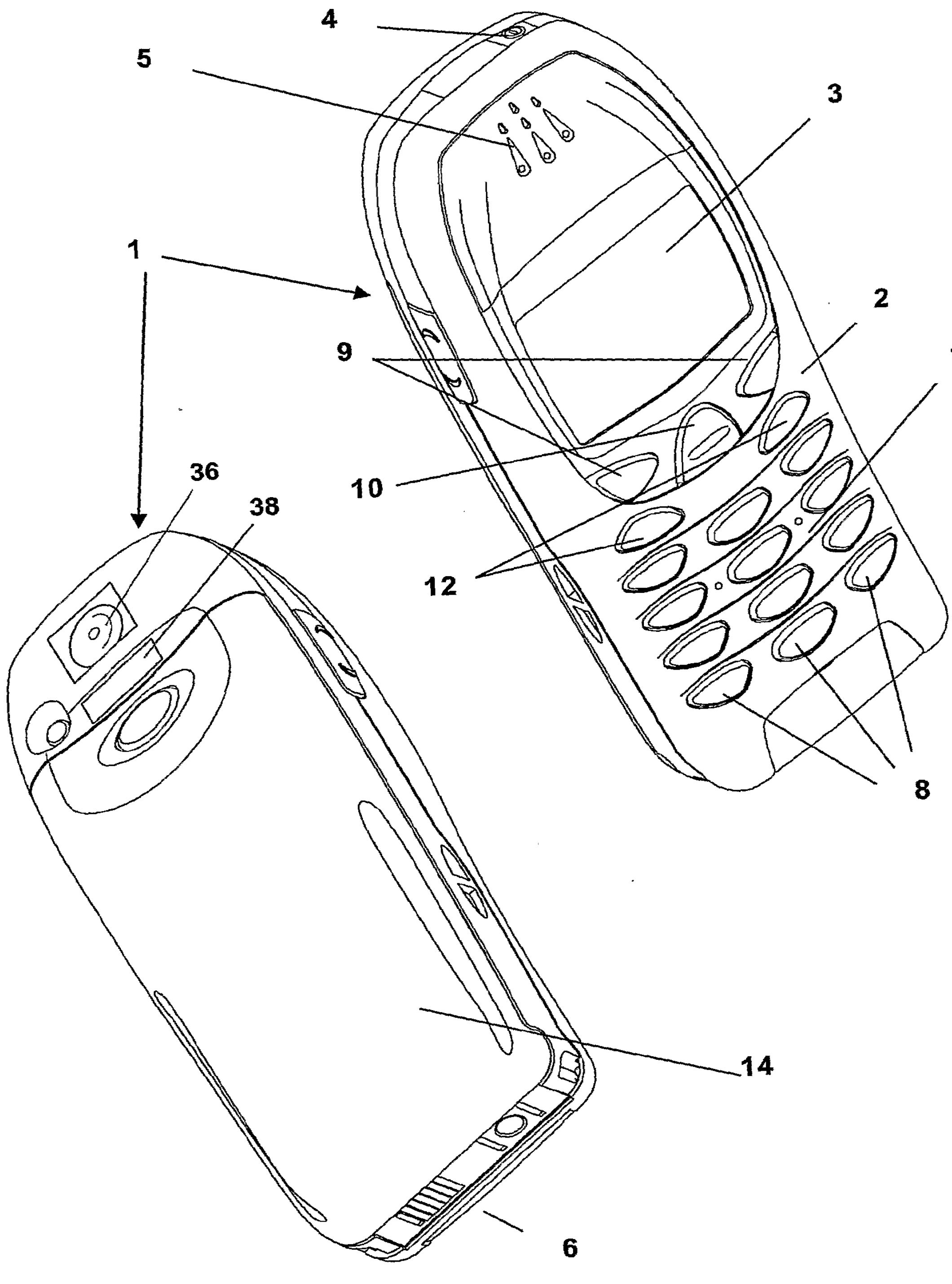
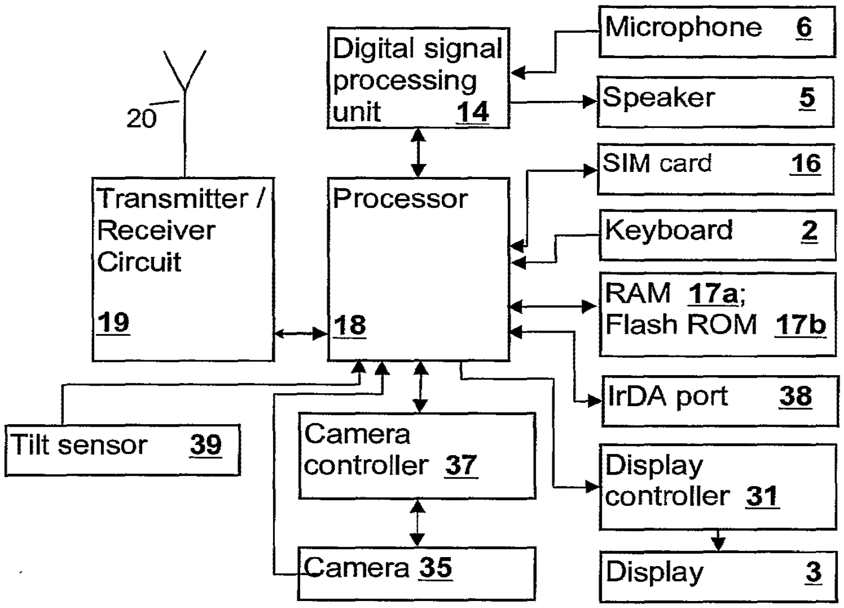


Fig. 1



Digital signal processing unit 14
Microphone 6
Speaker 5
20
Transmitter / Receiver Circuit 19
Processor 18
SIM card 16
Keyboard 2
RAM 17a; Flash ROM 17b
IrDA port 38
Tilt sensor 39
Camera controller 37
Display controller 31
Camera 35
Display 3

Fig. 2

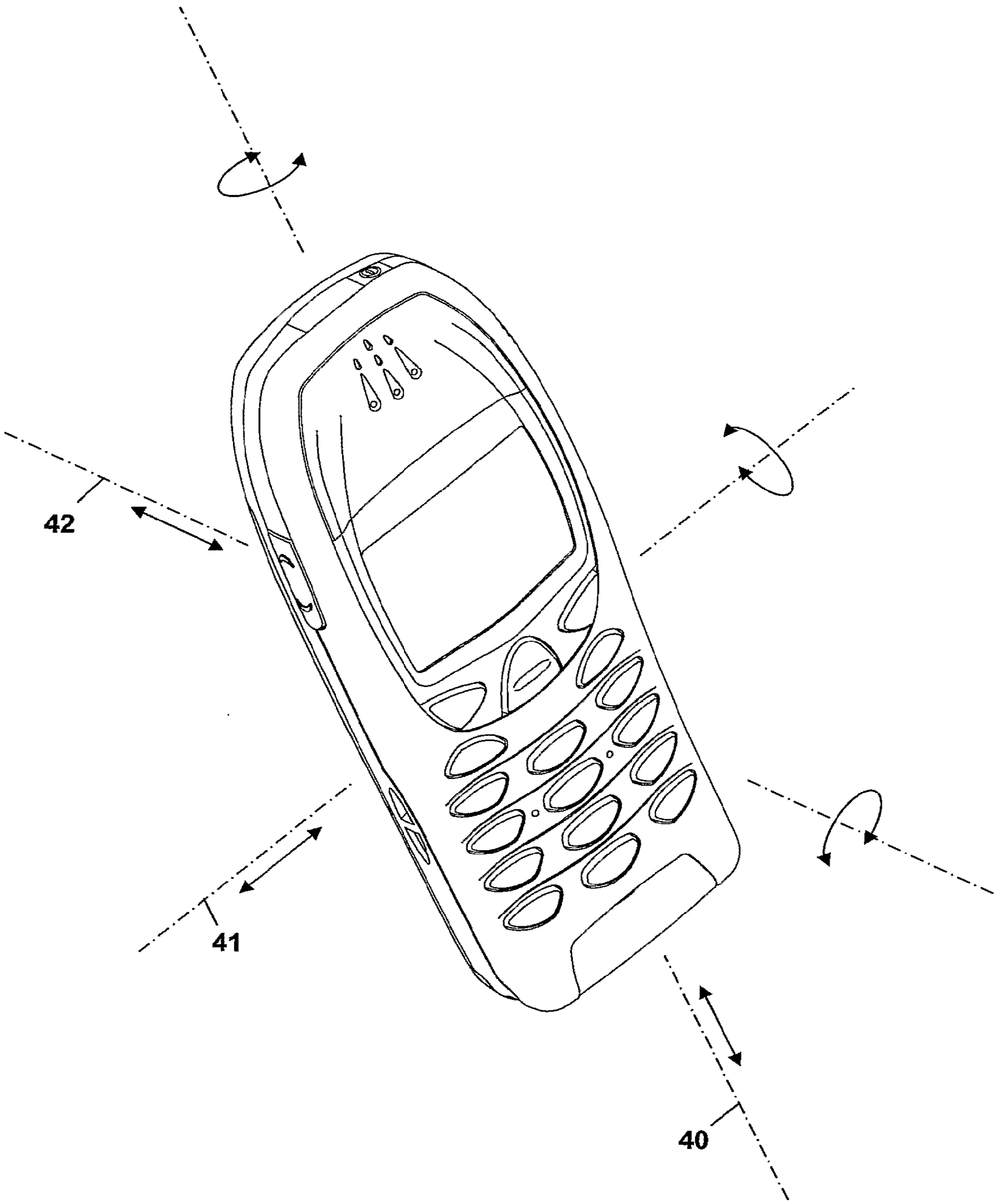


Fig. 3

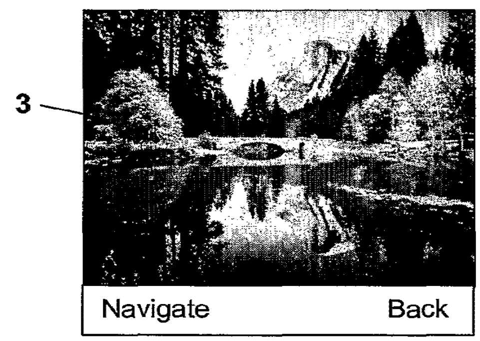


Fig. 3.1

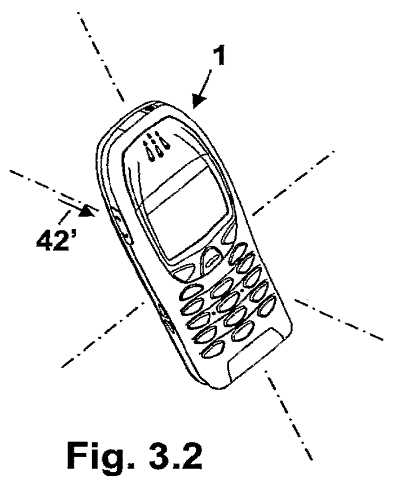


Fig. 3.2

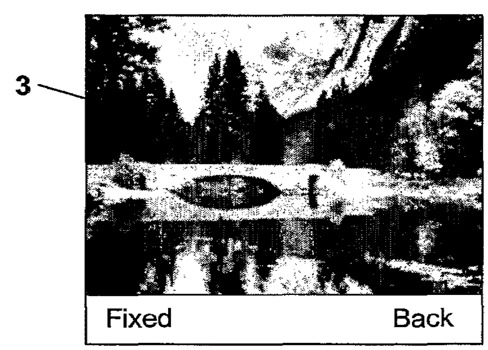


Fig. 3.3

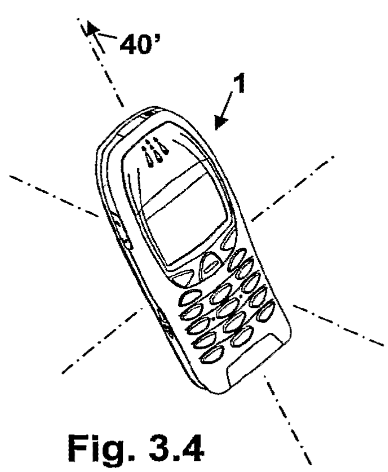


Fig. 3.4

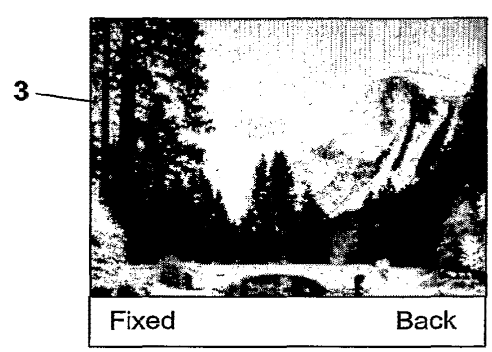


Fig. 3.5

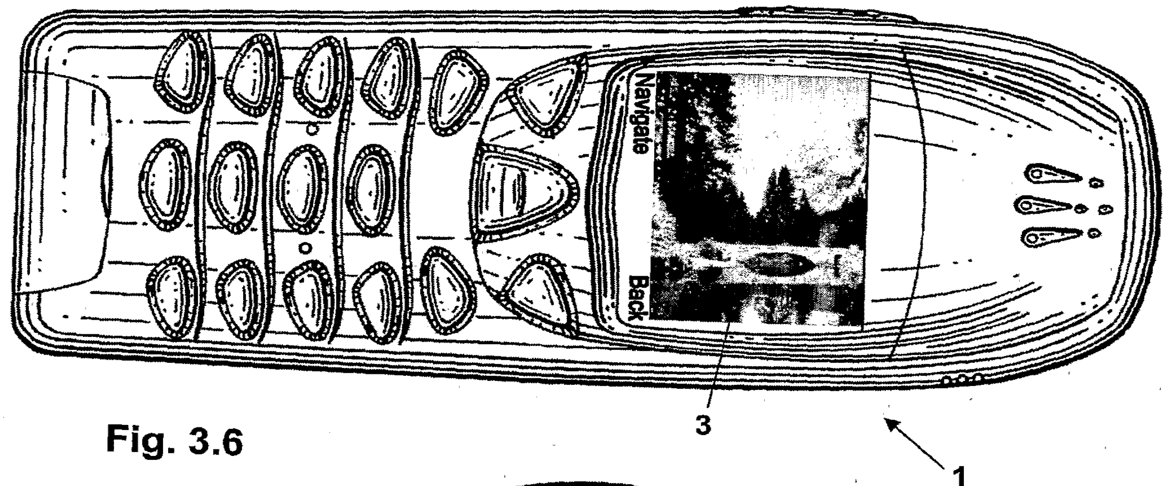


Fig. 3.6

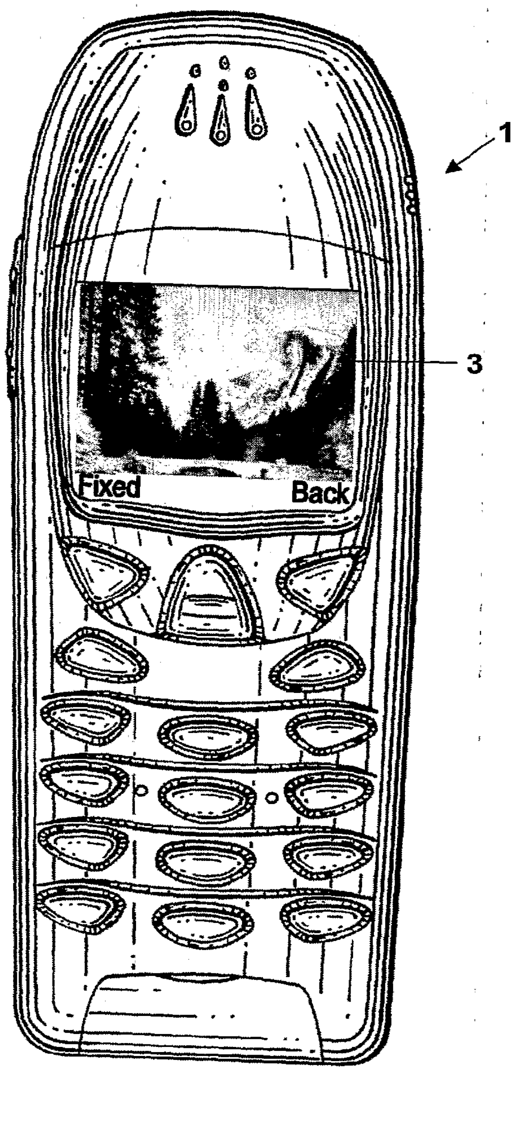


Fig. 3.7

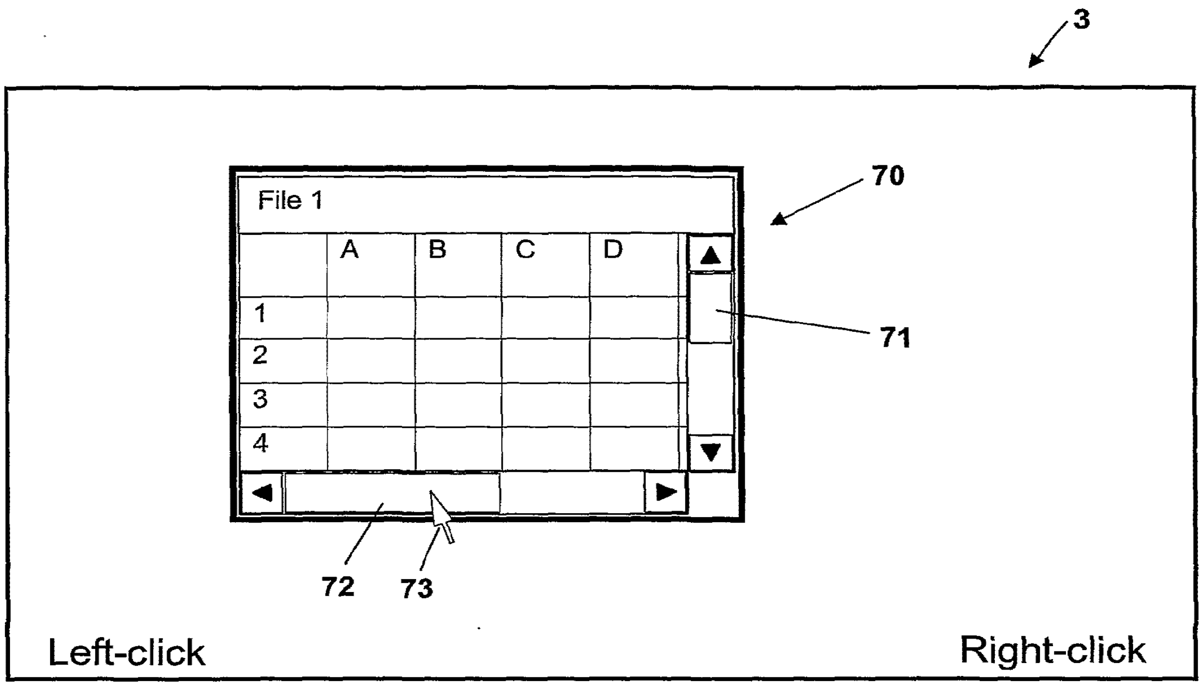

3
File 1
A
B
C
D
1
2
3
4
70
71
72
73
Left-click
Right-click

Fig. 3.8

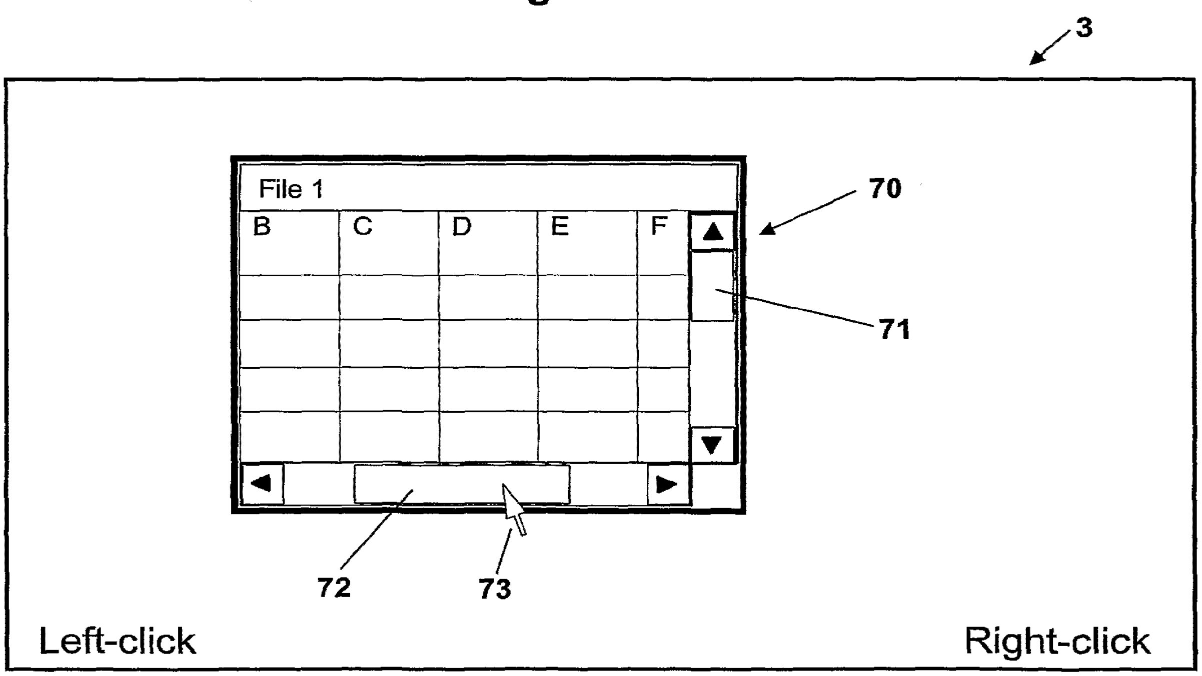

3
File 1
B
C
D
E
F
70
71
72
73
Left-click
Right-click

Fig. 3.9

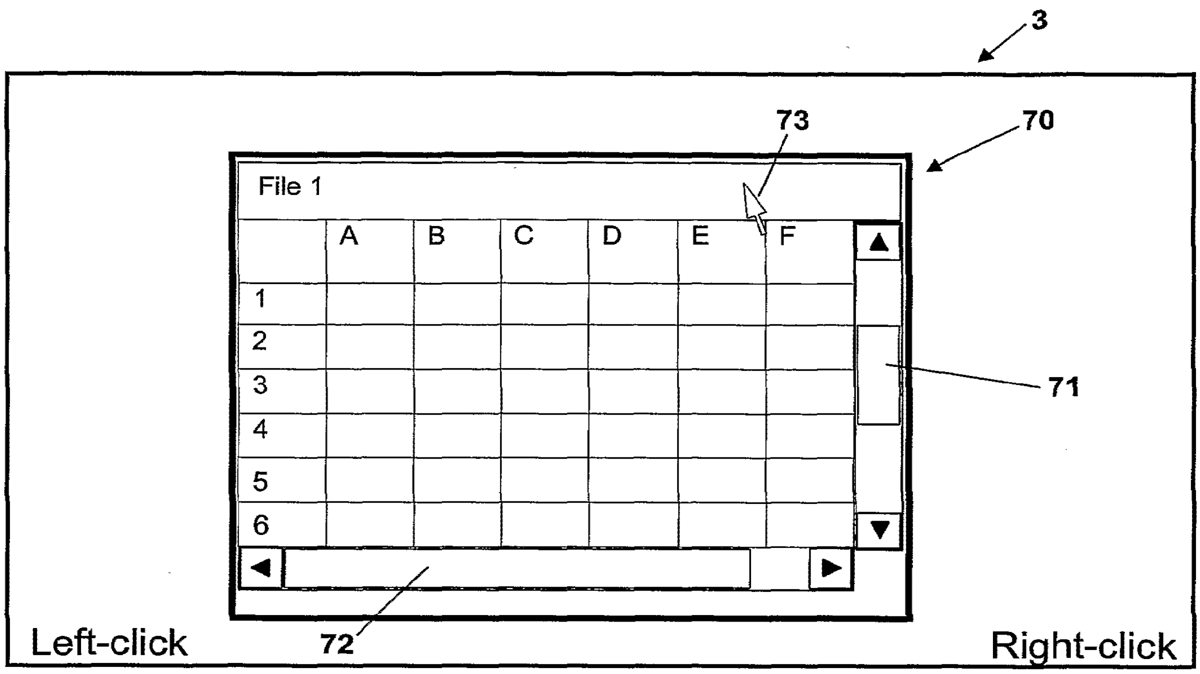


Fig. 3.10

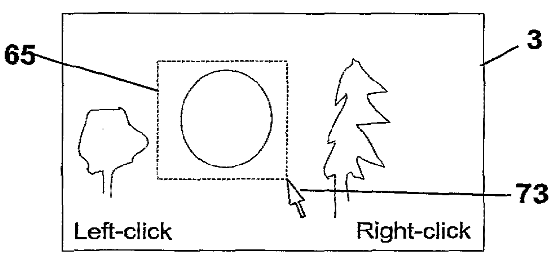


Fig. 3.14

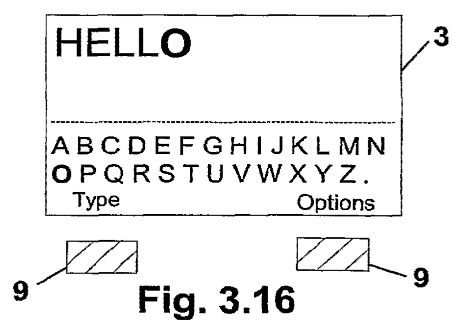


Fig. 3.16

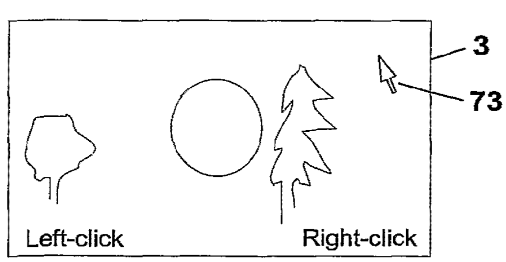


Fig. 3.15

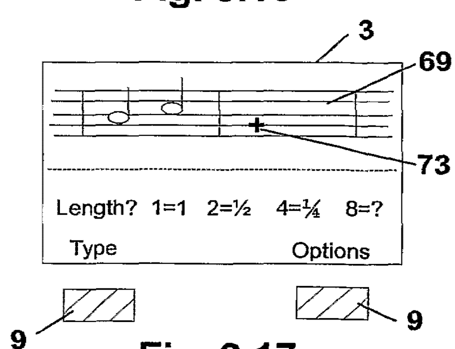


Fig. 3.17

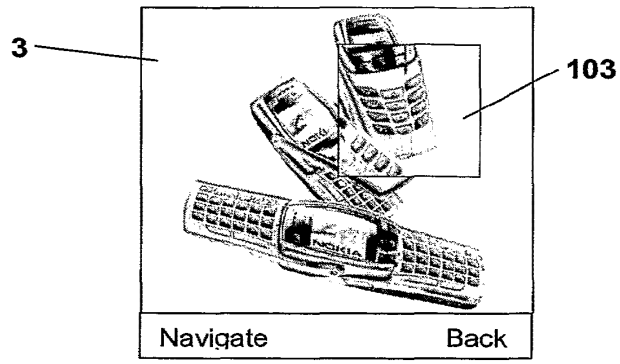


Fig. 3.11

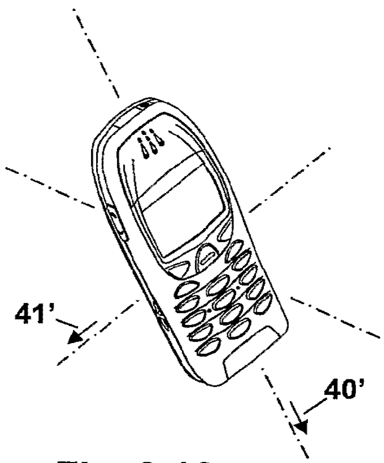


Fig. 3.12

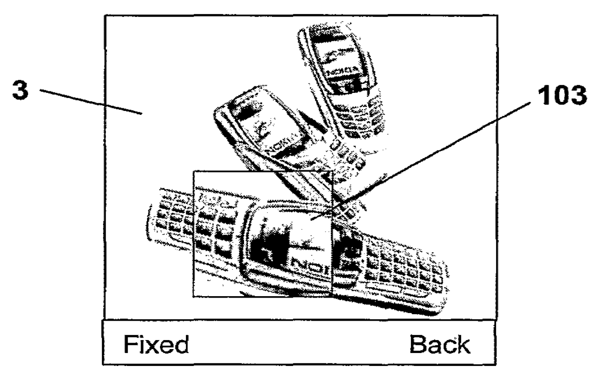


Fig. 3.13

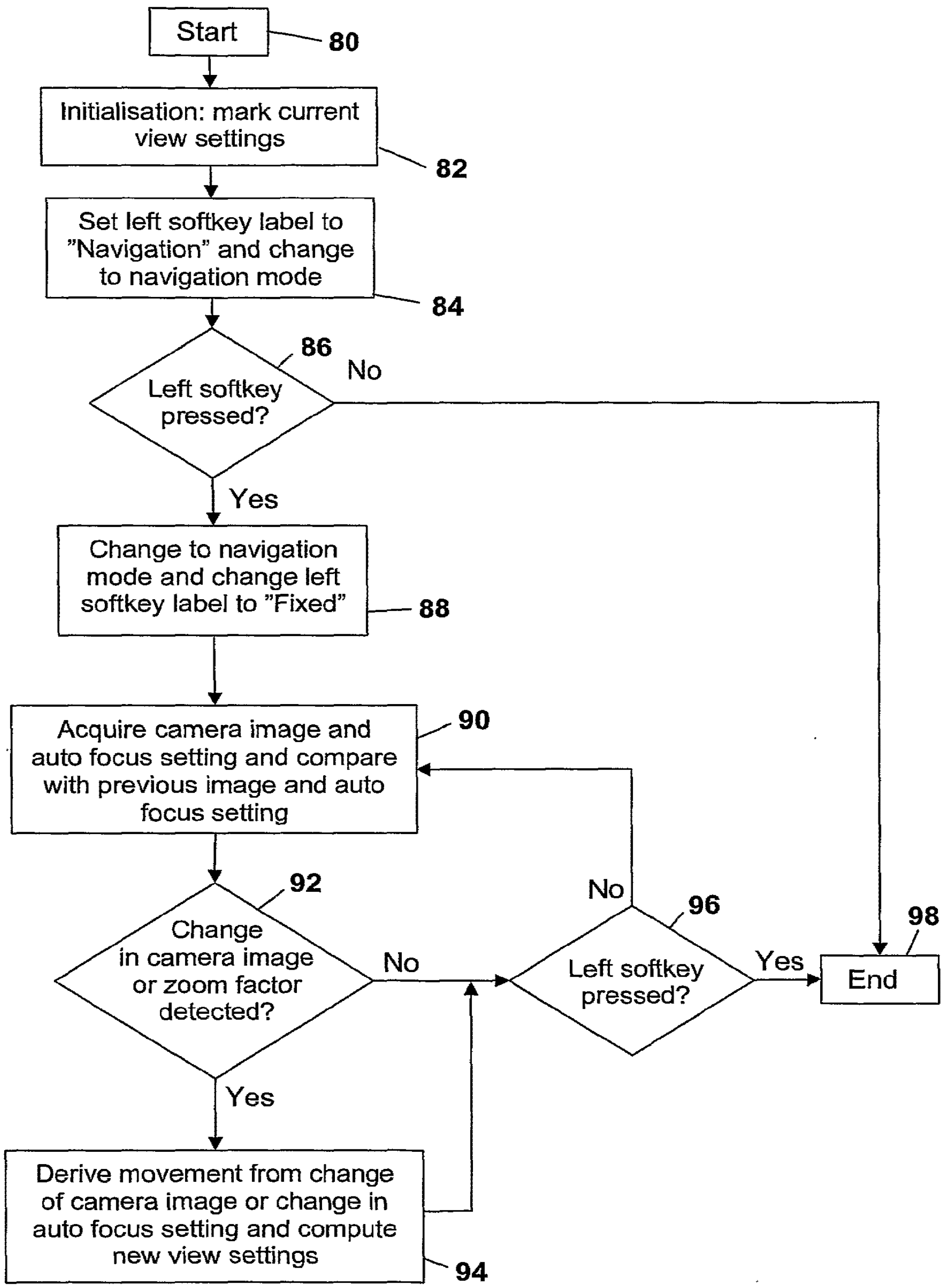

Start
80
Initialisation: mark current view settings
82
Set left softkey label to "Navigation" and change to navigation mode
84
86
Left softkey pressed?
No
Yes
Change to navigation mode and change left softkey label to "Fixed"
88
Acquire camera image and auto focus setting and compare with previous image and auto focus setting
90
92
Change in camera image or zoom factor detected?
No
Yes
No
96
Left softkey pressed?
Yes
98
End
Derive movement from change of camera image or change in auto focus setting and compute new view settings
94

Fig. 4

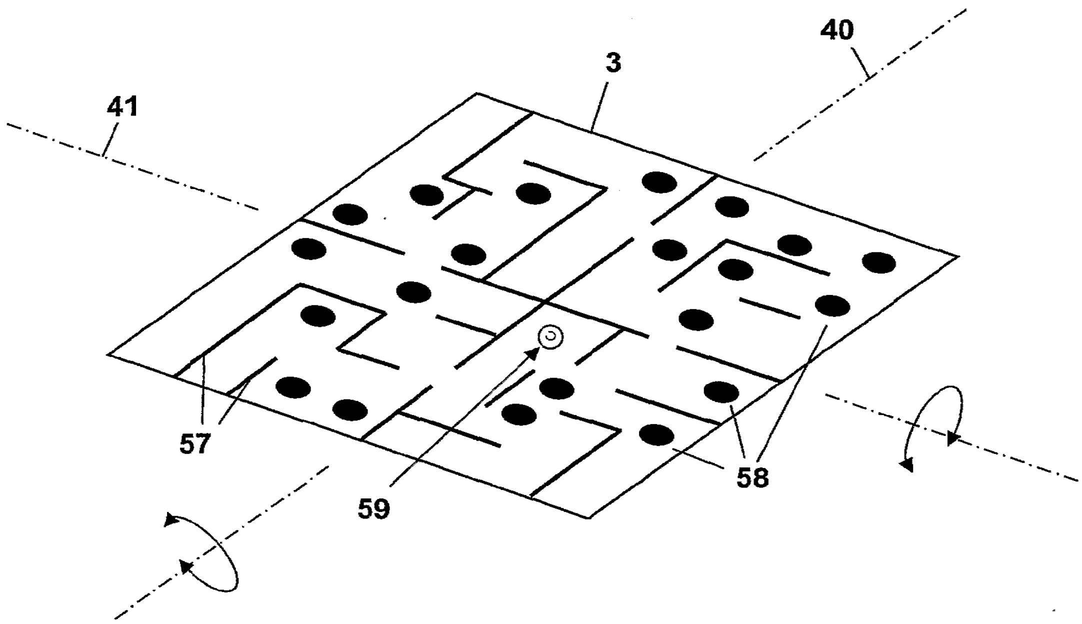


Fig. 3.18

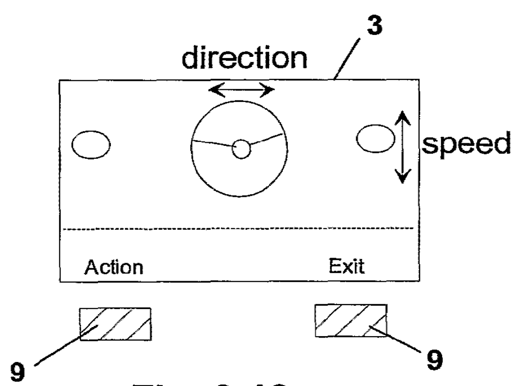


Fig. 3.19

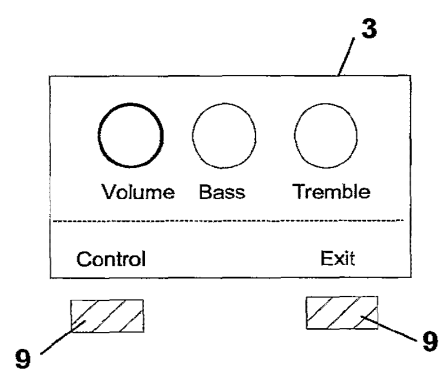


Fig. 3.20

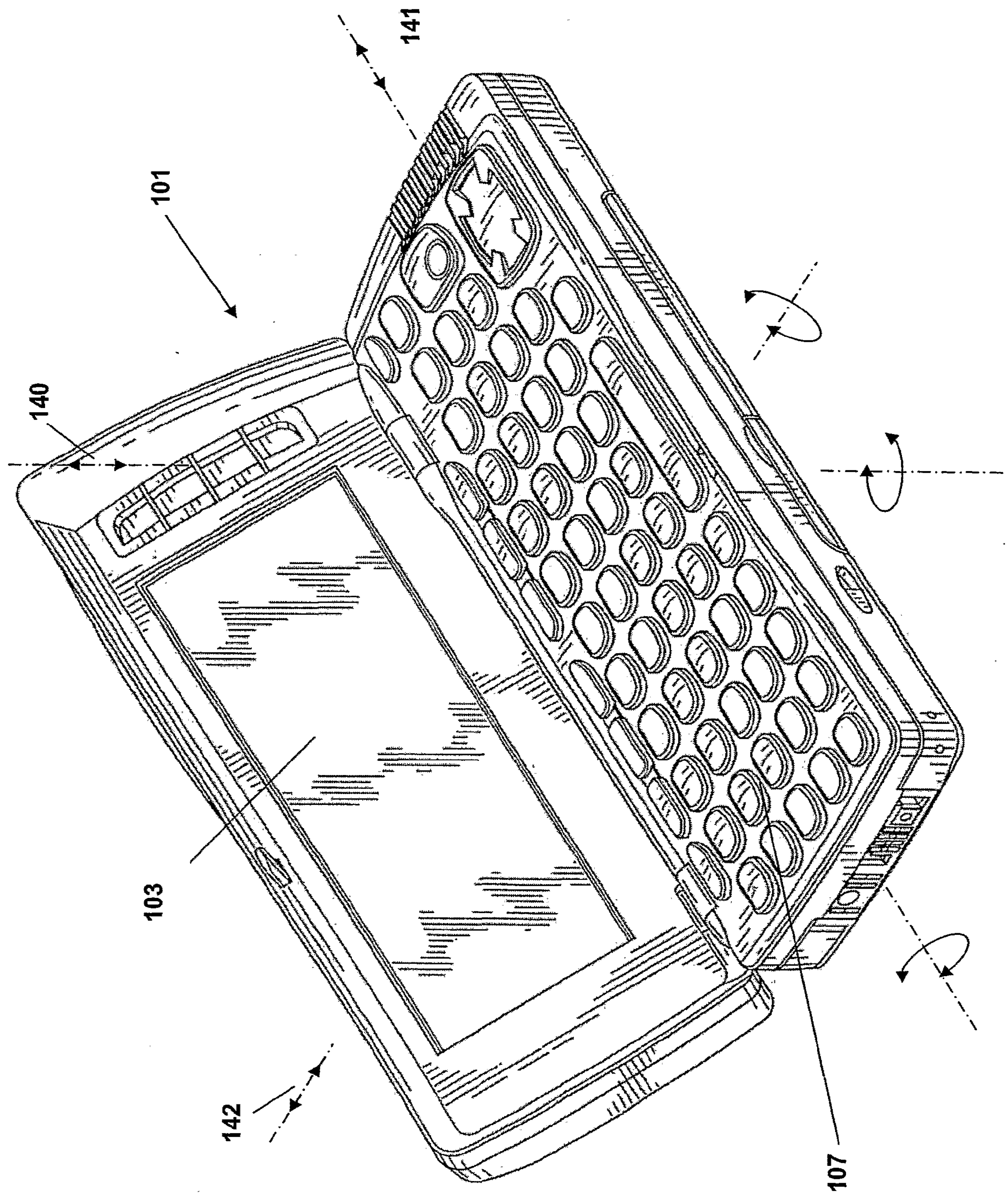


Fig. 5

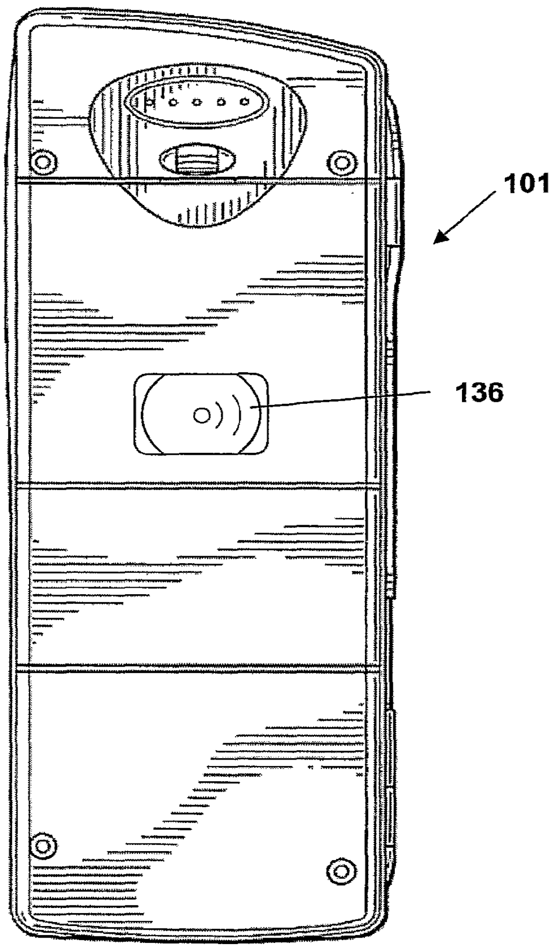


Fig. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/00607

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/225 H04N7/14 H04M1/725 H04N5/232 H04M1/247

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N H04M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01 86920 A (LAPIDOT ZVI) 15 November 2001 (2001-11-15)	1-7, 9-12,15, 17,20, 21,24, 25, 34-38, 41-46
Y	page 5, line 15 -page 11	16, 26-29,47
Y	EP 0 884 905 A (NOKIA MOBILE PHONES LTD) 16 December 1998 (1998-12-16) page 3, line 39 -page 5, line 34	16,47
Y	EP 1 246 464 A (MITSUBISHI ELECTRIC CORP) 2 October 2002 (2002-10-02) paragraph ‘0041! - paragraph ‘0066!	26-28

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
19 June 2003	26/06/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Materne, A

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/00607

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01 97495 A (SLOTZNICK BENJAMIN) 20 December 2001 (2001-12-20) page 8, line 20 -page 24 ---	29
X	EP 1 071 285 A (TEXAS INSTRUMENTS FRANCE ;TEXAS INSTRUMENTS INC (US)) 24 January 2001 (2001-01-24) column 5 -column 10, line 2 ---	1,34
X	WO 02 37179 A (KONINKL PHILIPS ELECTRONICS NV) 10 May 2002 (2002-05-10) page 3, line 14 -page 10 ---	1,34
A	WO 01 78055 A (FEINSTEIN DAVID Y) 18 October 2001 (2001-10-18) cited in the application page 8, line 11 -page 22 ---	1-48
A	US 2002/160724 A1 (ARAI FUJIO ET AL) 31 October 2002 (2002-10-31) page 2 -page 3 -----	1-48

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 03/00607

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 0186920	A	15-11-2001	AU	5657601 A	20-11-2001
			WO	0186920 A2	15-11-2001
EP 0884905	A	16-12-1998	FI	972509 A	14-12-1998
			EP	0884905 A2	16-12-1998
			JP	11075172 A	16-03-1999
			US	2002101517 A1	01-08-2002
EP 1246464	A	02-10-2002	JP	2002290793 A	04-10-2002
			CN	1378401 A	06-11-2002
			EP	1246464 A2	02-10-2002
			NO	20021509 A	30-09-2002
			US	2002142798 A1	03-10-2002
WO 0197495	A	20-12-2001	AU	7553801 A	24-12-2001
			WO	0197495 A1	20-12-2001
			US	2001055951 A1	27-12-2001
EP 1071285	A	24-01-2001	EP	1071285 A1	24-01-2001
WO 0237179	A	10-05-2002	WO	0237179 A2	10-05-2002
WO 0178055	A	18-10-2001	US	6466198 B1	15-10-2002
			EP	1290672 A1	12-03-2003
			WO	0178055 A1	18-10-2001
			US	2002190947 A1	19-12-2002
US 2002160724	A1	31-10-2002	JP	2001245267 A	07-09-2001
			CN	1363182 T	07-08-2002
			GB	2364194 A	16-01-2002
			WO	0163926 A1	30-08-2001

Form PCT/ISA/210 (patent family annex) (July 1992)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 July 2009 (16.07.2009)

PCT

(10) International Publication Number
WO 2009/089126 A1

(51) International Patent Classification:
H04N 13/00 (2006.01) *H04N 13/02* (2006.01)

(21) International Application Number:
PCT/US2009/030065

(22) International Filing Date: 4 January 2009 (04.01.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/019,159 4 January 2008 (04.0 1.2008) US

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(74) Agents: **VIETZKE, Lance, L.** et al.; 3M Innovative Properties Company, 3M Center, Post Office Box 33427, Saint Paul, MN 55133-3427 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(54) **Title:** THREE-DIMENSIONAL MODEL REFINEMENT

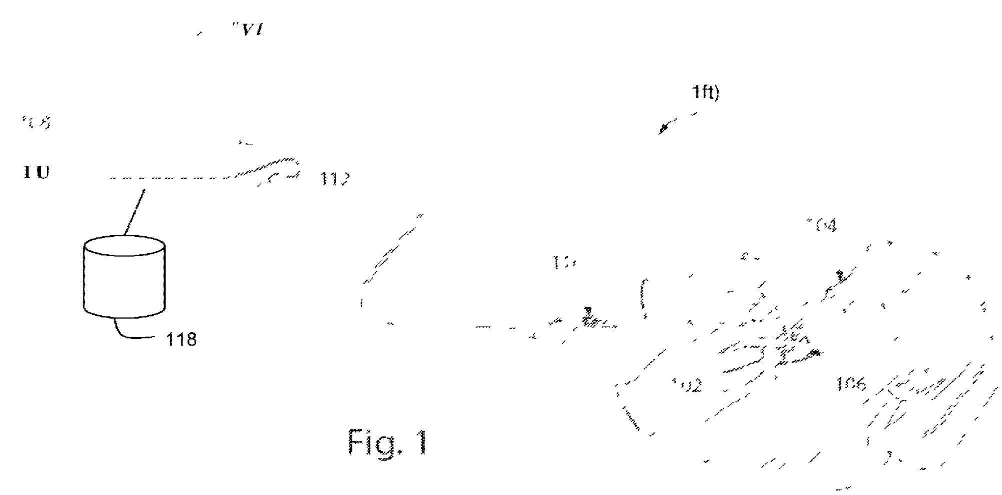

Fig. 1

(57) **Abstract:** A three-dimensional measurement is refined by warping two-dimensional images of an object from offset camera positions according to a three-dimensional model of the object, and applying any resulting discrepancies to refine the three-dimensional model, or to refine one of a number of three-dimensional measurements used to create the three-dimensional model.

WO 2009/089126 A1

THREE-DIMENSIONAL MODEL REFINEMENT

[0001] The present application claims priority from the U.S. Provisional Patent Application No. 61/019,159, filed January 4, 2008, which is hereby incorporated by reference in its entirety.

FIELD OF INVENTION

[0002] This invention relates generally to three-dimensional imaging and more specifically to refinement of three dimensional models reconstructed from a sequence of three-dimensional measurements captured along a camera path.

BACKGROUND

[0003] In one technique for three-dimensional image reconstruction, a number of images or image sets of an object are captured with a camera that travels in a path over the surface of the object. Information from this image catalogue can then be used to reconstruct a three-dimensional model of the object based upon each camera position and three-dimensional measurement captured along the path. While individual measurements from the camera can contain noise from a variety of sources, the resulting three-dimensional model tends to smooth out this noise to recover three-dimensional data points more accurate than the individual measurements.

[0004] There remains a need for post-processing techniques to refine individual three-dimensional measurements based upon the full data set available for a completed three-dimensional scan.

SUMMARY

[0005] A three-dimensional measurement is refined by warping two-dimensional images of an object from offset camera positions according to a three-dimensional model of the object, and applying any resulting discrepancies to refine the three-dimensional model, or to refine one of a number of three-dimensional measurements used to create the three-dimensional model.

[0006] In one aspect, a method of refining a three-dimensional model described herein includes providing a three-dimensional model of an object; obtaining a first two-dimensional image of the object from a first camera pose; obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image; deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose; comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and correcting the three-dimensional model based upon the one or more discrepancies.

[0007] The first camera pose and the second camera pose may be a position and an orientation of a single camera in two dependent positions. The first camera pose and the second camera pose may be a position and an orientation of two offset channels of a multi-aperture camera. The first camera pose and the second camera pose may be a position and an orientation of a single camera in two independent positions. A relationship between the first camera pose and the second camera pose may be calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose. The method may include deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose. The method may include applying the one or more discrepancies to directly refine the three-dimensional model. The method may include applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement. The method may include refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path. The method may include using the refined camera path and the refined measurement to refine the three-dimensional model. The three-dimensional model may be a point cloud or a polygonal mesh. The object may be human dentition. The second camera pose may correspond to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object. The method may include obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

[0008] In another aspect, computer program product for refining a three-dimensional model of an object described herein includes computer executable code embodied on a computer readable medium that, when executing on one or more computing devices, performs the steps of providing a three-dimensional model of an object; obtaining a first two-dimensional image of the object from a first camera pose; obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image; deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose; comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and correcting the three-dimensional model based upon the one or more discrepancies.

[0009] The first camera pose and the second camera pose may be a position and an orientation of a single camera in two dependent positions. The first camera pose and the second camera pose may be a position and an orientation of two offset channels of a multi-aperture camera. The first camera pose and the second camera pose may be a position and an orientation of a single camera in two independent positions. A relationship between the first camera pose and the second camera pose may be calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose. The computer program produce may include code for performing the step of deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose. The computer program produce may include code for performing the step of applying the one or more discrepancies to directly refine the three-dimensional model. The computer program produce may include code for performing the step of applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement. The computer program produce may include code for performing the step of refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path. The computer program produce may include code for performing the step of using the refined camera path and the refined measurement to refine the three-dimensional model. The three-dimensional model may be a point cloud or a polygonal mesh. The object may be human dentition. The second camera pose may correspond to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object. The computer program product may include code for performing the steps of obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[0011] Fig. 1 shows a three-dimensional scanning system.

[0012] Fig. 2 shows a schematic diagram of an optical system for a three-dimensional camera.

[0013] Fig. 3 shows a processing pipeline for obtaining three-dimensional data from a video camera.

[0014] Fig. 4 illustrates a coordinate system for three-dimensional measurements.

[0015] Fig. 5 illustrates a sequence of images captured from a moving camera.

[0016] Fig. 6 is a conceptual representation of a three-dimensional data acquisition process.

[0017] Fig. 7 is a flow chart of a process for refining three-dimensional data.

[0018] Fig. 8 is a flow chart of a global path optimization.

DETAILED DESCRIPTION

[0019] In the following text, references to items in the singular should be understood to include items in the plural, and vice versa, unless explicitly stated otherwise or clear from the text. Grammatical conjunctions are intended to express any and all disjunctive and conjunctive combinations of conjoined clauses, sentences, words, and the like, unless otherwise stated or clear from the context.

[0020] The following description details specific scanning technologies and focuses on dental applications of three-dimensional imaging; however, it will be appreciated that variations, adaptations, and combinations of the methods and systems below will be apparent to one of ordinary skill in the art. For example, while an image-based system is described, non-image based scanning techniques such as infrared time-of-flight techniques or structured light techniques using patterned projections may similarly employ reconstruction based on camera path that may benefit from the improvements described herein. Similarly, while the following description emphasizes a refinement using concurrent images from two offset channels of a multi-aperture camera, it will be understood that the techniques may be similarly applied to refine frame-to-frame data for a camera path of a multi-aperture camera, or different frames of data for a conventional camera. As another example, while digital dentistry is one useful application of the improved accuracy that results from the techniques described herein, the teachings of this disclosure may also usefully be employed to refine three-dimensional animation models, three-dimensional scans for machine vision applications, and so forth. All such variations, adaptations, and combinations are intended to fall within the scope of this disclosure.

[0021] In the following description, the term "image" generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term "image set" generally refers to a set of related two-dimensional images that might be resolved into three-dimensional data. The term "point cloud" generally refers to a three-dimensional set of points forming a three-dimensional view of the subject reconstructed from a number of two-dimensional images. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[0022] The terms "three-dimensional model", "three-dimensional surface representation", "digital surface representation", "three-dimensional surface map", and the like, as used herein, are intended to refer to any three-dimensional reconstruction of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context. A "three-dimensional representation" may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[0023] In general, the terms "render" or "rendering" refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that a variety of three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. For example, the systems and methods described herein may usefully employ a holographic display, an autostereoscopic display, an anaglyph display, a head-mounted stereo display, or any other two-dimensional and/or three-dimensional display. As such, rendering as described herein should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[0024] The term "dental object", as used herein, is intended to refer broadly to subject matter related to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches (which may be separate or in occlusion of various types), soft tissue, and the like, as well bones and any other supporting or surrounding structures. As used herein, the term "intraoral structures" refers to both natural structures within a mouth as described above and artificial structures such as any of the dental objects described below that might be present in the mouth. Dental objects may include "restorations", which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a "prosthesis" that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include "appliances" used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also include "hardware" affixed to dentition for an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include "interim components" of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. Dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above.

[0025] Terms such as "digital dental model", "digital dental impression" and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as "dental model" or "dental impression" are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of a dental object. Unless specified, the term "model", when used alone, may refer to either or both of a physical model and a digital model.

[0026] It will further be understood that terms such as "tool" or "control", when used to describe aspects of a user interface, are intended to refer generally to a variety of techniques that may be employed within a graphical user interface or other user interface to receive user input that stimulates or controls processing including without limitation drop-down lists, radio buttons, cursor and/or mouse actions (selections by point, selections by area, drag-and-drop operations, and so forth), check boxes, command lines, text input fields, messages and alerts, progress bars, and so forth. A tool or control may also include any physical hardware relating to the user input, such as a mouse, a keyboard, a display, a keypad, a track ball, and/or any other device that receives physical input from a user and converts the physical input into an input for use in a computerized system. Thus in the following description the terms "tool", "control" and the like should be broadly construed unless a more specific meaning is otherwise provided or clear from the context.

[0027] Fig. 1 depicts a three-dimensional scanning system that may be used with the systems and methods described herein. In general, the system 100 may include a camera 102 that captures images from a surface 106 of an object 104, such as a dental patient, and forwards the images to a computer 108, which may include a display 110 and one or more user-input devices 112, 114 such as a mouse 112 or a keyboard 114. The camera 102 may also include an integrated input or output device 116 such as a control input (e.g., button, touchpad, thumbwheel, etc.) or a display (e.g., LCD or LED display) to provide status information.

[0028] The camera 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud or other three-dimensional data may be recovered. For example, the camera 102 may employ a multi-aperture system as disclosed in U.S. Pat. No. 7,372,642 to Rohaly et al., the entire content of which is incorporated herein by reference. While Rohaly discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the camera 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens that provides a center channel for the camera 102, along with any associated imaging hardware. In such embodiments, the center channel may provide a conventional video image of the scanned subject matter, while a number of axially offset channels yield image sets containing disparity information that can be employed in three-dimensional reconstruction of a surface. In other embodiments, a separate video camera and/or channel may be provided to achieve the same result, i.e., a video of an object corresponding temporally to a three-dimensional scan of the object, preferably from the same perspective, or from a perspective having a fixed, known relationship to the perspective of the camera 102. The camera 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of different perspectives. The camera 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the camera 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data. While the techniques described below can usefully employ video data acquired by a video-based three-dimensional scanning system, it will be understood that any other three-dimensional scanning system may be supplemented with a video acquisition system that captures suitable video data contemporaneously with, or otherwise synchronized with, the acquisition of three-dimensional data.

[0029] In one embodiment, the camera 102 is a handheld, freely-positionable probe having at least one user-input device 116, such as a button, a lever, a dial, a thumb wheel, a switch, or the like, for user control of the image capture system 100 such as starting and stopping scans. In an embodiment, the camera 102 may be shaped and sized for dental scanning. More particularly, the camera 102 may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing over an intraoral surface 106 at a suitable distance to acquire surface data from teeth, gums, and so forth. The camera 102 may, through such a continuous data acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as prosthetics, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental model such as a dental prosthesis, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the prosthesis.

[0030] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the object 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The camera 102 may also, or instead, include a strobe, a flash, or some other light source to supplement illumination of the object 104 during image acquisition.

[0031] The object 104 may be any object, collection of objects, portion of an object, or other subject matter. More particularly with respect to the dental techniques discussed herein, the object 104 may include human dentition captured intraorally from a dental patient's mouth. A scan may capture a three-dimensional representation of some or all of the dentition according to a particular purpose of the scan. Thus the scan may capture a digital model of a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches, as well as soft tissue or any other relevant intraoral structures. The scan may capture multiple representations, such as a tooth surface before and after preparation for a restoration. As will be noted below, this data may be employed for subsequent modeling such as designing a restoration or determining a margin line for same. During the scan, a center channel of the camera 102 or a separate video system may capture video of the dentition from the point of view of the camera 102. In other embodiments where, for example, a completed fabrication is being virtually test fitted to a surface preparation, the scan may include a dental prosthesis such as an inlay, a crown, or any other dental prosthesis, dental hardware, dental appliance, or the like. The object 104 may also, or instead, include a dental model, such as a plaster cast, a wax-up, an impression, or a negative impression of a tooth, teeth, soft tissue, or some combination of these.

[0032] The computer 108 may include, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm hard drive. In one current embodiment, the system can be operated to capture more than five thousand points per image set in real time using the techniques described herein, and store an aggregated point cloud of several million points. Of course, this point cloud may be further processed to accommodate subsequent data handling, such as by decimating the point cloud data or generating a corresponding mesh of surface data. As used herein, the term "real time" means generally with no observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which may vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. More generally, processing capabilities of the computer 108 may vary according to the size of the object 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display 110. In another aspect, the display may include an autostereoscopic display or the like capable of displaying stereo images.

[0033] Communications between the computer 108 and the camera 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.1 1 (also known as wireless Ethernet), BlueTooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the camera 102 to the computer 108 may be secured. The computer 108 may generate control signals to the camera 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or zoom.

[0034] In an example of general operation of a three-dimensional image capture system 100, the camera 102 may acquire two-dimensional image sets at a video rate while the camera 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set may be derived and fitted or "stitched" to existing three-dimensional data using a number of different techniques. Such a system may employ camera motion estimation to avoid the need for independent tracking of the position of the camera 102. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire content of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[0035] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In general, the display 110 may be operatively coupled to, and capable of receiving display signals from, the computer 108. This display may include a CRT or flat panel monitor, a three-dimensional display (such as an anaglyph display), an autostereoscopic three-dimensional display or any other suitable two-dimensional or three-dimensional rendering hardware. In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110.

[0036] The system 100 may include a computer-usable or computer-readable medium. The computer-usable medium 118 may include one or more memory chips (or other chips, such as a processor, that include memory), optical disks, magnetic disks or other magnetic media, and so forth. The computer-usable medium 118 may in various embodiments include removable memory (such as a USB device, tape drive, external hard drive, and so forth), remote storage (such as network attached storage), volatile or non-volatile computer memory, and so forth. The computer-usable medium 118 may contain computer-readable instructions for execution by the computer 108 to perform the various processes described herein. The computer-usable medium 118 may also, or instead, store data received from the camera 102, store a three-dimensional model of the object 104, store computer code for rendering and display, and so forth.

[0037] Fig. 2 depicts an optical system 200 for a three-dimensional camera that may be used with the systems and methods described herein, such as for the camera 102 described above with reference to Fig. 1.

[0038] The optical system 200 may include a primary optical facility 202, which may be employed in any kind of image processing system. In general, a primary optical facility refers herein to an optical system having one optical channel. Typically, this optical channel shares at least one lens, and has a shared image plane within the optical system, although in the following description, variations to this may be explicitly described or otherwise clear from the context. The optical system 200 may include a single primary lens, a group of lenses, an object lens, mirror systems (including traditional mirrors, digital mirror systems, digital light processors, or the like), confocal mirrors, and any other optical facilities suitable for use with the systems described herein. The optical system 200 may be used, for example in a stereoscopic or other multiple image camera system. Other optical facilities may include holographic optical elements or the like. In various configurations, the primary optical facility 202 may include one or more lenses, such as an object lens (or group of lenses) 202b, a field lens 202d, a relay lens 202f, and so forth. The object lens 202b may be located at or near an entrance pupil 202a of the optical system 200. The field lens 202d may be located at or near a first image plane 202c of the optical system 200. The relay lens 202f may relay bundles of light rays within the optical system 200. The optical system 200 may further include components such as aperture elements 208 with one or more apertures 212, a refocusing facility 210 with one or more refocusing elements 204, one or more sampling facilities 218, and/or a number of sensors 214a, 214b, 214c.

[0039] The optical system 200 may be designed for active wavefront sampling, which should be understood to encompass any technique used to sample a series or collection of optical data from an object 220 or objects, including optical data used to help detect two-dimensional or three-dimensional characteristics of the object 220, using optical data to detect motion, using optical data for velocimetry or object tracking, or the like. Further details of an optical system that may be employed as the optical system 200 of Fig. 2 are provided in U.S. Pat. No. 7,372,642, the entire content of which is incorporated herein by reference. More generally, it will be understood that, while Fig. 2

depicts one embodiment of an optical system 200, numerous variations are possible. One salient feature of the optical system related to the discussion below is the use of a center optical channel that captures conventional video or still images at one of the sensors 214b concurrent with various offset data (at, e.g., 214a and 214c) used to capture three-dimensional measurements. This center channel image may be presented in a user interface to permit inspection, marking, and other manipulation by a user during a user session as describe below.

[0040] Fig. 3 shows a three-dimensional reconstruction system 300 employing a high-speed pipeline and a high-accuracy pipeline. In general, the high-speed processing pipeline 330 aims to provide three-dimensional data in real time, such as at a video frame rate used by an associated display, while the high-accuracy processing pipeline 350 aims to provide the highest accuracy possible from camera measurements, subject to any external computation or time constraints imposed by system hardware or an intended use of the results. A data source 310 such as the camera 102 described above provides image data or the like to the system 300. The data source 310 may for example include hardware such as LED ring lights, wand sensors, a frame grabber, a computer, an operating system and any other suitable hardware and/or software for obtaining data used in a three-dimensional reconstruction. Images from the data source 310, such as center channel images containing conventional video images and side channels containing disparity data used to recover depth information may be passed to the real-time processing controller 316. The real-time processing controller 316 may also provide camera control information or other feedback to the data source 310 to be used in subsequent data acquisition or for specifying data already obtained in the data source 310 that is needed by the real-time processing controller 316. Full resolution images and related image data may be retained in a full resolution image store 322. The stored images may, for example, be provided to the high-accuracy processing controller 324 during processing, or be retained for image review by a human user during subsequent processing steps.

[0041] The real-time processing controller 316 may provide images or frames to the high-speed (video rate) processing pipeline 330 for reconstruction of three-dimensional surfaces from the two-dimensional source data in real time. In an exemplary embodiment, two-dimensional images from an image set such as side channel images, may be registered by a two-dimensional image registration module 332. Based on the results of the two-dimensional image registration, a three-dimensional point cloud generation module 334 may create a three-dimensional point cloud or other three-dimensional representation. The three-dimensional point clouds from individual image sets may be combined by a three-dimensional stitching module 336. Finally, the stitched measurements may be combined into an integrated three-dimensional model by a three-dimensional model creation module 338. The resulting model may be stored as a high-speed three-dimensional model 340.

[0042] The high-accuracy processing controller 324 may provide images or frames to the high-accuracy processing pipeline 350. Separate image sets may have two-dimensional image registration performed by a two-dimensional image registration module 352. Based on the results of the two-dimensional image registration a three-dimensional point cloud or other three-dimensional representation may be generated by a three-dimensional point cloud generation module 354. The three-dimensional point clouds from individual image sets may be connected using a three-dimensional stitching module 356. Global motion optimization, also referred to herein as global path optimization or global camera path optimization, may be performed by a global motion optimization module 357 in order to reduce errors in the resulting three-dimensional model 358. In general, the path of the camera as it obtains the image frames may be calculated as a part of the three-dimensional reconstruction process. In a post-processing refinement procedure, the calculation of camera path may be optimized - that is, the accumulation of errors along the length of the camera path may be minimized by supplemental frame-to-frame motion estimation with some or all of the global path information. Based on global information such as individual frames of data in the image store 322, the high-speed three-dimensional model 340, and intermediate results in the high-accuracy processing pipeline 350, the high-accuracy model 370 may be processed to reduce errors in the camera path and resulting artifacts in the reconstructed model. As a further refinement, a mesh may be projected onto the high-speed model by a mesh projection module 360. The resulting images may be warped or deformed by a warping module 362. Warped images may be utilized to ease alignment and stitching between images, such as by reducing the initial error in a motion estimation. The warped images may be provided to the two-dimensional image registration module 352. The feedback of the high-accuracy three-dimensional model 370 into the pipeline may be repeated until some metric is obtained, such as a stitching accuracy or a minimum error threshold.

[0043] Various aspects of the system 300 of Fig. 3 are described in greater detail below. In particular, a model refinement process is described that may be used by the high-accuracy processing controller 324 to refine the high accuracy three-dimensional model 370 using measured data in the image store 322. It should be understood that various processing modules, or the steps implied by the modules, shown in this figure are exemplary in nature and that the order of processing, or the steps of the processing sequence, may be modified, omitted, repeated, re-ordered, or supplemented, without departing from the scope of this disclosure.

[0044] Fig. 4 illustrates a coordinate system for three-dimensional measurements using a system such as the optical system 200 described above. The following description is intended to provide useful context, and should not be interpreted as limiting in any sense. In general an object 408 within an image plane 402 of a camera has world coordinates $\{X_w, Y_w, Z_w\}$ in a world coordinate system 410, camera coordinates $\{X_c, Y_c, Z_c\}$ in a camera coordinate system 406, and image set coordinates $\{x_i, y_i, \underline{d}_i(x_i, y_i)\}$ for i = 1 to N points or pixels within a processing mesh of the field of view 402, where $\underline{d}_i$ is a disparity vector 412 containing one or more disparity values that characterize z-axis displacement (Z_c) or depth 404 of a point in the image plane 402 based upon x-axis and/or y-axis displacement in the image plane 402 between a number of physically offset apertures or other imaging channels. The processing mesh may be understood as any overlay or grid for an image or other two-dimensional data that identifies locations where processing will occur. While a processing mesh may be a regular grid of locations in a square, rectangular, triangular, or other pattern, the processing mesh may also, or instead, include irregular patterns selected randomly or according to the specific subject matter being processed. The disparity vector 412 may be expressed, for example, in terms of displacement relative to a center channel, if any, for the camera. In general, the disparity vector 412 encodes depth, and in various other three-dimensional imaging systems, this disparity vector 412 may be replaced by one or more other measured quantities that encode depth. Thus terms such as disparity vector, disparity value, and disparity data and the like should be understood broadly to include any one or more scalar and/or vector quantities measured by a system to capture depth information. Also more generally, a three-dimensional measurement as used herein may refer to any form of data encoding three-dimensional data including without limitation, groups of two dimensional images from which disparity vectors might be obtained, the disparity field (of disparity vectors) itself, or a three-dimensional surface reconstruction derived from the disparity field. In image-based three-dimensional reconstruction, a camera model may be employed to relate disparity vectors to depth within a field of view of a camera. The camera model may be determined theoretically based upon optical modeling or other physics, empirically through observation, or some combination of these, and may be calibrated to compensate for optical aberrations, lens defects, and any other physical variations or features of a particular physical system.

[0045] While a single image plane 402 is illustrated for purposes of explanation, it will be appreciated that a multi-aperture camera (or other multi-channel system) may have a number of physically offset optical channels that provide a different image plane for each channel, and the differences in feature locations (the x-y displacement) between the images for each optical channel may be represented as the disparity field. In various certain processing steps, the disparity data may be referenced to a single image plane such as a center channel image plane of the camera.

[0046] Fig. 5 illustrates a sequence of images captured from a moving camera. In the sequence 500, a camera 502, which may include, for example, any of the cameras 102 described above, may capture an image of an object 504 from a number of different positions 506a-506e along a camera path 507. While the camera path 507 is depicted as a continuous curvilinear path which represents the physical path of a camera, it will be understood that analytically the camera path 507 may be represented by discrete, straight line transformations along with associated rotations in three-dimensional space. While five camera positions are shown in the camera path 507 of Fig. 5, it will be appreciated that more or fewer camera positions may be used consistent with the principles described herein. In an embodiment, the camera 502 may at each position 506 capture an image set:

$$IS_n = \left\{ x_i = (x_i, y_i)^T \mid i = 1, \cdots, N_n \right\} \qquad \text{[Eq. 1]}$$

of two-dimensional images from which a point cloud:

$$PC_n = \left\{ X_i = (X_i, Y_i, Z_i)^T \mid i = 1, \cdots, N_n \right\} \qquad \text{[Eq. 2]}$$

may be reconstructed (or any other suitable three-dimensional measurement for the camera position). In general, these three-dimensional point clouds (or other three-dimensional data) captured from the sequence 500 may be combined into a three-dimensional model such as an aggregate point cloud or other three-dimensional model of the object, such as by minimization of errors in a three-dimensional registration of individual three-dimensional measurements, or any of a variety of other techniques. It should also be understood that, in certain embodiments, the camera may remain fixed while the subject moves. In such cases, motion of the object 504 is determined, rather than motion of the camera 502, although the use of camera motion versus object motion may be a relatively arbitrary matter of convenience, or of the computational efficiency of a camera coordinate system versus an object coordinate system.

[0047] Fig. 6 is a conceptual representation of a three-dimensional data acquisition process 600 that may be used in the systems described above. In general, the camera (which may be any of the cameras described above) obtains two-dimensional measurements of a surface of an object 601 such as a first measurement 602 from a side channel (e.g., a left channel image), a second measurement from another side channel 604 (e.g., a right channel image), and a third measurement from a center channel 603 (e.g., a center channel image). It will be understood that while three channels are depicted, a system may recover three-dimensional data from more or less channels using various techniques that will be apparent to one of ordinary skill, and any such techniques that might be improved with the refinement techniques described herein are intended to fall within the scope of this disclosure. These measurements 602, 603, 604 may be processed, for example, to obtain a disparity field 606 that identifies relative movement of features within the images of each measurement. A camera model 610 for the camera may be used to relate the disparity field 606 to the three-dimensional reconstruction 612 of the surface of the object 610 as measured from a camera pose. While a center channel image may conveniently be used as the reference for the camera pose of the resulting three-dimensional reconstruction 612, this is not required and may not, in certain systems be available as a reference in any event. The three-dimensional reconstruction 612 can be stitched to other such three-dimensional measurements using camera path information or the like to obtain a three-dimensional model 620 of the object 601.

[0048] In a model refinement process as described below, one of the two-dimensional measurements, such as the first measurement 602, may be projected onto the three-dimensional model using available spatial information (e.g., the camera position and orientation). The resulting projection may then be backprojected to the second camera pose using warping or other deformation techniques to obtain an expected measurement at the second camera position. In the case of a side channel two-dimensional image or the like, the expected measurement may be a corresponding image expected in the center channel or another side channel. By adapting the three-dimensional measurement from this image pair to reduce or minimize an error between the actual and expected measurements in an overlapping area of the object, the three-dimensional measurement may be refined for that camera position to more accurately represent a surface of the object 601 . In one aspect, the three-dimensional model may be directly refined with the new spatial information. In another aspect, the improved three-dimensional measurement for the camera may be used in a new motion estimation to recover camera path and three-dimensional model data for an entire scan or any portion thereof. By refining the individual three-dimensional measurements and the camera path in this manner, a more accurate three-dimensional model for the object may be obtained. It will be appreciated that, in general, error minimization may be performed on a number of different data sets that encode three-dimensional information, such as the two-dimensional image sets, or upon processed representations of these measurement such as the disparity field.

[0049] Fig. 7 is a flow chart of a process for refining three-dimensional data. In general, the process 700 refines a three-dimensional model by refining individual three-dimensional-measurements taken at different camera positions, which information may be employed to refine the resulting model. This process 700 may be usefully employed, for example, to warp two-dimensional images in a module 362 of a high accuracy processing pipeline 350, such as to improve two-dimensional registration and/or three-dimensional stitching results. While a particular embodiment is described below in detail, it will be appreciated that any similar technique for generating an expected two-dimensional measurement at one camera position using an actual two-dimensional measurement from a different camera position, along with a three-dimensional model of the imaged subject matter (and a camera model as appropriate), may similarly be employed. Thus the techniques described herein may be readily adapted to other systems that obtain a three-dimensional model from a series of individual three-dimensional measurements, such as systems using structured light or systems using a series of two-dimensional images.

[0050] As shown in step 710, the process 700 may begin by acquiring frames of image data along a camera path. This image data may include image pairs that capture an image from two or more offset optical channels of a multi-aperture camera or other multi-channel imaging device. In one embodiment, each image in an image pair contains a two-dimensional image from two coupled poses having a known, fixed relationship to one another. In such an embodiment, a center channel may also be provided that captures a third image as a part of the frame of image data to provide a conventional, undistorted two-dimensional view of the scanned subject matter (where distortions in the side channels encode distance to a surface). The center channel may also serve as a reference pose for a three-dimensional measurement derived from the pair of two-dimensional images. It will be understood, however, that this arrangement is somewhat arbitrary, and other cameras may be employed such as a camera with a center channel and a single side channel, or only two side channels, or any of a number of other arrangements. More generally, any camera that captures two-dimensional images for use in a three-dimensional reconstruction may be used with techniques described herein.

[0051] As shown in step 712, three-dimensional measurements may be obtained from the image data. In general, this may include processing image sets or the like to obtain disparity data across a processing mesh of the camera, and further processing the disparity data to obtain a three-dimensional surface reconstruction. In one embodiment, the disparity data encodes depth information, and may be employed to recover a three-dimensional measurement using a camera model or the like to relate disparity data to depth information for each pixel of the processing mesh. This step 712 may be repeated for each individual measurement (e.g., image set) obtained by the camera. As a result, a three-dimensional measurement or reconstruction may be obtained for each camera pose along a camera path. It will be understood that the disparity data is itself a three-dimensional measurement, and may be employed in place of a three-dimensional reconstruction for many of the processing steps described herein, with suitable adaptations being readily understood by one of ordinary skill in the art. It will further be understood that other three-dimensional imaging techniques are known and may be adapted to obtain three-dimensional measurements from an object surface.

[0052] As shown in step 714, a three-dimensional model may be constructed from the individual three-dimensional measurements obtained in step 712. Where the three-dimensional measurements of the surface of the object overlap, these three-dimensional measurements may be registered to one another using any of a variety of known techniques. As a result, the camera path from pose to pose may be recovered, and the three-dimensional measurements from each pose may be combined into a full three-dimensional model of scanned regions of the surface of the object.

[0053] As shown in step 716, a two-dimensional image or other measurement from one channel of a camera may be spatially projected onto the full three-dimensional model obtained in step 714. In general, the raw camera measurement includes a two-dimensional image of pixel values, which may be projected onto the three-dimensional model using texture mapping or any other suitable techniques to place the two-dimensional data from the image sets into the coordinate system of the three-dimensional model. As a significant advantage, this approach employs a three-dimensional model of the object that may, for example, contain global information that was not available when the data was initially collected. The model may, for example, average errors and/or reduce noise in individual camera measurements, as well as minimizing errors in a global camera path where possible. Using this initial model as a starting spatial reference point, the process 700 may revisit the individual three-dimensional measurements as further described below.

[0054] As shown in step 718, the projected measurement may be backprojected from the three-dimensional model to another channel of the camera, which may be the center channel or another side channel of the camera described above. The projected result from step 716 may be backprojected using any suitable techniques to obtain a synthetic view of the measurement from one camera channel as it should appear from the other camera channel, based upon the spatial relationship between the projected result, the three-dimensional model, and the position and rotation of the other channel. It will be appreciated that if there were no errors in the initial measurement, this synthetic view would exactly correspond to the actual two-dimensional image obtained from the other channel. However, in a high-speed processing pipeline such as that described above, an initial three-dimensional model may fail to accurately capture surface details for any number of reasons (lower resolution processing, absence of global surface data such as the completed three-dimensional model, etc.). Thus it is expected that in a practical system there may be variations between a synthesized view (based on observations from a different position) and an actual view. Backprojection may be accomplished, for example, by warping or otherwise deforming the projected result based upon the three-dimensional model and camera pose information for respective measurements. By processing these synthesized image sets to obtain disparity data, and further backprojecting the synthesized disparity data through the camera model, a backprojected result may be obtained that represents a synthesized or expected version of the three-dimensional measurement from the second camera position.

[0055] As shown in step 720, a three-dimensional measurement by a camera (e.g., the measurement derived from an image set in a frame of data) may be refined by adjusting the three-dimensional reconstruction to minimize an error between the backprojected result obtained in step 718 and an actual corresponding two-dimensional measurement captured in step 710. More generally, where two images contain measurements from an overlapping portion of the surface of the object, the backprojected (e.g., synthesized) measurement and the actual measurement may be directly compared. In one embodiment, camera calibration data and other information descriptive of the camera or the channels of the camera may be incorporated into the projection and/or backprojection in order to improve three-dimensional accuracy of the resulting three-dimensional measurement.

[0056] As shown in step 722, the three-dimensional model may be refined based upon the refined three-dimensional measurements for each frame of image data. A number of techniques may be employed to refine the model. In one aspect, the three-dimensional data for a refined three-dimensional measurement may be used to directly modify the three-dimensional model, e.g., by estimating the contribution of the changes in the refined three-dimensional measurement on the reconstruction process for the three-dimensional model. In another aspect, a new motion-based reconstruction for some or all of the scan data may be performed using the refined three-dimensional measurements in place of the initial three-dimensional measurements to recover a camera path used to relate the individual measurements to a global coordinate system. In another aspect, this process may be repeated to obtain iterative refinements in the three-dimensional model, e.g., for a predetermined number of iterations, or until a predetermined error threshold is reached, or until no further refinement is obtained from a previous iteration, and so forth, as well as various combinations of these. Iterations may be performed locally (e.g., on specific regions where errors are large) or globally (e.g., for every overlapping region between camera positions), or some combinations of these.

[0057] It will also be appreciated that this approach may be usefully employed with other three-dimensional reconstruction techniques, as well as in other ways within the image-pair based processing described above. For example, while the model-based refinement of a specific three-dimensional measurement may improve accuracy, the same approach may be employed to backproject a two-dimensional image from one image set onto a two-dimensional image from another image set in order to achieve frame-to-frame improvements in accuracy. Further, these image sets may be offset by any number of intervening image sets, and complementary, bi-directional refinements may be performed for any and all of the foregoing wherever the two measurements contain some overlap on the surface of the object. More generally, while a technique for testing a specific set of overlapping measurements is described above, this technique may be repeated any number of times, in any order, for some or all of the overlapping regions in measurements used to obtain a three-dimensional model, and all such variations are intended to fall within the scope of this disclosure.

[0058] Fig. 8 is a flow chart of a global path optimization. In one aspect, the refinement of individual three-dimensional measurements may be used in combination with numerical techniques for global path optimization for an entire camera path to yield further iterative improvement to a resulting three-dimensional model. A suitable global path optimization technique is now described in greater detail.

[0059] The process 800 may begin with preprocessing as shown in step 810. It will be understood that preprocessing as described herein presupposes the availability of a number of frames of image data from which a camera path and three-dimensional model can be reconstructed. The information for the three-dimensional reconstruction may be generated in numerous ways including coming from structured light projection, shading based three-dimensional reconstruction, or disparity data. Disparity data may be generated by a conventional image plus one or more other channels or side channels. The preprocessing may include determining the number of available frames, the amount of overlap between neighboring frames, identification and elimination of frames with blurred or badly distorted images, and any other suitable preprocessing steps. An estimate of the number of desired key frames may be initially determined during the preprocessing step.

[0060] As shown in step 812, key frames may be selected from among all of the frames of data acquired from a scanner along a camera path. In general, computational costs can be reduced by storing certain data and performing certain calculations and processing steps exclusively with reference to key frames. These key frames may be related to one another in a manner that permits characterization of a complete camera path, typically through the registration of overlapping three-dimensional data in respective key frames. Various methods are known in the art for selecting a subset of frames of data as key frames, including techniques based on image overlap, camera path distance, the number of intervening non-key frames and so forth. Key frames may also or instead be selected based upon an amount of image overlap from the preceding key frame and/or a candidate for a following key frame (if available). Too little overlap may impair frame-to-frame registration. Too much overlap may produce excess key frames requiring additional processing. Key frames may be selected based on spatial displacement. Key frames may also be selected based on sequential displacement. This type of sequential displacement could mean for example that every tenth frame is selected as a key frame. In one aspect, key frames may be selected as data is acquired based on any number of suitable criteria. In another aspect, key frame pairs may be determined post hoc by examining all possible candidate key frames. All possible key frame pairs may be examined and candidates may be removed, for example, where there is insufficient overlap to form a stitch. Still more generally, any technique suitable for selecting a subset of frames in a data set may be usefully employed to select key frames for processing in order to reduce computational complexity.

[0061] Once key frames have been selected, additional processing may be performed. For example, full image data (e.g., full resolution center and side channel images) may be stored for each key frame, along with image signature data, point cloud centroid calculations, and any other measured or calculated data to support use of the key frames in a three-dimensional reconstruction process as described herein.

[0062] As shown in step 814, candidate stitches may be identified. In general, a stitch is a relationship between two separate three-dimensional measurements from two different camera poses. Once a stitch is established, a rotation and a translation may be determined for the path of a camera between the two poses. In a complementary fashion, the three-dimensional measurements from the poses may be combined into a portion of a three-dimensional model. Candidate stitches may be analyzed around each key frame, such as from the key frame to some or all of the frames of data between the key frame and neighboring key frames. In another aspect, a candidate stitch may be made to every other key frame, or in order to reduce computational complexity, every key frame within a spatial or sequential neighborhood around a key frame. Stitches may be based on the originally imaged frames. It may also be useful to deform or warp two-dimensional images during registration and other steps in a stitching process in order to improve accuracy and/or speed. Stitches may also or instead be based on other observed epipolar relationships in source data.

[0063] As shown in step 816, stitches may be selected for the complete camera path from the universe of candidate stitches. The selection of stitches may be made based upon, e.g., the lowest calculated error in resulting portions of the three-dimensional model. In general, each key frame may be stitched to one or more other key frames and each non-key frame may be stitched to at least one sequentially neighboring key frame.

[0064] As shown in step 818, a graph analysis may be performed using the key frames and the associated stitching to calculate a global path for the camera used to obtain a three-dimensional model. The graph analysis may consider each key frame as a node or vertex and each stitch as an edge between a pair of nodes. A key frame is selected as a starting point. A breadth- or depth-first search may be performed through the graph to identify stitches which may connect the current key frame to another key frame. Each key frame may be marked as the graph is processed. A check may be performed to see if all key frames have been reached within the graph. If all key frames have not been reached through traversing stitches in the graph analysis, the largest sub-graph is identified. This sub-graph may be examined to see if the entire three-dimensional image may be modeled.

[0065] It may be that certain sub-graphs are not required to complete the three-dimensional imaging. If the camera lingered over a particular region of a surface of an object, or if the camera looped on a region multiple times, the associated sub-graph(s) may not be needed. If a separate sub-graph is identified, which is needed to complete the three-dimensional imaging, an optional branch back to step 812 may be performed. For example, a set of key frames may have been selected which did not have sufficient stitching from one key frame to the next key frame. By choosing a different set of key frames, sufficient stitching may be obtained in order to obtain a complete graph of all needed aspects of the three-dimensional imaging. A key frame which is too sparse, meaning it has insufficient stitches to aid in building a graph, may indicate that a different set of key frames should be selected. Based on the graph analysis, a global path may be selected, and the graph may then be analyzed to optimize the path calculation.

[0066] As shown in step 820, a numerical optimization may be performed to reduce errors in the calculated camera path based upon available data for the complete camera path such as, for example, cross links that interrelate temporally distant measurements. In general, the objective of numerical optimization is to minimize a calculated error based upon an error function for the camera path and/or reconstructed three-dimensional model. A useful formulation of the error minimization problem for a global camera path is presented below.

[0067] There may be a set of candidate camera poses, each including a rotation and a translation (or position) referenced to a world coordinate system. There may also be a set of measured frame-to-frame camera motions, each including a rotation and a translation between poses. A measured camera motion may be referenced in the coordinate system of one camera pose. An example set of three key frames may be considered with an origin "O" and three other points "A", "B", and "C", each of the points having a position in a three-dimensional space. In addition to the position of these points, a camera at each of these points may have a different orientation. Therefore, between each of these points is a translation, meaning a change in position, and a rotation, meaning a change in orientation. The translation and rotation values comprise the motion parameters. The relationship between a point, X, expressed in the world coordinate system as Xo and the same point expressed in the A coordinate system, X_A may be expressed as:

$$X_A = R_{0A} X_0 + T_{0A} \qquad \text{[Eq. 3]}$$

R_{OA} is the rotation taking points from the world to the A coordinate system. T_{OA} is the translation of the world coordinate system to the A coordinate system. It should be understood that symbols X and T may represent a vector, rather than a scalar, e.g. where X includes x, y, and z coordinate values. Further, it should be understood that symbol R may represent a matrix. The following equations may similarly represent the transformation between the world and the B and C coordinate systems respectively:

$$X_B = R_{0B} X_0 + T_{0B} \qquad \text{[Eq. 4]}$$

$$X_c = R_{0C} X_0 + T_{oc} \qquad \text{[Eq. 5]}$$

[0068] By rearranging, equations 4 and 5 may be represented as follows:

$$X_0 = R_{0A}^{-1}(X_A - T_{0A}) = R_{0B}^{-1}(X_B - T_{0B}) \qquad \text{[Eq. 6]}$$

[0069] The representation of a point in one camera's coordinate system may be related to the same point in another coordinate system. For example, as in equations 3-5, coordinates of a point, X, may be transformed from the A coordinate system to the B coordinate system as follows:

$$X_B = R_{AB} X_A + T_{AB} \quad \text{[Eq. 7]}$$

[0070] The rotation R_{AB} rotates points from the A to the B coordinate system and T_{AB} translates the origin of the A coordinate system to the B coordinate system.

[0071] In optimization, the pose of every camera may be optimized based on measured transformations between poses. That is, a number of camera-to-world rotations and camera-to-world translations, Ro_n and To_n may be performed. In general, one of these may be defined as the identity rotation and zero translation, with the remaining values may be optimized as described below.

[0072] The rotations and translations may be measured for many pairs of cameras. For the zth such measured frame-to-frame motion, let one of the cameras of the pair be camera A and the other be camera B. This may also be considered the zth stitch. Let $R^{\prime}_{AB}$ be the measured rotation taking points in the A system to the B system and T_{AB} be the coordinates of the A position expressed in the B system, as in equation 7.

[0073] The rotations and translations for all cameras, Ro_n and To_n may be optimized. $R^{\prime}_{c,0A}$ and $R^{\prime}_{c,0B}$ may be defined to be the candidate rotations; $T^{\prime}_{c,0A}$ and $T^{\prime}_{c,0B}$ may be defined to be the candidate translations corresponding to the A and B camera of the zth stitch. Further, $R^{\prime}_{c,AB} = R^{\prime}_{c,0B}(R^{\prime}_{c,0A})^{-1}$ may be defined as the candidate rotation from A to B, and $T^{\prime}_{c,AB} = T^{\prime}_{c,0B} - R^{\prime}_{c,M} T^{\prime}_{c,0A}$, the candidate translation for the transformation from A to B.

[0074] Note that with sufficient stitches, the motion constraints may form an overdetermined system of motion constraint equations. Using these equations as a starting point, numerical optimization may be performed on the rotational and translational components of each camera based on the measured stitches.

[0075] In a decoupled optimization, the rotational and translational components may be independently optimized. Given a candidate set of camera rotations, $R^{\prime}_{c}$ the corresponding candidate camera-to-camera rotations, $R^{\prime}_{c,AB}$, may be computed that correspond to each of the measured camera-to-camera rotations, $R^{\prime}_{AB}$. Thus the corresponding residual rotations are given by $R^{\prime}_{residual,AB} = R^{\prime}_{C,AB}(R^{\prime}_{AB})^{-1}$. A scalar-valued rotational cost function, e_r, may be computed that depends on the candidate camera rotations

$$e_r(R_{C,On}) = \sum_{i=1}^{\#stitches} K^T K, \quad where \quad r_r^i = \log_{SO(3)} R_{residual,AB} \qquad [Eq.\ 8]$$

[0076] In equation 8, $\log_{SO(3)}(R)$ returns the axis-angle vector, v, that corresponds to the rotation R. In other words, $\log_{SO(3)}(R)$ returns the vector, v, that has a cross-product matrix, $[v]_x$, that is the matrix logarithm of R.

[0077] Next, a similar scalar-valued cost function may be computed for translation that depends on the candidate rotations and translations.

$$e_t(R_{C,O_n}, T_{C,O_n}) = \sum_{i=1}^{\#stitches} r_t^{i\,T} r_t^i, \quad where \quad r_t^i = T_{C,M} - T_{AB} \qquad [Eq.\ 9]$$

[0078] Equation 8 may be minimized as a nonlinear optimization; equation 9 may be minimized as a linear optimization.

[0079] In one conventional, decoupled approach to solving these simultaneous systems of equations, the rotational error function may be converted into a quaternion expression in order to translate the numerical problem into a linear system of equations for solution. While this approach may increase computational efficiency, it offers an incomplete optimization solution.

[0080] The decoupled approach described above does not provide a truly optimal one, in a maximum-likelihood sense, as it cannot use information from the translation portion of the stitches in determining rotation. In order to achieve a coupled optimization a weighting may be used to balance the contributions of rotational and translational components to a combined cost function:

$$e_c(R_{C,On}, T_{C,On}) = \sum_{i=1}^{\#stitches} \left(\begin{bmatrix} r_t^i \\ r_r^i \end{bmatrix}^T W_i \begin{bmatrix} r_r^i \\ r_t^i \end{bmatrix} \right) \qquad [Eq.\ 10]$$

Multiple approaches may be used to optimize this cost function, but in one embodiment the weights may be expressed as matrices. Different stitches may receive different weightings based upon a number of factors including the number of points in the stitch (e.g., the shared content), the quality of a particular three-dimensional measurement, and/or any other factors impacting the known reliability of a stitch. In one approach, the weight matrices may also account for anisotropic error in the individual points collected, such as due to acquisition of depth information from disparity measurements, which results in measurement precision that varies with distance from the camera.

[0081] In some cases, equation 10 may be reformulated so that the rotation and translation weights are decoupled for each stitch (i.e., W_c^l is a block diagonal). In particular, this may occur in the case where the motion stitches are recovered from three-dimensional point correspondences with isotropic point error. In that case, for a given stitch i, between camera A and camera B, the optimal solution may bring the point cloud as seen from camera A into correspondence with that seen from camera B. If $\overline{X}'_A$ and $\overline{X}'_B$ are the positions of the center of the point cloud in the A and B systems respectively, then r_t' may be replaced in equation 10 with the residual displacement between the point-cloud centers based on the candidate camera pose as follows:

$$r^i_{t,ctr} = \overline{X}'_B - (Rc'_{,AB}\overline{X}'_A + T^i_{C,AB}) \quad \text{[Eq. 11]}$$

Equation 10 may then be reformulated as:

$$e_c(R_{c,o_n} Jc, o_n) = {}^{\#}\mathrm{T}_{i=1} \left(r_{i;ctr} \mathrm{V} ; r^i_{t,ctr} + rfwX' \right) \quad \text{[Eq. 12]}$$

This coupled optimization problem may still be considered as being non-linear. It should be understood that other optimizations are also possible that would fall within the scope of this disclosure.

[0082] In general, by minimizing equation 10, both rotational errors and translational errors may be minimized simultaneously. The weight matrices can be chosen, for example, according to "First Order Error Propagation of the Procrustes Method for 3D Attitude Estimation" by Leo Dorst, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 27, No. 2, Feb. 2005, pp. 221-9 which is incorporated in its entirety by reference. Once a more consistent set of motion parameters has been generated the three-dimensional model may be updated.

[0083] In one aspect, the residual error may be employed as a calibration metric. When total error or some portion of error has been minimized, the residual error may be evaluated. If a minimized error falls beyond a certain threshold then calibration for the scanner and associated hardware may be recommended, based upon an inference that the inability to produce better quality results is due to a miscalibration or other malfunction of the camera system. The threshold value may be empirically determined based on the specific scanner hardware equipment or it may be learned experientially over time for a given system. When a system is new or has been freshly aligned, expected minimized error values may be obtained. When minimized error values deviate from these expected values, a calibration state evaluation flag may be set, or other alert or message generated, indicating that the tool should be calibrated.

[0084] As shown in step 822, upsampling may be performed to augment a three-dimensional model with data from non-key frames. For example, non-key frames may be registered to nearby key frames to create small, local reconstruction patches including the full image detail available from non-key frames. In this manner, path optimization may be performed on a key-frame-based data set, thus reducing the data requiring processing, while retaining additional data points from non-key frames for use in the final three-dimensional model.

[0085] It will be appreciated that any of the above system and/or methods may be realized in hardware, software, or any combination of these suitable for the data acquisition and modeling technologies described herein. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable devices, along with internal and/or external memory. The may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. Thus in one aspect there is disclosed herein a computer program product comprising computer executable code that, when executing on one or more computing devices, performs any and/or all of the steps described above. At the same time, processing may be distributed across devices such as a camera and/or computer and/or fabrication facility and/or dental laboratory and/or server in a number of ways or all of the functionality may be integrated into a dedicated, standalone device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[0086] While the invention has been disclosed in connection with the preferred embodiments shown and described in detail, various modifications and improvements thereon will become readily apparent to those skilled in the art. Accordingly, the spirit and scope of the present invention is not to be limited by the foregoing examples, but is to be understood in the broadest sense allowable by law.

CLAIMS

What is claimed is:

1. A method of refining a three-dimensional model comprising the steps of:

providing a three-dimensional model of an object;

obtaining a first two-dimensional image of the object from a first camera pose;

obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image;

deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose;

comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and

correcting the three-dimensional model based upon the one or more discrepancies.

2. The method of claim 1 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two dependent positions.

3. The method of claim 2 wherein the first camera pose and the second camera pose include a position and an orientation of two offset channels of a multi-aperture camera.

4. The method of claim 1 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two independent positions.

5. The method of claim 4 wherein a relationship between the first camera pose and the second camera pose is calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose.

6. The method of claim 1 further comprising deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose.

7. The method of claim 1 further comprising applying the one or more discrepancies to directly refine the three-dimensional model.

8. The method of claim 1 further comprising applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement.

9. The method of claim 8 further comprising refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path.

10. The method of claim 9 further comprising using the refined camera path and the refined measurement to refine the three-dimensional model.

11. The method of claim 1 wherein the three-dimensional model includes a point cloud or a polygonal mesh.

12. The method of claim 1 wherein the object includes human dentition.

13. The method of claim 1 wherein the second camera pose corresponds to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object.

14. The method of claim 14 further comprising obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected

image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

15. A computer program product for refining a three-dimensional model of an object comprising computer executable code embodied on a computer readable medium that, when executing on one or more computing devices, performs the steps of:

providing a three-dimensional model of an object;

obtaining a first two-dimensional image of the object from a first camera pose;

obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image;

deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose;

comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and

correcting the three-dimensional model based upon the one or more discrepancies.

16. The computer program product of claim 15 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two dependent positions.

17. The computer program product of claim 16 wherein the first camera pose and the second camera pose include a position and an orientation of two offset channels of a multi-aperture camera.

18. The computer program product of claim 15 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two independent positions.

19. The computer program product of claim 18 wherein a relationship between the first camera pose and the second camera pose is calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose.

20. The computer program product of claim 15 further comprising code for performing the step of deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose.

21. The computer program product of claim 15 further comprising code for performing the step of applying the one or more discrepancies to directly refine the three-dimensional model.

22. The computer program product of claim 15 further comprising code for performing the step of applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement.

23. The computer program product of claim 22 further comprising code for performing the step of refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path.

24. The computer program product of claim 23 further comprising code for performing the step of using the refined camera path and the refined measurement to refine the three-dimensional model.

25. The computer program product of claim 15 wherein the three-dimensional model includes a point cloud or a polygonal mesh.

26. The computer program product of claim 15 wherein the object includes human dentition.

27. The computer program product of claim 15 wherein the second camera pose corresponds to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object.

28. The computer program product of claim 15 further comprising code for performing the steps of obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

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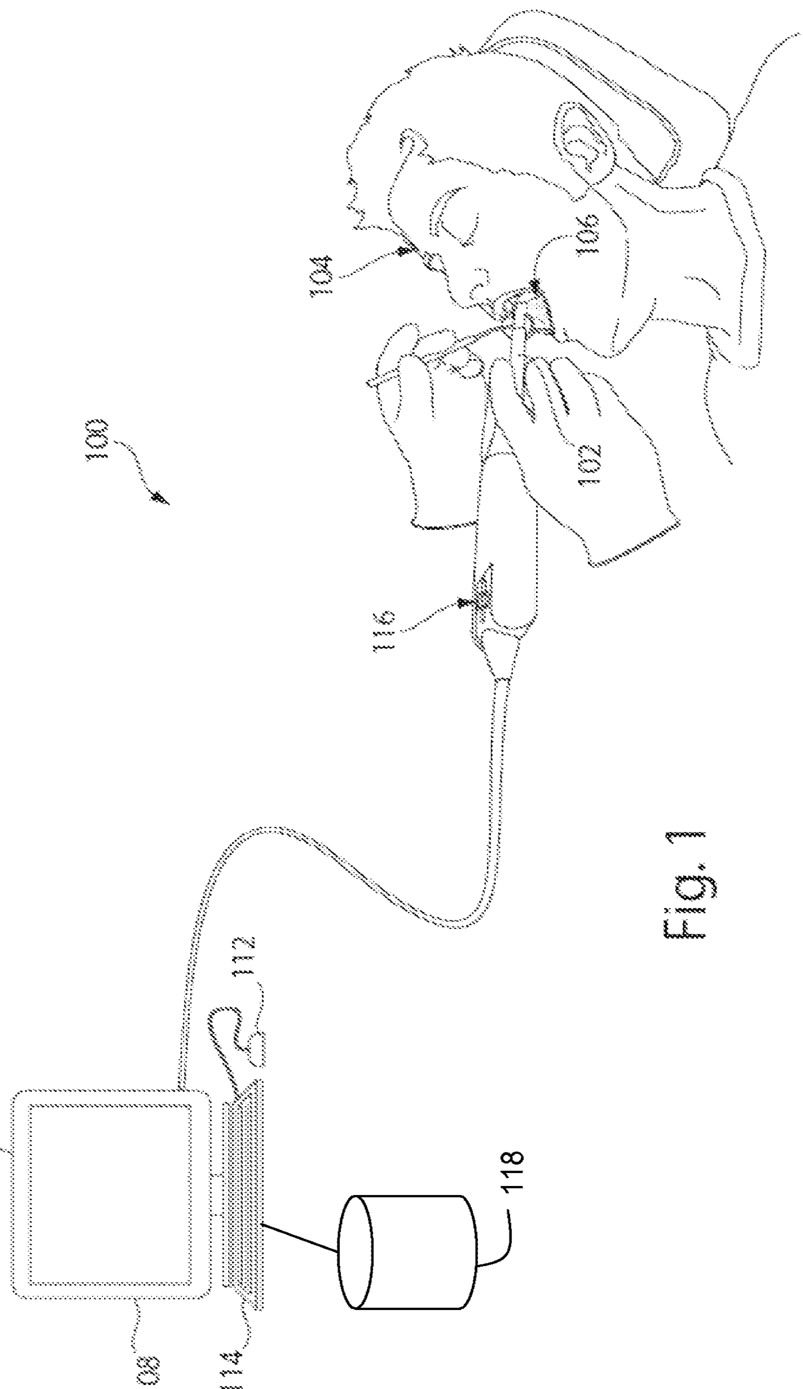

Fig. 1

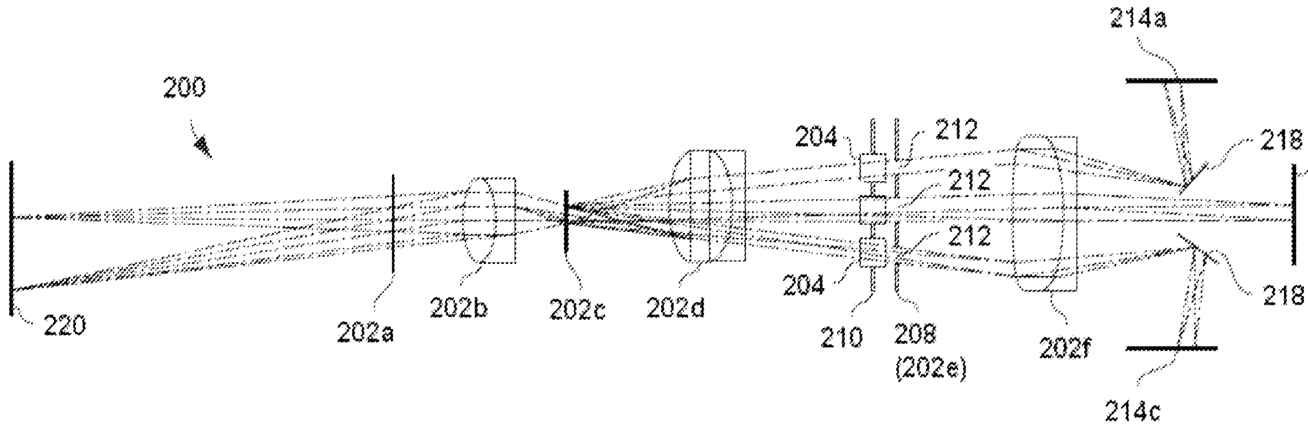
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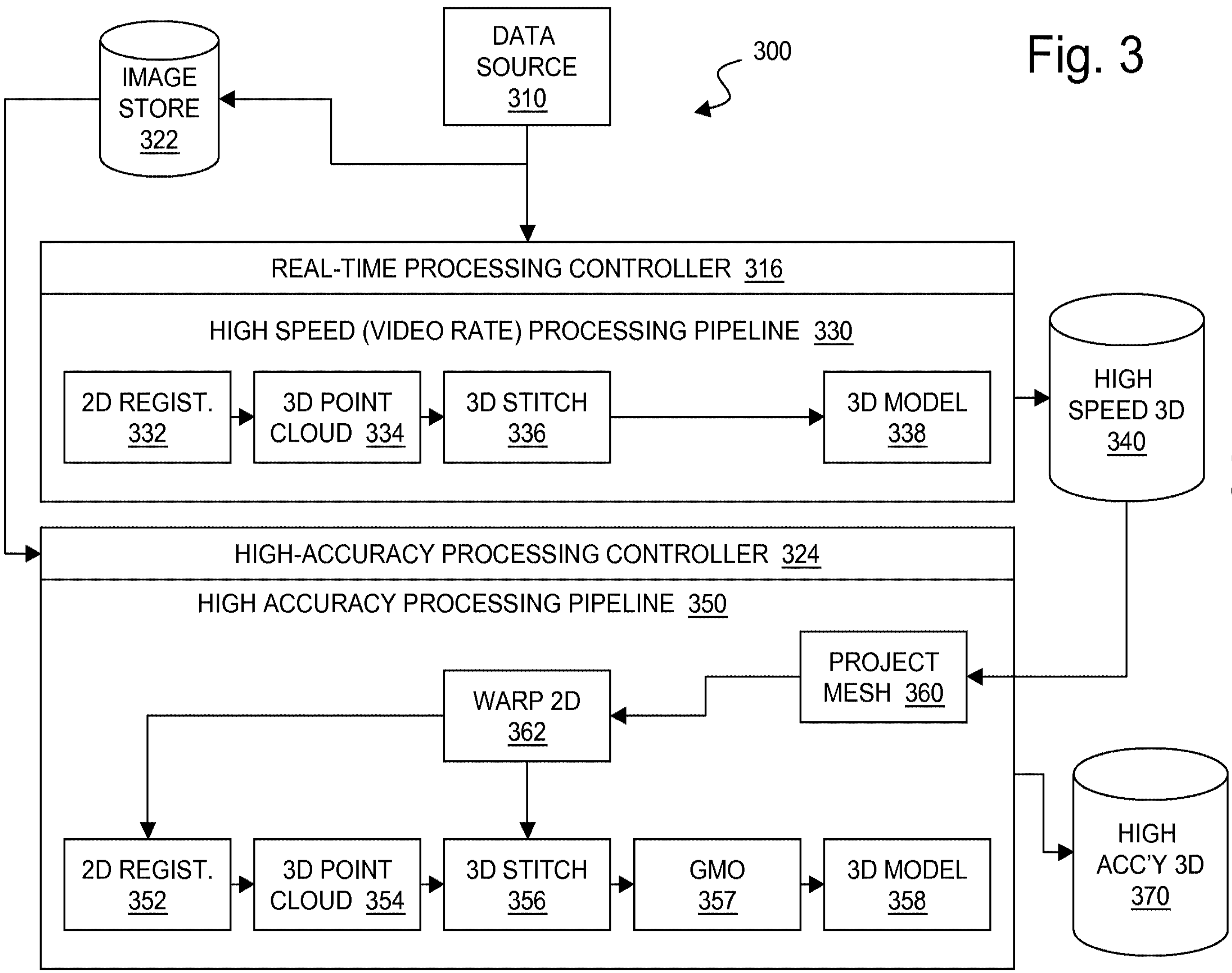
Fig. 2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2D REGIST. 332
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3D STITCH 336
3D MODEL 338
HIGH SPEED 3D 340
HIGH-ACCURACY PROCESSING CONTROLLER 324
HIGH ACCURACY PROCESSING PIPELINE 350
PROJECT MESH 360
WARP 2D 362
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3D STITCH 356
GMO 357
3D MODEL 358
HIGH ACC'Y 3D 370

Fig. 3

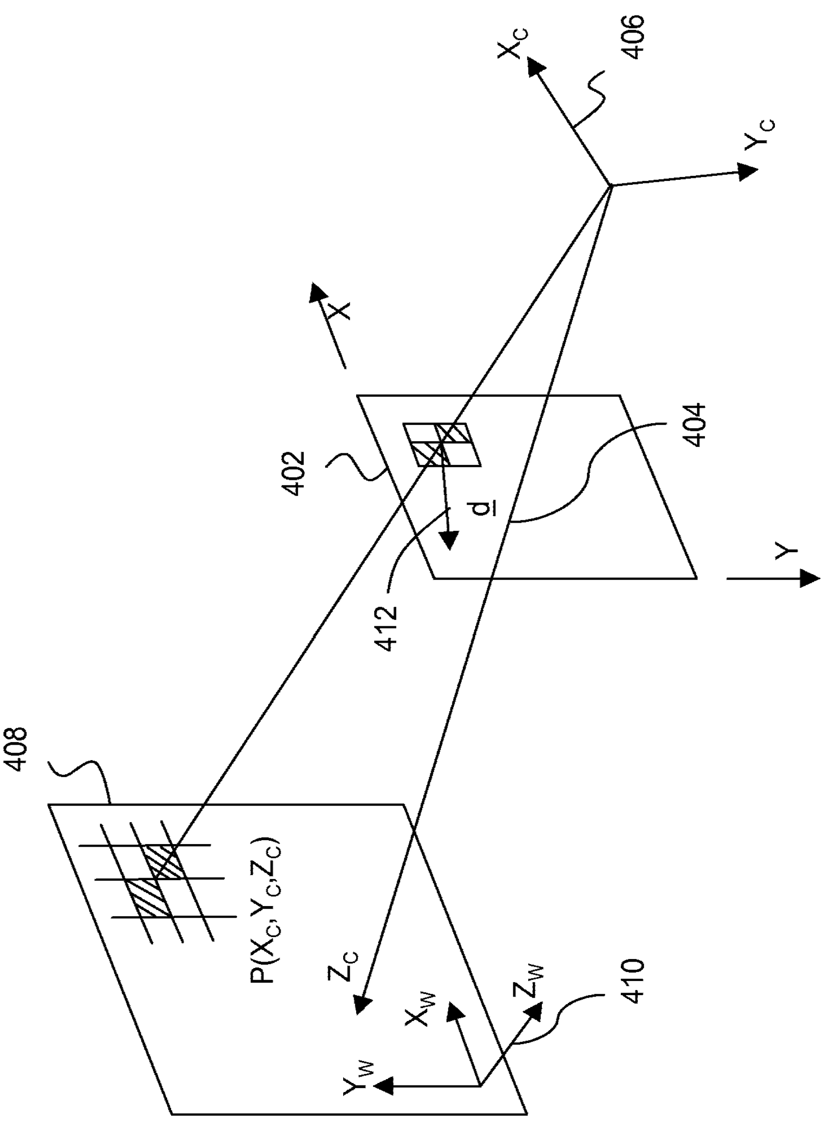

Fig. 4

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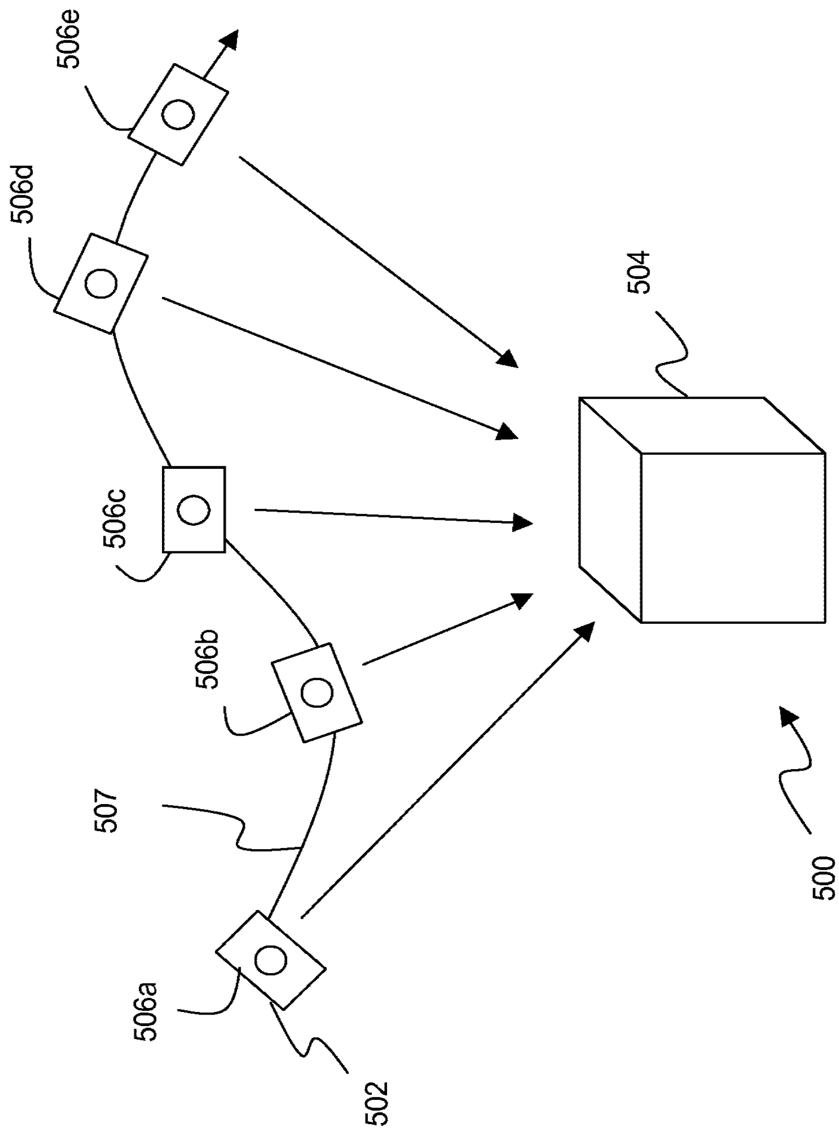
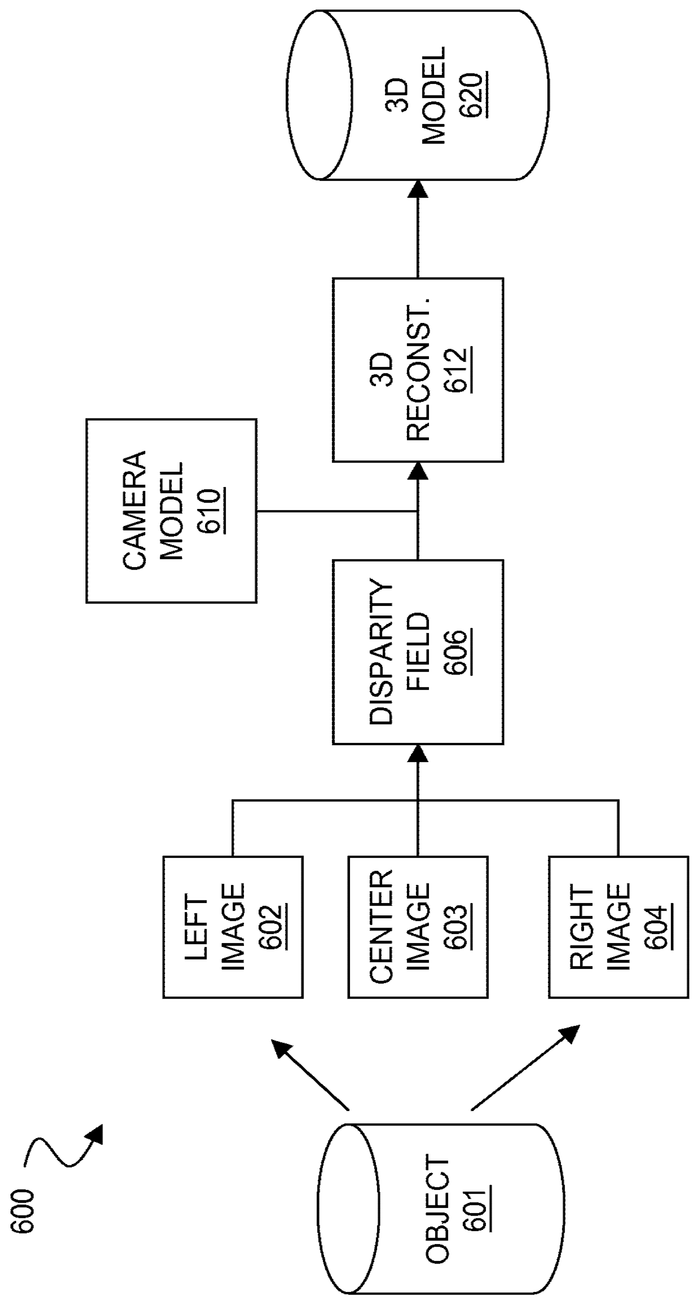


Fig. 5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CAMERA MODEL 610
DISPARITY FIELD 606
LEFT IMAGE 602
CENTER IMAGE 603
RIGHT IMAGE 604
OBJECT 601
600

Fig. 6

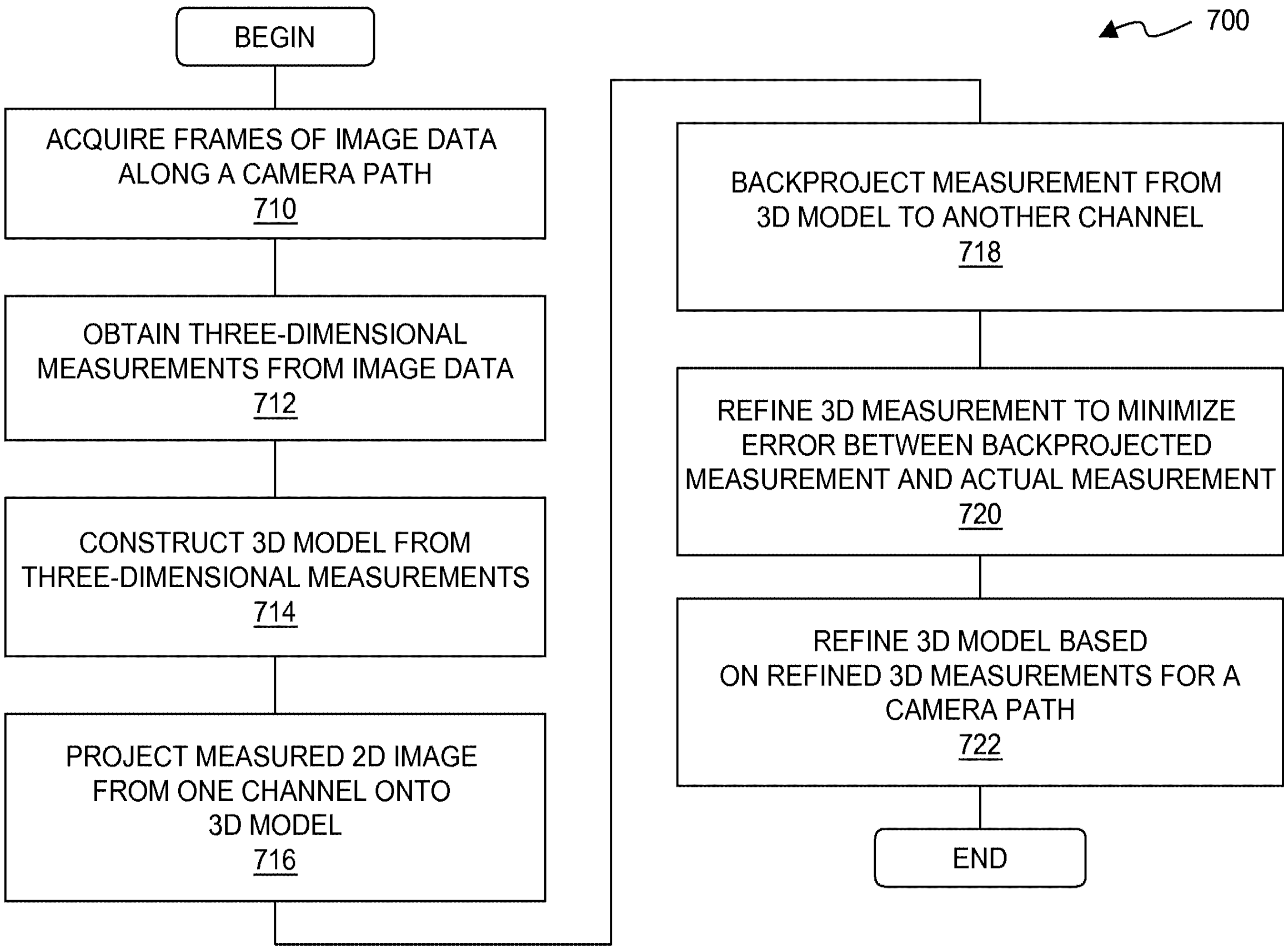
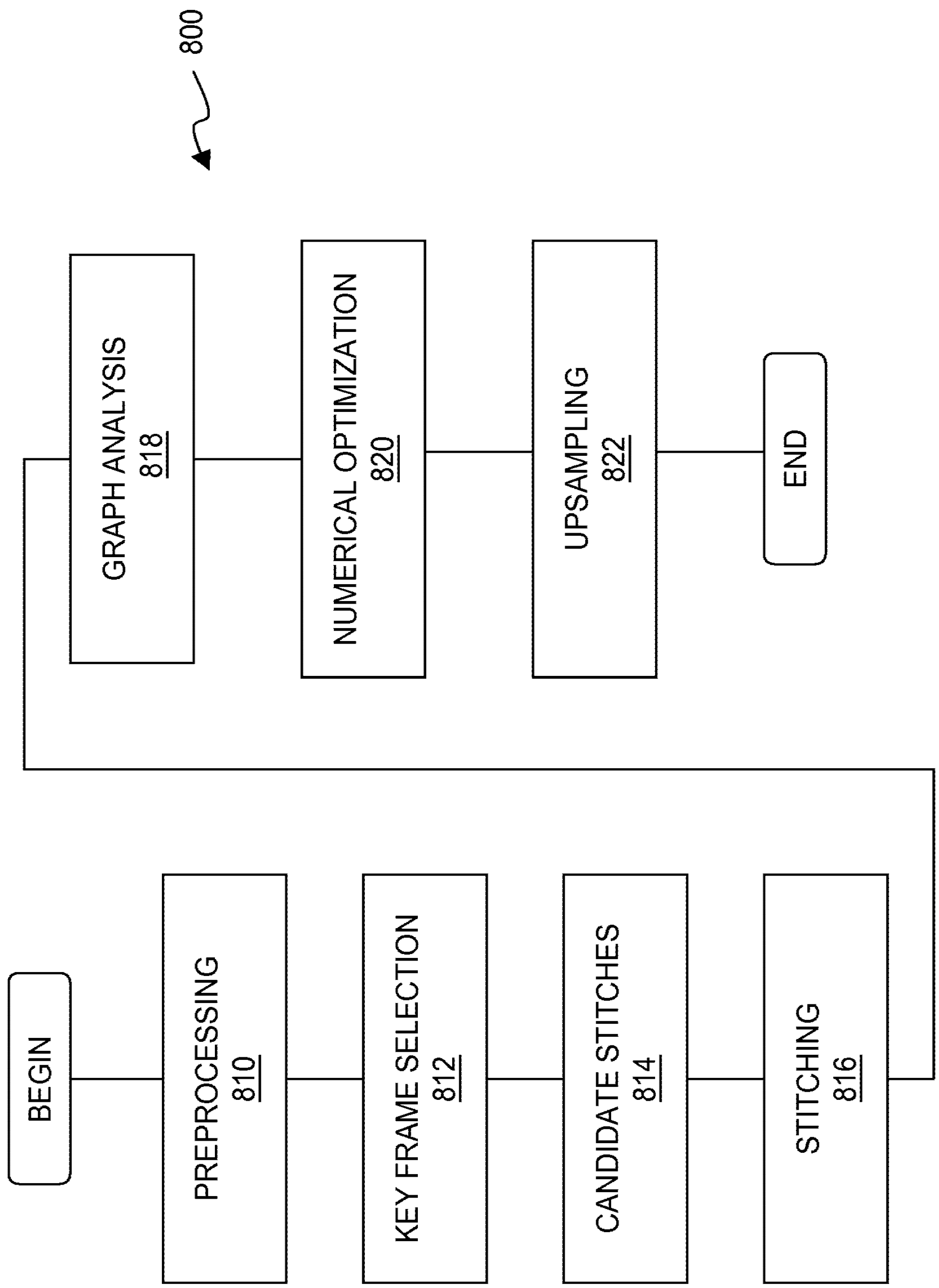

700
BEGIN
ACQUIRE FRAMES OF IMAGE DATA ALONG A CAMERA PATH 710
OBTAIN THREE-DIMENSIONAL MEASUREMENTS FROM IMAGE DATA 712
CONSTRUCT 3D MODEL FROM THREE-DIMENSIONAL MEASUREMENTS 714
PROJECT MEASURED 2D IMAGE FROM ONE CHANNEL ONTO 3D MODEL 716
BACKPROJECT MEASUREMENT FROM 3D MODEL TO ANOTHER CHANNEL 718
REFINE 3D MEASUREMENT TO MINIMIZE ERROR BETWEEN BACKPROJECTED MEASUREMENT AND ACTUAL MEASUREMENT 720
REFINE 3D MODEL BASED ON REFINED 3D MEASUREMENTS FOR A CAMERA PATH 722
END

Fig. 7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810
KEY FRAME SELECTION
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CANDIDATE STITCHES
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STITCHING
816
GRAPH ANALYSIS
818
NUMERICAL OPTIMIZATION
820
UPSAMPLING
822
END

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/030065

A. CLASSIFICATION OF SUBJECT MATTER

H04N 13/00(2006.01)i, H04N 13/02(2006.01)1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility Models IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS(KIPO Internal) "3D", "MODEL", "CAMERA", "DISCREPANCY"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
Y A	US 2006-0204076 A1 (GOPAL B AVINASH et al) 14 September 2006 See abstract, claims 1-25, figures 1-9	1, 4,1 1-12,15,18,25-26 2-3,5-10,13-14, 16-17, 19-24, 27-28
Y A	US 2007-0103460 A1 (TONG ZHANG et al) 10 May 2007 See abstract, claims 1-53, figures 1-5	1, 4,1 1-12,15,18,25-26 2-3,5-10,13-14, 16-17, 19-24, 27-28
A	KR 10-2007-0039641 A (PANTECH CO , LTD) 13 April 2007 See abstract, claims 1-13, figures 1-7	1-28

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 MAY 2009 (27 05 2009)	28 MAY 2009 (28.05.2009)

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea	JUNG, Yun Seok
Facsimile No 82-42-472-7140	Telephone No 82-42-481-8123

Form PCT/ISA/210 (second sheet) (July 2008)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No
PCT/US2009/030065

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0204076 A1	14.09.2006	DE 102006009570 A1	07.09.2006
		JP 2006-239420 A	14.09.2006
US 2007-0103460 A1	10.05.2007	EP 1952354 A2	06.08.2008
		WO 2007-056768 A2	18.05.2007
KR 10-2007-0039641 A	13.04.2007	None	

Form PCT/ISA/210 (patent family annex) (July 2008)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 February 2001 (15.02.2001)

PCT

(10) International Publication Number
WO 01/11193 A1

(51) International Patent Classification[7]: E21D 20/00

(21) International Application Number: PCT/SE00/01541

(22) International Filing Date: 4 August 2000 (04.08.2000)

(25) Filing Language: Swedish

(26) Publication Language: English

(30) Priority Data:
9902843-3 5 August 1999 (05.08.1999) SE

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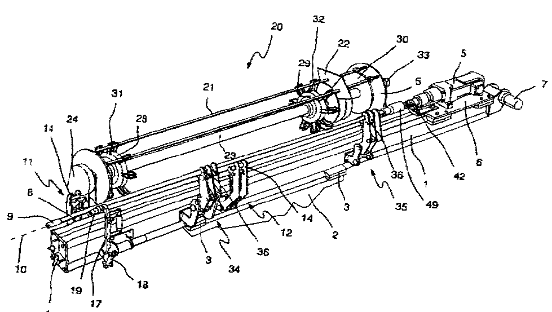
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ARRANGEMENT FOR FIXING ROCK BOLTS DURING ROCK REINFORCEMENT



(57) Abstract: The invention concerns an arrangement for fixing rock bolts during rock reinforcement that includes: a drilling machine (5) that is forwards and backwards displaceable along an axis of rotation (10); an adapter (42) attached to the chuck of the drilling machine, the free end of which is designed for the removable fixation and rotatable driving of one end of a drilling rod (8) with a drilling cutter (9) that is appropriate for rock drilling, or of one end of a rock bolt (21) for introduction into a drilled hole; holder devices (20; 34, 35) for removable retention of the drilling rod or rock bolt in a storage position; and devices (20; 34, 35) for transfer of the drilling rod or rock bolt from the storage position to a position for connection to the adapter that is coaxial with the axis of rotation of the drilling machine; together with devices (20; 34, 35) for removal of the drilling rod from the said connection position to the storage position. In order to make possible the use of only one machine for both drilling and insertion of bolts, the drilling machine (5) is reversible and the free end of the adapter (42) and the end of the drilling rod (8) for attachment to the adapter include sections that are designed to enter into and be removed from rotational engagement with each other by mutual rotation whereby the grip devices (36) are arranged to be brought into and out of engagement with the drilling rod, that the free end of the adapter (42) and the end of the rock bolt (21) for connection to the adapter include sections (46; 21') that can be axially connected to each other whereby one of the sections is rotationally incorporated into the other.

WO 01/11193 A1

Arrangement for fixing rock bolts during rock reinforcement

The present invention concerns an arrangement for fixing rock bolts during rock reinforcement according to the preamble to claim 1.

The invention particularly concerns an arrangement for fixing roof-anchoring bolts or what are known as "rock bolts" in tunnels and other underground constructions in mine locations.

Specially developed devices known as "rigs" are used during rock reinforcement by the fixing of rock bolts. The rigs are equipped with equipment for drilling holes in the rock, injecting cartridges that contain a hardenable resin into the drilled hole and finally fixing a rock bolt into the hole. The rock bolt is set into the hole by the execution of a slow rotary motion and it is provided at its front end with a drilling tip, the purpose of which is to perforate the cartridges so that the hardenable resin is brought into contact with the atmosphere and hardens. The rock bolt that is anchored in the hole is pressed against the rock surface by the tightening of a nut, with its associated plate, arranged on a threaded part of the free end of the rock bolt.

The use of a special adapter for transfer of the rotary motion of the drilling machine and blows to the drilling rod and its associated drilling cutter is known. The known adapter is designed for the connection of a drilling rod and displays at its free end a centrally placed bottom hole for connection to the end of the drilling rod and a radial hole that communicates with the axial bottom hole. The opening of the radial hole is surrounded by a water box by means of which fluid can be led to flow *via* the said opening into the radial hole and further through the axial hole before being finally led through the drilling rod and out through the drilling cutter in order to rinse away debris and dust that has been produced during the drilling operation.

Once the hole has been drilled and the cartridge containing resin has been injected into the drilled hole, the drilling machine is taken away and replaced by a machine for fixing the rock bolts in the drilled hole that is placed in line with the drilled hole. Thus it should be realised that the operation requires two sets of machines, a drilling machine with its associated drilling rod for drilling the hole and a drilling machine for fixing the rock bolt itself.

One disadvantage of known arrangements for this purpose is thus that they require two separate machines. Furthermore, arrangements for swapping between the said machines are required.

The intention of the present invention is to achieve an arrangement of the type described above that makes it possible to use only one machine for both drilling and for fixing the bolt.

The intention is achieved by the arrangement according to the present invention demonstrating the characteristics that are specified in the claims.

The invention will be described in more detail in the following with reference to the attached drawings, of which **fig. 1** shows a view in perspective of the arrangement for fixing rock bolts according to the invention, **fig. 2** shows the parts that are included in the arrangement according to the invention in an exploded view, **fig. 3** shows a side view, in partial longitudinal section, of a drilling machine that is part of the arrangement when in the drilling position, **fig. 4** shows a side view, in partial cross section, of the drilling machine seen in fig. 2 when in the position for fixing a rock bolt into a drilled hole, **fig. 5** and **fig. 6** show a schematic cross-section through a part of a provision that is included in the arrangement for removal of a drilling rod from the drilling machine, **fig. 7** and **fig. 8** show a schematic cross-section through part of a magazine for rock bolts that is included in the arrangement together with a provision for transfer of rock bolts from the magazine to the position for fixing into a drilled hole, **fig. 9** and **fig. 10** show a schematic cross-section through a part of a support for the drilling rod that is included in the arrangement in an inactive position and in an active position, and **fig. 11** and **fig. 12** show a schematic cross-section through a part of a provision that is included in the arrangement for injecting plastic cartridges that contain resin into a drilled hole.

The arrangement shown in fig. 1 includes a feed beam 1 that is supported on a feed beam holder 2. The feed beam holder 2 is supported in a known manner on a bar that in turn is supported by a carrier, not shown in the figure. The feed beam holder 2 is arranged to pivot around the said bar *via* a joint, not shown in the figure. The feed beam 1 is displaceably guided in the longitudinal direction by means of the guides 3, and can be adjusted relative to the feed beam holder 2 by the influence of suitably arranged piston- and cylinder devices. The feed beam 1 is equipped at its front end with a tip 4 for pressing against a rock surface.

A reversible drilling machine 5 is carried by a sledge 6 which can be guided as it slides along the feed beam 1. A driving mechanism for the sledge 6 is arranged in the form of a chain transmission, taken up into the feed beam, that is driven by a driving device 7, with the aid of which the drilling machine 5 can perform forward and backward, working and return motions along the feed beam 1. During the said motions, a drilling rod 8 that is fixed into the drilling machine 5 moves, together with its associated drilling cutter 9, along an axis

10 that is coaxial with the axis of rotation of the drilling machine and that lies parallel to the principal axis of the feed beam 1. The drive device 7 is designed in a known manner in such a way that the sledge 6 can be driven with a variable speed of feeding, and is equipped with pulse sensors or other known technology that makes it possible to determine the position of the sledge 6, and thus also the position of the drilling machine 5, on the feed beam 1 at any instant. Signals from the said sensor are fed to a control unit, and it is appropriate that the control unit includes a computer.

The arrangement is equipped with supports for the drilling rod 8, of which a first, forward, drill support 11 is arranged at the front end of the feed beam 1 and a second, rear, drill support 12 is arranged in the region of the approximate centre of the length of the feed beam 1. The drill supports 11, 12 are positioned on opposite sides of the feed beam 1 and each includes, as is shown in figs. 7-10, an arm 13 that is jointed to pivot with the feed beam 1 and arranged to pivot into and out from the feed beam 1 by means of a piston- and cylinder device, not shown in the figure, that operates between the feed beam and the arm 13. The arm 13 is equipped at its free end with a claw-like control 14 for the drilling rod 8. As is most clearly seen in figs. 7-10, the claw-like control 14 includes a holder defined by two halves of circles that can be moved relative to each other, one half 15 being stationary while the other half 16 is designed as a link that is jointed to pivot with the arm 13 and arranged to pivot between an open and a closed position with the aid of a piston- and cylinder device 16′. When the control 14 is in the closed position, it follows that a ring-shaped holder for the drilling rod 8 is formed, while the drilling supports 11, 12 are allowed to pivot out from the drilling rod when the control is in its open position.

As is most clearly shown in figs. 11 and 12, one end of an arm 17 is pivotally fixed at the front end of the feed beam 1, opposite to the front drill support 11, and arranged to pivot into and out from the feed beam 1 by means of a piston- and cylinder device 18 that is active between the feed beam and the arm. At its free end, the arm 17 supports a mouthpiece 19 that forms part of a device for the injection of plastic cartridges containing resin into a drilled hole. When the arm is pivoted in against the feed beam 1, the mouthpiece 19 can be brought into a position in which it coincides with the central axis 10 of the drill.

As is shown in fig. 1, a holder in the form of a drum-like magazine for rock bolts, generally denoted by the figure 20, is attached to the feed beam. The rock bolts 21 are of the type that is provided at one end with plates 22 for pressing against the rock surface. The magazine for rock bolts 21 is constructed around a shaft 23 that is supported in rotating bearings by a first arm 24 and a second arm 25, each of which is jointed to pivot with the feed beam 1 and arranged for simultaneous pivoting into and out from the feed beam 1 by means of a piston- and cylinder device 26, 27. The shaft 23 is provided at each end with a set of flange-like parts 28, 29, 30 that protrude radially from the shaft, around the perimeter of which the rock bolts are equally distributed. The functions of the said flange-like parts are to hold the rock bolts separate at a distance from each other both in the radial and in the axial direction, and to allow a detachable mounting of the rock bolts, which in the embodiment that is described here is achieved by means of sprung finger-like grip devices 31, 32 produced from wire-like material and arranged at mutually equal distances around the circumference of two of the said flange-like parts 28, 29.

The shaft 23 provides rotational driving of the magazine 20, by means of a transmission that is connected in a manner that transfers power from a drive unit in the form of a motor 33. The said drive unit is designed in such a way that the magazine 20 can be positioned into specified angular positions. Transfer of rock bolts 21 from the magazine 20 to a position that is coaxial with a previously drilled hole occurs by the magazine 20 being turned or indexed forward to a specified angular position, after which the magazine is pivoted in towards the feed beam 1 such that the rock bolt 21 that is to be fixed into the hole is positioned coaxial with the axis of rotation 10 of the drilling machine 5.

A first holder 34 and a second holder 35 for the drilling rod are arranged on the side of the feed beam that is situated opposite to the magazine 20, each of which includes grip devices 36 that can be engaged with and disengaged from a drilling rod 8 that is fixed into the drilling machine 5, and that can also remove the gripped drilling rod from its working position in the drilling machine. As is most clearly seen in figs. 5 and 6, each of the said holders contains an arm 37 that is jointed to pivot with the feed beam 1 and arranged to pivot into and out from the feed beam 1 by means of a piston- and cylinder device 38. The grip device 36 is arranged at the free end of the arm 37 and contains a stationary part 39 in the form of an opening in the form of a semicircle positioned at one end of the arm, together with a mobile part 40 in the form of an opening similarly shaped in the form of a semicircle attached by a pivot to the arm which, by means of a piston- and cylinder device 41, is arranged to pivot between an open position and a closed position in collaboration with the stationary part 39. In order to ensure that the drilling rod is securely fixed in the grip devices it is appropriate that at least one of the grip devices 36 is provided with internal teeth that act against the circumference of the gripped drilling rods.

An adapter 42 that is part of the present invention is shown in fig. 2. The adapter demonstrates a first end 43 that is designed for attachment to the chuck of the drilling machine 5 and a second free end to which it is intended that one end of the drilling rod 8 or one end of the rock bolt 21 is to be removably attached, for rotating driving. The free end 43 of the adapter is provided with an external thread that is designed to collaborate with an equivalent internal thread 45 arranged at the end of the drilling rod 8. An axial recess, generally denoted by 46, is arranged at the centre of the free end of the adapter, and demonstrates a non-circular section 47 at its outer part and a circular section 48 at its inner part, and in which sections it is intended that one end, denoted by 21′, of the rock bolt 21 is to be screwed in.

Since the free end of the adapter 42 and the end of the drilling rod 8 that is intended for connection to it both normally demonstrate external threads, an intermediate piece 49 has been arranged for the connection between the free end of the adapter 42 and the drilling rod 8, which intermediate piece is arranged with internal threads in the bottom hole. The holes in the intermediate piece 49 are connected with each other *via* a channel 50 such that rinse water can be led through the intermediate piece 49 and onwards through the drilling rod 8.

It is appropriate if the free end of the adapter 42 and the end of the intermediate piece 49 for attachment to the same are provided with pipe threads of type R55, and that the connection to the drilling rod is provided with pipe threads of type R32.

The non-circular recess 46 in the centre of the operative end of the adapter 42 demonstrates a shape that is hexagonal when seen in cross-section and, in other words, has a shape that is equivalent to the shape of nut 51 that is arranged at the end of the rock bolt 21. The axial circular bore 48 that is positioned further into the depression 46 has a diameter that is selected such that the threaded axial section of the rock bolt 21 can be inserted into the same. Somewhat further into the recess 46, the axial bore 48 becomes a bore with a reduced diameter that communicates with a channel that runs radially and that opens out into the perimeter of the adapter (not shown in the figure). The opening can, by means of a water box that surrounds the adapter 42, or similar, be connected in a known manner with a source that supplies rinse water which, *via* the said opening and radial holes, is led onwards through the axial hole in the adapter 42 *via* the hole 50 in the separate intermediate piece 49 before being finally led through the drilling rod 8 and further out through the drilling cutter in order to rinse away debris and dust that is produced during the drilling operation.

As is shown in figs. 3 and 4, the sledge is equipped with a device 52 the function of which is to lock the nut 51 of the rock bolt 21 in place when it is located in the recess 46 of the adapter 42. The locking device in principle includes a fork 53 that can be moved *via* a manoeuvring link 54 and a piston- and cylinder device 55 between a first, non-operational position in which the fork 53 is positioned at a distance such that the end of the drilling rod 8 can be connected to the free end of the adapter 42, as is shown in fig. 3, and a second, operational position in which the nut 51 of the rock bolt 21 is fixed to the adapter 42, as is shown in fig. 4.

The function and method of operation of the arrangement described above are most clearly

explained by figs. 5-12. When the sledge 6, and thus also the drilling machine 5, is located at the rear end position along the feed beam 1, the first holder 34 and the second holder 35 of the drilling rod 8 are pivoted inwards, as is shown by the arrow 44 in fig. 5, such that the drilling rod that is positioned in the grip devices 36 of the holders is positioned with an orientation that is coaxial with the axis of rotation 10 of the drill, and is thus positioned for connection to the free end of the adapter 42 of the drilling machine 5. The sledge 6 is fed forwards during slow anti-clockwise rotation of the adapter 42 positioned in the chuck of the drilling machine 5, until the drilling rod 8 has been screwed fast onto the end of the adapter. The rear support 12 for the drilling rod is pivoted inwards from its outward rest position and the claw-like control 14 is closed around the drilling rod 8 in order to control the same. The grip devices 36 of the first holder 34 and the second holder 35 for the drilling rod 8 are opened and the said holders return to their rest positions, as is shown in fig. 6.

The drilling machine 5 is rotated and fed forwards along the feed beam 1 by means of the sledge 6 with parameters with respect to rate of revolution and speed of feed that are determined for the drilling operation. When the drilling cutter 9 has passed the forward drilling support 11, which in this case is positioned in an outward rest position, this support is also pivoted in and the drilling rod 8 is enclosed by the claw-like control 14 of the same. During the forward motion of the sledge 6 along the feed beam 1 the supports 11 and 12 are pivoted outwards at appropriate times in order to prevent collision with the drilling machine 5. When the sledge 6, and thus also the drilling machine 5, has reached its end position on the feed beam 1, a hammer arrangement that is part of the drilling machine is activated in order to free initially the drilling rod 8 from the adapter 42. The sledge 6 is fed backwards along the feed beam 1 towards the rear initial position, whereby the drill supports 11, 12 are pivoted inwards during the motion of the sledge as the drilling machine passes the said drill support. When the sledge 6 is located in the rear initial position, the first holder 34 and the second holder 35 for the drilling rod are pivoted in and their respective grip devices 36 are activated in order to grip the drilling rod 8, whereby the drilling machine is slowly rotated clockwise until the drilling rod 8 has been unscrewed from the adapter 42.

In association with the exchange of tools in the drilling machine described above, the arm 17 is pivoted in, as is shown in figs. 11-12, such that the mouthpiece 19 that is part of the injection device is positioned coaxial with the drilled hole. By means of the injection device, which is connected by the tube 56 to a source of pressure medium for injection of cartridges containing resin, the said cartridges are fed into the hole, after which the arm 17 that carries the mouthpiece 19 is pivoted outwards to its resting position.

The bolt magazine 20 is indexed as is shown in figs. 7 and 8 such that a rock bolt 21 is presented in a position for delivery, after which the magazine is pivoted in such that the said rock bolt is placed coaxial with the drilled hole and thus is also positioned in line with the axis of rotation 10 of the drilling machine, and hence for connection to the free end of the adapter 42 of the drilling machine 5. The sledge 6 is fed forwards during slow anti-clockwise rotation of the adapter 42 that is fixed into the chuck of the drilling machine 5, until the nut of the rock bolt has been inserted into the recess of the adapter, after which the locking device 52 for the nut 51 is placed into its operational position such that the nut is securely located in the adapter. The forward support 11 and the rear support 12 are pivoted in from their outward rest positions and the claw-like control 14 is caused to enclose the rock bolt 21 for control of the same, after which the rock bolt magazine 20 is pivoted out to its rest position. The drilling machine 5 is rotated anticlockwise and fed forwards along the feed beam by means of the sledge 6 towards the rock surface for fixing of the rock bolt 21 into the drilled hole. During the forward motion of the sledge 6 along the feed beam 1, the supports 11, 12 are pivoted outwards at appropriate times in order to prevent collision with the drilling machine 5. The locking device 52 for the nut is positioned into its inactive position just before the rock bolt 21 reaches its end position. When the rock bolt 21 reaches its end position, the drilling machine 5 stops until the resin has hardened in the hole, after which the drilling machine is reactivated and rotated clockwise for placement of the nut 51 and plate 22 against the rock surface. The sledge 6 is once again fed backwards along the feed beam 1 towards its initial position, and a new work-cycle can begin.

The present invention is not limited to that which is described above and shown in the drawings, but can be changed and modified in a number of different ways within the framework of the innovative concept specified in the following claims.

CLAIMS

1. Arrangement for fixing rock bolts during rock reinforcement that includes a drilling machine (5) that is forwards and backwards displaceable along an axis of rotation (10), an adapter (42) attached to the chuck of the drilling machine, the free end of which is designed for the removable fixation and rotatable driving of one end of a drilling rod (8) with a drilling cutter (9) that is appropriate for rock drilling, or of one end of a rock bolt (21) for introduction into a drilled hole whereby the rock bolt is of the type that for pressing against the rock surface demonstrates at one end a body (51) that can be axially positioned on a thread with a non-circular outer cross-section designed for influence by turning, holder devices (20; 34, 35) for removable retention of the drilling rod or rock bolt in a storage position and devices (20; 34, 35) for transfer of the drilling rod or rock bolt from the storage position to a position for connection to the adapter that is coaxial with the axis of rotation of the drilling machine, together with devices (20; 34, 35) for removal of the drilling rod from the said connection position to the storage position, **c h a r a c t e r i s e d in that** the drilling machine (5) is reversible and that the free end of the adapter (42) and the end of the drilling rod (8) for attachment to the adapter include sections that are designed to enter into and be removed from rotational engagement with each other by mutual rotation whereby grip devices (36) are arranged to be brought into and out of engagement with the drilling rod, that the free end of the adapter (42) and the end of the rock bolt (21) for connection to the adapter include sections (46; 21') that can be axially connected to each other whereby one of the sections is rotationally incorporated into the other.

2. Arrangement according to claim 1, wherein the free end of the adapter (42) includes an external thread (44) designed to collaborate with an equivalent internal thread (45) arranged at the end of the drilling rod (8) and in that an axially running recess (46) is arranged at the centre of the free end of the adapter into which it is intended that the adjustable body (51) of the rock bolt is to be rotationally inserted.

3. Arrangement according to claim 1 or 2, wherein the grip devices (36) form part of the holder devices (34, 35) for the drilling rod (8).

4. Arrangement according to any of claims 1-3, wherein the holder devices (34, 35; 20) for the drilling rod (8) and the rock bolt (21) are located on opposite sides of the axis of rotation (10) of the drilling machine (5).

5. Arrangement according to any of claims 1-4, wherein it includes controls (14) for the drilling rod (8) that is attached to the drilling machine, which controls can be opened and moved between a closed position in which they form a holder that surrounds the drilling rod,

and an open position in which the control can be removed from the said drilling rod.

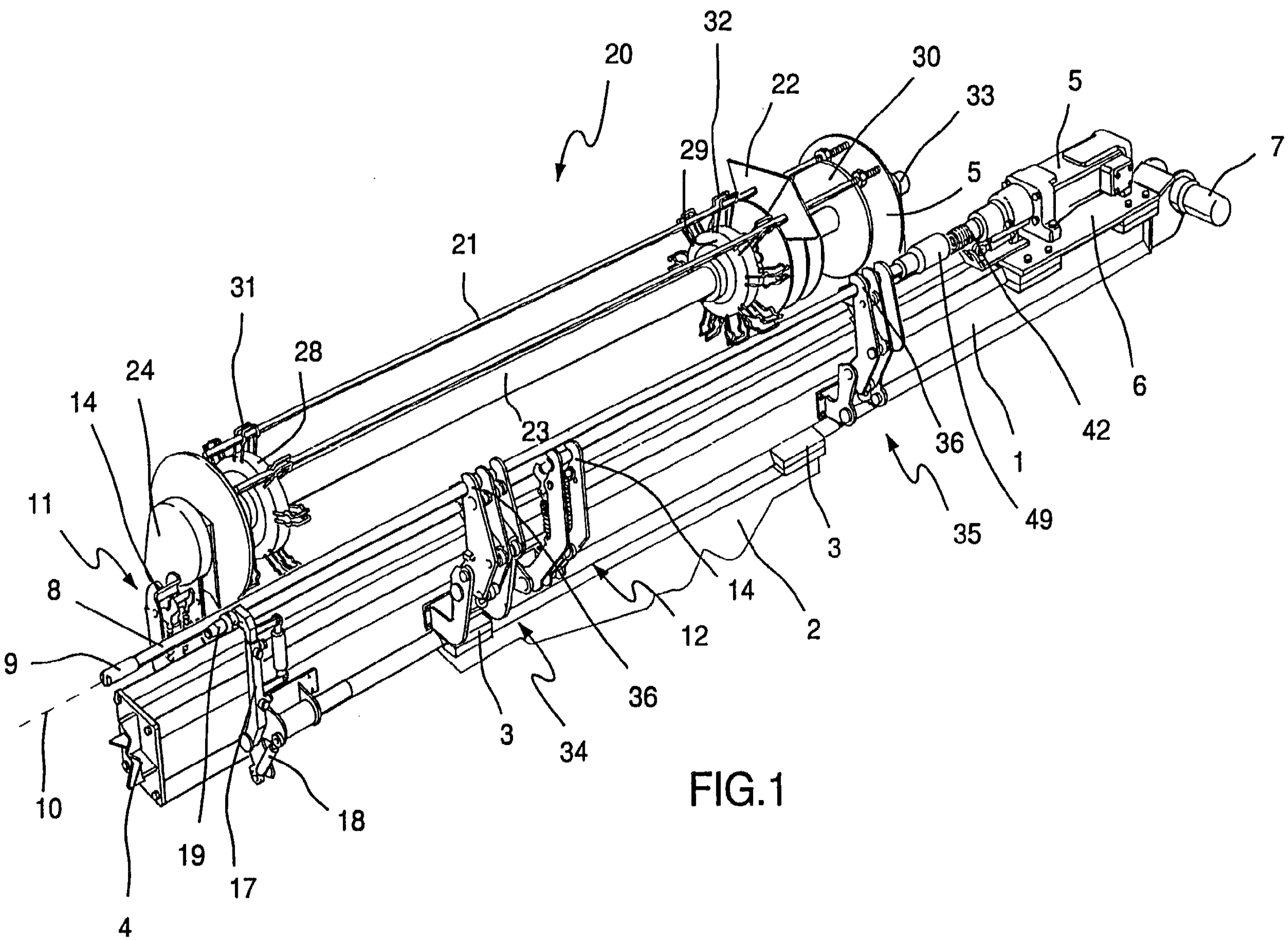

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FIG.1

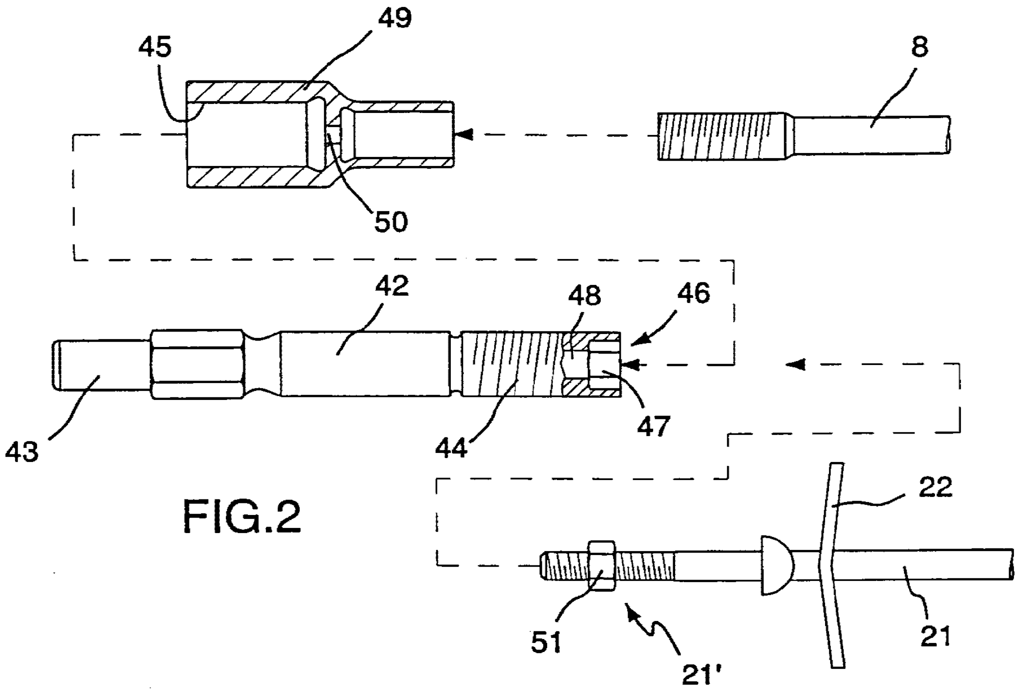

FIG.2

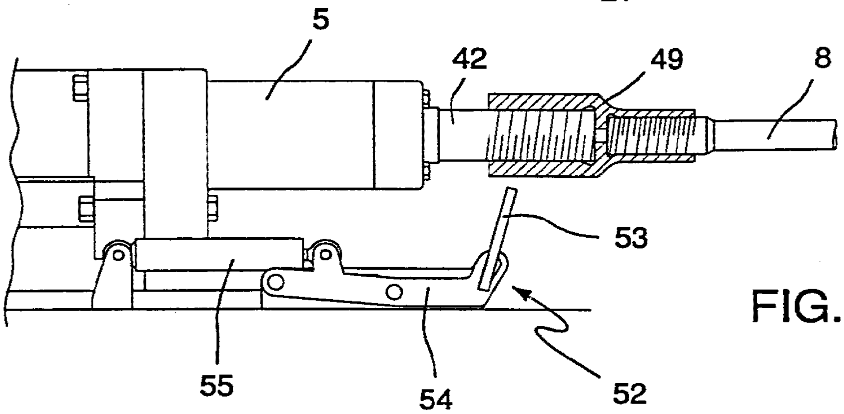

FIG.3

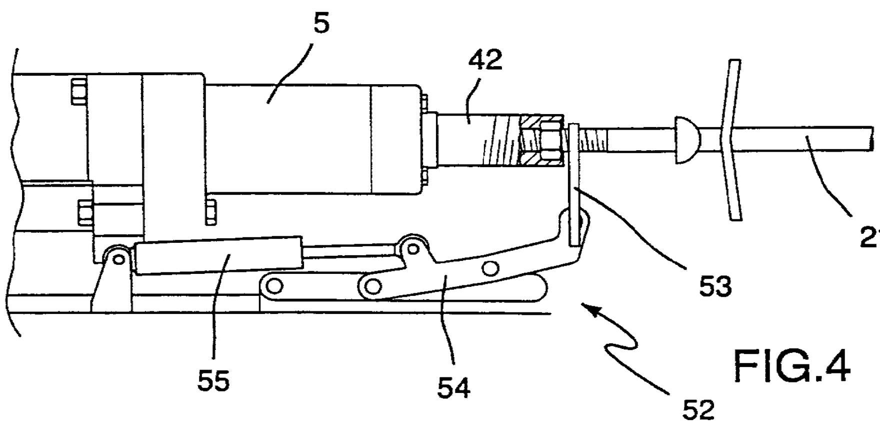

FIG.4

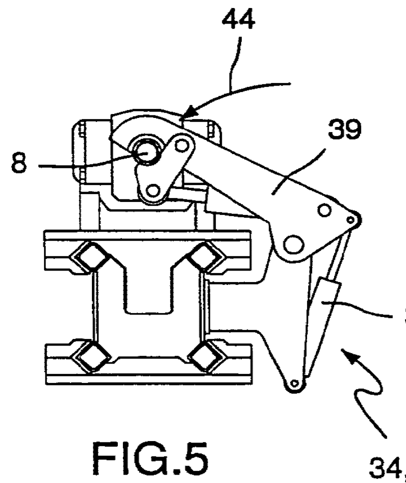

FIG.5

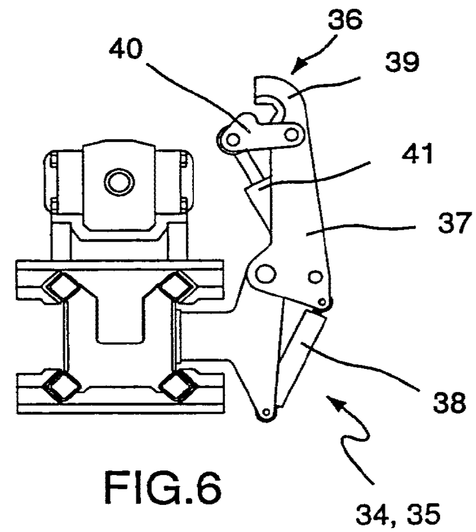

FIG.6

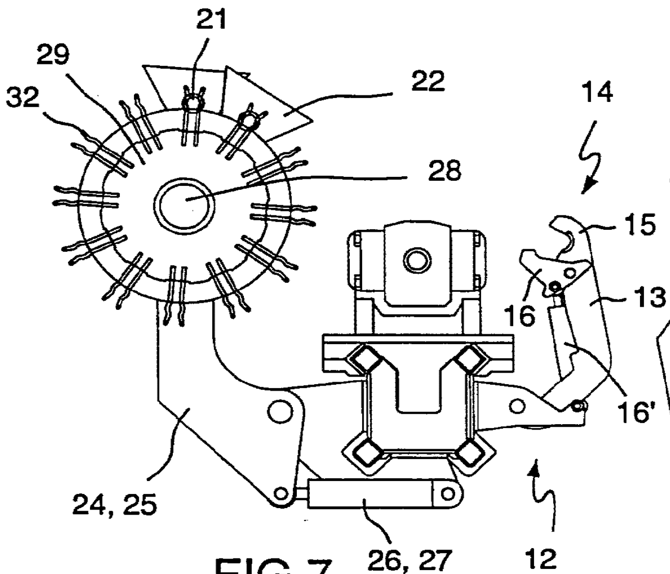

FIG.7

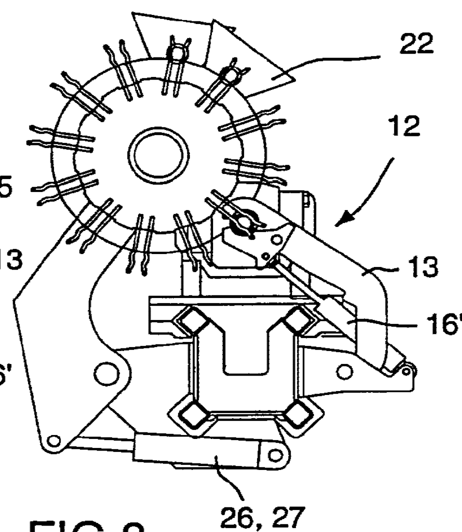

FIG.8

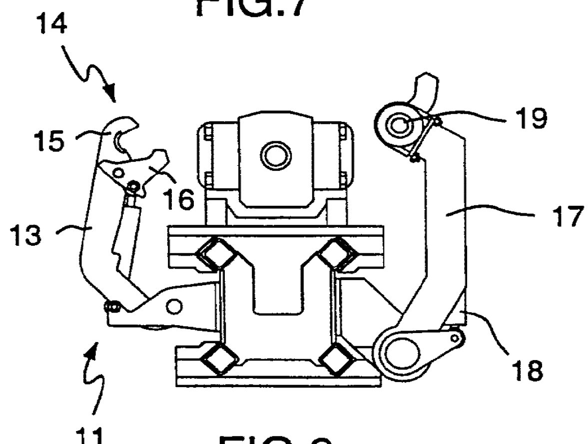

FIG.9

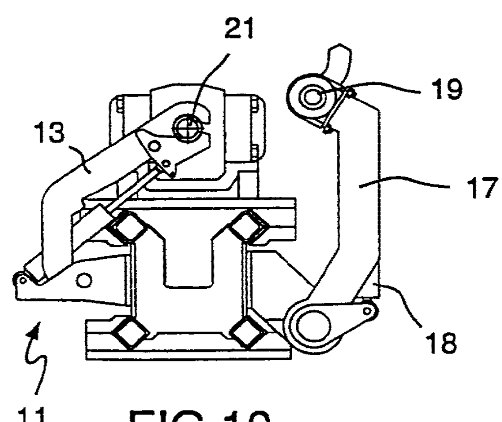

FIG.10

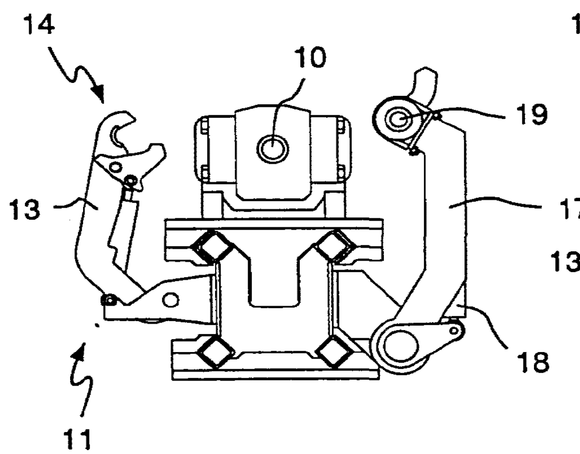

FIG.11

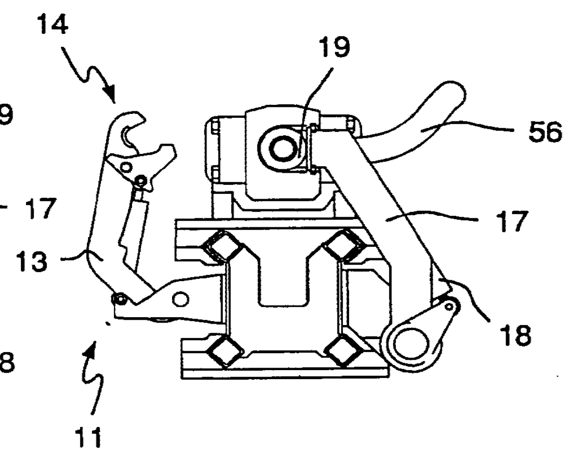

FIG.12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01541

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E21D 20/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: E21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2196884 A (SIG SCHWEIZERISCHE INDUSTRIE-GESELLSCHAFT), 11 May 1988 (11.05.88), the whole document --	1-5
A	EP 0130969 A2 (VEREINIGTE EDELSTAHLWERKE AKTIENGESELLSCHAFT (VEW)), 9 January 1985 (09.01.85), the whole document -- --------	1-5

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 November 2000	09 -11- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Björn Salén / MRo Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1998)

GB	2196884	A	11/05/88	AU	580225 B	05/01/89
				AU	8048187 A	26/05/88
				CH	673873 A	12/04/90
				DE	3735388 A	11/05/88
				GB	8725231 D	00/00/00
				US	4832536 A	23/05/89
EP	0130969	A2	09/01/85	SE	0130969 T3	
				AT	240583 A	15/06/87
				AT	384860 B	25/01/88
				AU	569091 B	21/01/88
				AU	2972484 A	17/01/85
				CS	273315 B	12/03/91
				CS	8405054 A	14/08/90
				DE	3481856 D	00/00/00
				FI	80948 B,C	30/04/90
				FI	842438 A	31/12/84
				IN	161322 A	14/11/87
				PL	248098 A	16/01/85
				ZA	8404662 A	26/02/86

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

PCT

(43) International Publication Date
26 July 2007 (26.07.2007)

(10) International Publication Number
WO 2007/084727 A1

(51) International Patent Classification:
G06Q 10/00 (2006.01)

(21) International Application Number:
PCT/US2007/001547

(22) International Filing Date: 19 January 2007 (19.01.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/761,078 20 January 2006 (20.01.2006) US

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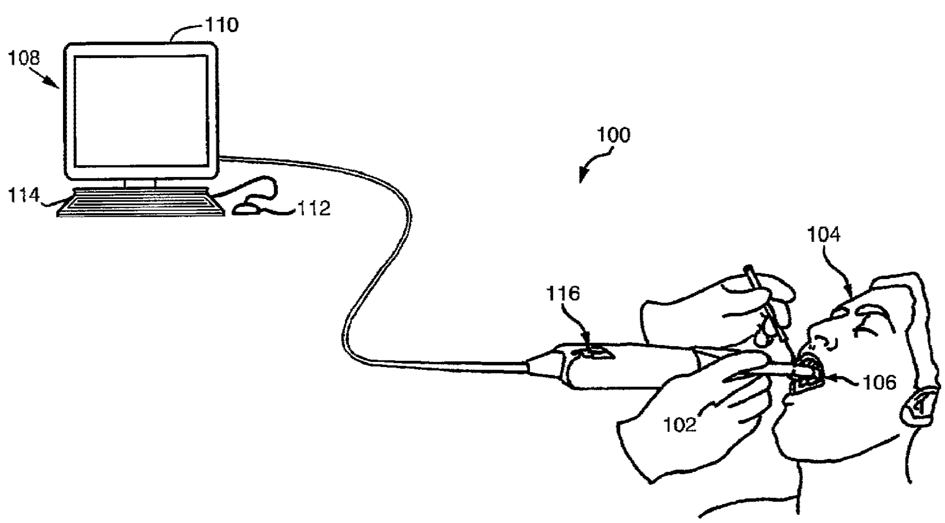
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH,

[Continued on next page]

(54) Title: DIGITAL DENTISTRY



(57) **Abstract:** The systems and methods disclosed herein employ a scanning system for capturing highly detailed digital dental models. These models may be used within a dentist's office for a wide array of dental functions including quality control, restoration design, and fitting. These models may also, or instead, be transmitted to dental laboratories that may, alone or in collaboration with the originating dentist or other dental professionals, transform the digital model into a physical realization of a dental hardware item.

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GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DIGITAL DENTISTRY

RELATED APPLICATIONS

[0001] This application claims priority to U.S. App. No. 60/761,078, filed on January 20, 2006.

BACKGROUND

1. Field of the Invention.

[0002] The invention relates to dentistry, and more particularly **for** dental applications of digital, three-dimensional representations of dentition.

2. Description of the Related **Art.**

[0003] Dentistry today largely continues in the mold of the past, using techniques pioneered by ancient Egyptians. One basic technique for manufacturing a dental restoration, the so-called lost wax method, employs a wax pattern from which a metal casting is made. A mold of the wax pattern is made using a high-heat investment material. The mold is then heated in a furnace, the pattern is then burned out, and the investment ring is cast or filled with some type of alloy or some other substance to provide a final version of a dental restoration. A dentist bonds this prosthetic to a site in a patient's mouth that has been hand-prepared to match the prosthetic. As a significant disadvantage, a substantial burden is placed on practicing dentists to physically match restorations and tooth surfaces. Further complicating this process, the wax model itself is typically created from a physical cast of the patient's mouth. The casting process can introduce errors into a final restoration, as can material handling in the multiple steps carried out by a dental laboratory to go from the original dental impression to the final restoration.

[0004] In theory, digital dentistry offers manifest advantages of quality, portability, and durability as compared to cast models of physical impressions. However, advances in dentistry have been muted, at least in part due to the inability to easily capture adequate three-dimensional data for teeth and surrounding soft tissue. In addition, dentistry has achieved only limited gains from general improvements in manufacturing technologies because each dental patient and restoration presents a unique, one-off product.

[0005] There remains a need for dentistry tools that capture high-quality digital dental models, as well as tools that permit the design and manufacture of dental hardware from such models.

SUMMARY

[0006] The systems and methods disclosed herein employ a scanning system for capturing highly detailed digital dental models. These models may be used within a dentist's office for a wide array of dental functions including quality control, restoration design, and fitting. These models may also, or instead, be transmitted to dental laboratories that may, alone or in collaboration with the originating dentist or other dental professionals, transform the digital model into a physical realization of a dental hardware item.

[0007] A method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures of a dental patient using an intraoral scanner; and providing the three-dimensional representation to a dental fabrication facility.

[0008] The method may further include fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation. The dental fabrication facility may include a dental laboratory. The one or more intraoral structures may include at least one dental implant, at least one tooth, at least one tooth surface prepared for a dental restoration, at least one previously restored tooth, and/or at least one area of soft tissue. The method may further include fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.

[0009] The method may further include transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality for the three-dimensional representation from the dental laboratory. The assessment of quality may be received before the dental patient leaves a dentist's office. The assessment of quality may include an assessment of acceptability of the three-dimensional representation. The method may further include transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality of the at least one prepared tooth surface. Transmitting the three-dimensional representation to a dental fabrication facility may include transmitting to a remote dental laboratory for fabrication of a dental restoration for the one or more intraoral structures. The method may further include transmitting the three-dimensional representation to a dental data hub. The method may further include transmitting a prescription for the dental restoration with the three-dimensional representation. The method may further include transmitting the three-dimensional representation to a model production laboratory. The model production laboratory may be a milling facility, a manufacturing facility, or a three-dimensional rapid prototyping facility. Transmitting the three-dimensional representation to a dental fabrication facility may include providing the three-dimensional representation to an in-office dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.

[0010] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of one or more intraoral structures of a dental patient from an intraoral scanner; converting the one or more images into a three-dimensional representation of the one or more intraoral structures; and transmitting the three-dimensional representation to a dental fabrication facility.

[0011] The computer program may further include computer code that performs the step of comparing quality of the three-dimensional representation to predefined quality criteria. The predefined quality criteria may include acceptability of the three-dimensional representation for fabrication. The computer program may further include computer code that performs the steps of: retrieving a prescription for at least one of a prosthesis or an appliance by a dentist; and combining the prescription with the three-dimensional representation prior to transmitting the three-dimensional representation. The one or more intraoral structures may include at least one dental implant, one tooth, or one tooth surface prepared for a dental restoration. The computer program may further include computer code that performs the step of comparing quality of the at least one prepared tooth surface to predefined quality criteria. The one or more intraoral structures may include at least one area of soft tissue.

[0012] A system disclosed herein includes an intraoral scanner for acquiring a three-dimensional representation of one or more intraoral structures of a dental patient; and a transmission means for transmitting the three-dimensional representation to a dental fabrication facility.

[0013] The system may further include a first fabrication means for fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation. The one or more intraoral structures may include at least one dental implant, one tooth, least one tooth surface prepared for a dental restoration, or one area of soft tissue. The system may further include a second fabrication means for fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation. The system may further include a quality assessment means for assessing quality of the three-dimensional representation. The quality assessment means may include a means for determining acceptability of the three-dimensional representation for use with the first fabrication means. The quality assessment means may include a means for determining acceptability of the three-dimensional representation for use with the second fabrication means. The one or more intraoral structures may include at least one tooth surface prepared for a dental restoration, wherein the quality assessment means includes a means for determining quality of the at least one prepared tooth surface.

[0014] In another aspect, a method disclosed herein includes receiving a three-dimensional representation of a tooth, the tooth prepared for a dental restoration; specifying a cementation void between the tooth surface and the dental restoration; and fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

[0015] The method may include adjusting the cementation void, such as according to a dentist's preferences or according to the type of cement to be used in the cementation void. The cementation void may be specified by a dentist. The dentist may send the specification to a dental laboratory. The cementation void may be specified by a dental laboratory. The method may include three-dimensionally printing a die including the cementation void. The method may include fabricating a die including the cementation void with a stereo lithography apparatus. The method may include three-dimensionally printing a wax-up including the cementation void. The method may include milling a die including the cementation void. The method may include integrating the cementation void into a digital surface representation of the tooth. The method may include integrating the cementation void into a dental model. The three-dimensional representation may include a digital surface representation of the tooth. Fabricating the dental restoration may include fabricating the dental restoration in an in-house laboratory in a dentist's office. The method may further include fabricating an opposing arch for an arch including the tooth, the opposing arch including a die spacer having a predetermined thickness.

[0016] In another aspect, a computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of a tooth of a dental patient from an intraoral scanner, the tooth including a tooth surface prepared for a dental restoration; converting the one or more images into a three-dimensional representation of the tooth; specifying a cementation void between the tooth surface and the dental restoration; combining the specification for the cementation void with the three-dimensional representation into a fabrication specification; and transmitting the fabrication specification to a dental fabrication facility.

[0017] A dentist may specify the cementation void. The computer program product may include code that performs the step of receiving a specification of the cementation void from the dental fabrication facility. The computer program product may include code for three-dimensionally printing the cementation void to a die. The computer program product may include code for three-dimensionally printing the cementation void to a wax up. The computer program product may include code that performs the step of integrating the cementation void into a digital surface representation of the tooth.

[0018] In another aspect, a system disclosed herein includes a first means for three-dimensionally representing a tooth, the tooth prepared for a dental restoration; a second means for specifying a cementation void, the cementation void representing an empty space between the tooth surface and the dental restoration; and a fabrication means for fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

[0019] The system may include an adjustment means for adjusting the cementation void. The adjustment means may include means for incorporating a dentist's preferences. The adjustment means may include means for adjusting the cementation void according to a type of cement. The system may include a first printing means for three-dimensionally printing a die including the cementation void. The system may include a second printing means for three-dimensionally printing a wax-up including the cementation void. The system may include a milling means for milling a die including the cementation void. The system may include a milling means for milling an investment chamber for casting including the cementation void. The system may include a model means for integrating the cementation void into a model of a dental impression. The three-dimensional representation of a tooth may include a digital surface representation of the tooth.

[0020] In another aspect, a method disclosed herein includes fabricating a dental object; acquiring a first three-dimensional representation of the object; and measuring a dimensional accuracy of the first three-dimensional representation. The first three-dimensional representation may include a digital surface representation. The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The method may include acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The method may further include acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The method may further include acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The second three-dimensional representation may be acquired as a plurality of separate scans. The second three-dimensional representation may be acquired as a continuous scan of the at least one tooth surface and the at least one opposing tooth in occlusion. A dentist may specify tightness of fit of the dental object. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy includes measuring quality of a margin.

[0021] A computer program product may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of a dental object; converting the one or more images of the dental object into a first three-dimensional representation of the item; and measuring a dimensional accuracy of the first three-dimensional representation. The first three-dimensional representation may include a digital surface representation.

[0022] The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The computer program product may include code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; and converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The computer program product may include code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth; and generating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.

[0023] The computer program product may further include computer code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth; converting the one or more images of the one or more teeth and the at least one opposing tooth into a second three-dimensional representation of the one or more teeth and the at least one opposing tooth; and generating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy may include measuring quality of a margin.

[0024] A system disclosed herein includes a fabrication means for fabricating a dental object; a first means for acquiring a first three-dimensional representation of the item; and a measurement means for measuring a dimensional accuracy of the first three-dimensional representation. The first three-dimensional representation may include a digital surface representation.

[0025] The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. A dentist may specify tightness of fit of the dental object. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy includes measuring quality of a margin.

[0026] A method disclosed herein includes acquiring a three-dimensional representation including three-dimensional surface data for at least two independent dental structures; and acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another within a mouth.

[0027] The method may include deriving TMJ condyle paths of rotation and translation from the motion data and the three-dimensional surface data. The method may include providing input to a virtual dental articulator. The method may include providing specifications for a physical dental articulator. The method may include providing specifications for a disposable dental articulator. Acquiring the three-dimensional representation may include acquiring the three-dimensional representation using an intraoral scanner. Acquiring motion data may include acquiring motion data from a video source.

[0028] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of at least two independent dental structures of a dental patient from an intraoral scanner; converting the one or more images into a three-dimensional representation of the at least two independent dental structures; acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another; and combining the three-dimensional representation with the motion data to derive TMJ condyle paths of rotation and translation.

[0029] The computer program may include code that performs the steps of: generating an image sequence of the combined three-dimensional representation and the motion data; generating a display signal of the image sequence. Acquiring motion data may include acquiring motion data from a video source.

[0030] A system disclosed herein includes a first means for acquiring one or more images of at least two independent dental structures of a dental patient; a conversion means for converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and a second means for acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another. The system may include an analysis means for deriving TMJ condyle paths of rotation and translation using the three-dimensional representation and the motion data.

[0031] The system may include an action means for combining the three-dimensional representation and the motion data to generate an articulation input. The system may include a first model means for virtually articulating the articulation input. The system may include a second model means for physically articulating the articulation input. The system may include a disposable model means for physically articulating the articulation input. The first means may include a means for acquiring the one or more images using an intraoral scanner. The second means may include a means for acquiring the motion data from a video source.

[0032] In another aspect, a method disclosed herein includes receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and fabricating the artificial dental object for the one or more intraoral structures using the electronic dental prescription.

[0033] Receiving an electronic dental prescription may include receiving a three-dimensional representation from a dental data hub or from a dentist. Receiving a three-dimensional representation may include receiving a prescription for a dental restoration for the tooth surface. At least one of the first and second three-dimensional representations may include a digital surface representation of a full arch. The electronic dental prescription may include a prescription for an appliance, a prosthesis, or an item of dental hardware. Fabricating an artificial dental object may include fabricating a dental restoration in an in-house laboratory in a dentist's office.

[0034] A system disclosed herein includes a communication means for receiving a prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and a fabrication means for fabricating a dental restoration for the one or more intraoral structures using the three-dimensional representation.

[0035] The communication means may include a means for receiving the electronic dental prescription from a dental data hub or a dentist. The electronic dental prescription may include a prescription for a dental restoration. At least one of the first and second three-dimensional representations may include a digital surface representation of a full arch. The electronic dental prescription may include a prescription for one or more of an appliance, a prosthesis, and an item of dental hardware. The fabrication means may include in an in-house laboratory in a dentist's office.

[0036] In another aspect, a method disclosed herein includes a single dental visit, the steps of: acquiring a three-dimensional representation of one or more intraoral structures from a dental patient, the intraoral structures may include at least one tooth surface prepared for an artificial dental object; and processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth surface.

[0037] The feedback may identify corrective action. The corrective action may include acquiring an additional three-dimensional representation of the one or more intraoral structures. The corrective action may include additional surface preparation of the at least one tooth. The feedback may identify a margin for fitting the dental restoration to the at least one tooth surface. The margin for fitting may be edited. The feedback may include a visual display of one or more regions of inadequate margin for fitting the dental restoration to the at least one tooth surface. The feedback may include a visual display recommending additional preparatory work required for the at least one tooth surface. The feedback may include a visual display recommending acquiring additional three-dimensional representations of one or more regions of the one or more intraoral structures. The feedback may include identifying an incomplete three-dimensional representation. The feedback may include identifying errors in the three-dimensional representation. The feedback may include visual highlighting of a margin line on a display of the three-dimensional representation.

[0038] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures of a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object; converting the one or more images into a three-dimensional representation of the one or more intraoral structures; analyzing the at least one tooth surface within the three-dimensional representation; generating a feedback signal, the feedback signal representative of the result of analyzing the at least one tooth surface; and outputting the feedback signal to provide feedback to a dentist.

[0039] The feedback signal may identify corrective action. The corrective action may include acquiring an additional one or more images of the one or more intraoral dental structures. The corrective action may include additional surface preparation of the at least one tooth. The feedback signal may identify a margin for fitting the dental restoration to the at least one tooth surface. The margin for fitting may be edited.

[0040] In another aspect, a system disclosed herein includes a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient; a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a digital surface reconstruction, the computer further configured to generate a visualization of the digital surface reconstruction and provide the visualization as a display signal; and a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image of the visualization. The surface may include dentition.

[0041] The scanning device may capture surface image data at a video frame rate. The system may include a user interface controlled by the computer and rendered on the display. The user interface may provide at least one tool for analyzing the surface. The user interface may include a tool that may provide real time feedback to the user. The real time feedback may include visual cues within the rendered image. The at least one tool may include a distance measurement tool, a tool that may evaluate adequacy of tooth structure removal from a dental restoration surface preparation, a tool that may evaluate adequacy of margin preparations, a tool that evaluates taper, a tool that evaluates undercut, or a tool that identifies scan deficiencies. The scan deficiencies may include holes in the surface. The at least one tool may include a tool that evaluates adequacy of removal path in multiple unit preparation. The at least one tool may include a tool that identifies irregularities in one or more occlusal surfaces requiring further preparation. Analyzing the surface may include an evaluation of suitability for three-dimensional printing, of suitability for milling, or of suitability for manual fabrication.

[0042] The computer may be further configured to automatically annotate the visualization with a visual indication of an evaluation. The visual indication includes an evaluation of contour of a surface preparation. The surface image data may include at least two tooth surfaces in occlusion. The visual indication may include an evaluation of margin of a surface preparation. The visual indication includes an evaluation of occlusal clearance of a surface preparation. The surface may include at least one surface prepared for a dental restoration, the evaluation

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including an evaluation of an adequacy of the at least one surface for receiving the dental restoration. The visual indication may include display of a contour of an actual tooth and a computer-generated surface preparation. The computer-generated surface preparation may be based upon intact configuration of the actual tooth prior to preparation.

[0043] In another aspect, a method disclosed herein includes receiving a three-dimensional representation that may include three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and presenting the three-dimensional representation in a user interface, the user interface may include a first tool for identifying a margin line for the dental restoration on the at least one tooth and a second tool for recessing a region of the three-dimensional representation below the margin line.

[0044] The first tool may provide automated identification of the margin line. The method may include removing a portion of the three-dimensional representation below the margin line with the second tool. The method may include removing a portion of the three-dimensional representation below the margin line with the second tool to provide a virtual ditched die, and three-dimensionally printing the ditched die.

[0045] A system disclosed herein includes a means for receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure that may include at least one tooth having a tooth surface prepared for a dental restoration; and a user interface means for presenting the three-dimensional representation to a user, the user interface means may include a first tool means for identifying a margin line for the dental restoration on the at least one tooth and a second tool means for recessing a region of the three-dimensional representation below the margin line.

[0046] The first tool means may include a means for providing automated identification of the margin line. The system may include a means for removing a portion of the three-dimensional representation below the margin line. The system may include a means for removing a portion of the three-dimensional representation below the margin line to provide a virtual ditched die, and a means for three-dimensionally printing the ditched die.

[0047] In another aspect, a method disclosed herein includes acquiring a digital dental impression that may include three-dimensional surface data for at least two independent dental structures; and acquiring orientation data that may define a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

[0048] The orientation data may include three-dimensional surface data that spans the at least two independent dental structures while in occlusion. The orientation data may include three-dimensional surface data from each of the at least two independent dental structures while in occlusion. The occlusion may include a centric occlusion. The method may include applying the orientation data to position a virtual model of the at least two independent dental structures in a virtual articulator. The method may include fabricating models of each of the at least two independent dental structures and may apply the orientation data to position the models within a dental articulator. Acquiring orientation data may include acquiring three-dimensional data of a buccal side of dentition. Acquiring orientation data may include acquiring three-dimensional data of a labial side of dentition.

[0049] A system disclosed herein includes a first acquisition means for acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and a second acquisition means for that may acquire orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

[0050] The orientation data may include three-dimensional surface data that spans the at least two independent dental structures while in occlusion. The orientation data may include three-dimensional surface data from each of the at least two independent dental structures while in occlusion. The occlusion may include a centric occlusion. The system may include a model means for virtually articulating the at least two independent dental structures. The system may include a fabrication means for fabricating models of each of the at least two independent dental structures; and a model means for physically articulating the fabricated models. The orientation data may include three-dimensional data of a buccal side of dentition. The orientation data may include three-dimensional data of a labial side of dentition.

[0051] In another aspect, a method disclosed herein includes providing an intraoral three-dimensional scanning device; and scanning a plurality of teeth in an arch with the device in a scan path that may include a motion that begins at a first lingual point, traverses laterally over a first occlusal point and a first buccal point, translates to a second buccal point adjacent to the first buccal point, and then traverses laterally over a second occlusal point adjacent to the first occlusal point and a second lingual point adjacent to the first lingual point.

[0052] The method may include scanning the plurality of teeth in the arch with the device using a motion that translates to a third lingual point, and then may traverse laterally over a third occlusal point adjacent to the second occlusal point and a third buccal point adjacent to the second buccal point. The first lingual point and the second lingual point may be spaced apart such that a field of view of the scanning device includes at least one overlapping portion of the plurality of teeth when the scanning device is positioned to image the first and second lingual points respectively. The scan path may begin at a third buccal point, a third palatal point, or a third labial point.

[0053] In another aspect, a method disclosed herein includes within a single dental visit, the steps of: acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; and processing the three-dimensional representation that may provide feedback to a dentist concerning the at least one tooth.

[0054] The feedback may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth. The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0055] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures that may include at least one tooth prepared for a dental restoration; analyzing the three-dimensional representation; generating a feedback signal, the feedback signal may represent the analysis of the three-dimensional representation; and outputting the feedback signal to a dentist.

[0056] The feedback signal may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth.

The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0057] A system disclosed herein includes an acquisition means for acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; an analysis means for analyzing the three-dimensional representation; a means for generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and a signal means for providing the feedback signal to a dentist.

[0058J The feedback signal may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth. The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0059] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures; and providing a visual display of the three-dimensional representation in real time. The visual display of the three-dimensional representation may be superimposed on a real time two-dimensional video image of the one or more intraoral structures.

[0060] The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The method may include processing the three-dimensional representation to generate user feedback concerning the one or more intraoral structures, and may provide a visual display of the user feedback. The feedback may include highlighting areas in the three-dimensional representation requiring additional attention.

[0061] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures; processing the one or more images into a three-dimensional representation including a digital surface representation of the one or more intraoral structures; and generating a first visual display signal of the three-dimensional representation in real time.

[0062] The computer program product may include computer code that performs the step of generating a second visual display signal wherein the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures. The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The computer program product may include computer code that performs the steps of: analyzing the three-dimensional representation; may generate a feedback signal representative of the analysis of the three-dimensional representation; generate a third visual display signal including the feedback signal. The third visual display signal may include highlighted areas of the three-dimensional representation requiring additional attention.

[0063] A system disclosed herein includes: an acquisition means for acquiring a three-dimensional representation from a dental patient, the three-dimensional representation may include a digital surface representation of one or more intraoral structures; and a display means for visually displaying the three-dimensional representation in real time.

[0064] The display means may include a means for superimposing the three-dimensional representation on a real time two-dimensional video image of the one or more intraoral structures. The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The system may include: an analysis means for analyzing the three-dimensional representation; a feedback means for generating a feedback signal representative of the analysis of the three-dimensional representation, wherein the display means includes a means for visually displaying the feedback signal. The feedback means may include a means for highlighting areas in the three-dimensional representation requiring additional attention.

[0065] In another aspect, a handheld imaging device for a three-dimensional imaging system disclosed herein includes: an elongated body including a first end, a second end, and a central axis; a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device may have an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and the second end adapted for gripping by a human hand, and the second end may include a user input responsive to user manipulation to generate control signals for transmission to a processor associated with the imaging system. The user input may include a mouse, track ball, button, switch, mini joystick, touchpad, keypad, or thumb wheel. The control signals may be transmitted to the processor through a wireless communication medium. The user input may control a user interface associated with the imaging system.

[0066] A handheld imaging device for a three-dimensional imaging system disclosed herein includes: an elongated body including a central axis, a first end, and a second end, the second end adapted for gripping by a human hand and a central axis; a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and a physical offset shaped and sized to maintain a desired distance of the first end from an imaging subject along the optical axis. The physical offset may include one or more wheels for slidably engaging a surface of the imaging subject.

[0067] In another aspect, a method disclosed herein includes: acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; processing the three-dimensional representation that may provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and fabricating a physical model from the digital dental model.

[0068] The method may include constructing the orthodontic fixture on the physical model using the alignment guides. The method may include constructing a support for the orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the orthodontic fixture. Processing may include virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model. The method may include fabricating the physical realization of the plurality of orthodontic brackets, positioning each one of the plurality of orthodontic brackets onto the physical model, and vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another. The method may include applying the appliance with the plurality of orthodontic brackets to the dental arch. The appliance may be formed of a soft, clear material. The method may include transmitting the digital dental model to a remote dental laboratory. Processing may include virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch. The method may include three-dimensionally printing the bracket guide. The physical model may include fabricating the physical model in an in-house dental laboratory in a dentist's office.

[0069] In another aspect, a method disclosed herein includes: acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; adding a plurality of virtual brackets to the three-dimensional representation to provide a bracket model; processing the bracket model to generate a bracket guide model, the bracket guide model adapted to maintain a physical realization of the plurality of virtual brackets in a fixed orientation with respect to one another, the fixed orientation corresponding to a desired orientation of the physical realization on the dental arch; fabricating a bracket guide from the bracket guide model; and attaching the physical realization of the plurality of virtual brackets to the bracket guide model.

[0070] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures, the intraoral structures may include a dental arch; processing the one or more images into a three-dimensional representation of the one or more intraoral structures; transforming the three-dimensional representation into a digital dental model, the digital dental model including one or more orthodontic fixture alignment guides; and generating a virtual orthodontic fixture using the alignment guides.

[0071] The computer program product may include code that performs the step of constructing a support for the virtual orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the virtual orthodontic fixture. Transforming may include virtually placing a plurality of orthodontic brackets onto the dental arch of the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model. The computer program product may include code that performs the step of transmitting the digital dental model to a remote dental laboratory.

[0072] A system disclosed herein includes: an acquisition means for acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; a processing means for processing the three-dimensional representation that may provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and a first fabrication means for fabricating a physical model from the digital dental model.

[0073] The system may include a means for constructing the orthodontic fixture on the physical model using the alignment guides. The processing means may include a means for constructing a support for the orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the orthodontic fixture. The processing means may include a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model. The system may include a second fabrication means for fabricating the physical realization of the plurality of orthodontic brackets, a positioning means for positioning each one of the plurality of orthodontic brackets onto the physical model, and a forming means for vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another. The system may include a means for applying the appliance with the plurality of orthodontic brackets to the dental arch. The appliance may be formed of a soft, clear material. The system may include a communication means for transmitting the digital dental model to a remote dental laboratory. The processing means may include a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and a model means for generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch. The system may include a printing means for three-dimensionally printing the bracket guide. The fabrication means may include a means for fabricating the physical model in an in-house dental laboratory in a dentist's office.

[0074J A three-dimensional data acquisition system adapted for intraoral acquisition of dental data from one or more intraoral structures, as disclosed herein, may include a first operating mode for capturing scan data and rendering a low-quality three-dimensional image from the scan data in real time, and a second operating mode for generating a high-quality three dimensional image from the scan data after exiting the first operating mode, the high-quality three-dimensional image may have greater spatial resolution than the low-quality three-dimensional image.

[0075] The system may further including a display that renders the low-quality three-dimensional image superimposed on a video image of the one or more intraoral structures. Rendering a low-quality three-dimensional image may include rendering the low-quality three-dimensional image at a frame rate of the video image. The system may include a communications interface for transmitting the high-quality three-dimensional image to a dental laboratory.

[0076] In another aspect, a system disclosed herein includes: a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient; a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a three-dimensional representation, the computer may be further configured to generate a visualization of the three-dimensional representation and to provide the visualization as a display signal; and a display coupled to the computer and receiving the display signal therefrom, the display adapted to convert the display signal into a viewable image, the display being a touch-screen display adapted to receive a user input through direct contact with a surface of the display, wherein the user input is interpreted by the computer to affect manipulation of the three-dimensional representation. The user input may affect rotational orientation of the visualization on the display.

[0077] The display may include areas for one or more user controls accessible through the touch-screen display. The user controls may include a zoom control, a pan control, or case management controls. The case management controls may include a control to transmit the three-dimensional representation to a dental lab, a control to evaluate quality of the three-dimensional representation, a tool to edit the three-dimensional representation, or a control to create a dental prescription.

[0078] The user controls may include a control to define a cementation void, a control to define a margin line, a control to infer a margin line from the three-dimensional representation, a control to recess a region of the three-dimensional representation below a margin line, a control to virtually fit a dental restoration to a prepared tooth surface, include a virtual dental articulator, or include a tool to design a dental restoration fitted to the surface within the mouth of the dental patient.

[0079] The three-dimensional model may include two arches; the display may include an area for one or more user controls accessible through the touch-screen display to permit positioning the two arches within a virtual articulator. The system may include a user interface displayed on the display and controlled by the computer. The user interface may be accessible through the touch-screen.

[0080] A system disclosed herein includes: a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures, the digital dental impression may be captured using a three-dimensional intraoral scanning device and stored in a computer readable medium; a first computer may be configured to render the digital dental impression from a point of view; and a second computer at a remote location may be configure to simultaneously render the digital dental impression from the point of view.

[0081] The system may include a control for passing control of the point of view between the first computer and the second computer. The system may include the first computer and the second computer including a collaborative tool for manipulating the model, for sectioning the model, or for rearranging one or more sections of the model. The system may include the first computer and the second computer including a collaborative cursor control tool. The system may include the first computer and the second computer connected by a communication channel. The communication channel may include one or more of VoIP, IRC, video conferencing, or instant messaging. The second computer may be operated by a consulting dentist, a dental technician, in a dental laboratory, or by an oral surgeon. The second computer may be operated by a dental specialist including one or more of a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and an oral and maxillofacial pathologist.

[0082] A method disclosed herein includes: seating a dental patient in a clinical office; acquiring a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of the dental patient; transmitting the digital dental impression to a dental laboratory before the patient leaves the office; receiving an evaluation of the digital dental impression from the dental laboratory before the patient leaves the office; and if the evaluation is unfavorable, repeating the step of acquiring the digital dental impression.

[0083] If the evaluation includes an identification of at least one region of the one or more intraoral structures requiring additional preparation, the method may include preparing the one or more intraoral structures according to the evaluation. The evaluation may include an evaluation of surface continuity, an evaluation of data density, or an evaluation of feature detail. The one or more intraoral structures may include a tooth surface prepared for a dental restoration. The digital dental impression may include a case plan for the restoration. The case plan may include a type of restoration, a design of restoration, or a list of restoration components. The list of restoration components may include a full ceramic component. The list of restoration components may include a PFM component. The case plan may include a specification of one or more restoration materials.

[0084] A system disclosed herein includes: a means for acquiring a digital dental impression, the digital dental impression may include three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of a dental patient seated in a clinical office; a request means for transmitting the digital dental impression to a dental laboratory before the patient leaves the office; an evaluation means for determining if the digital dental impression must be reacquired before the patient leaves the office; and a response means for transmitting the determination to the clinical office.

[0085] The evaluation means may include a means for evaluating surface continuity, a means for evaluating data density, or a means for evaluating feature detail. The one or more intraoral structures may include a tooth surface prepared for a dental restoration. The digital dental impression may include a case plan for the restoration, a type of restoration, a design of restoration, or a list of restoration components. The list of restoration components may include a full ceramic

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component. The list of restoration components may include a PFM component. The case plan may include a specification of one or more restoration materials.

[0086] A system disclosed herein includes: a scanning device for real time capture of three-dimensional surface data; a monitor that may render the three-dimensional surface data in real time; a processor that may be configure to evaluate quality of the three-dimensional surface data, and may generate a signal representative of a data quality during a scan; and a feedback device that may be responsive to the signal to produce a user alert concerning the data quality when the data quality degrades below a predetermined threshold.

[0087J The scanning device may resolve the three-dimensional surface data from a plurality of two-dimensional image sets, and wherein the evaluation of quality may include evaluation of ability to determine spatial relationships from the plurality of two-dimensional image sets. The evaluation of quality may include evaluation of point cloud density. The evaluation of quality may include evaluation of scanning device motion. The feedback device may include an LED, a speaker, a buzzer, a vibrator, or a wand. The feedback device may be positioned on the wand. The feedback device may be further responsive to the signal to produce a second user alert when the data quality is within an acceptable range.

[0088] In another aspect, a method disclosed in herein may include: scheduling a preparation visit for a dental restoration for a patient; obtaining a digital surface representation of one or more intraoral structures of the patient, this may include at least one tooth associated with the dental restoration; and fabricating a temporary restoration based upon the digital surface representation.

[0089] Fabricating a temporary restoration may include transmitting the digital surface representation to a dental laboratory. Fabricating a temporary restoration may include applying the digital surface representation to prepare a design for the temporary restoration and transmitting the design to a dental laboratory. The method may include three-dimensionally printing the temporary restoration. The method may include three-dimensionally printing the temporary restoration at a dentist's office where the preparation visit is scheduled. The method may include milling the temporary restoration. The method may include milling the temporary restoration at a dental office where the preparation visit is scheduled. Obtaining a digital surface representation may include three-dimensionally scanning the one or more intraoral structures on a day of the preparation visit. Obtaining a digital surface representation may include retrieving the digital surface representation from prior dental data for the patient. Fabricating the temporary restoration may include fabricating the temporary restoration prior to the preparation visit, the temporary restoration may include one or more characteristics of the at least *one* tooth. The method may include, on the day of the preparation visit, adapting a surface of the at least one tooth to receive the temporary restoration. The method may include, on the day of the preparation visit, adapting the temporary restoration to fit a prepared surface of the at least one tooth. The step of fabricating may be performed at an in-house dental laboratory at a dentist's office.

[0090] A method disclosed herein includes: acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the dental restoration.

[0091] The acquiring additional three-dimensional data may include acquiring additional data from the at least one tooth surface, post-processing source data for the digital dental impression, or post-processing the three-dimensional digital surface data.

[0092] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and generating a digital dental impression that may include three-dimensional digital surface data from the one or more images.

[0093] The computer program product may include code that performs the step of post-processing source data for the digital dental impression to generate additional three-dimensional data with greater spatial resolution. The computer program product may include code that performs the step of post-processing the three-dimensional digital surface data to generate additional three-dimensional data with greater spatial resolution.

[0094] A system disclosed herein includes: a first means for acquiring a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and a second means for acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the dental restoration.

[0095] The second means may include a means for acquiring additional data from the at least one tooth surface, a means for post-processing source data for the digital dental impression, or a means for post-processing the three-dimensional digital surface data.

[0096] A method disclosed herein includes: acquiring a digital surface representation for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; fabricating a kit from the digital surface representation, the kit may include two or more components suitable for use in fabrication of the dental restoration; and sending the kit to a dental laboratory for fabrication of the dental restoration. The kit may include one or more of a die, a quad model, an opposing quad model, an opposing model, a base, a pre-articulated base, and a waxup.

[0097] The method may include transmitting the digital surface representation to a production facility. The step of fabricating may be performed at the production facility. The kit may include one or more components selected from the group of pre-cut components, pre-indexed components, and pre-articulated components. The step of fabricating may be performed at a dentist's office.

[0098] An artificial dental object disclosed herein includes an exposed surface, the exposed surface finished with a texture to enhance acquisition of three dimensional image data from the exposed surface with a multi-aperture three-dimensional scanning device. The texture may include pseudo-random three-dimensional noise.

[0099] The artificial dental object may include an impression coping, a fixture, a healing abutment, or a temporary impression coping. The artificial dental object may include a dental prosthesis, a dental restoration, a dental appliance, or an item of dental hardware.

[00100] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object; transmitting the three-dimensional representation to a dental insurer; and

receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00101] The artificial dental object may include one or more of an implant, a crown, an impression coping, a bridge, a fixture, and an abutment. The intraoral surface may include at least one edentulous space. The intraoral surface may include at least one tooth surface.

[00102] A computer program product disclosed herein may include code that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object; transmitting the three-dimensional representation to a dental insurer; and receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00103] The artificial dental object may include one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment. The intraoral surface may include at least one edentulous space. The intraoral surface may include at least one tooth surface.

[00104] A system disclosed herein includes a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object; a first communication means for transmitting the three-dimensional representation to a dental insurer; and a second communication means for receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00105] The artificial dental object may include one or more of an implant, a crown, an impression coping, a fixture, a bridge and an abutment. The at least one intraoral surface may include an edentulous space. The at least one intraoral surface includes a tooth surface.

[00106] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00107] The dental procedure may relate to one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment. The method may

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include receiving a payment from the insurer for a procedure involving the artificial dental object. The intraoral surface may include an edentulous space. The intraoral surface may include a tooth surface prepared for an artificial dental object. The intraoral surface may include a restored tooth.

[00108] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at one intraoral surface related to a dental procedure; and transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00109] The dental procedure may relate to one or more of an implant, a crown, an impression coping, a bridge, and an abutment. The code may further include code that performs the step of receiving a record of payment from the insurer for the dental procedure. The intraoral surface may include an edentulous space. The intraoral surface may include a tooth surface prepared for an artificial dental object. The intraoral surface may include a restored tooth.

[00110] A system disclosed herein may include a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and a communication means for transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00111] The dental procedure may to one or more of an implant, a crown, an impression coping, a bridge, and an abutment. The communication means may include a means for receiving a payment from the insurer for the dental procedure.

[00112] In another aspect, a method disclosed herein includes receiving a three-dimensional representation of one or more intraoral structures from a dentist; receiving a proposed dental procedure from the dentist; determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The method may include authorizing payment for the dental procedure.

[00113] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, -when executed on one or more computer devices, may perform the steps of: receiving a three-

dimensional representation of one or more intraoral structures from a dentist; receiving a.proposed dental procedure from the dentist; comparing the proposed dental procedure to a predetermined list of appropriate procedures for the one or more intraoral structures; and transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The computer program product may include computer code that performs the step of authorizing payment for the dental procedure.

[00114] A system disclosed herein includes: a first means for receiving a three-dimensional representation of one or more intraoral structures from a dentist; a second means for receiving a proposed dental procedure from the dentist; an evaluation means for determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and a reply means for transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The system may include a means for authorizing payment for the dental procedure.

[00115] A system disclosed herein includes: a dental data repository coupled to a communications network, the dental data repository may be adapted to receive dental data including three-dimensional representations of intraoral structures and prescriptions for dental procedures from a plurality of dentists.

[00116] The dental data repository may be adapted to transmit prescriptions and three-dimensional representations to a plurality of dental laboratories. The at least one of the prescriptions may identify a specific one of the plurality of dental laboratories. The dental data repository may be further adapted to communicate with one or more dental insurers for authorization of dental procedures. The dental data repository may be further adapted to communicate with one or more dental insurers to coordinate payment for dental procedures. The system may include a dental laboratory interface for the plurality of dental laboratories to provide status on work in progress. The system may include a dental laboratory interface for the plurality of dental laboratories to receive work assignments. The system may include a dentist interface for the plurality of dentists to monitor work in progress. The system may include a dentist interface for the plurality of dentists to submit prescriptions and three-dimensional representations. The system may include a transaction engine for transmitting payments among two or more of one of the plurality of dentists, one of the plurality of dental laboratories, and one of the one or more dental insurers. The

system may include a collaboration interface for two or more of the plurality of dentists to collaborate on a dental matter.

BRIEF DESCMPTION OF THE FIGURES

[00117] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[00118] Fig. 1 shows a dental image capture system.

[00119] Fig. 2 shows entities participating in a digital dentistry network.

[00120] Fig. 3 shows a user interface that may be used in a digital dental system.

[00121] Fig. 4 depicts a quality control procedure for use in a digital dental system.

[00122] Fig. 5 shows a dental laboratory procedure using a digital dental model.

[00123] Fig. 6 illustrates a scan path that may be used with a three-dimensional image capture system.

[00124] Figs. 7A and 7B show a modeling environment for creating alignment guides for orthodontic hardware.

DETAILED DESCRIPTION

[00125] Described are a wide array of systems and methods for digital dentistry. However, it will be appreciated that the inventive concepts disclosed herein are not limited to the specific embodiments disclosed. For example, the general techniques disclosed herein may be usefully employed in any environment where precise, three-dimensional data might be usefully captured and processed, including orthopedics, digital animation, and customized manufacturing. In addition, while numerous variations and implementations of digital dentistry techniques are described, it will be appreciated that other combinations of the specific scanning, processing, and manufacturing techniques described herein may be used, and that such variations are intended to fall within the scope of this disclosure.

[00126] In the following description, the term "image" generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term "image set" generally refers to a set of related two dimensional images that might be resolved into three-dimensional data. The term "point cloud" generally refers to a three-dimensional set of points forming a three-dimensional view of the subject reconstructed from a number of two-dimensional views. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[00127] The terms "three-dimensional surface representation", "digital surface representation", "three-dimensional surface map", and the like, as used herein, are intended to refer to any three-dimensional surface map of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context.

[00128] A "three-dimensional representation" may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[00129] In general, the terms "render" or "rendering" refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. As such, rendering should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[00130] The term "dental object", as used herein, is intended to refer broadly to subject matter specific to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches which may be separate or in occlusion of various types, soft tissue (e.g., gingival and mucosal surfaces of the mouth, or perioral structures such as the lips, nose, cheeks, and chin), and the like, as well bones and any other supporting or surrounding structures. As used herein, the term "intraoral structures" refers to both natural structures within a mouth as described above and artificial structures such as any of the dental objects described below. While the design and fabrication of artificial dental structures is the subject of much of the following discussion, it will be

understood that any of these artificial structures might be present in the mouth during a scan, either as a result of prior dental work (e.g., a previously restored tooth) or during an evaluation of fit and other aspects of a current procedure. Dental objects may include "restorations", which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a "prosthesis" that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include "appliances" used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also include "hardware" affixed to dentition for an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include "interim components" of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. As suggested above, dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above. It will be understood that any of the foregoing, whether natural or artificial, may be an intraoral structure when present within the mouth. Thus, for example, a previous restoration or an implant for a crown might be present within the mouth, and may be an intraoral structure scanned during an intraoral scan.

[00131] Terms such as "digital dental model", "digital dental impression" and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as "dental model" or "dental impression" are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of

a dental object. Unless specified, the term "model", when used alone, may refer to either or both of a physical model and a digital model.

[00132] Fig. 1 shows an image capture system. In general, the system 100 may include a scanner 102 that captures images from a surface 106 of a subject 104, such as a dental patient, and forwards the images to a computer 108, which may include a display 110 and one or more user input devices such as a mouse 112 or a keyboard 114. The scanner 102 may also include an input or output device 116 such as a control input (e.g., button, touchpad, thumbwheel, etc.) or a status indicator (e.g., LCD or LED display or light, a buzzer, or the like) to provide status information.

[00133] The scanner 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud may be recovered. For example, the scanner 102 may employ a multi-aperture system as disclosed, for example, in U.S. Pat. Pub. No. 20040155975 to Hart et al., the entire contents of which is incorporated herein by reference. While Hart discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the scanner 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens and any associated imaging hardware. The scanner 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of slightly different perspectives. The scanner 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the scanner 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data.

[00134] In one embodiment, a second scanner such as a PMD[vision] camera from PMD Technologies, may be employed to capture real-time, three-dimensional data on dynamic articulation and occlusion. While this scanner employs different imaging technology (time-of-flight detection from an array of LEDs) than described above, and produces results with resolution generally unsuitable for reconstruction of dental models, such a scanner may be employed to infer motion of, e.g., opposing dental arches with sufficient resolution to select an axis for articulation or otherwise capture dynamic information that can be applied to two or more rigid bodies of a dental object scan. This data may be supplemented with more precise alignment data statically captured from digital or manual bite registration to provide reference or calibration points for continuous, dynamic motion data.

[00135] In one embodiment, the scanner 102 is a handheld, freely positionable probe having at least one user input device 116, such as a button, lever, dial, thumb wheel, switch, track ball, mini joystick, touchpad, keypad, or the like, for user control of the image capture system 100 such as starting and stopping scans, or interacting with a user interface on the display 110. In an embodiment, the scanner 102 may be shaped and sized for dental scanning. More particularly, the scanner 102 may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing over an intraoral surface 106 at a suitable distance to acquire surface data from teeth, gums, and so forth. This may include a shape resembling an electric toothbrush or a dental tool, and including an elongated body with an optical port on one end that receives scan data, and user controls on (or near) the other end.

[00136] A physical offset may be provided for the optical port that physically maintains an appropriate distance from scanning subject matter. More particularly, the physical offset may prevent the optical port from getting too near the scanned subject matter, which permits a user to maintain proper distance through a steady application of pressure toward the subject matter. The physical offset may be adapted for particular subject matter and may include a simple rod or other rigid form extending toward the optical path of the scanner, or the physical offset may include contoured forms for mating with more complex surfaces. The physical offset may include wheels or plates for slidably engaging a surface of scanned subject matter, or other structures or surface treatments to improve operation in various applications.

[00137] The scanner 102 may, through a continuous acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as restorations, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental model such as a

dental restoration, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the restoration.

[00138] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the subject 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The scanner 102 may also, or instead, include a strobe, flash, or other light source to supplement illumination of the subject 104 during image acquisition.

[001391 The subject 104 may be any object, collection of objects, portion of an object, or other subject matter. More particularly with respect to the dental fabrication techniques discussed herein, the object 104 may include human dentition captured intraorally from a dental patient's mouth. A scan may capture a three-dimensional representation of some or all of the dentition according to particular purpose of the scan. Thus the scan may capture a digital model of a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches, as well as soft tissue or any other relevant intraoral and/or extraoral structures. In other embodiments where, for example, a completed fabrication is being virtually test fit to a surface preparation, the scan may include a dental restoration such as an inlay or a crown, or any other artificial dental object. The subject 104 may also, or instead, include a dental model, such as a plaster cast,.wax-up, impression, or negative impression of a tooth, teeth, soft tissue, or some combination of these.

[00140] Although not depicted, it will be understood that the scanner 102 may have a two-dimensional field of view or image plane where optical data is acquired. It will be appreciated that the term "image plane" as used in this paragraph, refers to a plane in the imaging environment rather than a plane within an optical sensor (such as film or sensors) where an image is captured. The image plane may form any number of two-dimensional shapes according to the construction of the scanner 102, such as a rectangle, a square, a circle, or any other two-dimensional geometry. In general, the scanner 102 will have a depth of field or range of depth resolution for image acquisition within the image plane determined by the physical construction of the scanner 102 and environmental conditions such as ambient light.

[00141] The computer 108 may be, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm hard drive. This system may be operated to capture approximately 1,500 points per image set in real time using the techniques described herein, and store an aggregated point cloud of over one million points. As used herein, the term "real time" means generally with no observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which typically vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. However, it will also be understood that terms such as "video" or "video rate" imply a wide range of possible frame rates associated with such video. While most modern video formats employ a frame rate of 25 to 30 frames per second, early video employed frame rates as low as 8 frames per second, and movies of the early 1900's varied from 12 to 18 frames per second. In addition, it is common for specialized imaging equipment to employ a rate adapted to the computational demands of particular imaging and rendering techniques, and some video systems operate with frame rates anywhere from 4 frames per second (for computationally extensive imaging systems) to 100 frames per second or higher (for high-speed video systems). As used herein, the terms video rate and frame rate should be interpreted broadly. Notwithstanding this broad meaning, it is noted that useful and visually pleasing three-dimensional imaging systems may be constructed as described herein with frame rates of at least ten frames per second, frame rates of at least twenty frames per second, and frame rates between 25 and 30 frames per second.

[00142] More generally, processing capabilities of the computer 108 may vary according to the size of the subject 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display **110.**

[00143] Communications between the computer 108 and the scanner 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.1 1 (also known as wireless Ethernet), BlueTooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the scanner 102 to the computer 108 may be secured. The computer 108 may generate control signals to the scanner 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or zoom. In addition, the computer 108 may include a network communications interface for connecting to a network such as the dental network described below.

[00144] In an example of general operation of a three-dimensional image capture system 100, the scanner 102 may acquire two-dimensional image sets at a video rate while the scanner 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set may be derived and fitted or "stitched" to existing three-dimensional data using a number of different techniques. Such a system employs camera motion estimation to avoid the need for independent tracking of the position of the scanner 102. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire contents of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[00145] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In addition, where three-dimensional visualization is desired, the display 110 may include a three-dimensional display using a wide variety of techniques including stereo pair imaging, holographic imaging, and multiplanar or volumetric imaging, each with a number of rendering modalities that may be usefully employed with the systems described herein.

[00146] In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110.

[00147] The touch screen may be usefully employed in a dental office or other context to provide keyboardless processing and manipulation of scanning and

any resulting three-dimensional representations. For example, the touch screen may be employed to permit user manipulation of a displayed model, such as panning, zooming, and rotating, through direct physical interaction with the displayed model and any corresponding controls within a user interface. For example, a user may touch a "rotate" button on the display 110, after which placing a finger on the screen and dragging may cause three-dimensional rotation of the displayed model around a corresponding axis (typically perpendicular to the direction of finger motion).

[00148] The touch screen may also provide tools for manipulating the digital model. For example, a user may define or specify a cementation void or die spacer. A user may define, edit, or annotate a margin line, such as a computer-generated margin line. A user may define a die and/or ditch a die by recessing one or more regions below the margin line. A user may place arches of a digital dental model into a virtual articulator and articulate the arches. The touch screen may provide one or more tools for virtually designing a dental restoration fitted to a dental model, including fitting to a prepared surface, adjacent teeth, and/or teeth of an opposing arch.

[00149] The touch screen may also provide case management controls providing functions such as transmitting a digital model to a dental laboratory, evaluating quality of a digital model or performing other quality control functions as described below, or creating a dental prescription as described, for example, below with reference to Fig. 3.

[00150] The image capture system 100 may generally be adapted for real time acquisition and display, e.g., at a video rate, of three-dimensional data, which may be rendered, for example, as a point cloud superimposed on a video image from the scanner 102. For certain types of data acquisition, there may be a significant difference in the processing time required for resolution of a three-dimensional image adequate for two-dimensional perspective rendering (faster) and maximum or optimum resolution that might be achieved with post-processing. In such circumstances, the image capture system 100 may include two different operating modes. In a first operating mode, a relatively low-quality three-dimensional representation may be obtained and rendered in real time, such as within the display 110. In a second operating mode, a relatively high-quality three-dimensional representation may be generated for the source scan data using any desired degree of processing. The second operating mode may recover, through additional post-

processing steps, three-dimensional data having greater spatial resolution and/or accuracy. It will be understood that, while two different modes are described, it is not required that the two modes be mutually exclusive. For example, both modes may execute simultaneously on a computer as separate processes or threads, or the data from the first operating mode may be employed to seed the second operating mode with a model for refinement for post-processing. All such variations as would be apparent to one of ordinary skill in the art may be employed with the systems described herein. Either the high-quality representation or the low-quality representation, or both, may be transmitted to a dental laboratory for subsequent steps such as quality control and model fabrication, examples of which are provided below.

[00151] In another aspect, the system 100 may provide different levels of accuracy or spatial resolution, each associated with, for example, different degrees of post-processing, computing power, or rate of movement by the scanner 102 over a subject 104. Thus, for example, an entire dental arch may be scanned at a relatively low accuracy, while a surface preparation or other area of diagnostic or treatment significance may be scanned at a relatively higher accuracy which may, for example, require a slower scanning motion or additional post-processing delays. Similarly, certain areas such as the surface preparation may be designated for supplemental post-processing to achieve enhanced accuracy or spatial resolution.

[00152] The input or output device 116 may include a feedback device that provides warnings or indicators to an operator of the image capture system 100 with respect to scan quality or progress. The device 116 may include, for example, a buzzer, speaker, light emitting diode, an incandescent light, or any other acoustic, haptic, tactile, or visual signal to notify the operator of an event without requiring the operator to look at the display 110. For example, data quality may be continuously monitored by the system 100, and an alert may be generated when the data quality drops below a quantitative threshold, or data acquisition is lost completely (or different alerts may be provided for each of these events). The evaluation of data quality may depend, for example, on an ability of the system 100 to fit a new data set to existing three-dimensional data, or the ability to resolve two-dimensional image sets into three-dimensional data, or the density of acquired data, or any other objective criterion, either alone or in combination. The evaluation of data quality may also, or instead, be inferred from other parameters such as motion of the scanner 102 or distance from the subject 104. It will be understood that while a data quality indicator

may be positioned on the scanner 102 as shown, the device 116 may also, or instead, be positioned at any other location suitable for alerting an operator, which may depend on the type of alert generated (i.e., a visual alert may have different positioning parameters than an audio alert or a tactile alert). In another aspect, the input or output device 116 may provide feedback when data quality is within an acceptable range. In another aspect, the input our output device 116 may provide both positive feedback (good data quality) and negative feedback (poor data quality) so that continuous feedback is available to the operator concerning an ongoing scan.

[00153] Fig. 2 shows entities participating in a digital dentistry network. As depicted, a network 200 may include a plurality of clients 202 and servers 204 connected via an internetwork 210. Any number of clients 202 and servers 204 may participate in such a system 200. The network 200 may include one or more local area networks ("LANs") 212 interconnecting clients 202 through a hub 214 (in, for example, a peer network such as a wired or wireless Ethernet network) or a local area network server 214 (in, for example, a client-server network). The LAN 212 may be connected to the internetwork 210 through a gateway 216, which provides security to the LAN 212 and ensures operating compatibility between the LAN 212 and the internetwork 2 10. Any data network may be used as the internetwork 210 and the LAN 212.

[00154] The internetwork 210 may include, for example, the Internet, with the World Wide Web providing a system for interconnecting clients 202 and servers 204 in a communicating relationship through the internetwork 210. The internetwork 210 may also, or instead, include a cable network, a satellite network, the Public Switched Telephone Network, a WiFi network, a WiMax network, cellular networks, and any other public, private, and/or dedicated networks, either alone or combination, that might be used to interconnect devices for communications and transfer of data.

[00155] An exemplary client 202 may include a processor, a memory (e.g. RAM), a bus which couples the processor and the memory, a mass storage device (e.g. a magnetic hard disk or an optical storage disk) coupled to the processor and the memory through an I/O controller, and a network interface coupled to the processor and the memory, such as modem, digital subscriber line ("DSL") card, cable modem, network interface card, wireless network card, or other interface device capable of wired, fiber optic, or wireless data communications. One example of such a client 202 is a personal computer equipped with an operating system such as Microsoft

Windows XP, UNIX, or Linux, along with software support for Internet and other communication protocols. The personal computer may also include a browser program, such as Microsoft Internet Explorer.; Netscape Navigator, or FireFox to provide a user interface for access to the internetwork 210. Although the personal computer is a typical client 202, the client 202 may also be a workstation, mobile computer, Web phone, VOIP device, television set-top box, interactive kiosk, personal digital assistant, wireless electronic mail device, or other device capable of communicating over the Internet. As used herein, the term "client" is intended to refer to any of the above-described clients 202 or other client devices, and the term "browser" is intended to refer to any of the above browser programs or other software or firmware providing a user interface for navigating through an internetwork 210 such as the Internet. The client 202 may also include various communications capabilities such as instant messaging, electronic mail, syndication (such as RSS 2.0), Web-based conferencing,. Web-based application sharing, Web-based videoconferencing, Voice over IP ("VoIP"), and any other standards-based, proprietary, or other communication technologies, either in hardware, software, or a combination of these, to enable communications with other clients 202 through the internetwork 210.

[00156J An exemplary server 204 includes a processor, a memory (e.g. RAM), a bus which couples the processor and the memory, a mass storage device (e.g. a magnetic or optical disk) coupled to the processor and the memory through an I/O controller, and a network interface coupled to the processor and the memory. Servers may be clustered together to handle more client traffic, and may include separate servers for different functions such as a database server, an application server, and a Web presentation server. Such servers may further include one or more mass storage devices 206 such as a disk farm or a redundant array of independent disk ("RAID") system for additional storage and data integrity. Read-only devices, such as compact disk drives and digital versatile disk drives, tape drives, and the like may also be connected to the servers. Suitable servers and mass storage devices are manufactured by, for example, IBM, and Sun Microsystems. Generally, a server 204 may operate as a source of content, a hub for interactions among various clients, and platform for any back-end processing, while a client 202 is a participant in the dental activities supported by the digital dentistry systems described herein. However, it should be appreciated that many of the devices described above may be configured to respond to remote requests, thus operating as a server, and the devices described as servers 204 may participate as a client in various digital dentistry applications.

[00157] Focusing now on the internetwork 210, one embodiment is the Internet. The structure of the Internet 210 is well known to those of ordinary skill in the art and includes a network backbone with networks branching from the backbone. These branches, in turn, have networks branching from them, and so on. The backbone and branches are connected by routers, bridges, switches, and other switching elements that operate to direct data through the internetwork 210. For a more detailed description of the structure and operation of the Internet 210, one may refer to "The Internet Complete Reference," by Harley Hahn and Rick Stout, published by McGraw-Hill, 1994. However, one may practice the present invention on a wide variety of communication networks. For example, the internetwork 210 can include interactive television networks, telephone networks, wireless voice or data transmission systems, two-way cable systems, customized computer networks, Asynchronous Transfer Mode networks, and so on. Clients 202 may access the internetwork 210 through an Internet Service Provider ("ISP", not shown) or through a dedicated DSL service, ISDN leased lines, T1 lines, OC3 lines, digital satellite service, cable modem service, or any other connection, or through an ISP providing same. Further, the internetwork 210 may include a variety of network types including wide-area networks, local area networks, campus area networks, metropolitan area networks, and corporate area networks.

[00158] In an exemplary embodiment, a browser, executing on one of the clients 202, retrieves a Web document at an address from one of the servers 204 via the internetwork 210, and displays the Web document on a viewing device, e.g., a screen. A user can retrieve and view the Web document by entering, or selecting a link to, a URL in the browser. The browser then sends an http request to the server 204 that has the Web document associated with the URL. The server 204 responds to the http request by sending the requested Web document to the client 202. The Web document is an HTTP object that includes plain text (ASCII) conforming to the HyperText Markup Language ("HTML"). Other markup languages are known and may be used on appropriately enabled browsers and servers, including the Dynamic HyperText Markup Language ("DHTML"), the Extensible Markup Language ("XML"), the Extensible Hypertext Markup Language ("XHML"), and the Standard Generalized Markup Language ("SGML").

[00159] Each Web document usually contains hyperlinks to other Web documents. The browser displays the Web document on the screen for the user and the hyperlinks to other Web documents are emphasized in some fashion such that the user can identify and select each hyperlink. To enhance functionality, a server 204 may execute programs associated with Web documents using programming or scripting languages, such as Perl, C, C++, C#, or Java, or a Common Gateway Interface ("CGI") script to access applications on the server. A server 204 may also use server-side scripting languages such as ColdFusion from MacroMedia or PHP. These programs and languages may perform "back-end" functions such as order processing, database management, and content searching. A Web document may also contain, or include references to, small client-side applications, or applets, that are transferred from the server 204 to the client 202 along with a Web document and executed locally by the client 202. Java is one popular example of a programming language used for applets. The text within a Web document may further include (non-displayed) scripts that are executable by an appropriately enabled browser, using a scripting language such as JavaScript or Visual Basic Script. Browsers may further be enhanced with a variety of helper applications to interpret various media including still image formats such as JPEG and GIF, document formats such as PS and PDF, motion picture formats such as AVI and MPEG, animated media such as Flash media, and sound formats such as MP3 and MIDI. These media formats, along with a growing variety of proprietary media formats, may be used to enrich a user's interactive and audio-visual experience as each Web document is presented through the browser. In addition, user interaction may be supplemented with technologies such as RSS (for syndication), OPML (for outlining), AJAX (for dynamic control of a web page), and so forth. The term "page" as used herein is intended to refer to the Web document described above, as well as any of the above-described functional or multimedia content associated with the Web document. A page may be employed to provide a user interface to the digital dentistry systems described herein. In addition, one or more applications running on a client 202 may provide a user interface for local and/or networked digital dentistry functions as described herein.

[00160] In Fig. 2, each client 202 represents a computing device coupled to the internetwork 210. It will be understood that a client 202 may be present at a location associated with digital dentistry such as a dental laboratory, a rapid manufacturing facility, a dental office, and/or a dental data center. Each of these

potential participants in a digital dentistry system will now be described in greater detail.

[00161] One of the clients 202 may reside at a dental office. The dental office may include any office or other physical facility that provides dental care including individual dentist offices, dental group offices, retail dental centers, university dental schools, and the like. A dental patient may visit the dental office for a routine check up or cleaning, or for a visit scheduled due to oral discomfort, dental injury, or the like.

[00162] During the dental visit, a dentist may examine the dental patient and provide a dental assessment, such as the need for a restoration, tooth extraction, or the like. The dental office may include a three-dimensional scanner, such as any of the scanners described above, which the dentist may use to capture a three-dimensional digital representation of the dental patient's dentition including scans both before and after one or more tooth surfaces have been prepared for a dental object such as a restoration or the like. While a scan may be performed in the context of a specific dental issue, such as a planned restoration, the dentist may also capture scans during routine visits so that a dental history for the dental patient is accumulated over time. Using the client 202, which may include the image capture system 100 described above, the dentist may obtain one or more three-dimensional representations and, after discussing treatment with the dental patient, input any relevant dental prescription information. The dentist may then electronically transmit the three-dimensional representations, along with the prescription, to a dental laboratory or other fabrication facility using a network such as the internetwork 210 described above. In general, an electronic dental prescription, as used herein, includes a dental prescription in electronic form along with any three-dimensional data such as tooth surfaces before and after surface preparation, teeth in occlusion, and so forth. Additional data, such as x-ray, digital radiographic, or photograph data may be incorporated into the electronic dental prescription, or otherwise used with the systems and methods described herein. In certain instances, an electronic dental prescription may instead refer exclusively to the prescription data. In general, the meaning should be clear from the context, however, in the absence of explicit guidance, the broadest possible meaning is intended.

[00163] As a significant advantage, a practicing dentist may maintain a history of three-dimensional representations of dentition and surrounding soft tissue for each dental patient. Where a new procedure, such as a restoration, is scheduled for the patient, the dentist may pre-fabricate a temporary restoration using historic dental data. The temporary restoration may be fabricated for example, at the dental office where the procedure is scheduled using a three-dimensional printer and/or a copy milling machine, or at a remote facility such as the dental laboratory or rapid manufacturing facility described below. In one aspect, a scan may be obtained of a prepared surface during the scheduled visit, and the temporary restoration (or a final restoration) may be fabricated, such as at the dental office during the visit, by combining historical three-dimensional data with a three-dimensional representation of the prepared surface. In another embodiment, a treating dentist may shape the surface preparation to receive a pre-fabricated temporary restoration.

[00164] More generally, the client 202 at the dental office may be coupled in a communicating relationship with a client 202 at one or more of a dental laboratory, another dental office, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like. Participation may include, for example, consultation, online or distance collaboration, approval, payment authorization, or any other collaborative or unilateral participation, examples of which are provided throughout this description. Thus there is disclosed herein methods and systems for sharing digital dental data, such as digital dental impressions captured using the techniques described above. This may permit a wide array of collaborative communications using a shared view of dentition or related digital models. For example, a dentist may collaborate with another dentist, a dental technician at a dental laboratory, an oral surgeon, a technician at a rapid manufacturing facility, or any other participant in a dental network at a remote location using a shared view of a patient's dentition. Various dental specialists may participate from remote (or local) locations, such as a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and/or an oral and maxillofacial pathologist. Tools may be provided, such as collaborative tools, for sharing control of model manipulation, sectioning, rearranging, marking, and visualizing or simulating proposed clinical procedures. Each participant may view a rendering of the three-dimensional representation of dentition from a common or shared point of view. Control of the

view and any modeling tools may be passed among participants, as well as a cursor or command prompt shared by participants within a user interface. In one aspect, this system forms a collaborative dental environment in which a three-dimensional representation of a dental patient's dentition is shared among participants. Communications among participants may include any network-supported communications protocol including electronic mail, instant messaging, Internet Relay Chat, Voice-over-IP, and the like, as well as conventional teleconferencing.

[00165] Turning next to the dental laboratory, a dental laboratory may provide a fabrication resource for dental practitioners. A conventional dental laboratory may have a number of production departments specializing in various dental objects such as complete dentures, partial dentures, crowns and bridges, ceramics, and orthodontic appliances. A dental laboratory may employ trained technicians to perform various tasks associated with filling a dental prescription such as preparing dental models, dies, articulated models, and the like from impressions and occlusal registrations received from dentists. Typically, a dentist submits an order with specific instructions (a prescription) to a dental laboratory, and the laboratory fabricates the corresponding dental object(s) for use by the dentist. A client 202 at a dental laboratory may be coupled in a communicating relationship with a client 202 at one or more of a dental office, another dental laboratory, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like.

[00166] Dental laboratories may for example create restorative products such as crowns and bridges. A traditional crown formed of gold, other metal alloys, or ceramic may replace all visible areas of a tooth. An onlay is a partial crown that does not fully cover the visible tooth. Crowns may include a precision attachment incorporated into the design that may receive and connect a removable partial denture. Inlays are restorations fabricated to fit a prepared tooth cavity and then cemented into place. A bridge is a restoration of one or more missing teeth, such as a fixed partial, a three unit bridge, or the like. A bridge may be permanently attached to the natural teeth or attached to custom-made or prefabricated posts and cores that are first cemented into the roots.

[00167J Another major area of dental objects includes reconstructive products, most typically dentures. Partial dentures are a removable dental prosthesis that replaces missing teeth and associated structures. Full dentures substitute for the total loss of teeth and associated structures. Some dental labs also make precision attachments that connect a crown to an artificial prosthesis. Implants are fixtures anchored securely in the bone of the mouth to which an abutment, crown or other dental object can be attached using screws, clips, or the like. This may include, for example, a titanium root replacement integrated with the bone, an abutment or transfer coping, and an implant secured to the abutment. Implant procedures also typically involve a healing abutment to assist with healing of affected soft tissue and to maintain positioning of teeth while the root replacement attaches to the bone (which may take several months). An additional impression may be taken of the implant using an impression coping or abutment after it has attached to the bone for preparation of a final restoration.

[00168] A dental laboratory may also manufacture cosmetic products such as ceramic or composite resin veneers and crowns. Veneers are thin coverings cemented to the front of the tooth for aesthetic affect. Crowns are designed to cover the entire tooth preparation and will resemble natural teeth. Composite or ceramic inlays and onlays may be manufactured to replace amalgams and give teeth a more natural appearance. Orthodontic appliances move existing teeth to enhance function and/or appearance.

[00169] In general, the procedures described above involve transfer of a dental impression to a laboratory for fabrication of the final dental object. In some cases, such as implants, a number of impressions may be taken over the course of treatment. Using a scanner such as that described above, a dentist may capture an accurate three-dimensional representation of dentition and surrounding tissue and transmit this digital version of the dental impression to a dental laboratory using a network such as the internetwork 210 described above. The dental laboratory may receive the data and proceed with any appropriate fabrication. In various procedures, the three-dimensional representation may include data from two or more scans, such as an initial three-dimensional representation of dentition prior to any dental work, and a prepared three-dimensional representation of the dentition after one or more tooth surfaces have been prepared for the dental object(s). The surface preparation may provide guidance to the laboratory concerning fit of the restoration or other

dental object to the tooth surface, and the initial scan may provide valuable information concerning the appropriate dimensions for the final dental object and its relationship to surrounding teeth. A dentist may also optionally specify a number of parameters for the dental laboratory as described in various examples below.

[00170] Where a particular dental object is temporary, or will be covered by another dental object at a subsequent dental visit, the object may be fabricated with one or more characteristics that improve scanning of any exposed surfaces once the object is placed within a dental patient's mouth. For example, an object such as an impression coping, fixture, or healing abutment may be fabricated with scanning-optimized surfaces such as an optical or textured finish. An optical finish may, for example, include randomly (or pseudo-randomly) distributed coloration such as black or other high-contrast dots. A textured finish may, for example, include a pseudo¬random texture or one or more discrete landmarks.

[00171J It will be appreciated that in certain embodiments the dental laboratory may be an in-office dental laboratory physically located within or near a dental office where a dental patient is receiving treatment. In various embodiments, the in-office dental laboratory may provide facilities for a subset of dental objects described above, such as those most commonly used by a particular dentist.

[00172] Rapid manufacturing facilities may also be employed with the systems described herein. A rapid manufacturing facility may include equipment for designing and/or fabricating dental objects for use in dental procedures. A client 202 at a rapid manufacturing facility may be coupled in a communicating relationship with a client 202 at one or more of a dental office, another dental laboratory, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like.

[00173] Rapid manufacturing facilities may include, for example one or more stereo lithography apparatuses, three-dimensional printers, computerized milling machines, or other three-dimensional rapid prototyping facilities or similar resources. A particular facility may include one or more of a number of different types of machines which may be scheduled for various fabrication jobs received through the internetwork 210. In one embodiment, a single facility may provide a large number of machines along with suitably trained technical personal to provide a centralized fabrication facility. In another embodiment, machines may be distributed at various locations, including,one or more machines within dental offices and dental laboratories. Where copings, crowns, or the like are to be finished at the rapid manufacturing facility rather than, for example, a dental laboratory, the rapid manufacturing facility may also include machinery such as pressing machines and electroplating machines.

[00174] More generally, a dental fabrication facility may include one or more of the rapid manufacturing facilities, dental laboratory facilities, or in-office dental laboratories described above, either alone or in combination.

[00175J A dental data center may provide a hub for a digital dentistry network. A server 204 at a dental laboratory may be coupled in a communicating relationship with a client 202 at one or more of a dental office, a dental laboratory, a rapid manufacturing facility, and/or another dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like. The dental data center may, for example operate as an intermediary between dentists, laboratories, and fabrication facilities to provide a common repository for new dental jobs from a dental office, which may be distributed to available resources at one or more dental laboratories and/or rapid fabrication facilities. In addition to scheduling and workload allocation, the dental data center may provide various value-added services such as quality control for incoming three-dimensional representation, financial transaction management, insurance authorization and payment, and the like.

[00176] The dental data center may coordinate a number of transactions within a digital dentistry network. For example, the dental data center may engage in continuous bidding for fabrication work in order to ensure competitive pricing for fabrication facility and dental laboratory work sourced from the dental data center. As another example, the dental data center may provide status updates concerning a fabrication job to a dentist or other participant, including up-to-date information such as job received, job at fabrication facility, job at dental laboratory, model completed, waxing completed, investing completed, casting completed, porcelain build-up completed, restoration completed, finishing, shipping, and so forth. The dental data center may provide a web-based work-in-progress interface through which a dentist may monitor progress. Other known systems, such as electronic mail alerts or RSS

updates, may be used to provide status updates to dentists or other interested parties. While a dental data center may be usefully employed with the digital dentistry systems described herein, it will also be understood that various dental networks may operate independently between parties, such as between a dental office and a dental laboratory or between a dental laboratory and a rapid manufacturing facility, or between a number of dental offices and a rapid manufacturing facility, without a centralized server at a dental data center. All such embodiments are intended to fall within the scope of this disclosure. Further, it will be understood that a wide array of software platforms, communications protocols, security protocols, user interfaces, and the like are known, and may be suitably adapted to a web-based, web-services based, or other dental data center as described herein.

[00177] A digital dentistry network may include other participants, such as a consulting dentist, and oral surgeon, an insurer, a federal or state regulator or oversight entity, or any other dental entity. Each of these participants may communicate with other participants in the digital dentistry network through use of a client 202. Through this digital dentistry network, various methods and systems may be deployed. For example, in one aspect a three-dimensional representation and a dental prescription may be electronically transmitted to an insurer through the network, and the insurer may respond with authorization to perform the specified dental procedure (or a denial, which may include any reasons for the denial), including fabrication of any related dental objects. The insurer may maintain an electronic copy of three-dimensional representations relevant to the authorization, such as an image of the tooth surface prepared for the procedure. The insurer may also render payment, or authorize payment, to a treating dentist. The insurer may also, or instead, render payment to related entities, such as a dental laboratory or rapid manufacturing facility, for fabrication services provided. In one common practice, the insurer makes a single payment to the treating dentist who may in turn contract desired vendors for fabrication services. However, the insurer may render payments separately to one or more parties involved including a dentist, a dental patient, a dental laboratory, a rapid manufacturing facility, and so on.

[00178J In one aspect, dental laboratory procedures may be improved by fabricating a kit of components for use by a dental laboratory in subsequent fabrication of a final restoration, prosthesis, or the like. For example, a kit may include one or more of a die, a quad model, an opposing quad model, a foil arch model, an opposing arch model, a base, a pre-articulated base, a waxup, and so forth. More generally, the kit may include one or more pre-cut components, pre-indexed components, and pre-articulated components for assembly into a dental model, such as a model adapted for use with an articulator. The kit may also, or instead, include various interim components of dental manufacture, such as required or commonly used components for particular procedures, e.g., the PFM crown kit, the bridge kit, and so on. All or some of these components may be automatically fabricated as a kit by a production facility specializing in high-throughput such as the rapid manufacturing facility described above, and the kit may be forwarded to a dental laboratory specializing in creation of final restorations and the like. This approach leverages the relative expertise of these two participants in a digital dentistry network, and may achieve significant decreases in cost and time to a final restoration or other dental object. Alternatively, a dentist may determine and directly fabricated any required kit components using, for example, an in-house three-dimensional printer. In one aspect, a group of different kits may be established for different dental work, so that a dental prescription automatically triggers fabrication of the corresponding kit.

[00179] Fig. 3 shows a user interface that may be used in a digital dental system. The user interface may be presented, for example, as a Web page viewed using a Web browser, or as an application executing on one of the clients 202 described above, or as a remotely hosted application, or as a combination of these.

[00180] The interface 300 may include navigation features such as a home control 302, a name directory control 304, a toolbox control 306, and a security control 30S. Each of these features may direct the interface 300 to a different functional area. For example, the home control 302 may access a top level menu that provides access to, for example, system login, data source selection, hardware/software configuration, administrative tools, and so forth. The name directory control 304 may access a directory of patients, physicians, dental laboratories, rapid manufacturing facilities and like, and permit searching, data input, and so forth. The directory may, for example, provide access to patient dental records and history, contact information, and the like. The toolbox control 306 may provide access to tools for scanning, case planning and management, scheduling, and the like. The security control 308 may provide access to account management, communications configuration, and other security-oriented features and functions of a digital dentistry system.

[00181] Within each main area of top-level navigation, the interface 300 may provide a number of tabs, such as the scanning tab 310, the prescription tab 312, and the status tab 314 depicted in Fig. 3. The scanning tab 310 may, for example, invoke an interface for controlling operation of an image capture system 100 such as that described above in reference to Fig. 1. The prescription tab 312 may, for example, invoke an interface that permits specification of a restoration or other dental object, including a specification of teeth being treated, treatment type, manufacturer, and details of the dental object including color, material, texture, and so forth. The interface of the prescription tab 312 may also include tools for transmitting a prescription, along with any three-dimensional data obtained from scans of a patient, to a dental laboratory, dental data center, rapid manufacturing facility, or the like. The status tab 314 may, for example, invoke an interface for obtaining or updating status information on a case such as the fabrication status of a prescription (e.g., prescription and scan received, scan evaluated and approved, models complete, object fabricated, object shipped to dentist, and so forth).

[00182] Fig. 3 depicts in more detail a prescription window of the interface 300, as accessed by selecting the prescription tab 312. This window may show current data for a prescription within a text window 320. A scroll bar 322 or other control may be provided for selecting options relating to a prescription. In operation, and by way of example only, a feature of the prescription, such as the material or manufacturer, may be highlighted within the text window 320, and options for that feature may selected from the scroll bar 322. The window may also include additional navigational or process controls such as a next button 324, a back button 326, and a finish button 328, which may be used to navigate through one or more different windows of a prescription and/or case planning interface. This may include, for example, input of patient data, selection of a dental laboratory, scheduling of dental visits, and the like. It will be understood that the above interface 300 is an example only and that other hierarchical arrangements of functions, and/or arrangements of data and controls within a particular interface, are possible and may be employed with a digital dental system as described herein. For example, the interface may control scanning, marking or annotation of scanned models, case planning, access to databases of patient records and dental data, preparation of prescriptions, analysis of dentition, scheduling, management of patient data, communications with remote fabrication facilities, and so forth. Any user interface or combination of user interfaces and user interface technologies suitable for a digital dental system as described herein may be employed without departing from the scope of this disclosure. As such, a user interface 300 should be understood more generally with reference to the systems and methods described herein, and not by specific reference to the example interface shown in Fig. 3.

[00183] Having described a number of aspects of a digital dentistry system and network, along with various participants in such a network, specific uses of the system will now be discussed in greater detail.

[00184] Fig. 4 depicts a quality control procedure for use in a digital dental system. The process 400 may start 402 by obtaining a digital model, such as a three-dimensional representation of dental subject matter as described generally above.

[00185] The digital model may include a single model, such as a digital model of dentition prior to any dental work, such as for archival or comparison purposes. This may also, or instead, be a digital model of dentition including one or more prepared surfaces, such as a single tooth surface prepared for a crown, or a number of tooth surfaces prepared for a multi-unit bridge. This may also include a scan of bite registration. For example, a scan may be obtained of the teeth of a dental patient in centric relation, centric occlusion, or with maximum intercuspation, in protrusion (e.g., for sleep apnea guards), in lateral excursions, or in any other static orientation useful for any of the dental procedures described herein. As a significant advantage, the upper and lower arches may be treated as rigid bodies, thus permitting relative three-dimensional orientation for a full bite registration to be obtained from a scan of a relatively small region of the upper and lower arches while in occlusion, such as centric occlusion. Thus for example, a three-dimensional scan that spans the two arches, such as a scan of the exterior surfaces of one or two teeth in a buccal or labial area, may be used to register bite. In addition, the digital model may include motion information describing the relative motion of, e.g., an upper and lower jaw throughout one or more jaw motions such as opening and closing the mouth or simulated chewing. Such motion data may, for example, be obtained through a variety of techniques suitable for tracking three-dimensional motion, which may include extrapolation from video data, use of transmitters on the moving jaws, mechanical or electromechanical sensors and/or transmitters,, and so forth. Motion data may also be inferred by capturing orientation data for the jaws in a variety of positions. Motion data may be employed, for example, to derive the position of TMJ condyle paths of rotation and translation, or to provide input to a virtual or conventional dental articulator.

[00186] In addition, dynamic three-dimensional data may be obtained and used. As noted elsewhere herein, some systems permit direct three-dimensional video capture. However, other techniques may be employed to capture dynamic data. For example, in one example process, two opposing arches may be brought into natural occlusion. The dental patient may then slide the arches forward and back and from side to side, during which the scanner may capture relative motion of the two rigid bodies defined by the two opposing arches. The captured data may be used to characterize and animate a three-dimensional transformation that captures the full excursion of the dentition. This data may, in turn, be registered to detailed scans of the opposing arches. As a further use of this type of data, the excursion data may be used in combination with detailed arch data to provide a cutting tool or path for occlusal surfaces of a restoration. Thus, occlusal surfaces may be measured or otherwise determined during a scan, and applied to define surfaces of a restoration. Using various CAD modeling tools, the restoration may be further refined, such as by shaping side walls of the restoration, adding visually appealing and/or functional cusps to the occlusal surfaces, and so forth. Thus in one aspect there is disclosed herein a method for determining one or more occlusal surfaces of a dental restoration using dynamic three-dimensional data acquired during a scan. The method may include obtaining a three dimensional model of two opposing arches of a patient's dentition, obtaining excursion data for the two opposing arches, preparing a tooth surface of the dentition for a restoration, and determining an occlusal surface of the restoration using the excursion data and the three-dimensional model.

[00187] More generally, any digital model or other data useful in dental procedures, restorations, and the like as described herein may be obtained in step 404.

[00188] Once a digital model (or models) is obtained in step 404, the process 400 may proceed to one or more quality control steps as depicted in steps 406-410.

[00189] This may include automated quality control, as shown in step 406, which may be simple quantitative analysis such as measures of accuracy, variability, or density of three-dimensional surface data for a digital model. This may also, or instead, include more sophisticated, automated analyses such as adequacy and/or suitability of margins and prepared surfaces for an anticipated restoration. For example, an automated quality control tool may examine a prepared tooth surface to

ensure that a margin line is present all the way around a preparation, or examine the prepared surface to ensure that adequate material has been removed to accommodate a restoration. Similarly, an automated process may locate areas of potential problems, such as occlusal high spots, occlusal clearance, occlusal irregularities, areas of poor margin preparation, areas of inadequate tooth removal, improper taper, improper draw path or removal path for a multiple unit preparation, inappropriate contour, and so forth.

[00190] In one aspect, quality control may include real time feedback during a scan, or between successive scans. The feedback may be rendered with suitable visualizations on a display to permit immediate observation and correction by a dentist. Thus it will be appreciate that, while depicted in Fig. 4 as a post-scanning operation, quality control may be implemented at any time in a digital dentistry process, or throughout the entire process. Real time feedback may include for example, textual annotations identifying teeth as they are recognized within a scan, and providing one or more dimensions of a tooth, or an analysis of contour, clearance relative to adjacent teeth, or a position of the tooth relative to other teeth or relative to a global coordinate system. By providing this information in real time within the context of a single dental visit, treatment may be generally improved by reducing or eliminating a need for follow up scans.

[00191] In another aspect, quality control may include an evaluation of suitability of a surface preparation, or a restoration or other dental object prepare for the restoration, for manufacturing using one or more techniques, including three-dimensional printing, milling, stereo lithography, and or conventional dental fabrication, or various combinations of these.

[00192] Although not depicted in Fig. 4, it will be appreciated that quality control may be semi-automated. Thus, for example, a user interface may provide a number interactive, three-dimensional tools such as markup tools that a dentist or other dental professional may use to measure, mark, annotate, or otherwise manipulate a digital model to evaluate suitability for subsequent processing and the creation of a physical dental object such as a restoration.

[00193] As shown in step 408, quality control may include manual quality control. For example, a dentist may inspect a scan in an interactive, three-dimensional environment to visually identify, e.g., holes or areas of incomplete scan needed for an intended dental procedure. The dentist may employ various features,

such as rotation, zooming, and panning to inspect various surfaces of the three-dimensional digital representation from a scan.

[00194] As shown in step 410, quality control may include remote quality control. For example, after completing a scan, a dental office may transmit a digital model to a dental laboratory or a fabrication facility for evaluation of adequacy of the scan. As a significant advantage, the recipient, such as a dental laboratory may provide immediate feedback to a dentist while a dental patient is still in the dental office, or still in a dentist's chair at a dental office, thus avoiding a need to schedule repeat visits for additional surface scanning or surface preparation. A dental laboratory may inspect a prepared surface to ensure that a restoration can be fit to the prepared surface, or that there is adequate space (especially thickness) for a restoration or other dental object. The dental laboratory may also evaluate color and suggest shade matching for a dentist. The dental laboratory may request manual marking of a margin by a dentist where the margin is not visible on a prepared tooth surface. The dental laboratory may also apply separate standards for data quality (density, accuracy, surface continuity, feature detail, etc.), and may request additional or new scan data consistent with its own specifications. The dental office may transmit a case plan prior to (or during) transmission of a scan, which may permit more detailed analysis of the scan data by the recipient. Thus, for example, a dental laboratory may evaluate suitability of the scan and/or surface preparation for a type of restoration and any prescribed components (e.g., full ceramic, porcelain-fused-to-metal, etc.). Where the dental laboratory can quickly generate an accurate or rough model for a restoration or other dental object according to any fabrication or end use constraints, the rough model may, in digital form, be virtually fit to the prepared surface, and feedback may be provided to a dentist such as an identification of regions requiring further reduction.

[00195] Quality control, whether automated or manual, and whether local or remote, may include a variety of different dental evaluations. For example, a prepared tooth in an arch that will receive a restoration may be evaluated to determine whether there is adequate space for cement to bond the restoration to the prepared tooth surface. As another example, a dentist may visually confirm accuracy of a scan by inspection for gross errors or omissions such as holes, gaps, distortions, twists, and the like. The dentist may also visually inspect margin lines on surface preparations, and may annotate margins for identification by a dental laboratory or other fabrication

facility. Similarly, a dental laboratory may, during a quality control evaluation, request that the dentist identify the margins on a surface preparation where the margin lines are not self-evident.

[00196] Feedback from a quality control step, whether automated or manual, and whether remote or local, may include various forms of feedback. For example, an evaluation may conclude with an identification of regions of a prepared tooth surface requiring additional preparation or reduction, or regions of a digital model requiring additional or supplemental scanning due to incomplete, erroneous, or potentially erroneous data, which may be identified, for example, by comparison to models of expected shape for dentition, surface preparations, and the like. An evaluation from a dental laboratory may request new data, or additional shaping of a prepared surface. An evaluation from a dental laboratory may include a request for an oral consultation. In addition other dental professionals such as a consulting dentist, an oral surgeon, a dental specialist, or a laboratory technician may be called upon for evaluation, approval, and/or recommendations. Feedback may be presented to a dentist in a number of forms. For example, the feedback may include text or audible narrative concerning additional scanning, additional surface preparation, or requests for confirmation. The feedback may be graphical feedback provided by highlighting questionable or erroneous areas of a preparation within a rendered display of scan data. The feedback may identify corrective action on a scan or a surface preparation. The feedback may identify a margin line which may be displayed on a two-dimensional rendering of a three-dimensional representation, and a user interface may permit the margin line to be edited or confirmed. The feedback may include a visual display with regions of inadequate margin highlighted, such as through use of color, texture, or explicit annotations, arrows, callouts, or the like, and any combination of these.

[00197] It will be understood that the quality control steps indicated in Fig. 4 are not mutually exclusive. That is each of the quality control steps 406-410 may be performed during the process 400, such as in sequence or in parallel (as where a dentist and a laboratory evaluate a scan simultaneously), and all such variations are intended to fall within the scope of this disclosure.

[00198] Any of the quality control steps above may advantageously be performed while a dental patient is still present at a dental office, or while the patient

is still in a dental chair, thus reducing or eliminating the need for follow up dental visits for additional scanning.

[00199] After one or more quality control steps 406-410, a determination may be made as to whether a scan and/or surface preparations are satisfactory. If the data is not satisfactory, the process 400 may proceed to step 414 where the digital model may be supplemented or replaced with new scan data. This may include, for example, new scanning to replace apparently erroneous or inadequate scan data, or a new scan of the dental subject matter following, e.g., additional surface preparation consistent with errors identified during quality control. The process 400 may then return to step 404 where a new digital model is obtained.

[00200J If it is determined in step 412 that the data is satisfactory, the process 400 may proceed to step 416 where a dentist may prepare a prescription. The prescription may include, for example, a dental patient identification, an identification of one or more teeth being treated, a type of treatment (e.g., for a restoration, one or more of a bridge, a crown, an inlay, a laminate veneer, an onlay, or a temporary), an identification of missing teeth (if appropriate), a material or fabrication technology (e.g., full ceramic, cast metal, PFM, etc.), an alloy type (e.g., for a PFM crown), a manufacturer (e.g., Cercon, Cerec, Empress, Everest, Lava; Procera, etc.), limited occlusal clearance (e.g., enamalplasty, reduction coping, etc.), a shade guide (e.g., Vita 3D Master, Vita Classical, etc.), a surface texture, a surface *glaze,* an opacity, an occlusal staining, dental notes, and any other information relevant to identification or preparation of the dental object. For example, for a crown the specification may include a material type, a design (such as metal band, 360-degree facial butt porcelain shoulder, facial butt porcelain shoulder, metal occlusal surface, or no metal showing), a return (e.g., biscuit bake, finish, metal try-in, etc.). Each specification may include subspecifications. For example, a metal band crown may be specified as having the metal band located at a buccal location, a lingual location, or 360-degree.

[00201] As shown in step 418, once the prescription has been completed, the digital model and prescription may be uploaded to a dental laboratory or other fabrication facility using, for example, the dental network described above. The process 400 may then end, as shown in step 420.

[00202] It will be understood that numerous variations and modifications to the above process 400 may be used. For example, the prescription may be prepared at a different point in the process, such as before scanning so that the prescription data

may be used to evaluate sufficiency of the scan data. As another example, each digital model (e.g., native tooth surfaces, bit registration, prepared tooth surfaces) may be separately presented to one or more quality control steps, or the entire digital model may be obtained prior to any quality control analysis. All such variations and modifications are intended to fall within the scope of the methods and systems described herein.

[002031 Fig. 5 shows a dental laboratory procedure using a digital dental model. While described as a dental laboratory procedure, it will be understood that the fabrication and quality control procedures described with reference to Fig. 5 may be performed by any fabrication facility including a dental fabrication facility such as a dental laboratory equipped to receive digital dental data, a model production laboratory (such as a rapid fabrication facility, milling facility, and the like), an in-office dental laboratory at a dental office, or any other dental fabrication facility. The fabrication facility may include a remote facility accessible through the dental network, and digital dental data may be communicated to the fabrication facility directly or through a hub for dental data such as the dental data center described above.

[00204] As shown in step 504, the process 500 may start 502 by receiving a digital model from a dentist or other source. This may include, for example, a digital model, such as a digital surface representation obtained using the image capture system 100 described above, of a surface prepared for a restoration such as a crown, or any other dental object.

[00205] As shown in step 506, the dental laboratory may design and/or fabricate a restoration or other dental object based upon the digital model received in step 504. This may include a variety of fabrication techniques, including working from a physical cast of a dental impression created using conventional dentistry techniques, or three-dimensional printing or other fabrication techniques to manufacture various interim components of dental manufacture such as dies, casts, and the like, or direct fabrication of a virtually designed restoration, such as through computerized milling of the restoration from ceramic.

[00206] In one aspect, designing the restoration may include a step of virtually adding a die spacer to a digital model. It is known in dentistry to employ a die spacer —a thin layer painted onto regions of dental models —to improve the final fit between a prepared tooth surface in a dental patient's mouth and a restoration or other dental object. The die spacer may for example provide a small void between a cast of the prepared surface and a restoration constructed for the cast which may provide a void for cement used with the final fitting, or to account for size changes in the restoration fabrication process. The die spacer may be virtually added to a digital model of a prepared surface to achieve a similar effect with a restoration that is to be directly fabricated from the digital model, or an interim component such as a fabricated cast of a dental impression used to create the restoration. Similarly, where a cast dental model is to be fabricated from a digital model, the die spacer may be added to appropriate regions of the prepared surface and any other suitable surfaces to remove or reduce the need for use of die spacers in subsequent fabrication steps. More generally, a virtual die spacer may be added to a digital model of a conventional dental model, a die, a waxup, or any other interim component of dental manufacture to account for a cementation void or other physical variations in the design of a final restoration. This cementation void or virtual die spacer may be fabricated directly into a die, waxup, or other interim component that may be three-dimensionally printed or otherwise manufactured from the digital model.

[00207] Thus in one aspect, disclosed herein is a virtual die spacer. In fabricating a dental restoration, a virtual dies spacer or cementation void may be specified, either by an originating dental office or a dental laboratory, and this void may be automatically or manually added to appropriate regions of a digital model to provide a corresponding cementation void in a final restoration. As a significant advantage, the thickness of the virtual die spacer may be explicitly specified, and may be adjusted according to, for example, a dentist's preference or according to a type of cement to be used with the restoration. Dentist preferences concerning die spacer thickness may also be stored for reuse, and dentist feedback (e.g., "too tight" or "inadequate void") may be recorded to provide sizing for a *final* restoration or other dental object that more closely meets and individual dentist's expectations.

[00208] In another aspect, designing the restoration may include virtually ditching a die for a restoration. In conventional dentistry, a material may be cut away from a die below the margin line (which would otherwise include bone, soft tissue, and the like) prior to use as a restoration model. This operation may be performed virtually within a user interface that includes interactive tools for manipulating a three-dimensional representation of dentition. Initially, this may include an automated, semi-automated, or manual step of defining a die in three-dimensional

space by identifying a plane, a point, or a line used to separate a die from a model in an operation analogous to physically cutting a die from a conventional dental model. This may be followed by additional steps such as separate steps of explicitly identifying a margin line with a first tool and then manipulating the digital model "below" the margin line, i.e., away from the tooth surface fitted to a restoration, with a second tool to remove unwanted or unneeded areas from a volume bounded by the digital surface representation. This process may be semi-automated or automated, such as by automatic identification of the margin line and removal of a predetermined amount of sub-margin volume. The ditched die may then be directly fabricated using techniques described above.

[00209J Regardless of the interim modeling and fabrication steps, this step may result in a restoration in physical form, such as a crown, bridge, inlay, onlay, or other dental object intended for use by a dental patient.

[00210] As shown in step 508, the restoration may be scanned using, for example, an image capture system 100 such as the system described above with reference to Fig. 1, to obtain a scanned restoration.

[00211] As shown in step 510, the scanned restoration may be test fit to the digital model received in step 504, such as by virtually superimposing the scanned restoration to the digital model. This may permit evaluation of a variety of fit criteria prior to an attempt to fit the physical restoration to a prepared surface in the dental patient's mouth. This includes, for example, an evaluation of margin fit, an evaluation of void space for cement used to affix the restoration to the prepared surface, and any other evaluation relating the prepared surface directly to the restoration or abutting tooth surfaces. This may also include an evaluation of bite, occlusions, lateral excursions and any other evaluation relating to jaw motion or the mating of lower and upper arches with the restoration in place.

[00212] In another aspect, test fitting may include measuring dimensional accuracy of the scanned restoration. For example, the restoration in this context may include a prosthesis, an implant, an appliance, a restorative component, an abutment, a fixture, or any other dental object. The scanned restoration may be measured for fit between adjacent teeth, or for evaluation of contact points with teeth of an opposing arch when the restoration is fitted to a prepared surface (or more specifically, when the scanned restoration is virtually fitted to a scan of the prepared surface), or a fit to the prepared surface, possibly including an allowance for die spacing on one or more

surfaces. A dentist may specify a desired tightness of fit, which may be quantified objectively (e.g., in millimeters or microns) or subjectively (e.g., loose, average, tight, etc.).

[00213] In one aspect, feedback from specific dentists may be monitored, so that subsequent restorations may more closely meet each dentist's expectations for a desired tightness of fit.

[00214] In another aspect, measuring dimensional accuracy may include evaluating a quality of margin fit between a scanned restoration and a scanned surface preparation, in order to avoid fitting difficulties at the time of fitting the physical restoration to a patient's dentition.

[00215] As shown in step 512, the test fit of step 510 may be followed by a determination of whether the physical restoration is satisfactory. If the physical restoration is not satisfactory, the process 500 may proceed to step 514 where the physical restoration is reworked, or a new restoration prepared. If the physical restoration is satisfactory, the physical model may be sent to a dental office for a final fitting procedure in the dental patient's mouth. It may also be advantageous to also forward the scan of the restoration to the originating dental office in order to begin preparation for the final fitting procedure. The process 500 may then end 518.

[00216] It will be understood that numerous variations and modifications to the above process 500 may be used. For example, although not depicted in Fig. 5, in certain instances where it appears that a physical restoration cannot be properly fabricated to fit the restoration site, e.g., the prepare surface and surrounding dentition, the dental laboratory may contact the originating dental office to request additional preparation of the target surface. All such variations and modifications are intended to fall within the scope of the methods and systems described herein.

[00217] It will further be appreciated that, even *in* a system where the digital surface representation is used directly to fabricate a cast dental model to which subsequent, conventional dental laboratory techniques are applied, significant advantages may be realized through elimination or mitigation of physical handling and shipping of a dental impression. Thus in one aspect, there is disclosed herein a technique for acquiring a digital model, such as a digital surface representation, of a prepared surface and/or surrounding dentition, and transmitting the digital model to a dental laboratory or rapid manufacturing facility for preparation of a restoration or other dental object.

[00218] Fig. 6 illustrates a scan path that may be used with a three-dimensional image capture system. In a system that operates to continuously acquire three-dimensional data in real time, and fits or registers incremental three-dimensional data to an aggregate three-dimensional model, it may be advantageous to scan in a manner that increases registration to the aggregate model. Thus, for example, a scan path that runs adjacent to edges of the aggregate model may provide additional registration or fit information and improve overall accuracy, particularly over large surfaces. With respect to scans of human dentition, this general approach suggests an s-shaped scan that traces from interior to exterior (or exterior to interior) surfaces of one tooth, and then reverses direction to trace an exterior-to-interior path immediately adjacent to the initial path, which may reduce overall spatial error between extremities of the arch. Without loss of generality, a more detailed example of this approach is set out below.

[00219] A scan path 600 for obtaining three-dimensional data from a dental arch 602 using a scanner such as the scanner 102 described above with reference to Fig. 1 may begin at a first lingual point 604. The scan path may then traverse laterally over an occlusal point 606 or surface of a molar to a first buccal point 608, translate to a second buccal point 610 by moving forward along the gum line, and then traverse laterally over a second occlusal point to a second lingual point. The scan path may then translate forward once again to a third lingual point, traverse laterally over a third occlusal point *to* a third buccal point, and once again translate forward. By scanning in this s-shaped manner, each successive pass over occlusal surfaces may be fit to data from an adjacent pass over the occlusal surfaces, as well as to one or more immediately prior frames of data. While the remainder of a scan path is not illustrated in Fig. 6, it will be understood that the scan may continue along the entire arch in this manner, finally reaching a molar 612 at the opposite extremity of the arch.

[00220] It will be understood that the spacing of adjacent passes may be greater or less than illustrated. For example, a buccal-to-lingual pass may cover a portion of a tooth, an entire tooth, or a number of teeth depending upon, for example, the field of view for data acquisition with the scanner. It will also be understood that the starting and ending points of the generally s-shaped scan are somewhat arbitrary. A scan may begin, for example at a lingual point, at an occlusal point, or at a buccal point. Further, the scan may begin at a molar, or the scan may begin at an incisor, with two consecutive scans performed from this central location to each molar

extremity of the arch. All such variations are intended to fall within the scope of the scan path described herein. In general, regardless of the starting point, a generally s-shaped scan may move along adjacent buccal-to-lingual passes in the manner described above. In one aspect, real-time feedback may be provided to a user by displaying on a display a next appropriate direction of motion for a scan that follows the generally s-shaped path.

[00221] Figs. 7A and 7B show a modeling environment for creating alignment guides for orthodontic hardware. A three-dimensional representation 702 of dentition and surrounding soft tissue may be acquired from a dental patient as described generally above, and rendered within a user interface 704 on a computer such as the image capture system 100 described above, or more generally, the client 202 described above. In various embodiments, orthodontic hardware may be virtually placed on the three-dimensional representation 702, which may be used to determine appropriate positions for one or more alignment guides, or brackets may themselves be virtually positioned on the three-dimensional representation 702 with corresponding alignment guides being generated by computer, or the alignment guides may be directly positioned on the three-dimensional representation 702. The user interface may include interactive tools for virtually positioning orthodontic hardware and/or brackets for orthodontic hardware and/or alignment guides onto the three-dimensional representation 702 within the user interface 704. The design of orthodontic hardware and any corresponding positioning of brackets or the like, may be performed by a dentist at a dental office and transmitted to a dental laboratory or other fabrication facility, or the unmodified three-dimensional representation may be transmitted to the dental laboratory along with a prescription for orthodontic hardware.

[00222] Fig. 7A shows a three-dimensional representation 702 with visual markings 706 that serve as alignment guides. This marked three-dimensional representation 702, or digital dental model, may serve as a basis for subsequent fabrication of custom orthodontic hardware. The markings 706 may be fabricated directly into a physical realization of the digital dental model, such as using pigmented printing techniques, or the markings 706 may be added to the physical realization after fabrication using additional computerized or manual marking techniques.

[00223J Fig. 7B shows a three-dimensional representation 702 with supports 708 that serve as a physical alignment guide. This three-dimensional representation 702, or digital dental model, may serve as a basis for subsequent fabrication of custom orthodontic hardware. As depicted, each support 708 may include a horizontal top surface or shelf for supporting an orthodontic fixture or other hardware. However, it will be understood that any physical form capable of supporting or engaging the intended hardware may suitable by employed, and fabricated into a physical model. The supports 708 may be fabricated directly into a physical realization of the digital dental model using techniques such as three-dimensional printing, stereo lithography, or computerized milling.

[00224] The alignment guides may serve to guide positioning of an orthodontic fixture onto the physical realization of the digital dental model to assist in fabricating custom orthodontic hardware. In an additional processing step, once the corresponding orthodontic hardware, such as brackets, is positioned onto the physical model, the position of a number of brackets may be captured in a physical template such as a foam, a vacuum-formed appliance, or the like, for direct transfer to an arch within a dental patient's mouth. The appliance may, for example, be formed of a soft, clear material for easy handling by a dentist and/or greater comfort for a dental patient. In such a process, a treating dentist may perform an additional scan of the patient's dentition immediately prior to affixing the brackets to ensure that the natural dentition still corresponds closely to the model used for virtual bracket positioning.

[00225] In another embodiment, additional modeling may be employed to create a virtual bracket carrier model —a device to carry brackets in a specific relative orientation —that can be physically realized as a bracket positioning appliance through direct fabrication using any of the techniques described above. The bracket carrier model may include one or more alignment guides for brackets such as those described generally above. Brackets may then be attached to the bracket positioning appliance for transfer to an arch within a dental patient's mouth. The treating dentist may perform an additional scan of the patient's dentition immediately prior to affixing the brackets to ensure that the natural dentition still corresponds closely to the model used to create the bracket positioning appliance.

[00226] It will be appreciated that the processes and methods disclosed herein may be realized in hardware, software, or any combination of these suitable for the three-dimensional imaging and modeling techniques described herein. This includes

realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable device, along with internal and/or external memory. The may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. At the same time, processing may be distributed across devices such as a camera and/or computer in a number of ways or all of the functionality may be integrated into a dedicated, standalone image capture device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[00227] It will also be appreciated that means for performing the steps associated with the processes described above may include any suitable components of the image capture system 100 described above with reference to Fig. 1, along with any software and/or hardware suitable for controlling operation of same. The user interfaces described herein may, for example, be rendered within the display 110 of the image capture system 100 of Fig. L

[00228] While the invention has been disclosed in connection with certain preferred embodiments, other embodiments will be recognized by those of ordinary skill in the art, and all such variations, modifications, and substitutions are intended to fall within the scope of this disclosure. Thus, the invention is to be understood with reference to the following claims, which are to be interpreted in the broadest sense allowable by law.

CLAIMS:

What is claimed is:

1. A method comprising:

acquiring a three-dimensional representation of one or more intraoral structures of a dental patient using an intraoral scanner; and

providing the three-dimensional representation to a dental fabrication facility.

2. The method of claim 1, further comprising fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation.

3. The method of claim 1, wherein the dental fabrication facility includes a dental laboratory.

4. The method of claim 1, wherein the one or more intraoral structures include at least one dental implant.

5. The method of claim 1, wherein the one or more intraoral structures include at least one tooth.

6. The method of claim 1, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

7. The method of claim 1, wherein the one or more intraoral structures include at least one area of soft tissue.

8. The method of claim 1, wherein the one or more intraoral structures include at least one previously restored tooth.

9. The method of claim 1, further comprising fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.

10. The method of claim 1, further comprising transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality for the three-dimensional representation from the dental laboratory.

11. The method of claim 10, wherein the assessment of quality is received before the dental patient leaves a dentist's office.

12. The method of claim 10, wherein the assessment of quality includes an assessment of acceptability of the three-dimensional representation.

13. The method of claim 6, further comprising transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality of the at least one prepared tooth surface.

14. The method of claim 1, wherein providing the three-dimensional representation to a dental fabrication facility includes transmitting to a remote dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.

15. The method of claim 14, further comprising transmitting the three-dimensional representation to a dental data hub.

16. The method of claim 14, further comprising transmitting a prescription for the dental restoration with the three-dimensional representation.

17. The method of claim 14, further comprising transmitting the three-dimensional representation to a model production laboratory.

18. The method of claim 17, wherein the model production laboratory is a milling facility.

19. The method of claim 17, wherein the model production laboratory is a manufacturing facility.

20. The method of claim 17, wherein the model production laboratory is a three-dimensional rapid prototyping facility.

21. The method of claim 1, wherein providing the three-dimensional representation to a dental fabrication facility includes providing the three-dimensional representation to an in-office dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.

22. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures of a dental patient from an intraoral scanner;

converting the one or more images into a three-dimensional representation of the one or more intraoral structures; and

transmitting the three-dimensional representation to a dental fabrication facility.

23. The computer program product of claim 22, further comprising computer code that performs the step of comparing quality of the three-dimensional representation to predefined quality criteria.

24. The computer program product of claim 23, wherein the predefined quality criteria includes acceptability of the three-dimensional representation for fabrication.

25. The computer program product of claim 22, further comprising computer code that performs the steps of:

retrieving a prescription for at least one of a prosthesis or an appliance prepared by a dentist; and

combining the prescription with the three-dimensional representation prior to transmitting the three-dimensional representation.

26. The computer program product of claim 22, wherein the one or more intraoral structures include at least one dental implant.

27. The computer program product of claim 22, wherein the one or more intraoral structures include at least one tooth.

28. The computer program product of claim 22, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

29. The computer program product of claim 28, further comprising computer code that performs the step of comparing quality of the at least one prepared tooth surface to predefined quality criteria.

30. The computer program product of claim 22, wherein the one or more intraoral structures include at least one area of soft tissue.

31. A system comprising:

an intraoral scanner for acquiring a three-dimensional representation of one or more intraoral structures of a dental patient; and

a transmission means for transmitting the three-dimensional representation to a dental fabrication facility.

32. The system of claim 3 1, further comprising a first fabrication means for fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation.

33. The system of claim 31, wherein the one or more intraoral structures include at least one dental implant.

34. The system of claim 3 1, wherein the one or more intraoral structures include at least one tooth.

35. The system of claim 3 1, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

36. The system of claim 3 1, wherein the one or more intraoral structures include at least one area of soft tissue.

37. The system of claim 31, further comprising a second fabrication means for fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.

38. The system of claim 31, further comprising a quality assessment means for assessing quality of the three-dimensional representation.

39. The system of claim 38, wherein the quality assessment means includes a means for determining acceptability of the three-dimensional representation for use with the first fabrication means.

40. The system of claim 38, wherein the quality assessment means includes a means for determining acceptability of the three-dimensional representation for use with the second fabrication means.

41. The system of claim 38, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration, and wherein the quality assessment means includes a means for determining quality of the at least one prepared tooth surface.

42. A method comprising:

receiving a three-dimensional representation of a tooth, the tooth prepared for a dental restoration;

specifying a cementation void between the tooth surface and the dental restoration; and

fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

43. The method of claim 42, further comprising adjusting the cementation void.

44. The method of claim 43, wherein adjusting the cementation void includes adjusting the cementation void according to a dentist's preferences.

45. The method of claim 43, wherein adjusting the cementation void includes:

specifying a type of cement to be used in the cementation void; and

adjusting the cementation void according to the type of cement to be used in the cementation void.

46. The method of claim 42, wherein the cementation void is specified by a dentist.

47. The method of claim 46, wherein the dentist sends the specification of the cementation void to a dental laboratory.

48. The method of claim 47, wherein the cementation void is specified by a dental laboratory.

49. The method of claim 42, further comprising three-dimensionally printing a die including the cementation void.

50. The method of claim 42, further comprising fabricating a die including the cementation void using a stereo lithography apparatus.

51. The method of claim 42, further comprising three-dimensionally printing a wax-up including the cementation void.

52. The method of claim 42, further comprising milling a die including the cementation void.

53. The method of claim 42, further comprising integrating the cementation void into a digital surface representation of the tooth.

54. The method of claim 42, further comprising integrating the cementation void into a dental model.

55. The method of claim 42, wherein the three-dimensional representation includes a digital surface representation of the tooth.

56. The method of claim 42, wherein fabricating the dental restoration includes fabricating the dental restoration in an in-house laboratory in a dentist's office.

57. The method of claim 42, further comprising fabricating an opposing arch for an arch including the tooth, the opposing arch including a die spacer having a predetermined thickness.

58. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of a tooth of a dental patient from an intraoral scanner, the tooth including a tooth surface prepared for a dental restoration;

converting the one or more images into a three-dimensional representation of the tooth;

specifying a cementation void between the tooth surface and the dental restoration;

combining the specification for the cementation void with the three-dimensional representation into a fabrication specification; and

transmitting the fabrication specification to a dental fabrication facility.

59. The computer program product of claim 58, wherein a dentist specifies the cementation void.

60. The computer program product of claim 58, further comprising computer code that performs the step of receiving a specification of the cementation void from the dental fabrication facility.

61. The computer program product of claim 58 further comprising code for three-dimensionally printing the cementation void to a die.

62. The computer program product of claim 58 further comprising code for three-dimensionally printing the cementation void to a wax up.

63. The computer program product of claim 58, further comprising computer code that performs the step of integrating the cementation void into a digital surface representation of the tooth.

64. A system comprising:

a first means for three-dimensionally representing a tooth, the tooth prepared for a dental restoration;

a second means for specifying a cementation void, the cementation void representing an empty space between the tooth surface and the dental restoration; and

a fabrication means for fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

65. The system of claim 64, further comprising an adjustment means for adjusting the cementation void.

66. The system of claim 65, wherein the adjustment means includes means for incorporating a dentist's preferences.

67. The system of claim 65, wherein the adjustment means includes means for adjusting the cementation void according to a type of cement.

68. The system of claim 64, further comprising a first printing means for three-dimensionally printing a die including the cementation void.

69. The system of claim 64, further comprising a second printing means for three-dimensionally printing a wax-up including the cementation void.

70. The system of claim 64, further comprising a milling means for milling a die including the cementation void.

71. The system of claim 64, further comprising a milling means for milling an investment chamber for casting including the cementation void.

72. The system of claim 64, further comprising a model means for integrating the cementation void into a model of a dental impression.

73. The system of claim 64, wherein the three-dimensional representation of a tooth includes a digital surface representation of the tooth.

74. A method comprising:

fabricating a dental object;

acquiring a first three-dimensional representation of the dental object; and

measuring a dimensional accuracy of the first three-dimensional representation.

75. The method of claim 74, wherein the first three-dimensional representation includes a digital surface representation.

76. The method of claim 74, wherein the dental object includes a dental prosthesis.

77. The method of claim 74, wherein the dental object includes a dental implant.

78. The method of claim 74, wherein the dental object includes a dental appliance.

79. The method of claim 74, wherein the dental object includes a restorative component.

80. The method of claim 74, wherein the dental object includes a dental restoration.

81. The method of claim 74, wherein the dental object includes an abutment.

82. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.

83. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

84. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

85. The method of claim 74 wherein the second three-dimensional representation is acquired as a plurality of separate scans.

86. The method of claim 74 wherein the second three-dimensional representation is acquired as a continuous scan of the at least one tooth surface and the at least one opposing tooth in occlusion.

87. The method of claim 74, wherein a dentist specifies tightness of fit of the dental object.

88. The method of claim 74, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.

89. The method of claim 74, wherein measuring a dimensional accuracy includes measuring quality of a margin.

90. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of a dental object;

converting the one or more images of the dental object into a first three-dimensional representation of the item; and

measuring a dimensional accuracy of the first three-dimensional representation.

91. The computer program product of claim 90, wherein the first three-dimensional representation includes a digital surface representation.

92. The computer program product of claim 90, wherein the dental object includes a dental prosthesis.

93. The computer program product of claim 90, wherein the dental object includes a dental implant.

94. The computer program product of claim 90, wherein the dental object includes a dental appliance.

95. The computer program product of claim 90, wherein the dental object includes a restorative component.

96. The computer program product of claim 90, wherein the dental object includes an abutment.

97. The computer program product of claim 90, wherein the dental object includes a restoration.

98. The computer program product of claim 90, further comprising computer code that performs the steps of:

acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; and

converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.

99. The computer program product of claim 90, further comprising computer code that performs the steps of:

acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object;

converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth; and

generating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.

100. The computer program product of claim 90, further comprising computer code that performs the steps of:

acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth;

converting the one or more images of the one or more teeth and the at least one opposing tooth into a second three-dimensional representation of the one or more teeth and the at least one opposing tooth; and

generating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.

101 . The computer program product of claim 90, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.

102. The computer program product of claim 90, wherein measuring a dimensional accuracy includes measuring quality of a margin.

103. A system comprising:

a fabrication means for fabricating a dental object;

a first means for acquiring a first three-dimensional representation of the item; and

a measurement means for measuring a dimensional accuracy of the first three-dimensional representation.

104. The system of claim 103, wherein the first three-dimensional representation includes a digital surface representation.

105. The system of claim 103, wherein the dental object includes a dental prosthesis.

106. The system of claim 103, wherein the dental object includes a dental implant.

107. The system of claim 103, wherein the dental object includes a dental appliance.

108. The system of claim 103, wherein the dental object includes a restorative component.

109. The system of claim 103, wherein the dental object includes a dental restoration.

110. The system of claim 103, wherein the dental object includes an abutment.

111. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth

surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.

112. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

113. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

114. The system of claim 103, wherein a dentist specifies tightness of fit of the dental object.

115. The system of claim 103, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.

116. The system of claim 103, wherein measuring a dimensional accuracy includes measuring quality of a margin.

117. A method comprising:

acquiring a three-dimensional representation including three-dimensional surface data for at least two independent dental structures; and acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another within a mouth.

118. The method of claim 117, further comprising deriving TMJ condyle paths of rotation and translation from the motion data and the three-dimensional surface data.

119. The method of claim 117, further comprising providing input to a virtual dental articulator.

120. The method of claim 117, further comprising providing specifications for a physical dental articulator.

121. The method of claim 117, further comprising providing specifications for a disposable dental articulator.

122. The method of claim 117, wherein acquiring the three-dimensional representation includes acquiring the three-dimensional representation using an intraoral scanner.

123. The method of claim 117, wherein acquiring motion data includes acquiring motion data from a video source.

124. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of at least two independent dental structures of a dental patient from an intraoral scanner;

converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and

acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another.

125. The computer program product of claim 124 further comprising code that performs the step of combining the three-dimensional representation with the motion data to derive TMJ condyle paths of rotation and translation.

126. The computer program product of claim 124, further comprising computer code that performs the steps of:

generating an image sequence of the combined three-dimensional representation and the motion data; and

generating a display signal of the image sequence.

127. The computer program product of claim 124, wherein acquiring motion data includes acquiring motion data from a video source.

128. A system comprising:

a first means for acquiring one or more images of at least two independent dental structures of a dental patient;

a conversion means for converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and

a second means for acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another.

129. The system of claim 128, further comprising an analysis means for deriving TMJ condyle paths of rotation and translation using the three-dimensional representation and the motion data.

130. The system of claim 128, further comprising an action means for combining the three-dimensional representation and the motion data to generate an articulation input.

131 . The system of claim 130, further comprising a first model means for virtually articulating the articulation input.

132. The system of claim 130, further comprising a second model means for physically articulating the articulation input.

133. The system of claim 130, further comprising a disposable model means for physically articulating the articulation input.

134. The system of claim 128, wherein the first means includes a means for acquiring the one or more images using an intraoral scanner.

135. The system of claim 128, wherein the second means includes a means for acquiring the motion data from a video source.

136. A method comprising:

receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and

fabricating the artificial dental object for the one or more intraoral structures using the electronic dental prescription.

137. The method of claim 136, wherein an electronic dental prescription includes receiving a three-dimensional representation from a dental data hub.

138. The method of claim 136, wherein an electronic dental prescription includes receiving a three-dimensional representation from a dentist.

139. The method of claim 136, wherein the electronic dental prescription includes a prescription for a dental restoration for the tooth surface.

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140. The method of claim 136, wherein at least one of the first and second three-dimensional representations includes a digital surface representation of a full arch.

141 . The method of claim 136, wherein the electronic dental prescription includes a prescription for one or more of an appliance, a prosthesis, or an item of dental hardware.

142. The method of claim 136, wherein fabricating an artificial dental object includes fabricating a dental restoration in an in-house laboratory in a dentist's office.

143. A system comprising:

a communication means for receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and

a fabrication means for fabricating an artificial dental object for the one or more intraoral structures using the three-dimensional representation.

144. The system of claim 143, wherein the communication means includes a means for receiving the electronic dental prescription from a dental data hub.

145. The system of claim 143, wherein the communication means includes a means for receiving the electronic dental prescription from a dentist.

146. The system of claim 143, wherein the electronic dental prescription includes a prescription for a dental restoration.

147. The system of claim 143, wherein the three-dimensional representation includes a digital surface representation of a full arch.

148. The system of claim 143, wherein the electronic dental prescription includes a prescription for one or more of an appliance, a prosthesis, and an item of dental hardware.

149. The system of claim 143, wherein the fabrication means includes an in-house laboratory in a dentist's office.

150. A method comprising, within a single dental visit, the steps of:

acquiring a three-dimensional representation of one or more intraoral structures from a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth surface.

151. The method of claim 150, wherein the feedback identifies corrective action.

152. The method of claim 151, wherein the corrective action includes acquiring an additional three-dimensional representation of the one or more intraoral structures.

153. The method of claim 151, wherein the corrective action includes additional surface preparation of the at least one tooth.

154. The method of claim 150, wherein the feedback identifies a margin for fitting the dental restoration to the at least one tooth surface.

155. The method of claim 154, wherein the margin for fitting can be edited.

156. The method of claim 150, wherein the feedback includes a visual display of one or more regions of inadequate margin for fitting the dental restoration to the at least one tooth surface.

157. The method of claim 150, wherein the feedback includes a visual display recommending additional preparatory work required for the at least one tooth surface.

158. The method of claim 150, wherein the feedback includes a visual display recommending acquiring additional three-dimensional representations of one or more regions of the one or more intraoral structures.

159. The method of claim 150, wherein the feedback includes identifying an incomplete three-dimensional representation.

160. The method of claim 150, wherein the feedback includes identifying errors in the three-dimensional representation.

161. The method of claim 150, wherein the feedback includes visual highlighting of a margin line on a display of the three-dimensional representation.

162. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures of a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object;

converting the one or more images into a three-dimensional representation of the one or more intraoral structures;

analyzing the at least one tooth surface within the three-dimensional representation;

generating a feedback signal, the feedback signal representative of the result of analyzing the at least one tooth surface; and

outputting the feedback signal to provide feedback to a dentist.

163. The computer program product of claim 162, wherein the feedback signal identifies corrective action.

164. The computer program product of claim 163, wherein the corrective action includes acquiring an additional one or more images of the one or more intraoral dental structures.

165. The computer program product of claim 163, wherein the corrective action includes additional surface preparation of the at least one tooth.

166. The computer program product of claim 162, wherein the feedback signal identifies a margin for fitting the dental restoration to the at least one tooth surface.

167. The computer program product of claim 162, wherein the margin for fitting can be edited.

168. A system comprising:

a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient, the scanning device adapted to provide real time feedback during a scan by superimposing surface image data onto a video image of the surface;

a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a digital surface reconstruction, the computer further configured to generate a visualization of the digital surface reconstruction and provide the visualization as a display signal; and

a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image of the visualization.

169. The system of claim 168, wherein the surface includes dentition.

170. The system of claim 168, further comprising a user interface controlled by the computer and rendered on the display, the user interface providing at least one tool for analyzing the surface.

171. The user interface of the system of claim 170, further comprising a tool that provides real time feedback to the user.

172. The user interface of the system of claim 171, wherein the real time feedback includes visual cues within the rendered image.

173. The system of claim 170, wherein the scanning device captures surface image data at a video frame rate.

174. The system of claim 170, wherein the at least one tool includes a distance measurement tool.

175. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of tooth structure removal from a dental restoration surface preparation.

176. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of margin preparations.

177. The system of claim 170, wherein the at least one tool includes a tool that evaluates taper.

178. The system of claim 170, wherein the at least one tool includes a tool that evaluates undercut.

179. The system of claim 170, wherein the at least one tool includes a tool that identifies scan deficiencies.

180. The system of claim 1*19*, wherein the scan deficiencies include holes in the surface.

181. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of removal path in multiple unit preparation.

182. The system of claim 170, wherein the at least one tool includes a tool that identifies irregularities in one or more occlusal surfaces requiring further preparation.

183. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for three-dimensional printing.

184. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for milling.

185. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for manual fabrication.

186. The system of claim 168, wherein the computer is further configured to automatically annotate the visualization with a visual indication of an evaluation.

187. The system of claim 186, wherein the visual indication includes an evaluation of contour of a surface preparation.

188. The system of claim 186, wherein the surface image data includes at least two tooth surfaces in occlusion.

189. The system of claim 186, wherein the visual indication includes an evaluation of margin of a surface preparation.

190. The system of claim 186, wherein the visual indication includes an evaluation of occlusal clearance of a surface preparation.

191. The system of claim 186, wherein the surface includes at least one surface prepared for a dental prosthesis, the evaluation including an evaluation of an adequacy of the at least one surface for receiving the dental prosthesis.

192. The system of claim 186, wherein the visual indication includes display of a contour of an actual tooth and a computer-generated surface preparation.

193. The system of claim 192, wherein the computer-generated surface preparation is based upon intact configuration of the actual tooth prior to preparation.

194. A method comprising:

receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and

presenting the three-dimensional representation in a user interface, the user interface including a first tool for identifying a margin line for the dental restoration on the at least one tooth and a second tool for recessing a region of the three-dimensional representation below the margin line.

195. The method of claim 194, wherein the first tool provides automated identification of the margin line.

196. The method of claim 194, further comprising removing a portion of the three-dimensional representation below the margin line with the second tool.

197. The method of claim 194, further comprising removing a portion of the three-dimensional representation below the margin line with the second tool to provide a virtual ditched die, and three-dimensionally printing the ditched die.

198. A system comprising:

a means for receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and

a user interface means for presenting the three-dimensional representation to a user, the user interface means including a first tool means for identifying a margin line for the dental restoration on the at least one tooth and a second tool means for recessing a region of the three-dimensional representation below the margin line.

199. The system of claim 198, wherein the first tool means includes a means for providing automated identification of the margin line.

200. The system of claim 198, further comprising a means for removing a portion of the three-dimensional representation below the margin line.

201 . The system of claim 198, further comprising a means for removing a portion of the three-dimensional representation below the margin line to provide a virtual ditched die, and a means for three-dimensionally printing the ditched die.

202. A method comprising:

acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and

acquiring orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

203. The method of claim 202, wherein the orientation data includes three-dimensional surface data that spans the at least two independent dental structures while in occlusion.

204. The method of claim 202, wherein the orientation data includes three-dimensional surface data from each of the at least two independent dental structures while in occlusion.

205. The method of claim 202, wherein the occlusion includes a centric occlusion.

206. The method of claim 202, further comprising applying the orientation data to position a virtual model of the at least two independent dental structures in a virtual articulator.

207. The method of claim 202, further comprising fabricating models of each of the at least two independent dental structures and applying the orientation data to position the models within a dental articulator.

208. The method of claim 202, wherein acquiring orientation data includes acquiring three-dimensional data of a buccal side of dentition.

209. The method of claim202, wherein acquiring orientation data includes acquiring three-dimensional data of a labial side of dentition.

210. A system comprising:

a first acquisition means for acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and

a second acquisition means for acquiring orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

211. The system of claim 210, wherein the orientation data includes three-dimensional surface data that spans the at least two independent dental structures while in occlusion.

212. The system of claim 210, wherein the orientation data includes three-dimensional surface data from each of the at least two independent dental structures while in occlusion.

213. The system of claim 210, wherein the occlusion includes a centric occlusion.

214. The system of claim 210, further comprising a model means for virtually articulating the at least two independent dental structures.

215. The system of claim 210, further comprising:

a fabrication means for fabricating models of each of the at least two independent dental structures; and

a model means for physically articulating the fabricated models.

216. The system of claim 2 10, wherein the orientation data includes three-dimensional data of a buccal side of dentition.

217. The system of claim2 10, wherein the orientation data includes three-dimensional data of a labial side of dentition.

218. A method comprising:

providing an intraoral three-dimensional scanning device; and

scanning a plurality of teeth in an arch with the device in a scan path that includes a motion that begins at a first lingual point, traverses laterally over a first occlusal point and a first buccal point, translates to a second buccal point adjacent to the first buccal point, and then traverses laterally over a second occlusal point adjacent to the first occlusal point and a second lingual point adjacent to the first lingual point.

2 19. The method of claim 218, further comprising scanning the plurality of teeth in the arch with the device using a motion that translates to a third lingual point, and then

traverses laterally over a third occlusal point adjacent to the second occlusal point and a third buccal point adjacent to the second buccal point.

220. The method of claim 218, wherein the first lingual point and the second lingual point are spaced apart such that a field of view of the scanning device includes at least one overlapping portion of the plurality of teeth when the scanning device is positioned to image the first and second lingual points respectively.

221. The method of claim 218, wherein the scan path begins at athird buccal point.

222. The method of claim 218, wherein the scan path begins at a third palatal point.

223. The method of claim 218, wherein the scan path begins at a third labial point.

224. A method comprising, within a single dental visit, the steps of:

acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; and

processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth.

225. The method of claim 224, wherein the feedback includes a physical dimension.

226. The method of claim 224, wherein the feedback includes a dimension of the at least one tooth prior to preparation for the dental restoration.

227. The method of claim 224, wherein the feedback includes a contour of the at least one tooth.

228. The method of claim 224, wherein the feedback includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

229. The method of claim 224, wherein the feedback includes a clearance relative to one or more teeth in an opposing occluded arch.

230. The method of claim 224, wherein the feedback includes a position of the at least one tooth.

231. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;

analyzing the three-dimensional representation;

generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and

outputting the feedback signal to a dentist.

232. The computer program product of claim 231, wherein the feedback signal includes a physical dimension.

233. The computer program product of claim 231, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.

234. The computer program product of claim 231, wherein the feedback signal includes a contour of the at least one tooth.

235. The computer program product of claim 231, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

236. The computer program product of claim 23 1, wherein the feedback signal includes a clearance relative to one or more teeth of an opposing occluded arch.

237. The computer program product of claim 23 1, wherein the feedback signal includes a position of the at least one tooth.

238. A system comprising:

an acquisition means for acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;

an analysis means for analyzing the three-dimensional representation;

a means for generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and

a signal means for providing the feedback signal to a dentist.

239. The system of claim 238, wherein the feedback signal includes a physical dimension.

240. The system of claim 238, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.

241 . The system of claim 238, wherein the feedback signal includes a contour of the at least one tooth.

242. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

243. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more teeth in an opposing occluded arch.

244. The system of claim 238, wherein the feedback signal includes a position of the at least one tooth.

245. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures; and

providing a visual display of the three-dimensional representation in real time.

246. The method of claim 245, wherein the visual display of the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.

247. The method of claim 245, wherein the one or more intraoral structures include at least one tooth.

248. The method of claim 245, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

249. The method of claim 245, wherein the one or more intraoral structures include at least one restored tooth.

250. The method of claim 245, wherein the one or more intraoral structures include at least one implant.

251. The method of claim 245, wherein one or more intraoral structures include at least one area of soft tissue.

252. The method of claim 245, further comprising processing the three-dimensional representation to generate user feedback concerning the one or more intraoral structures, and providing a visual display of the user feedback.

253. The method of claim 252 wherein the feedback includes highlighting areas in the three-dimensional representation requiring additional attention.

254. A computer program product comprising computer executable code embodied in a computer readable, medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures;

processing the one or more images into a three-dimensional representation including a digital surface representation of the one or more intraoral structures; and

generating a first visual display signal of the three-dimensional representation in real time.

255. The computer program product of claim 254, further comprising computer code that performs the step of generating a second visual display signal wherein the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.

256. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth.

257. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

258. The computer program product of claim 254, wherein the one or more intraoral structures include at least one area of soft tissue.

259. The computer program product of claim 254, wherein the one or more intraoral structures include at least one implant.

260. The computer program product of claim 254, wherein the one or more intraoral structures include at least one restored tooth.

261. The computer program product of claim 254, further comprising computer code that performs the steps of:

analyzing the three-dimensional representation;

generating a feedback signal representative of the analysis of the three-dimensional representation; and

generating a third visual display signal including the feedback signal.

262. The computer program product of claim 261, wherein the third visual display signal includes highlighted areas of the three-dimensional representation requiring additional attention.

263. A system comprising:

an acquisition means for acquiring a three-dimensional representation from a dental patient, the three-dimensional representation including a digital surface representation of one or more intraoral structures; and

a display means for visually displaying the three-dimensional representation in real time.

264. The system of claim 263, wherein the display means includes a means for superimposing the three-dimensional representation on a real time two-dimensional video image of the one or more intraoral structures.

265. The system of claim 263, wherein the one or more intraoral structures include at least one tooth.

266. The system of claim 263, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

267. The system of claim 263, wherein the one or more intraoral structures include at least one area of soft tissue.

268. The system of claim 263, wherein the one or more intraoral structures include at least one implant.

269. The system of claim 263, wherein the one or more intraoral structures include at least one restored tooth.

270. The system of claim 263, further comprising:

an analysis means for analyzing the three-dimensional representation;

a feedback means for generating a feedback signal representative of the analysis of the three-dimensional representation, wherein the display means includes a means for visually displaying the feedback signal.

271. The system of claim 270, wherein the feedback means includes a means for highlighting areas in the three-dimensional representation requiring additional attention.

272. A handheld imaging device for a three-dimensional imaging system comprising:

an elongated body including a first end, a second end, and a central axis;

a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and

the second end adapted for gripping by a human hand, and the second end including a user input responsive to user manipulation to generate control signals for transmission to a processor associated with the imaging system.

273. The device of claim 272, wherein the user input includes a mouse, track ball, button, switch, mini joystick, touchpad, keypad, or thumb wheel.

274. The device of claim 272, wherein the control signals are transmitted to the processor through a wireless communication medium.

275. The device of claim 272, wherein the user input controls a user interface associated with the imaging system.

276. A handheld imaging device for a three-dimensional imaging system comprising:

an elongated body including a central axis, a first end, and a second end, the second end adapted for gripping by a human hand and a central axis;

a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and

a physical offset shaped and sized to maintain a desired distance of the first end from an imaging subject along the optical axis.

277. The device of claim 276, wherein the physical offset includes one or more wheels for slidably engaging a surface of the imaging subject.

278. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and

fabricating a physical model from the digital dental model.

279. The method of claim 278, further comprising constructing the orthodontic fixture on the physical model using the alignment guides.

280. The method of claim 278, further comprising constructing a support for the orthodontic fixture on the digital dental model.

281. The method of claim 278, wherein the alignment guides include visual markings.

282. The method of claim 278, wherein the alignment guides include at least one substantially horizontal shelf for the orthodontic fixture.

283. The method of claim 278, wherein processing includes virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model.

284. The method of claim 283, further comprising fabricating the physical realization of the plurality of orthodontic brackets, positioning each one of the plurality of orthodontic brackets onto the physical model, and vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another.

285. The method of claim 284, further comprising applying the appliance with the plurality of orthodontic brackets to the dental arch.

286. The method of claim 284, wherein the appliance is formed of a soft, clear material.

287. The method of claim 278, further comprising transmitting the digital dental model to a remote dental laboratory.

288. The method of claim 278, wherein processing includes virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch.

289. The method of claim 288, further comprising three-dimensionally printing the bracket guide.

290. The method of claim 278, wherein fabricating the physical model includes fabricating the physical model in an in-house dental laboratory in a dentist's office.

291. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

adding a plurality of virtual brackets to the three-dimensional representation to provide a bracket model;

processing the bracket model to generate a bracket guide model, the bracket guide model adapted to maintain a physical realization of the plurality of virtual brackets in a fixed orientation with respect to one another, the fixed orientation corresponding to a desired orientation of the physical realization on the dental arch;

fabricating a bracket guide from the bracket guide model; and

attaching the physical realization of the plurality of virtual brackets to the bracket guide model.

292. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures, the intraoral structures including a dental arch;

processing the one or more images into a three-dimensional representation of the one or more intraoral structures;

transforming the three-dimensional representation into a digital dental model, the digital dental model including one or more orthodontic fixture alignment guides; and

generating a virtual orthodontic fixture using the alignment guides.

293. The computer program product of claim 292, further comprising computer code that performs the step of constructing a support for the virtual orthodontic fixture on the digital dental model.

294. The computer program product of claim 292, wherein the alignment guides include visual markings.

295. The computer program product of claim 292, wherein the alignment guides include at least one substantially horizontal shelf for the virtual orthodontic fixture.

296. The computer program product of claim 292, wherein transforming includes virtually placing a plurality of orthodontic brackets onto the dental arch of the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model.

297. The computer program product of claim 292, further comprising computer code that performs the step of transmitting the digital dental model to a remote dental laboratory.

298. A system comprising:

an acquisition means for acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

a processing means for processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and

a first fabrication means for fabricating a physical model from the digital dental model.

299. The system of claim 298, further comprising a means for constructing the orthodontic fixture on the physical model using the alignment guides.

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300. The system of claim 298, wherein the processing means includes a means for constructing a support for the orthodontic fixture on the digital dental model.

301. The system of claim 298, wherein the alignment guides include visual markings.

302. The system of claim 298, wherein the alignment guides include at least one substantially horizontal shelf for the orthodontic fixture.

303. The system of claim 298, wherein the processing means includes a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model.

304. The system of claim 303, further comprising a second fabrication means for fabricating the physical realization of the plurality of orthodontic brackets, a positioning means for positioning each one of the plurality of orthodontic brackets onto the physical model, and a forming means for vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another.

305. The system of claim 304, further comprising a means for applying the appliance with the plurality of orthodontic brackets to the dental arch.

306. The system of claim 304, wherein the appliance is formed of a soft, clear material.

307. The system of claim 298, further comprising a communication means for transmitting the digital dental model to a remote dental laboratory.

308. The system of claim 298, wherein the processing means includes a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and a model means for generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch.

309. The system of claim 308, further comprising a printing means for three-dimensionally printing the bracket guide.

310. The system of claim 298, wherein the fabrication means includes a means for fabricating the physical model in an in-house dental laboratory in a dentist's office.

311. A three-dimensional data acquisition system adapted for intraoral acquisition of dental data from one or more intraoral structures, the system including a first operating mode for capturing scan data and rendering a low-quality three-dimensional image from the scan data in real time, and a second operating mode for generating a high-quality three dimensional image from the scan data after exiting the first operating mode, the high-quality three-dimensional image having greater spatial resolution than the low-quality three-dimensional image.

312. The system of claim 311, further including a display that renders the low-quality three-dimensional image superimposed on a video image of the one or more intraoral structures.

313. The system of claim 312, wherein rendering a low-quality three-dimensional image includes rendering the low-quality three-dimensional image at a frame rate of the video image.

314. The system of claim 311, further including a communications interface for transmitting the high-quality three-dimensional image to a dental laboratory.

315. A system comprising:

a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient;

a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a three-dimensional representation, the computer further configured to generate a visualization of the three-dimensional representation and to provide the visualization as a display signal; and

a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image, the display being a touch-screen display adapted to receive a user input through direct contact with a surface of the display, wherein the user input is interpreted by the computer to affect manipulation of the three-dimensional representation.

316. The system of claim 315, wherein the user input affects rotational orientation of the visualization on the display.

317. The system of claim 315, wherein the display includes areas for one or more user controls accessible through the touch-screen display.

318. The system of claim 317, wherein the user controls include a zoom control.

319. The system of claim 317, wherein the user controls include a pan control.

320. The system of claim 317, wherein the user controls include case management controls.

321. The system of claim 320, wherein the case management controls include a control to transmit the three-dimensional representation to a dental lab.

322. The system of claim 320, wherein the case management controls include a control to evaluate quality of the three-dimensional representation.

323. The system of claim 320, wherein the case management controls include a tool to edit the three-dimensional representation.

324. The system of claim 320, wherein the case management controls include a control to create a dental prescription.

325. The system of claim 317, wherein the user controls include a control to define a cementation void.

326. The system of claim 317, wherein the user controls include a control to define a margin line.

327. The system of claim 317, wherein the user controls include a control to infer a margin line from the three-dimensional representation.

328. The system of claim 317, wherein the user controls include a control to recess a region of the three-dimensional representation below a margin line

329. The system of claim 317, wherein the user controls include a control to virtually fit a dental restoration to a prepared tooth surface.

330. The system of claim 317, wherein the user controls include a virtual dental articulator.

33 1. The system of claim 317, wherein the user controls include a tool to design a dental restoration fitted to the surface within the mouth of the dental patient.

332. The system of claim 315, wherein the three-dimensional model includes two arches; the display including an area for one or more user controls accessible through the touch-screen display to permit positioning the two arches within a virtual articulator.

333. The system of claim 3 15, further comprising a user interface displayed on the display and controlled by the computer.

334. The system of claim 333, wherein the user interface is accessible through the touch-screen.

335. A system comprising:

a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the digital dental impression captured using a three-dimensional intraoral scanning device and stored in a computer readable medium;

a first computer configured to render the digital dental impression from a point of view; and

a second computer at a remote location configured to simultaneously render the digital dental impression from the point of view.

336. The system of claim 335, further including a control for passing control of the point of view between the first computer and the second computer.

337. The system of claim 335, further including the first computer and the second computer including a collaborative tool for manipulating the model.

338. The system of claim 335, further including the first computer and the second computer including a collaborative tool for sectioning the model.

339. The system of claim 335, further including the first computer and the second computer including a collaborative tool for rearranging one or more sections of the model.

340. The system of claim 335, further including the first computer and the second computer including a collaborative cursor control tool.

341. The system of claim 335, further including the first computer and the second computer connected by a communication channel.

342. The system of claim 341, wherein the communication channel includes one or more of VoIP, IRC, video conferencing, or instant messaging.

343. The system of claim 335, wherein the second computer is operated by a consulting dentist.

344. The system of claim 335, wherein the second computer is operated by a dental technician.

345. The system of claim 335, wherein the second computer is operated in a dental laboratory.

346. The system of claim 335, wherein the second computer is operated by an oral surgeon.

347. The system of claim 335, wherein the second computer is operated by a dental specialist including one or more of a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and an oral and maxillofacial pathologist.

348. A method comprising:

seating a dental patient in a clinical office;

acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of the dental patient;

transmitting the digital dental impression to a dental laboratory before the patient leaves the office;

receiving an evaluation of the digital dental impression from the dental laboratory before the patient leaves the office; and

if the evaluation is unfavorable, repeating the step of acquiring the digital dental impression.

349. The method of claim 348, wherein the evaluation includes an identification of at least one region of the one or more intraoral structures requiring additional preparation, the method including preparing the one or more intraoral structures according to the evaluation.

350. The method of claim 348, wherein the evaluation includes an evaluation of surface continuity.

351. The method of claim 348, wherein the evaluation includes an evaluation of data density.

352. The method of claim 348, wherein the evaluation includes an evaluation of feature detail.

353. The method of claim 348, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.

354. The method of claim 353, wherein the digital dental impression includes a case plan for the restoration.

355. The method of claim 354, wherein the case plan includes a type of restoration.

356. The method of claim 354, wherein the case plan includes a design of restoration.

357. The method of claim 354, wherein the case plan includes a list of restoration components.

358. The method of claim 357, wherein the list of restoration components includes a full ceramic component.

359. The method of claim 357, wherein the list of restoration components includes a PFM component.

360. The method of claim 354, wherein the case plan includes a specification of one or more restoration materials.

361. The method of claim 348 wherein the evaluation includes an evaluation of a margin around a tooth prepared for a restoration.

362. A system comprising:

a means for acquiring a digital dental impression, the digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of a dental patient seated in a clinical office;

a request means for transmitting the digital dental impression to a dental laboratory before the patient leaves the office;

an evaluation means for determining if the digital dental impression must be reacquired before the patient leaves the office; and

a response means for transmitting the determination to the clinical office.

363. The system of claim 362, wherein the evaluation means includes a means for evaluating surface continuity.

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364. The system of claim 362, wherein the evaluation means includes a means for evaluating data density.

365. The system of claim 362, wherein the evaluation means includes a means for evaluating feature detail.

366. The system of claim 362, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.

367. The system of claim 366, wherein the digital dental impression includes a case plan for the restoration.

368. The system of claim 367, wherein the case plan includes a type of restoration.

369. The system of claim 367, wherein the case plan *includes* a design of restoration.

370. The system of claim 367, wherein the case plan includes a list of restoration components.

371. The system of claim 370., wherein the list of restoration components includes a full ceramic component.

372. The system of claim 370, wherein the list of restoration components includes a PFM component.

373. The system of claim 367, wherein the case plan includes a specification of one or more restoration materials.

374. A system comprising:

a scanning device for real time capture of three-dimensional surface data;

a monitor that renders the three-dimensional surface data in real time; .

a processor configured to evaluate quality of the three-dimensional surface data, and to generate a signal representative of a data quality during a scan; and

a feedback device responsive to the signal to produce a user alert concerning the data quality when the data quality degrades below a predetermined threshold.

375. The system of claim 374, wherein the scanning device resolves the three-dimensional surface data from a plurality of two-dimensional image sets, and wherein the evaluation of quality includes evaluation of ability to determine spatial relationships from the plurality of two-dimensional image sets.

376. The system of claim 374, wherein the evaluation of quality includes evaluation of point cloud density.

377. The system of claim 374, wherein the evaluation of quality includes evaluation of scanning device motion.

378. The system of claim 374, wherein the feedback device includes an LED.

379. The system of claim 374, wherein the feedback device includes a speaker.

380. The system of claim 374, wherein the feedback device includes a buzzer.

381. The system of claim 374, wherein the feedback device includes a vibrator.

382. The system of claim 374, wherein the scanning device includes a wand, the feedback device positioned on the wand.

383. The system of claim 374, wherein the feedback device is further responsive to the signal to produce a second user alert when the data quality is within an acceptable range.

384. A method comprising:

scheduling a preparation visit for a dental restoration for a patient;

obtaining a digital surface representation of one or more intraoral structures of the patient, including at least one tooth associated with the dental restoration; and

fabricating a temporary restoration based upon the digital surface representation.

385. The method of claim 384, wherein fabricating a temporary restoration includes transmitting the digital surface representation to a dental laboratory.

386. The method of claim 384, wherein fabricating a temporary restoration includes applying the digital surface representation to prepare a design for the temporary restoration and transmitting the design to a dental laboratory.

387. The method of claim 384, further including three-dimensionally printing the temporary restoration.

388. The method of claim 384, further including three-dimensionally printing the temporary restoration at a dentist's office where the preparation visit is scheduled.

389. The method of claim 384, further including milling the temporary restoration.

390. The method of claim 384, further including milling the temporary restoration at a dental office where the preparation visit is scheduled.

391 . The method of claim 384, wherein obtaining a digital surface representation includes three-dimensionally scanning the one or more intraoral structures on a day of the preparation visit.

392. The method of claim 384, wherein obtaining a digital surface representation includes retrieving the digital surface representation from prior dental data for the patient.

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393. The method of claim 384, wherein fabricating the temporary restoration includes fabricating the temporary restoration prior to Ihe preparation visit, the temporary restoration including one or more characteristics of the at least one tooth.

394. The method of claim 393, further comprising, on the day of the preparation visit adapting a surface of the at least one tooth to receive the temporary restoration.

395. The method of claim 393, further comprising, on the day of the preparation visit, adapting the temporary restoration to fit a prepared surface of the at least one tooth.

396. The method of claim 384, wherein the step of fabricating is performed at an in-house dental laboratory at a dentist's office.

397. A method comprising:

acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.

398. The method of claim 397, wherein acquiring additional three-dimensional data includes acquiring additional data from the at least one tooth surface.

399. The method of claim 397, wherein acquiring additional three-dimensional data includes post-processing source data for the digital dental impression.

400. The method of claim 397, wherein acquiring additional three-dimensional data includes post-processing the three-dimensional digital surface data.

401 . A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

generating a digital dental impression including three-dimensional digital surface data from the one or more images.

402. The computer program product of claim 401, further comprising computer code that performs the step of post-processing source data for the digital dental impression to generate additional three-dimensional data with greater spatial resolution.

403. The computer program product of claim 401 , further comprising computer code that performs the step of post-processing the three-dimensional digital surface data to generate additional three-dimensional data with greater spatial resolution.

404. A system comprising:

a first means for acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

a second means for acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.

405. The system of claim 404, wherein the second means includes a means for acquiring additional data from the at least one tooth surface.

406. The system of claim 404, wherein the second means includes a means for post-processing source data for the digital dental impression.

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407. The method of claim 404, wherein the second means includes a means for post-processing the three-dimensional digital surface data.

408. A method comprising:

acquiring a digital surface representation for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for a dental prosthesis;

fabricating a kit from the digital surface representation, the kit including two or more components suitable for use in fabrication of the dental prosthesis; and

sending the kit to a dental laboratory for fabrication of the dental prosthesis.

409. The method of claim 408, wherein the kit includes one or more of a die, a quad model, an opposing quad model, an opposing model, a base, a pre-articulated base, and a waxup.

410. The method of claim 408, further comprising transmitting the digital surface representation to a production facility, the step of fabricating being performed at the production facility.

411. The method of claim 408, wherein the kit includes one or more components selected from the group of pre-cut components, pre-indexed components, and pre-articulated components.

412. The method of claim 408, where in the step of fabricating is performed at a dentist's office.

413. An artificial dental object including an exposed surface, the exposed surface having a texture integrated therein adapted to enhance acquisition of three dimensional image data from the exposed surface with a multi-aperture three-dimensional scanning device.

414. The artificial dental object of claim 413 wherein the texture includes pseudo-random three-dimensional noise.

415. The artificial dental object of claim 413 wherein the artificial dental object includes an impression coping.

416. The artificial dental object of claim 413 wherein the artificial dental object includes a fixture.

417. The artificial dental object of claim 413 wherein the artificial dental object includes a healing abutment.

418. The artificial dental object of claim 413 wherein the artificial dental object includes a temporary impression coping.

419. The artificial dental object of claim 413 wherein the artificial dental object includes a dental prosthesis.

420. The artificial dental object of claim 413 wherein the artificial dental object includes a dental appliance.

421. The artificial dental object of claim 413 wherein the artificial dental object includes an item of dental hardware.

422. The artificial dental object of claim 413 wherein the artificial dental object includes a dental restoration.

423. A method comprising:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

transmitting the three-dimensional representation to a dental insurer; and

receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

424. The method of claim 423, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a bridge, a fixture, and an abutment.

425. The method of claim 423, wherein the intraoral surface includes at least one edentulous space.

426. The method of claim 423, wherein the intraoral surface includes at least one tooth surface.

427. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

transmitting the three-dimensional representation to a dental insurer; and

receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

428. The method of claim 427, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment.

429. The method of claim 427, wherein the intraoral surface includes at least one edentulous space.

430. The method of claim 427, wherein the intraoral surface includes at least one tooth surface.

431. A system comprising:

a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

a first communication means for transmitting the three-dimensional representation to a dental insurer; and

a second communication means for receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

432. The system of claim 43 1, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a fixture, a bridge and an abutment.

433. The system of claim 43 1, wherein the at least one intraoral surface includes an edentulous space.

434. The system of claim 43 1, wherein the at least one intraoral surface includes a tooth surface.

435. A method comprising:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and

transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

436. The method of claim 435, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment.

437. The method of claim 435, further comprising receiving a payment from the insurer for a procedure involving the artificial dental object.

438. The method of claim 435 wherein the intraoral surface includes an edentulous space.

439. The method of claim 435 wherein the intraoral surface includes a tooth surface prepared for an artificial dental object.

440. The method of claim 437 wherein the intraoral surface includes a restored tooth.

441 . A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at one intraoral surface related to a dental procedure; and

transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

442. The computer program product of claim 441, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a bridge, and an abutment.

443. The computer program product of claim 441, further comprising computer code that performs the step of receiving a record of payment from the insurer for the dental procedure.

444. The computer program product of claim 441, wherein the intraoral surface includes an edentulous space.

445. The computer program product of claim 441, wherein the intraoral surface includes a tooth surface prepared for an artificial dental object.

446. The Computer program product of claim 441, wherein the intraoral surface includes a restored tooth.

447. A system comprising:

a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and

a communication means for transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

448. The system of claim 447, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a bridge, and an abutment.

449. The system of claim 447, wherein the communication means includes a means for receiving a payment from the insurer for the dental procedure.

450. A method comprising:

receiving a three-dimensional representation of one or more intraoral structures from a dentist;

receiving a proposed dental procedure from the dentist;

determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and

transmitting a reply to the dentist.

451. The method of claim 450, wherein the reply includes an approval to perform the dental procedure.

452. The method of claim 450, wherein the reply includes a denial to perform the dental procedure.

453. The method of claim 450, further comprising authorizing payment for the dental procedure.

454. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

receiving a three-dimensional representation of one or more intraoral structures from a dentist;

receiving a proposed dental procedure from the dentist;

comparing the proposed dental procedure to a predetermined list of appropriate procedures for the one or more intraoral structures; and

transmitting a reply to the dentist.

455. The computer program product of claim 454, wherein the reply includes an approval to perform the dental procedure.

456. The computer program product of claim 454, wherein the reply includes a denial to perform the dental procedure.

457. The computer program product of claim 454, further comprising computer code that performs the step of authorizing payment for the dental procedure.

458. A system comprising:

a first means for receiving a three-dimensional representation of one or more intraoral structures from a dentist;

a second means for receiving a proposed dental procedure from the dentist;

an evaluation means for determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and

a reply means for transmitting a reply to the dentist.

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459. The system of claim 458, wherein the reply includes an approval to perform the dental procedure.

460. The system of claim 458, wherein the reply includes a denial to perform the dental procedure.

461. The system of claim 458, further comprising a means for authorizing payment for the dental procedure.

462. A system comprising:

a dental data repository coupled to a communications network, the dental data repository adapted to receive dental data including three-dimensional representations of intraoral structures and prescriptions for dental procedures from a plurality of dentists.

463. The system of claim 462, wherein the dental data repository is adapted to transmit prescriptions and three-dimensional representations to a plurality of dental laboratories.

464. The system of claim 463, wherein at least one of the prescriptions identifies a specific one of the plurality of dental laboratories.

465. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers for authorization of dental procedures.

466. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers to coordinate payment for dental procedures.

467. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to provide status on work in progress.

468. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to receive work assignments.

469. The system of claim 462, further comprising a dentist interface for the plurality of dentists to monitor work in progress.

470. The system of claim 462, further comprising a dentist interface for the plurality of dentists to submit prescriptions and three-dimensional representations.

471. The system of claim 462, further comprising a transaction engine for transmitting payments among two or more of one of the plurality of dentists, one of the plurality of dental laboratories, and one of the one or more dental insurers.

472. The system of claim 462, further comprising a collaboration interface for two or more of the plurality of dentists to collaborate on a dental matter.

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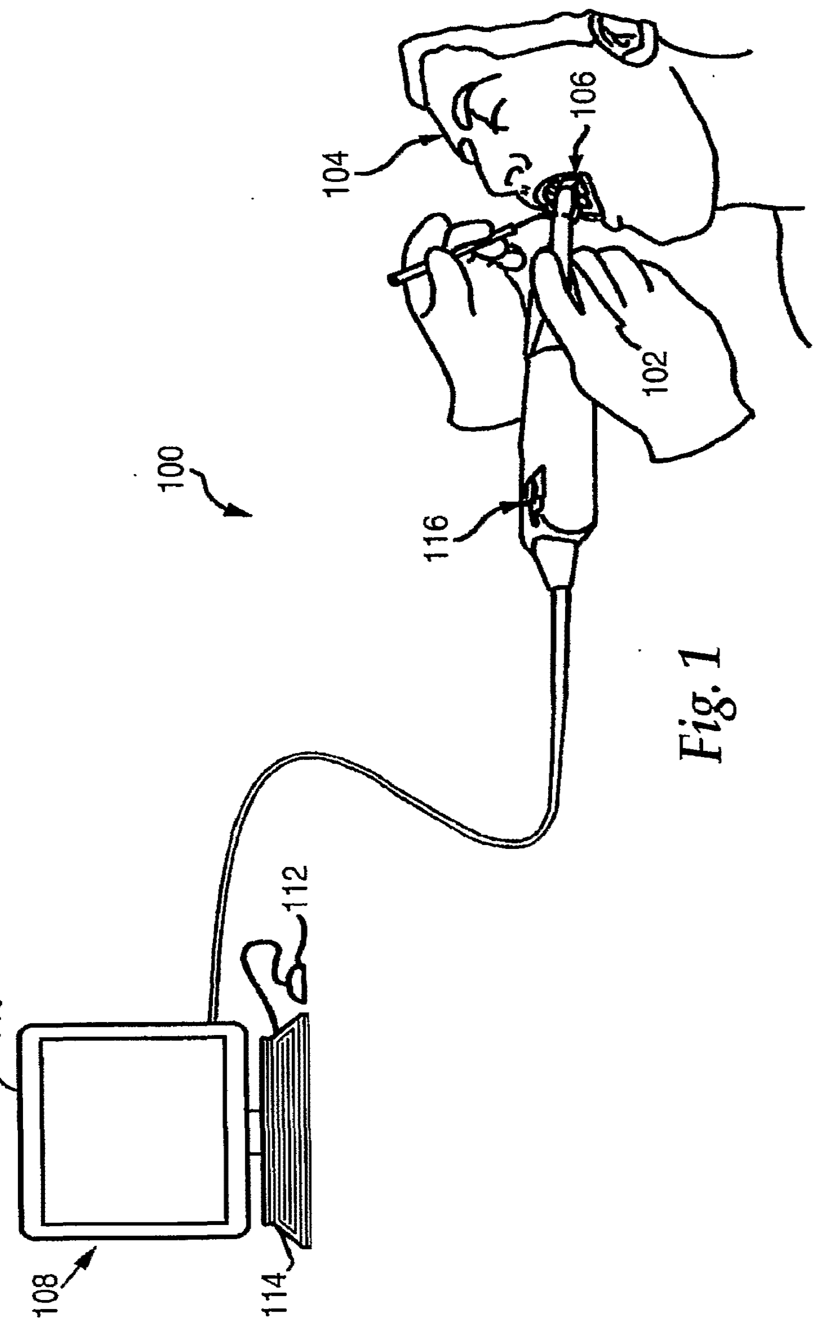


Fig. 1

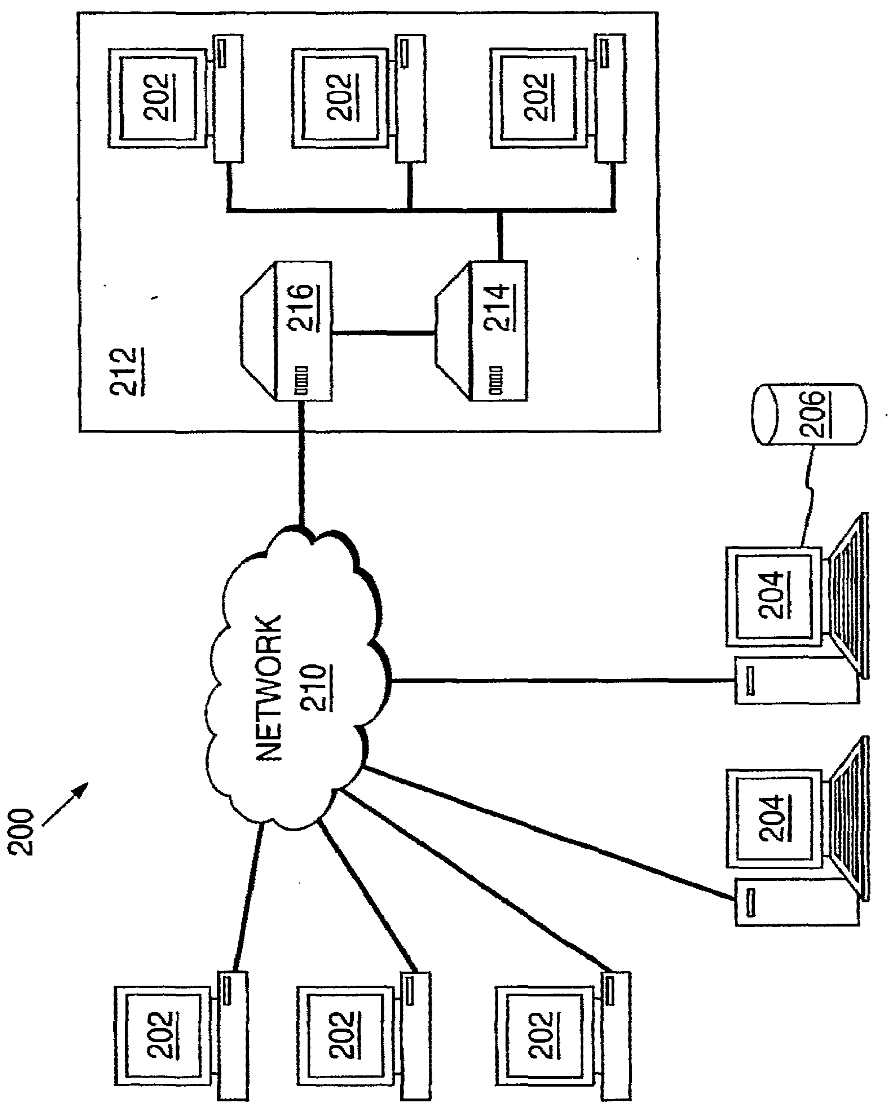
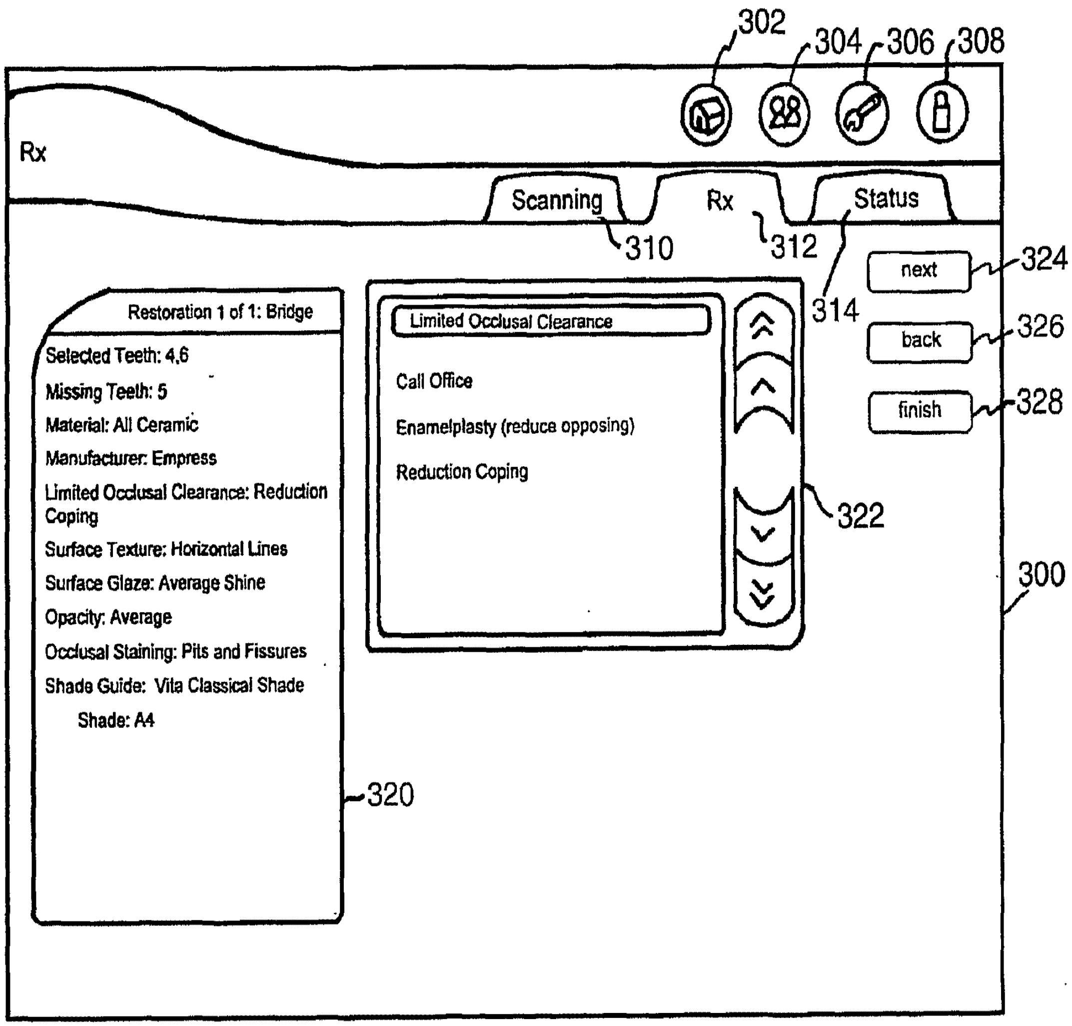


Fig. 2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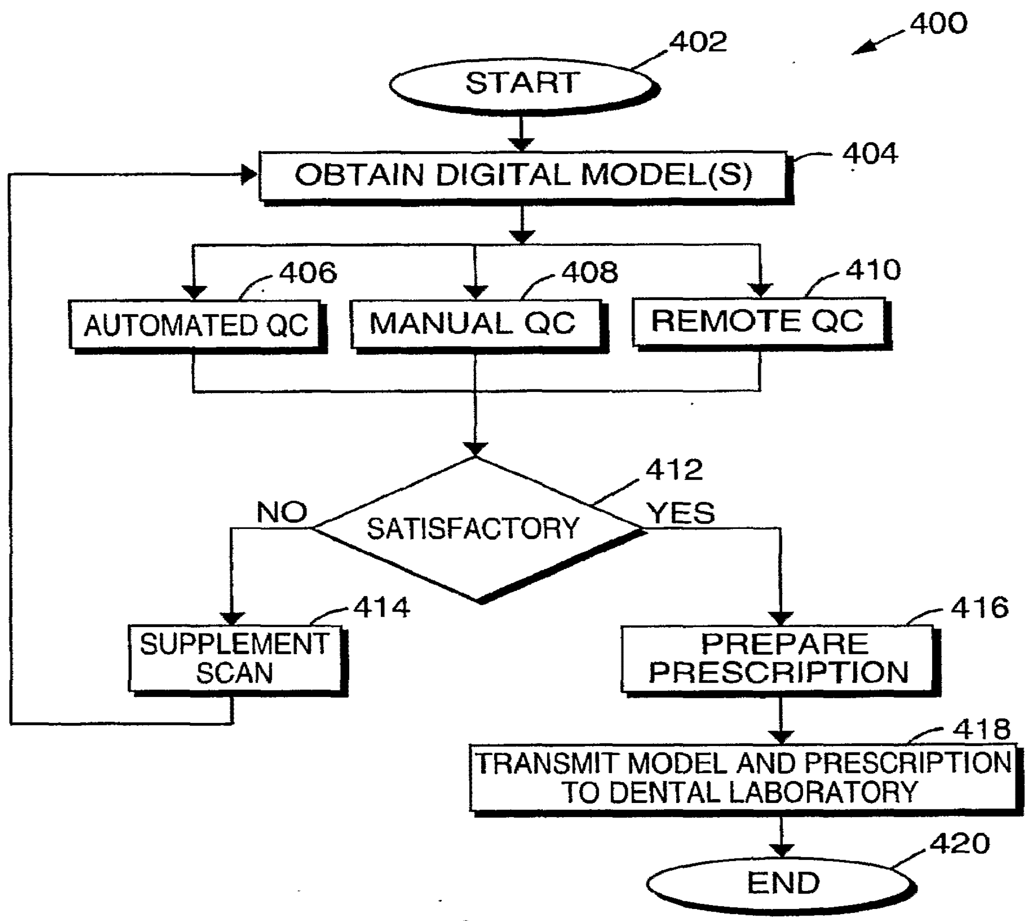
304
306
308
Rx
Scanning
Rx
Status
310
312
314
next
324
back
326
finish
328
Restoration 1 of 1: Bridge
Selected Teeth: 4,6
Missing Teeth: 5
Material: All Ceramic
Manufacturer: Empress
Limited Occlusal Clearance: Reduction Coping
Surface Texture: Horizontal Lines
Surface Glaze: Average Shine
Opacity: Average
Occlusal Staining: Pits and Fissures
Shade Guide: Vita Classical Shade
Shade: A4
Limited Occlusal Clearance
Call Office
Enamelplasty (reduce opposing)
Reduction Coping
322
300
320

Fig. 3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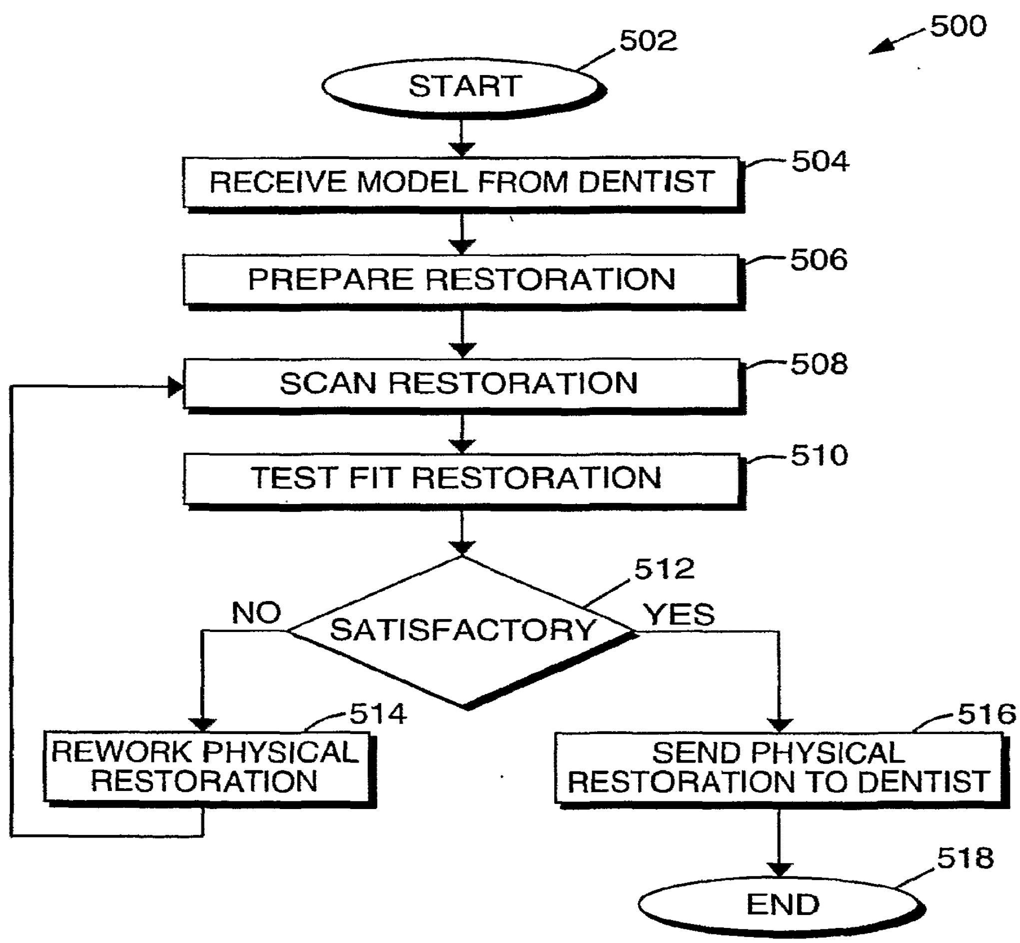
402
START
OBTAIN DIGITAL MODEL(S)
404
406
408
410
AUTOMATED QC
MANUAL QC
REMOTE QC
412
NO
SATISFACTORY
YES
414
SUPPLEMENT SCAN
416
PREPARE PRESCRIPTION
418
TRANSMIT MODEL AND PRESCRIPTION TO DENTAL LABORATORY
420
END

Fig. 4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502
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RECEIVE MODEL FROM DENTIST
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PREPARE RESTORATION
506
SCAN RESTORATION
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TEST FIT RESTORATION
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SATISFACTORY
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NO
YES
REWORK PHYSICAL RESTORATION
514
SEND PHYSICAL RESTORATION TO DENTIST
516
END
518

Fig. 5

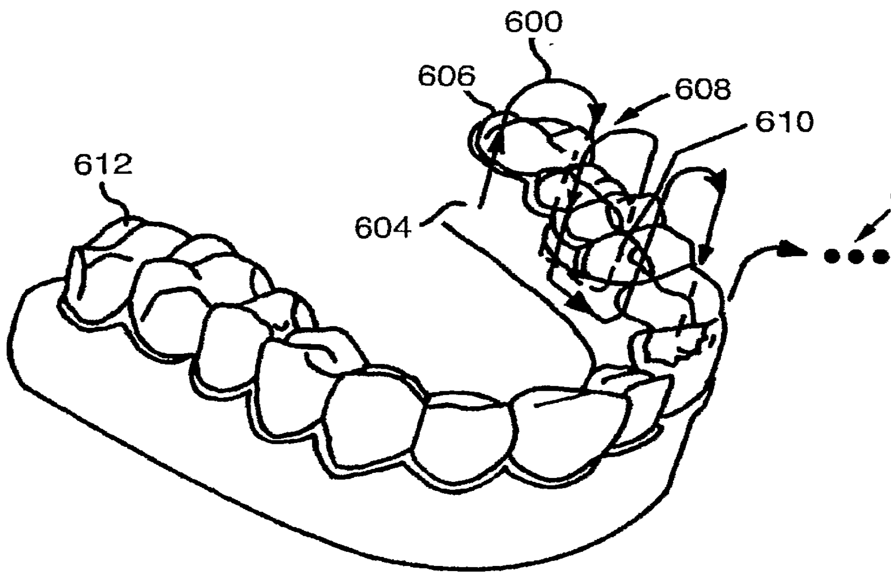

Fig. 6

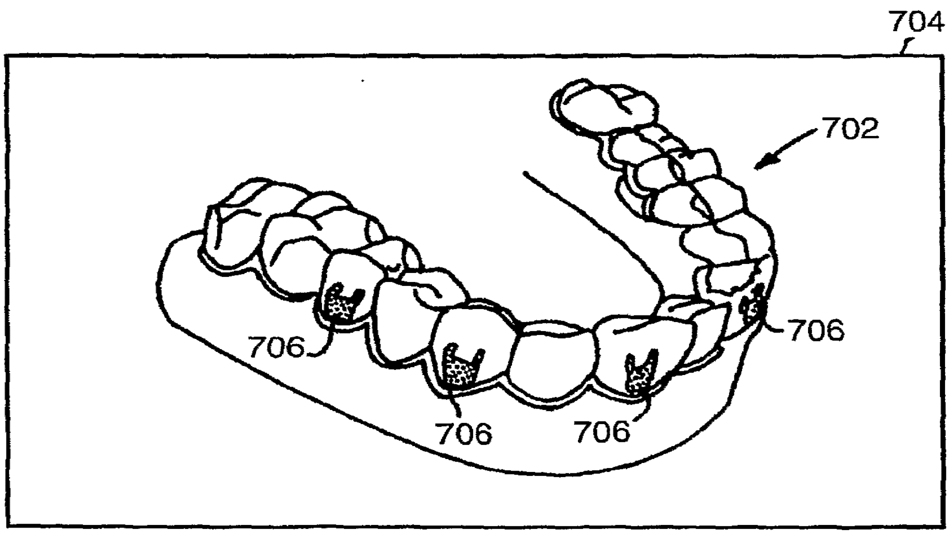

Fig. 7A

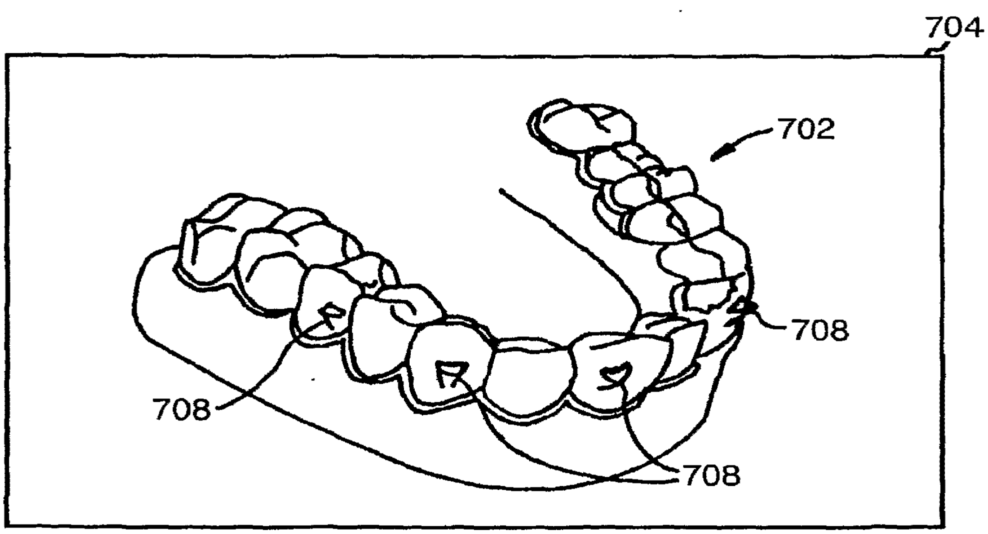

Fig. 7B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/001547

A. CLASSIFICATION OF SUBJECT MATTER

G06Q 10/00(2006.01)1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC G06Q 10/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PAJ, FPD, USPAT, eKIPASS "Keyword dental, intraoral, inter-oral, three-dimensional, fabrication"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
X Y	US 2005153257 A (DURBIN DUANE M , DURBIN DENNIS A) 14 JULY 2005 See the abstract, figures 1	1, 22 31, 245, 254, 263 2-9, 14-15, 17-22, 26-28, 30, 31-37, 74-135, 150-244, 246-253, 255-262, 264-277, 311-347, 384-412
Y	US 06648640 A (Ora Metπx, Inc) 18 NOVEMBER 2003 See the abstract, claims 1-35, figures 1-120	1-9, 14-15, 17-22, 26-28, 30, 31-37, 74-135, 150-277, 311-347, 384-412
A	US 2004029078 A (MARSHALL MICHAEL CRAIG) 12 FEBRUARY 2004 See the abstract, figures 1-2	1-472
A	US 2005170309 A (3M INNOVATIVE PROPERTIES CO) 04 AUGUST 2005 See the abstract, columns 1-2, figures 1-2	1-472

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 JULY 2007 (02 07 2007)	02 JULY 2007 (02.07.2007)

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
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Republic of Korea
Facsimile No 82-42-472-7140

Authorized officer
KOO, Young Hoi
Telephone No 82-42-481-8376

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2007/001547

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US2005153257A1	14. 07. 2005	US7118375BB	10.10.2006
US06648640	18. 11..2003	US20020015934A1	07.02.2002
		US2002150859A1	17.10.2002
		US2002156652A1	24.10.2002
		US2003021453A1	30.01.2003
		US2003096210A1	22.05.2003
		US2004015327A1	22.01.2004
		US2005095552A1	05.05.2005
		US2005095562A1	05.05.2005
		US2005118555A1	02.06.2005
		US2005153255A1	14.07.2005
		US2006079981AA	13.04.2006
		US6648640B2	18.11.2003
		US6971873BB	06.12.2005
		US7013191BB	14.03.2006
		US7029275BB	18.04.2006
		US7 1601 1OBB	09.01.2007
		US7172417BB	06.02.2007
US2004029078A1	12.02.2004	None	
US2005170309A1	04.08.2005	AU2004316121AA	01.09.2005
		EP1711120A1	18.10.2006
		WO2005079695A1	01.09.2005

Form PCT/ISA/210 (patent family annex) (April 2007)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 January 2013 (24.01.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/010910 A1

(51) International Patent Classification:
G06T 7/00 (2006.01)

(21) International Application Number:
PCT/EP2012/063687

(22) International Filing Date:
12 July 2012 (12.07.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PA 2011 00547 15 July 2011 (15.07.2011) DK
61/508,314 15 July 2011 (15.07.2011) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

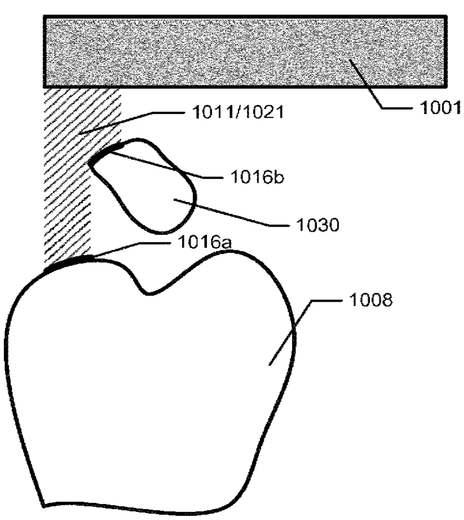
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: DETECTION OF A MOVABLE OBJECT WHEN 3D SCANNING A RIGID OBJECT

Fig. 10a)



(57) Abstract: Disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises: providing a first 3D representation of at least part of a surface by scanning at least part of the location; providing a second 3D representation of at least part of the surface by scanning at least part of the location; determining for the first 3D representation a first excluded volume in space where no surface can be present; determining for the second 3D representation a second excluded volume in space where no surface can be present; if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

WO 2013/010910 A1

Align 1040
Align v. 3Shape
IPR2018-00197

Detection of a movable object when 3D scanning a rigid object

Field of the invention

This invention generally relates to a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object. More particularly, the invention relates to scanning of a patient's set of teeth in the mouth of the patient by means of a handheld scanner.

Background of the invention

In traditional dentistry, the dentist makes a dental impression of the patient's teeth, when the patient needs a crown, a bridge, a denture, a removable, an orthodontic treatment etc.. An impression is carried out by placing a viscous liquid material into the mouth, usually in a dental impression tray. The material, usually an alginate, then sets to become an elastic solid, and, when removed from the mouth, provides a detailed and stable reproduction of teeth. When the impression is made, cheek retractors are arranged in the patient's mouth to avoid that the soft movable cheeks affect the impression of the teeth.

Today direct 3D scanning of the patient's teeth can be obtained using an intraoral handheld 3D scanner instead of making a physical dental impression.

When scanning a rigid object in a location for obtaining a virtual 3D model of the rigid object, such as scanning teeth in the mouth of a patient by means of a handheld scanner, it may happen that movable objects such as the patient's cheeks, tongue, or the dentist's instruments or fingers are captured in the sub-scans, because these movable object are located for example between the surface of the teeth and the scanner, whereby the movable object obstruct the view of the teeth for the scanner. As the movable objects are movable they will typically move, and therefore it is likely that the movable object is only captured in one or a few subscans. Since a number of subscans are typically acquired for obtaining a virtual 3D model of, it is likely that there will also be acquired subscans of the same part of the rigid object but without the movable object obstructing the rigid object. Typically the movable objects will move or be moved very fast, since both the patient knows that his tongue should not touch or be near for the teeth when his teeth is scanned and the dentist knows that his instruments should not obstruct the visual access to the teeth. Therefore the movable object will typically only obstruct the visual access of the teeth for a very short time, and this means that the movable object will typically only be captured in one or few subscans. Furthermore, if the dentist notice that a movable object was present when he scanned a part of the teeth, he may return to scan the same part of the teeth where the movable object was before, and thus in most cases, there will also be subscans where the movable object is not present. The problem is then to differentiate between the surface of the movable object and the surface of the rigid object, such that only the surfaces originating from the rigid object are used when generating the virtual 3D model.

In prior art geometry and colour data are used to distinguish between a first and a second tissue, such as hard tissue as teeth and soft tissue as gums, tongue, cheeks, and lips.

EP1607041B discloses a method of providing data useful in procedures associated with the oral cavity characterized by comprising: providing at least two numerical entities (I_1, I_2,...,I_n), each said numerical entity representative of the three-dimensional surface geometry and colour of at least part of the intra-oral cavity wherein said numerical entity comprises surface geometry and colour data associated with said part of the intra-oral cavity; wherein at least a portion of said entities (I_1, I_2,...I_n) comprise overlapping spatial data, comprising:

· (a) for each entity providing at least one sub entity (IS'_1, IS'_2,...IS'_n) comprising a first tissue data set comprising surface geometry and colour data, wherein said colour data thereof is correlated with a colour representative of a first tissue; and

· (b) stitching said first tissue data sets together based on registering portions of said data set comprising said overlapping spatial data (I_1, I_2,...I_n) and

· manipulating said entity to provide desired data therefrom.

Furthermore, in image processing a method called space carving is used for building up a 3D model.

The article "A Method for Registration of 3-D Shapes" by Besl and McKay, IEEE Transactions of Patten Analysis and Machine Intelligence, vol. 14, no. 2, February 1992 discloses a method for accurate and computationally efficient registration of 3-D shapes.

However, none of the prior art considers the case where some of the objects in the location are movable.

Thus it remains a problem to distinguish between movable objects and rigid objects, when both movable objects and rigid objects are present in a location, when scanning in the location for obtaining a virtual 3D model of the rigid object.

Summary

Disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- determining for the first 3D representation a first excluded volume in space where no surface can be present;
- determining for the second 3D representation a second excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

Consequently, it is an advantage to disregard a surface portion from one representation if the surface portion is located in space in the excluded volume of another representation, because a surface portion detected in an excluded volume represents a movable object which is not part of the rigid object.

Thus it is an advantage that the method provides a determination of whether a detected surface portion is a point in space where there should be no surface, by detecting the space of the surface portion in both a first representation and in the second representation. If the surface portion is only present in one of the representations and the representations cover the same space of the surface portion, then the surface portion must represent an object which was only present when one of the representations were acquired, and therefore the surface portion must originate from a movable object, which has moved during the acquisitions of the two representations.

When scanning a surface, then all space which is not occupied by the surface, may be defined as empty space, and if in a later scan, a surface is detected in the empty space, then that surface is disregarded.
Likewise, if in a later scan, a volume region is seen to be empty, but that volume region was covered by a surface in a previous scan, then the surface is disregarded from the 3D virtual model.

By disregarding is meant not taken into account, such as deleting or not adding, when generating the 3D virtual model. If a surface portion from the first representation has already been added to the virtual 3D model, it may be deleted from it again if it is found that the surface portion is in the second excluded volume. If a surface portion from the second representation is found to be in the first excluded volume, the surface portion is not added to the virtual 3D model.

If a volume region in one representation or subscan is empty then it is excluded from addition of new surfaces even though a later representation or subscan shows that a surface is present in the volume regions. If a later representation or subscan shows that the volume is empty then a surface from a previous subscan in that volume is removed from the 3D model.

A common scan volume can be defined, which is the volume in space where the first scan volume and the second scan volume are overlapping. Thus it may be defined as the volume in space, where all volume units are contained in both the first scan volume and in the second scan volume.

If a portion of the surface in the first 3D representation is not located in space in the second excluded volume, and/or if a portion of the surface in the second 3D representation is not located in space in the first excluded volume, no surface portions are disregarded yet, and the scanning may continue by providing a third representation, a fourth representation etc.

Typically when scanning an object, such as a set of teeth, more representations or subscans may be provided, such as 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000 etc. during a complete scanning process.

In some embodiments the rigid object is a patient's set of teeth, and the location is the mouth of the patient.

In some embodiments the movable object is a soft tissue part of the patient's mouth, such as the inside of a cheek, the tongue, lips, gums and/or loose gingival.

In some embodiments the movable object is a dentist's instrument or remedy which is temporarily present in the patient's mouth, such as a dental suction device, cotton rolls, and/or cotton pads.

In some embodiments the movable object is a finger, such as the dentist's finger or the dental assistant's finger.

In some embodiments the 3D scanner is a scanner configured for acquiring scans of an object's surface for generating a virtual 3D model of the object.

In some embodiments at least part of the surface captured in the first representation and at least part of the surface captured in the second representation are overlapping the same surface part on the rigid object.

In some embodiments the first representation of at least part of the surface is defined as the first representation of at least a first part of the surface, and the second representation of at least part of the surface is defined as the second representation of at least a second part of the surface.
The first part of the surface and the second part of the surface may be two different parts, or may be the same part, or may be partly the same part.

In some embodiments the first part of the surface and the second part of the surface are at least partially overlapping.

In some embodiments the surface is a surface in the location.

In some embodiments the surface is at least part of the surface of the rigid object and/or at least part of the surface of the movable object.
The purpose of scanning is to acquire a virtual 3D model of the rigid object, e.g. teeth, but if there is a movable object in the location, e.g. the mouth of the patient, when scanning, then the movable object may also be captured in some of the subscans.

In some embodiments the method comprises determining a first scan volume in space related to the first representation of at least part of the surface, and determining a second scan volume in space related to the second representation of at least part of the surface.
The scan volume may be the volume in space which is located in front of the captured surface relative to the scanner.

In some embodiments the scan volume is defined by the focusing optics in the 3D scanner and the distance to the surface which is captured.
The scan volume may be defined as the physical volume which the scanner is adapted to scan relative to the view position and the orientation of the scanner, such as relative to the scan head of the scanner.

Furthermore, the scanner comprises a scan head, and the scan volume may be defined as the distance in space between the surface and the scan head times the area of the opening of the scan head. The scan head may comprise the focusing optics of the scanner.
Instead of the area of the opening of the scan head, the area of the surface projected in the optical direction may be considered.

In some embodiments the first scan volume related to the first representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the first representation; and the second scan volume related to the second representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the second representation.

In some embodiments if no surface is captured in at least part of the first or second representation, then the first or second scan volume is the volume in space between the focusing optics of the 3D scanner and the longitudinally extent of the scan volume.

In some embodiments the first excluded volume and the second excluded volume in space where no surface can be present corresponds to the first scan volume and the second scan volume, respectively.
The space between the focusing optics of the 3D scanner and the captured surface must be an empty space, unless a transparent object, which is not detectable by the 3D scanner, was located in the scan volume.

The scan volume may be defined as the maximum volume which can be scanned, e.g. the maximum volume of light which can be transmitted from the scan head. In that case, the excluded volume would only correspond to the scan volume, if the captured surface is located at the end or edge of the scan volume. But in most cases the excluded volume would be smaller than the scan volume, if the definition of the scan volume was the maximum volume.

In some embodiments the volume of the 3D scanner itself is defined as an excluded volume.

In some embodiments the volume of the 3D scanner itself is comprised in the first excluded volume and in the second excluded volume.

In some embodiments a near threshold distance is defined, which determines a distance from the captured surface in the first representation and the second representation, where a surface portion in the second representation or the first representation, respectively, which is located within the near threshold distance from the captured surface and which is located in space in the first excluded volume or in the second excluded volume, respectively, is not disregarded in the generation of the virtual 3D model.

The near threshold defines how far from the representation or surface in a subscan possibly movable objects are disregarded from the generation of the virtual 3D model. The near threshold distance is defined for avoiding that too much of a representation of a surface is incorrectly disregarded, since there may be noise in the representation and since the registration/alignment between representations or sub-scans may not be completely accurate. Due to different levels of noise in different subscans or due to inaccurate