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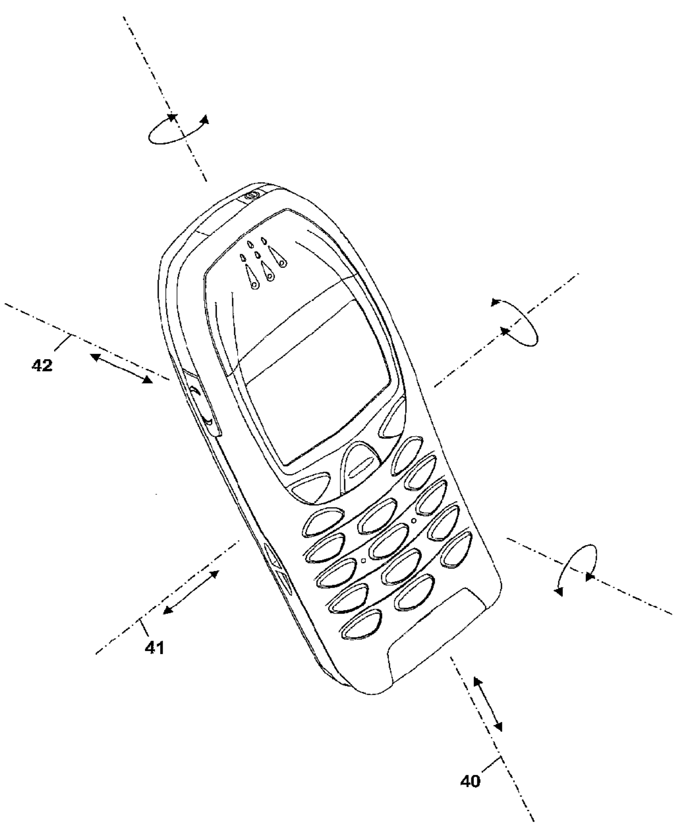

(57) Abstract: The present invention relates to the field of hand-held devices that are equipped wit a processor and a digital camera for capturing motion video or still images. Images captured by the camera are used to determine motion of the hand-held device. A resulting motion signal is used as input 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

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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 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.

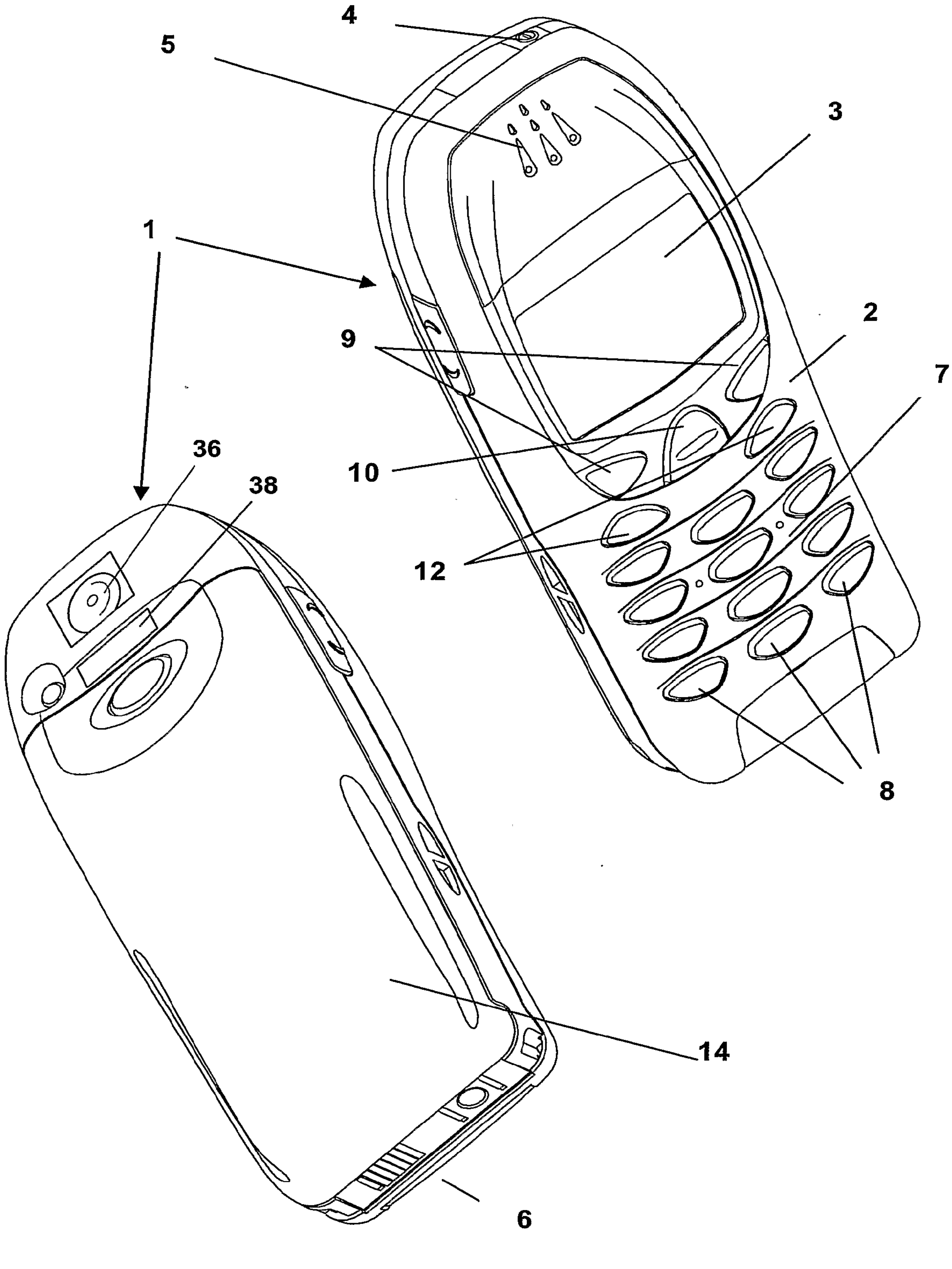

Fig. 1

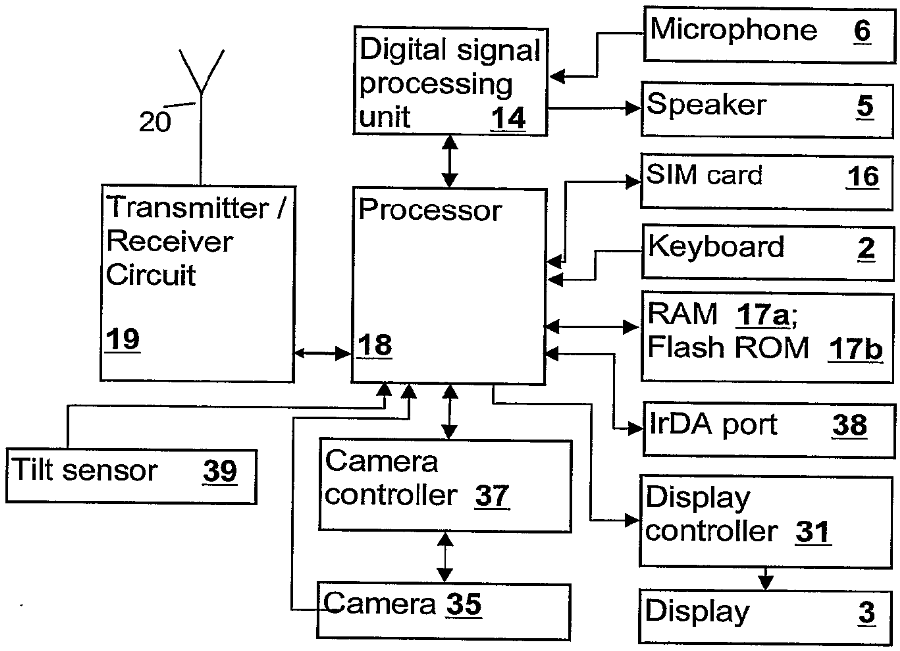
Digital signal processing unit 14
Microphone 6
Speaker 5
20
SIM card 16
Transmitter / Receiver Circuit 19
Processor 18
Keyboard 2
RAM 17a; Flash ROM 17b
IrDA port 38
Tilt sensor 39
Camera controller 37
Display controller 31
Camera 35
Display 3

Fig. 2

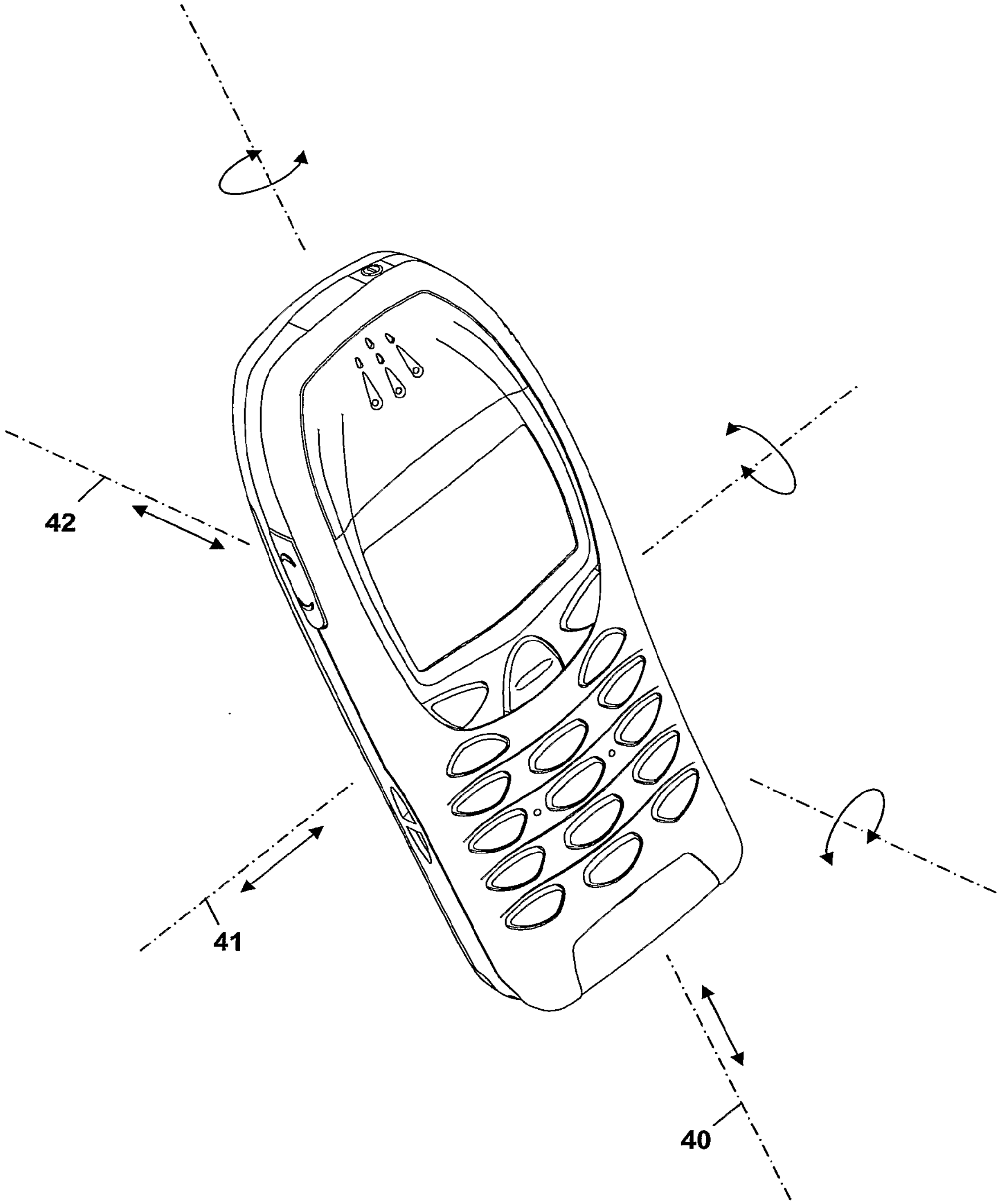

Fig. 3

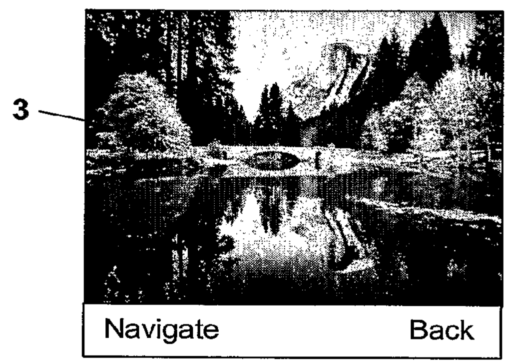

Fig. 3.1

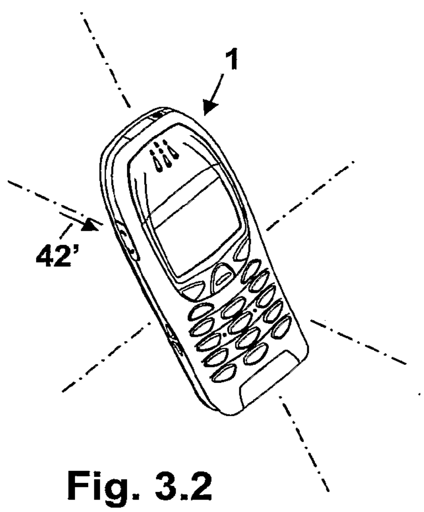

Fig. 3.2

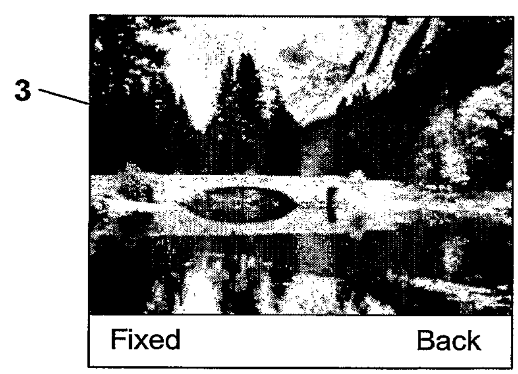

Fig. 3.3

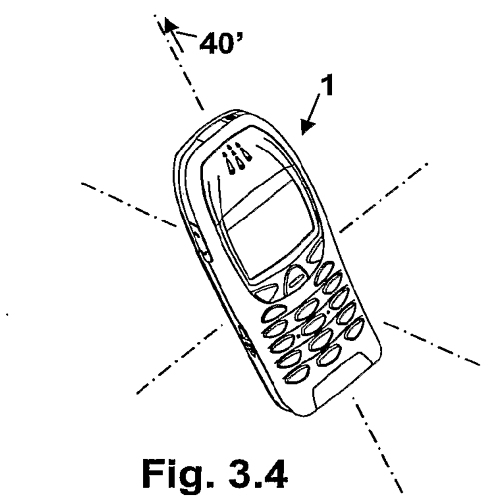

Fig. 3.4

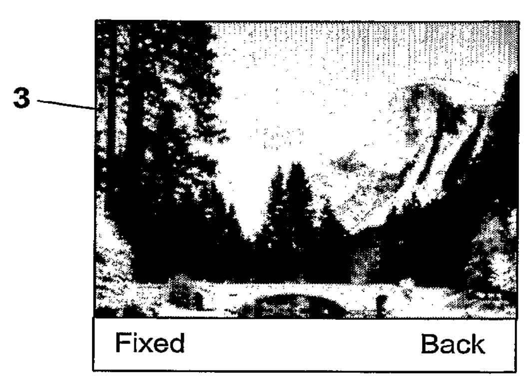

Fig. 3.5

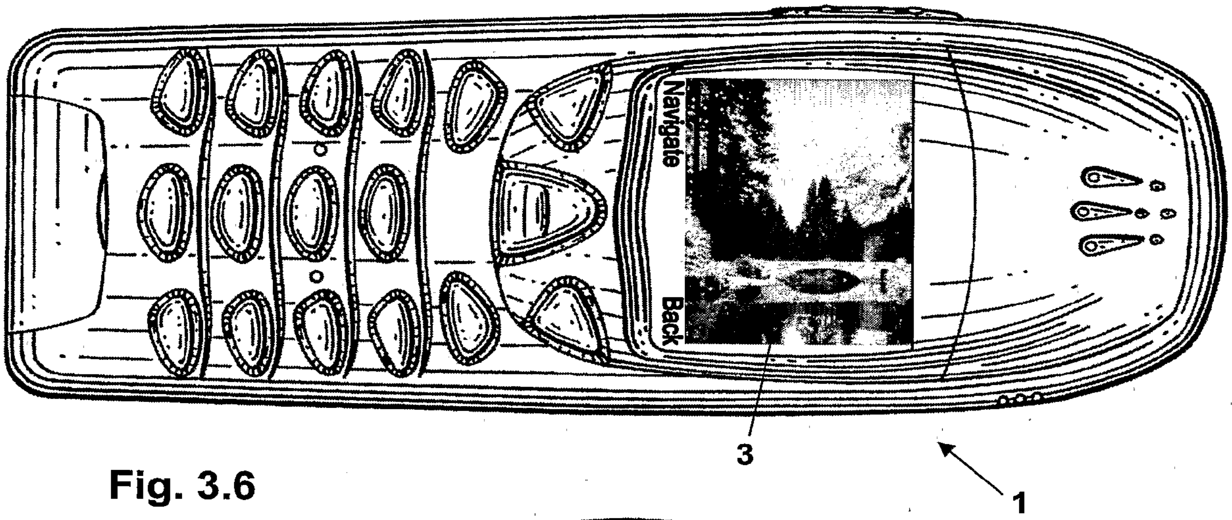

Fig. 3.6

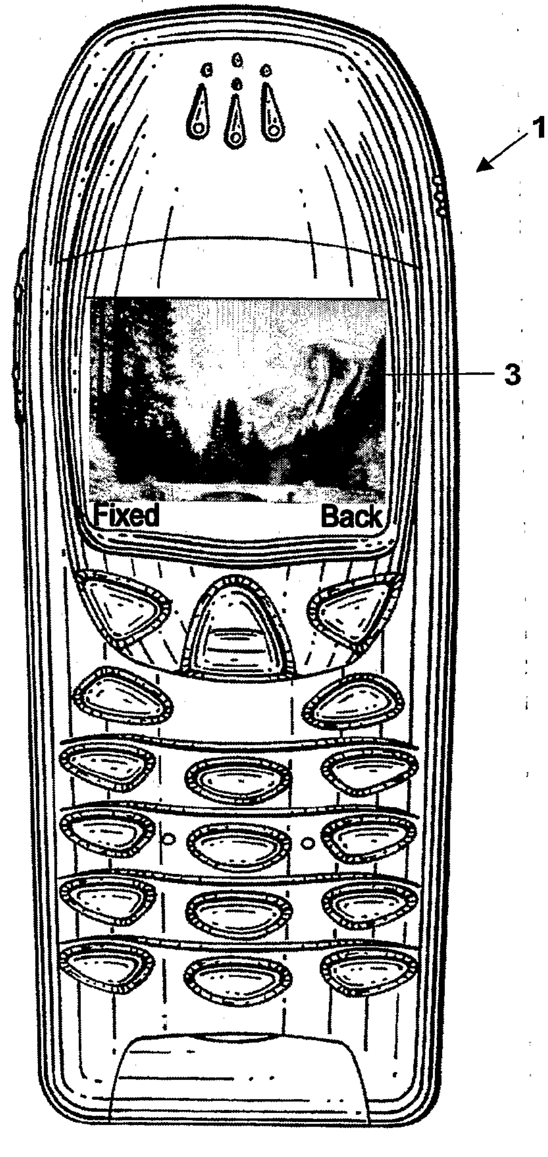

Fig. 3.7

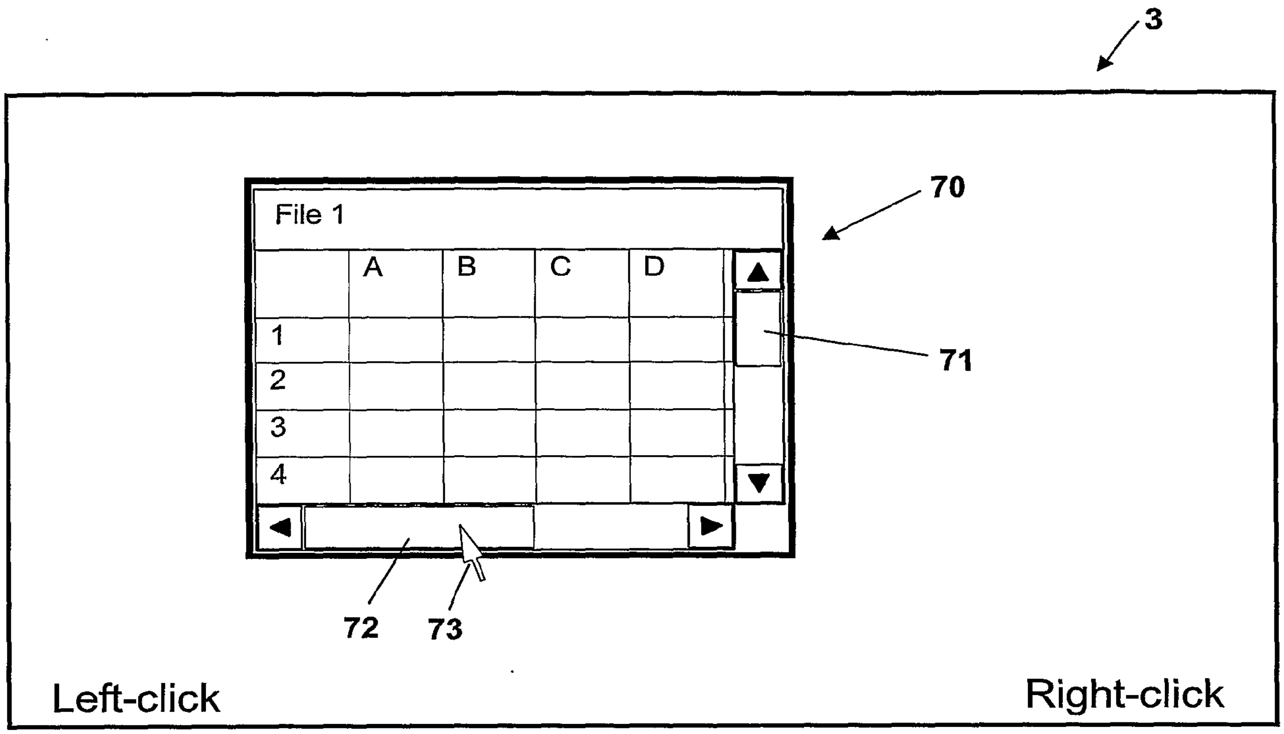
3
File 1
A
B
C
D
1
2
3
4
70
71
72
73
Left-click
Right-click

Fig. 3.8

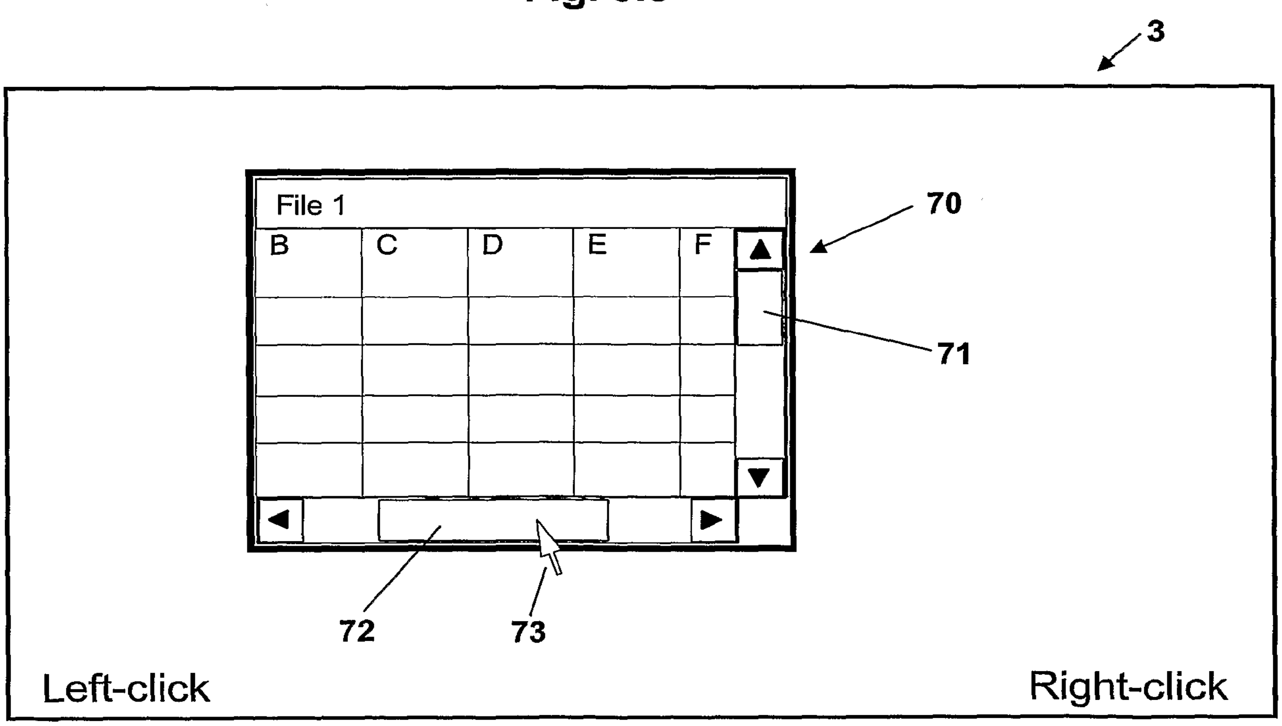
3
File 1
B
C
D
E
F
70
71
72
73
Left-click
Right-click

Fig. 3.9

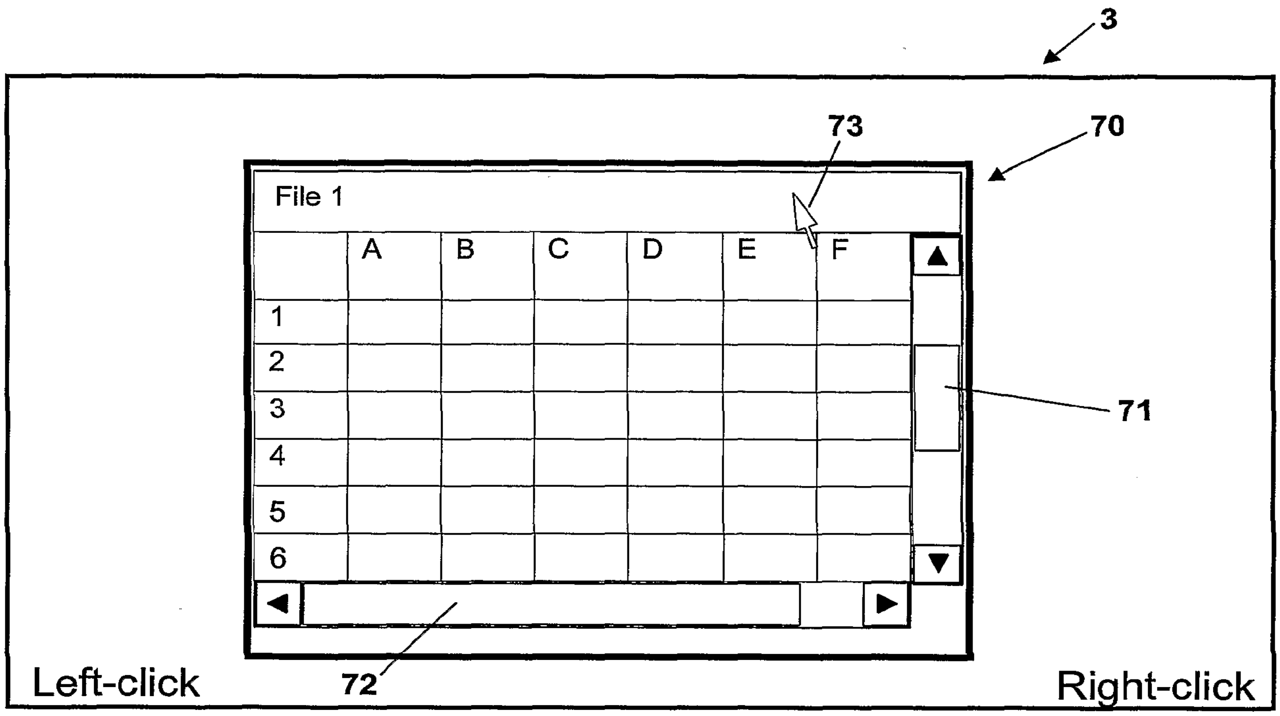

Fig. 3.10

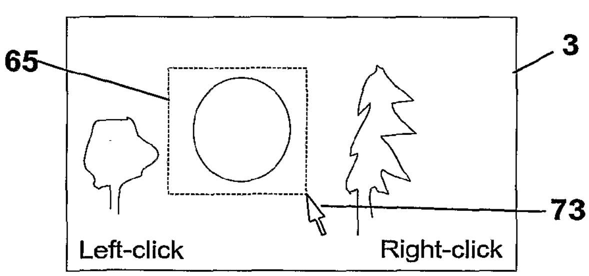

Fig. 3.14

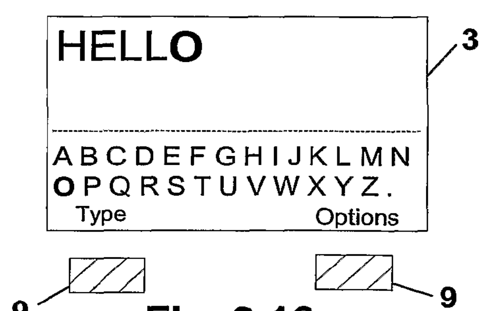

Fig. 3.16

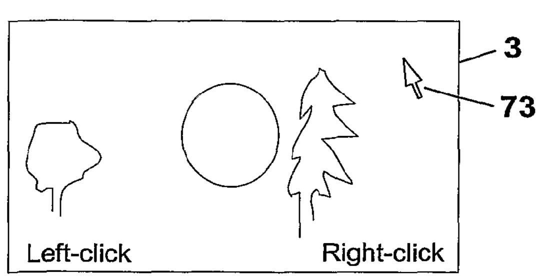

Fig. 3.15

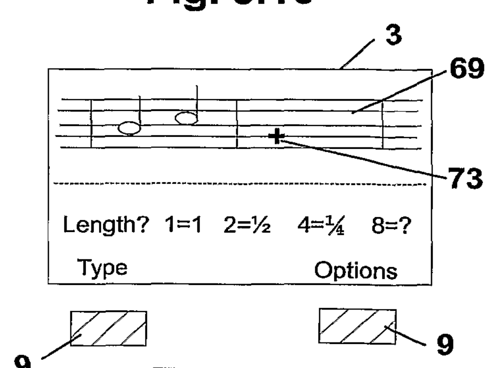

Fig. 3.17

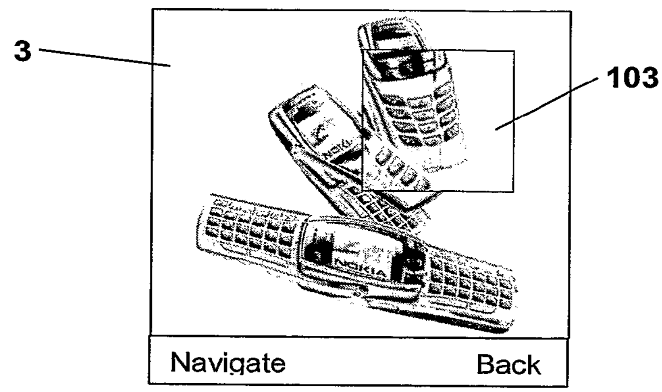

Fig. 3.11

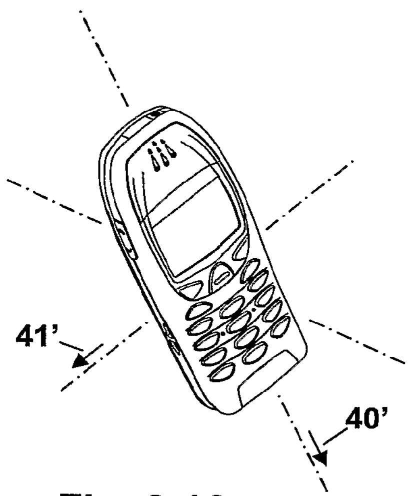

Fig. 3.12

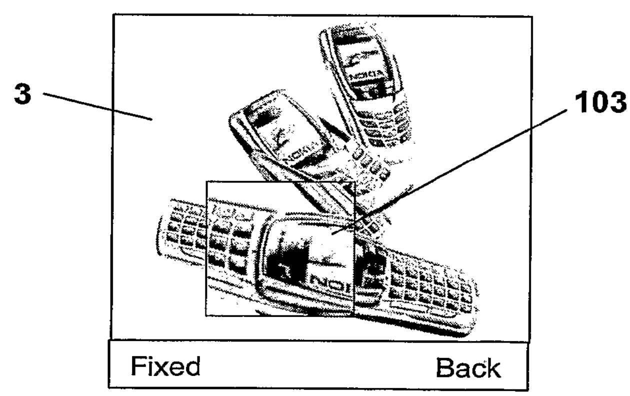

Fig. 3.13

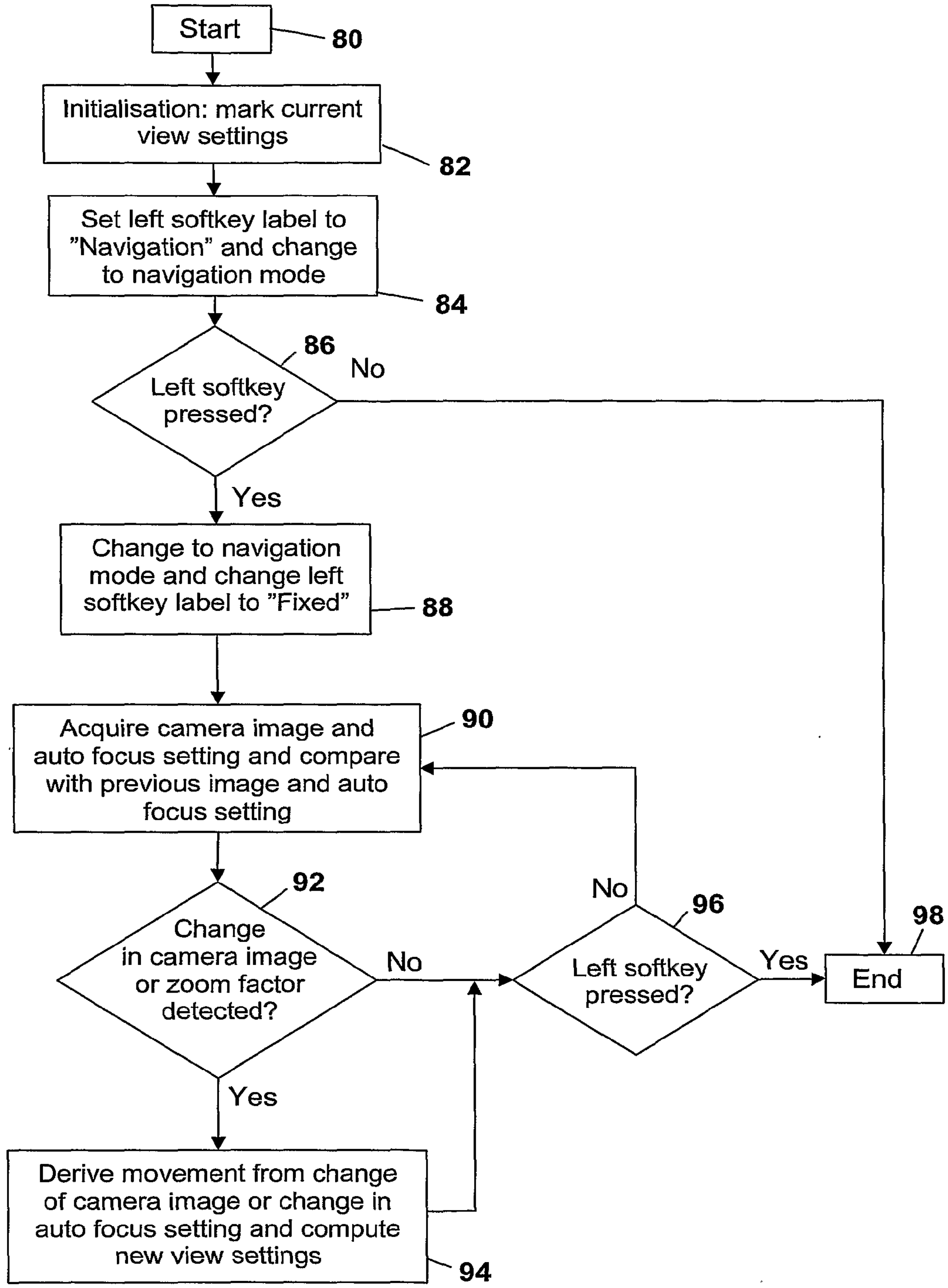
Start
80
Initialisation: mark current view settings
82
Set left softkey label to "Navigation" and change to navigation mode
84
86
Left softkey pressed?
No
Yes
Change to navigation mode and change left softkey label to "Fixed"
88
Acquire camera image and auto focus setting and compare with previous image and auto focus setting
90
92
Change in camera image or zoom factor detected?
No
Yes
Derive movement from change of camera image or change in auto focus setting and compute new view settings
94
No
96
Left softkey pressed?
Yes
98
End

Fig. 4

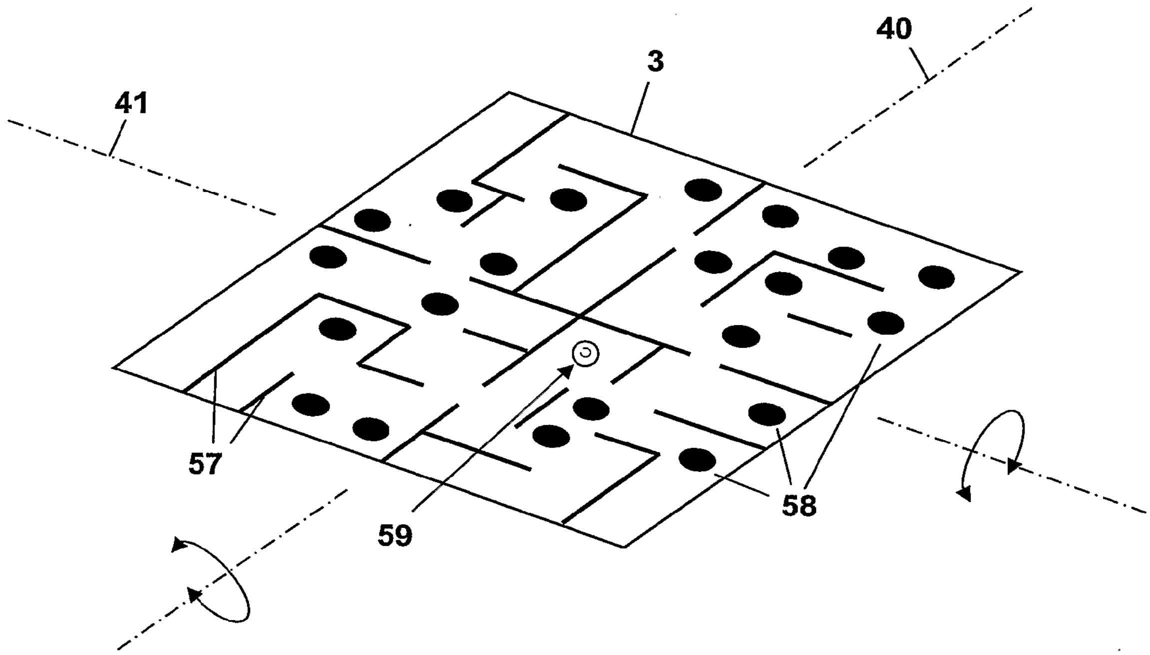

Fig. 3.18

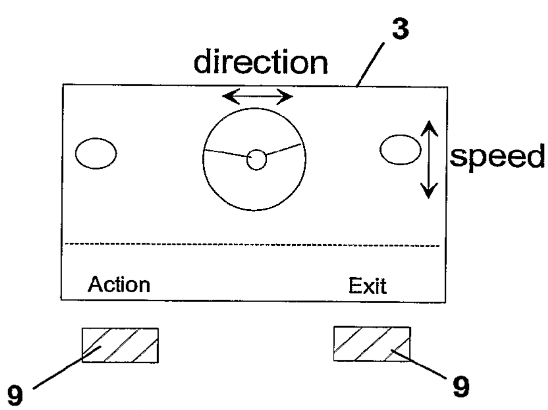

Fig. 3.19

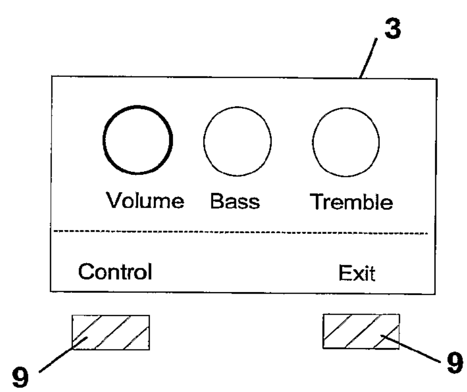

Fig. 3.20

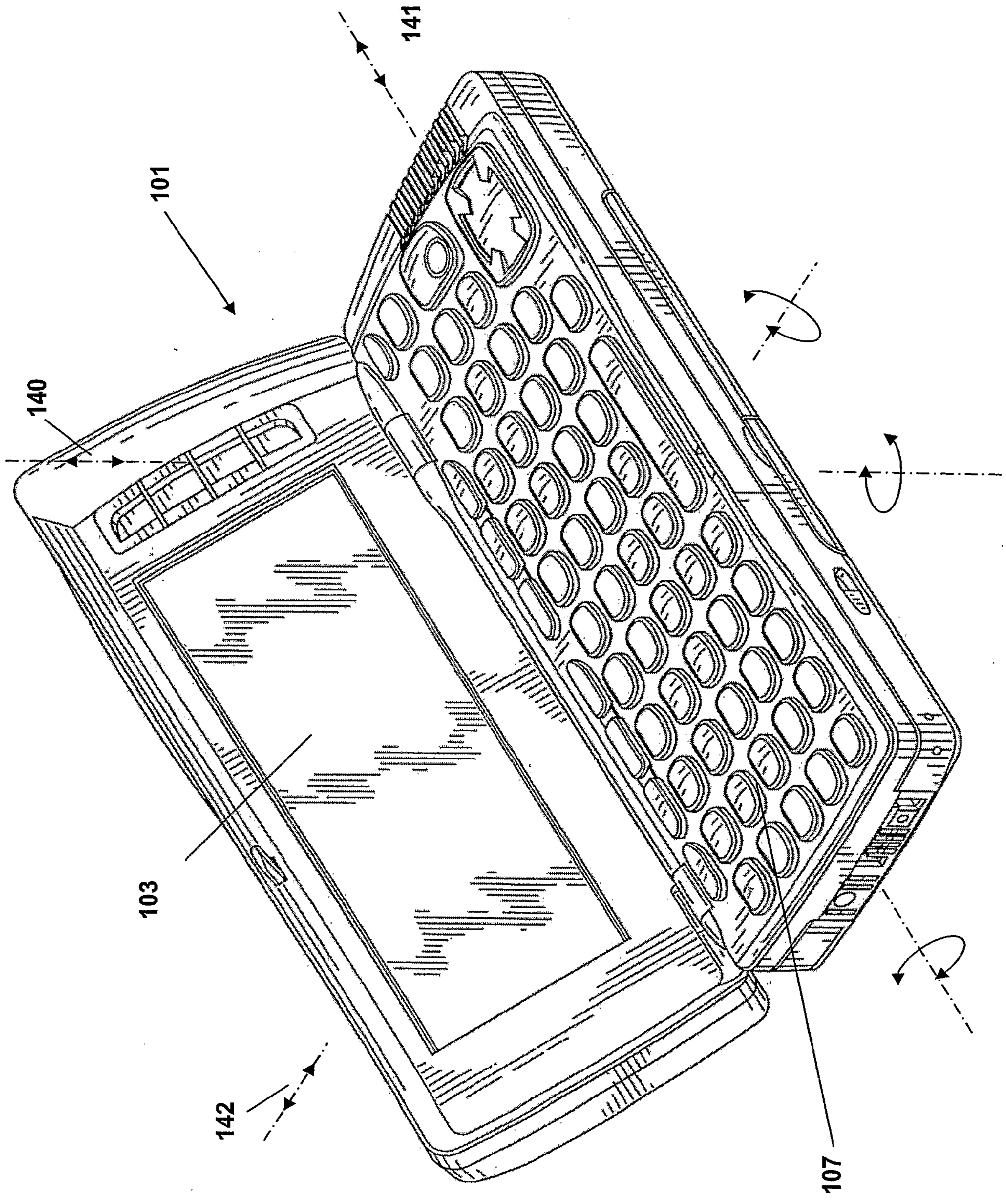

Fig. 5

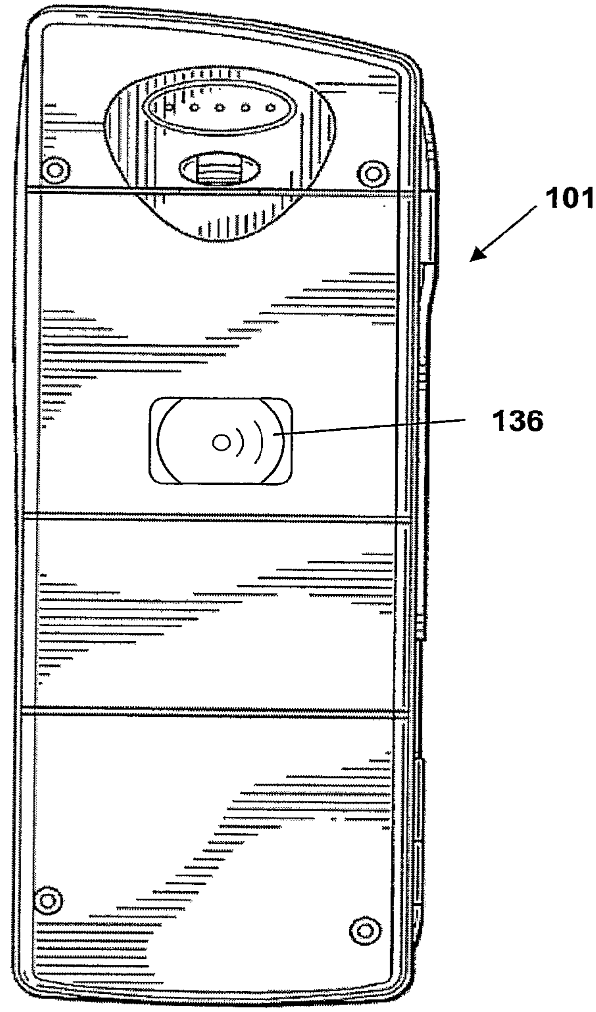

Fig. 6

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

[X] Patent family members are listed in annex.

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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
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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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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).

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(54) Title: THREE-DIMENSIONAL MODEL REFINEMENT

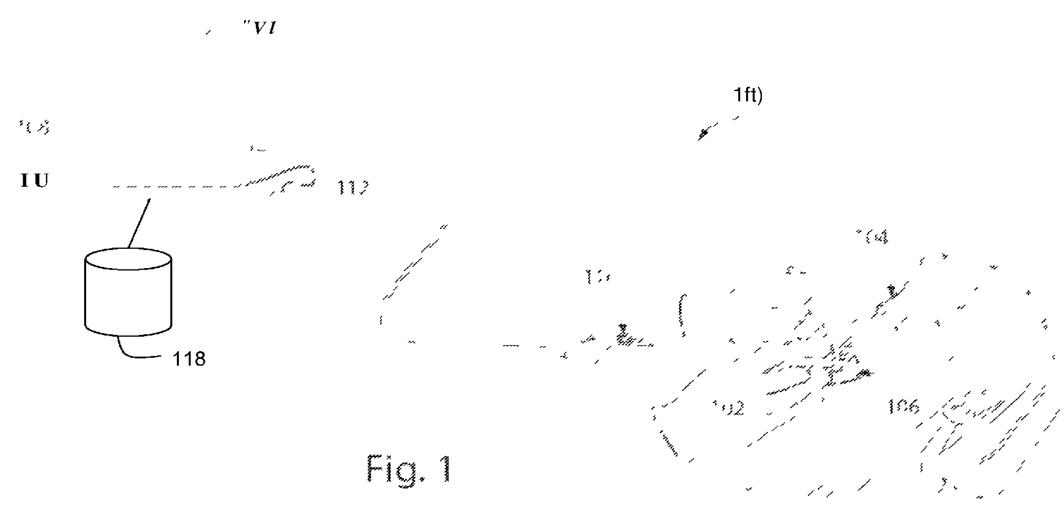

Fig. 1

(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 $\{x_i, y_i, d_i(x_i, y_i)\}$ 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 X_O 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:

$$X_0 = R_{OA}^{-1}(X_A - T_{0A}) = R_{0B}^{-1}(X_B - T_{0B}) \qquad \text{[Eq. 6]}$$

[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:

$$X_B = R_{AB} X_A + T_{AB} \qquad \text{[Eq. 7]}$$

[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^{ι}_{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. $R'_{c,0A}$ and $R'_{c,0B}$ may be defined to be the candidate rotations; $T'_{c,0A}$ and $T'_{c,0B}$ may be defined to be the candidate translations corresponding to the A and B camera of the zth stitch. Further, $R'_{c,AB} = R'_{c,0B}(R'_{c,0A})^{-1}$ may be defined as the candidate rotation from A to B, and $T'_{c,AB} = T^{\iota}_{c,0B} - R'_{c,M} T^{\iota}_{c,0A}$, 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'_c the corresponding candidate camera-to-camera rotations, $R'_{c,AB}$, may be computed that correspond to each of the measured camera-to-camera rotations, R^{ι}_{AB}. Thus the corresponding residual rotations are given by $R^{\iota}_{residual,AB} = R'_{C,AB}(R'_{AB})^{-1}$. 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:

$$e_c(R_{C,On}, T_{C,On}) = \sum_{i=1}^{\#stitches} \left(\begin{bmatrix} r_t^i \\ r_r^i \end{bmatrix}^T W_c \begin{bmatrix} r_t^i \\ r_r^i \end{bmatrix} \right) \qquad [Eq. 10]$$

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:

$$r^{\iota}_{t,ctr} = \overline{X}'_B - (Rc'_{,AB}\overline{X}'_A + T^{\iota}_{C,AB}) \qquad \text{[Eq. 11]}$$

Equation 10 may then be reformulated as:

$$e_c(R_{c},o_n Jc,o_n) = {}^{\#}\mathrm{T}_{\iota=1} \left(r_{t;ctr} \mathrm{V} \; ; r^{\iota}_{t,ctr} + rfwX' \right) \qquad \text{[Eq. 12]}$$

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.

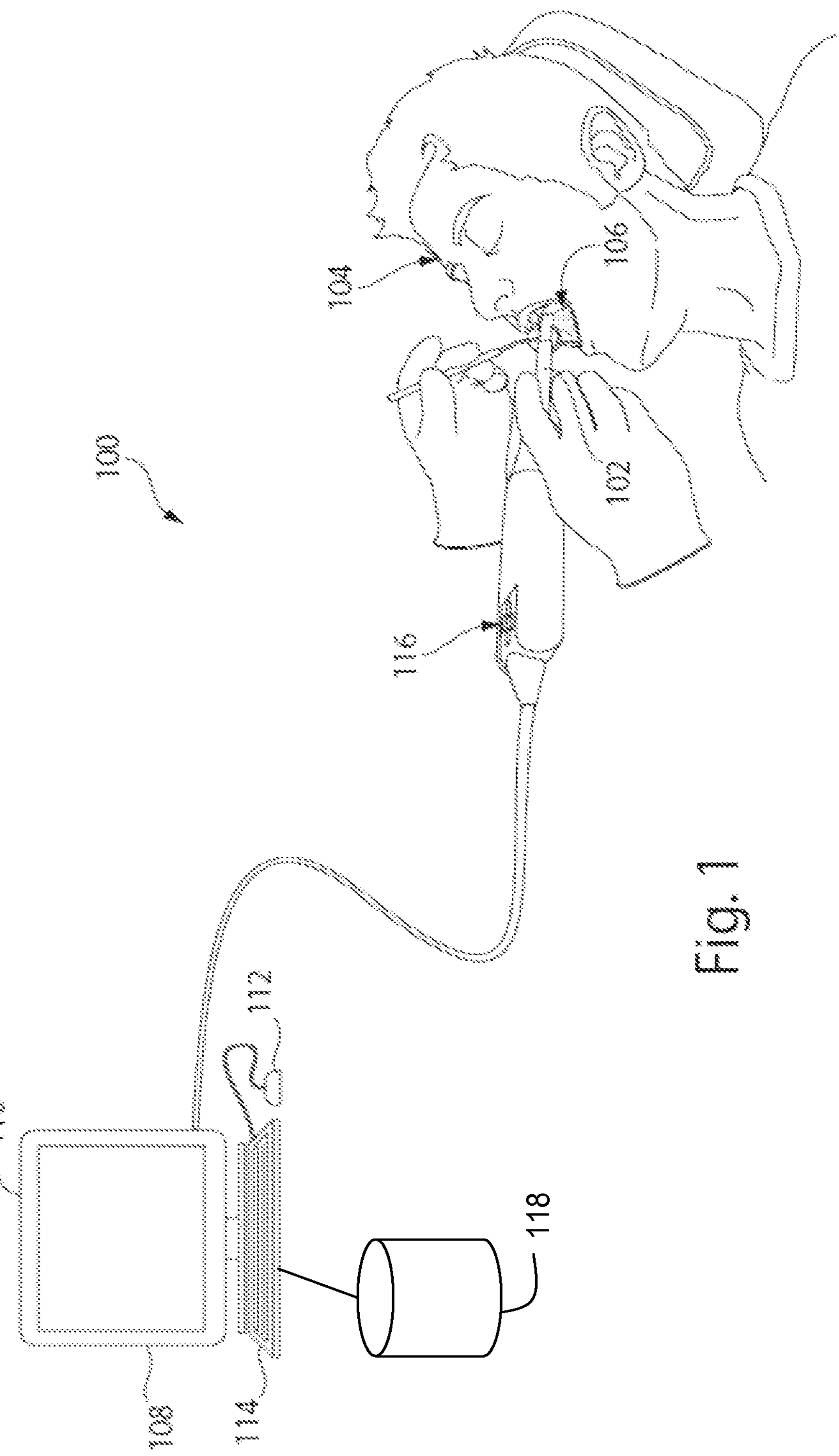

Fig. 1

2/8

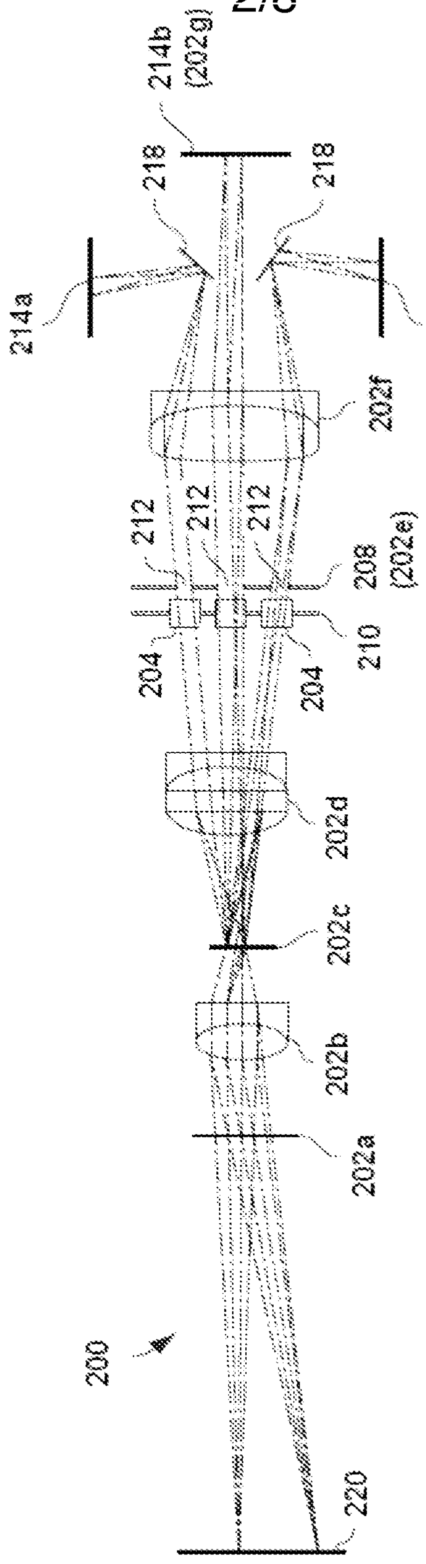
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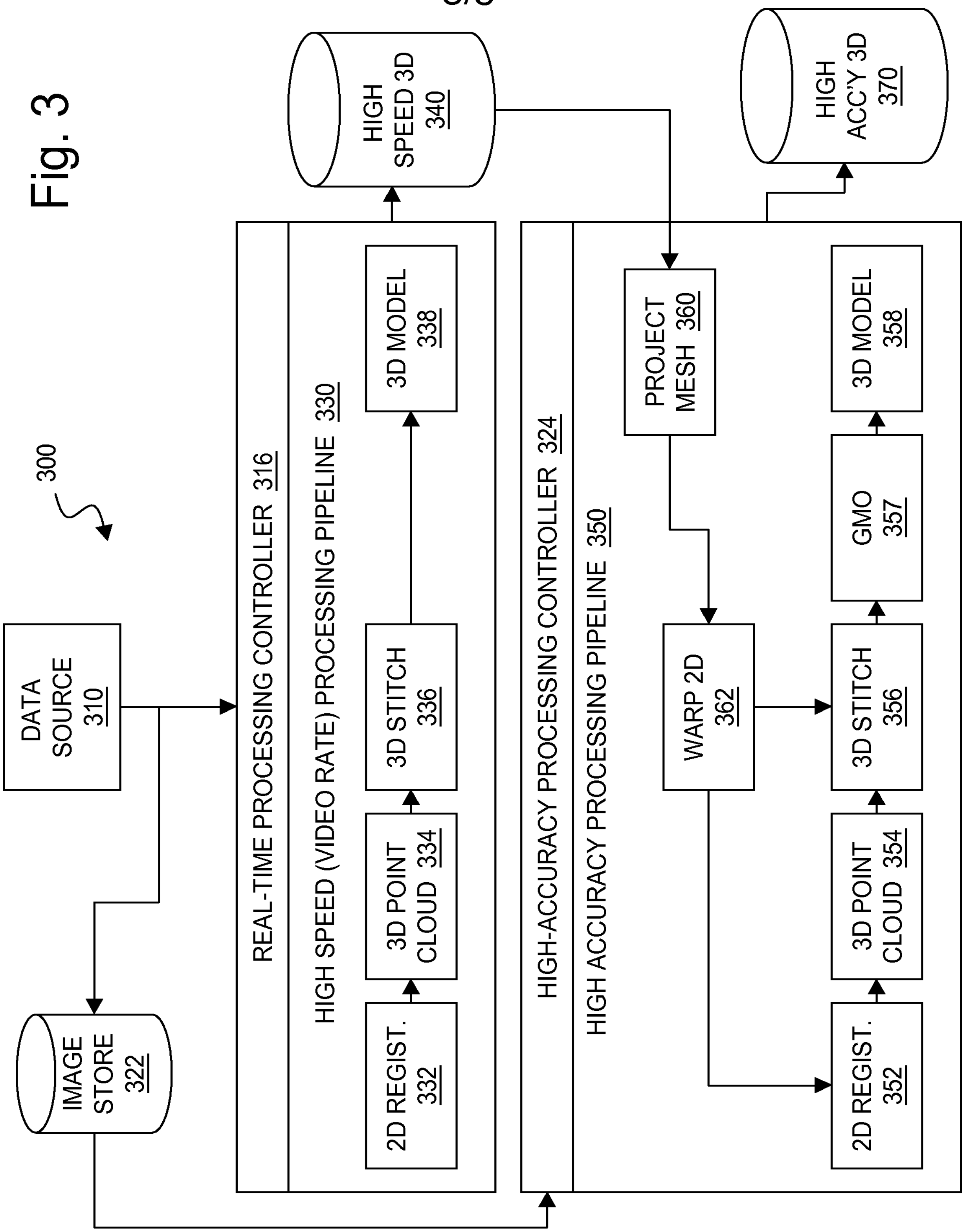
Fig. 2

3/8

Fig. 3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REAL-TIME PROCESSING CONTROLLER 316
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3D STITCH 336
3D MODEL 338
HIGH SPEED 3D 340
HIGH-ACCURACY PROCESSING CONTROLLER 324
HIGH ACCURACY PROCESSING PIPELINE 350
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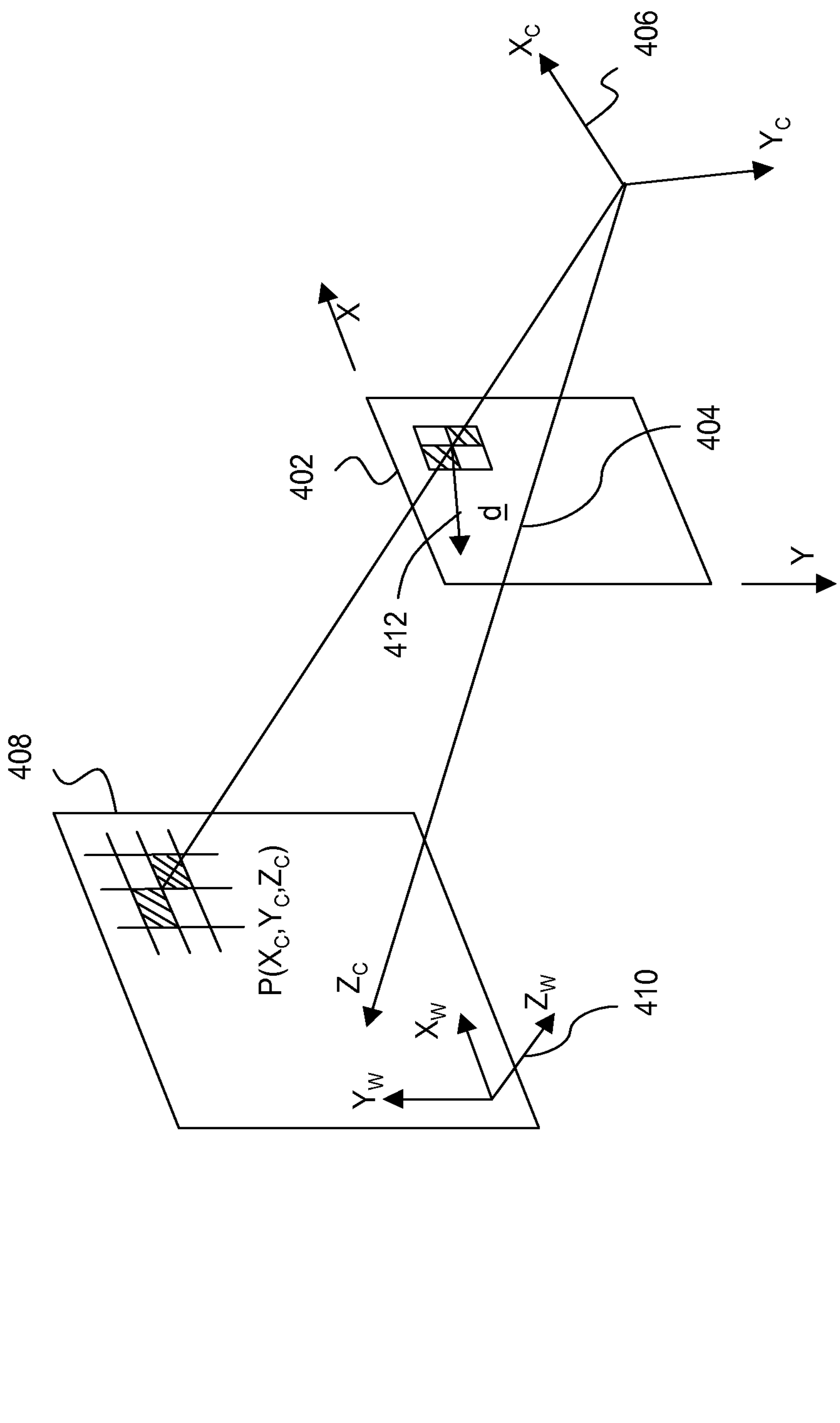

Fig. 4

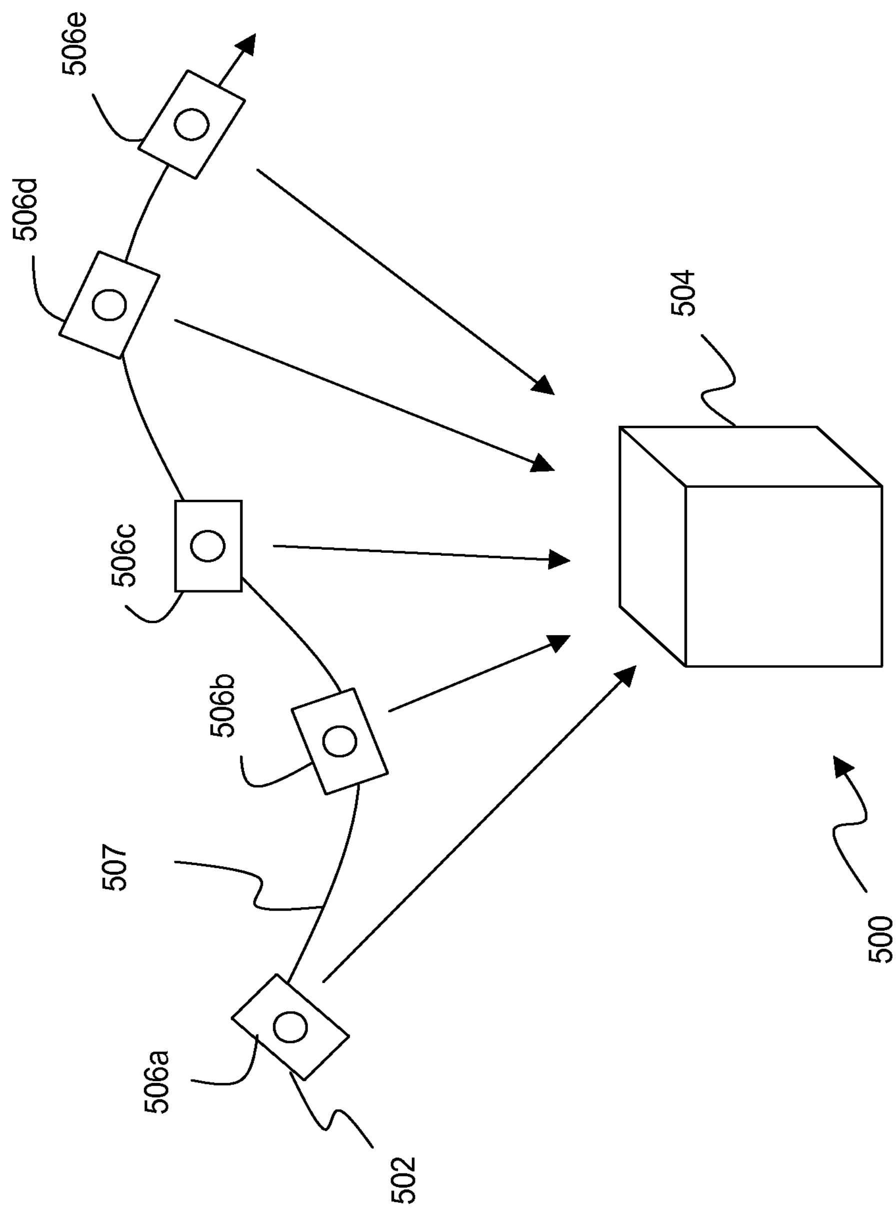

Fig. 5

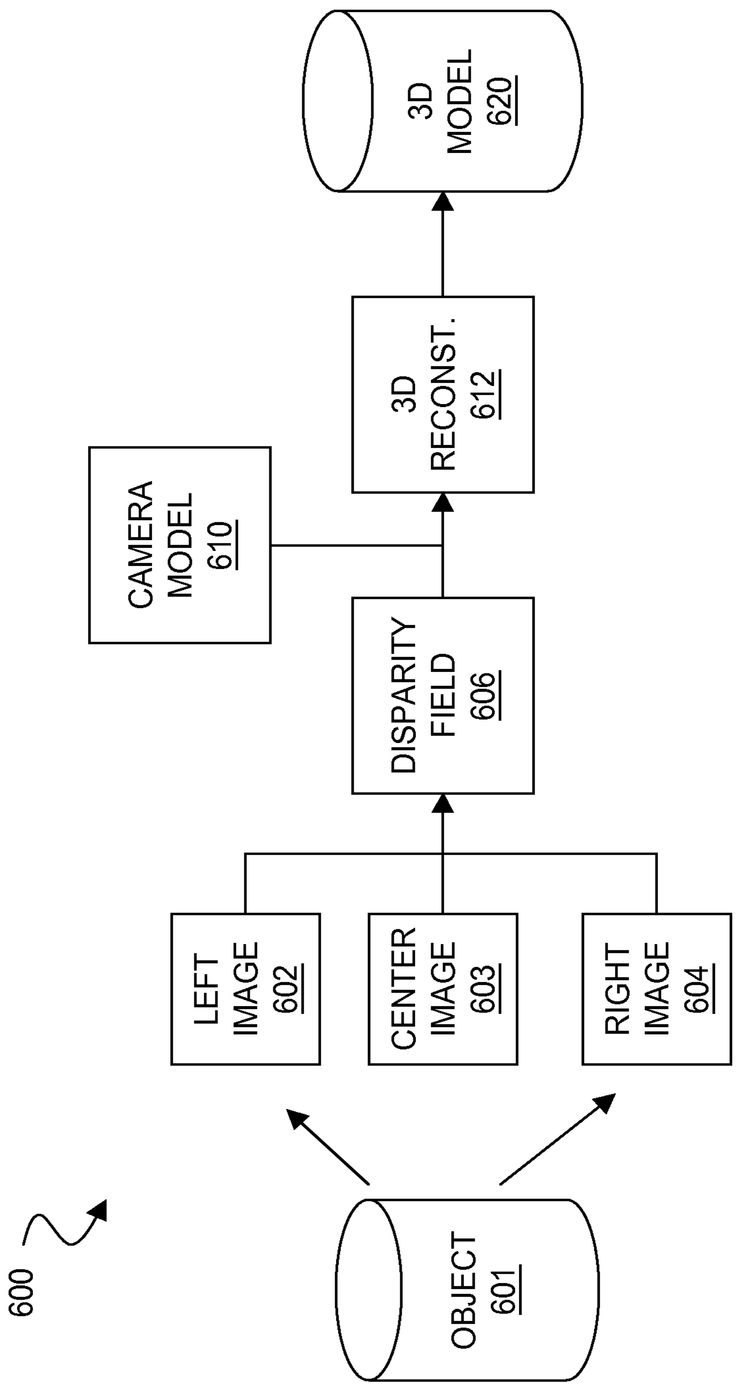
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IMAGE
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CENTER
IMAGE
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RIGHT
IMAGE
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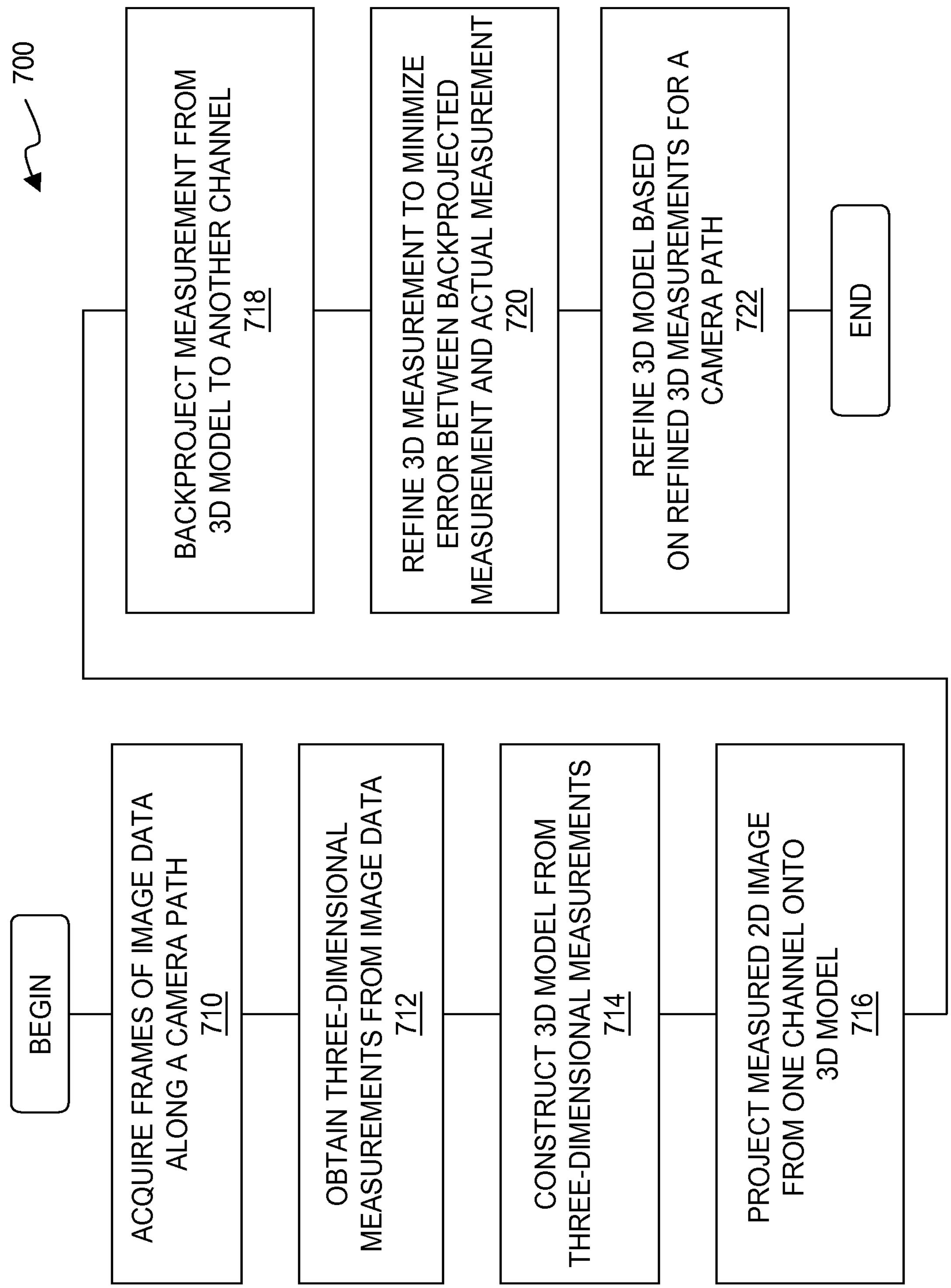
MODEL
620

Fig. 6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BEGIN
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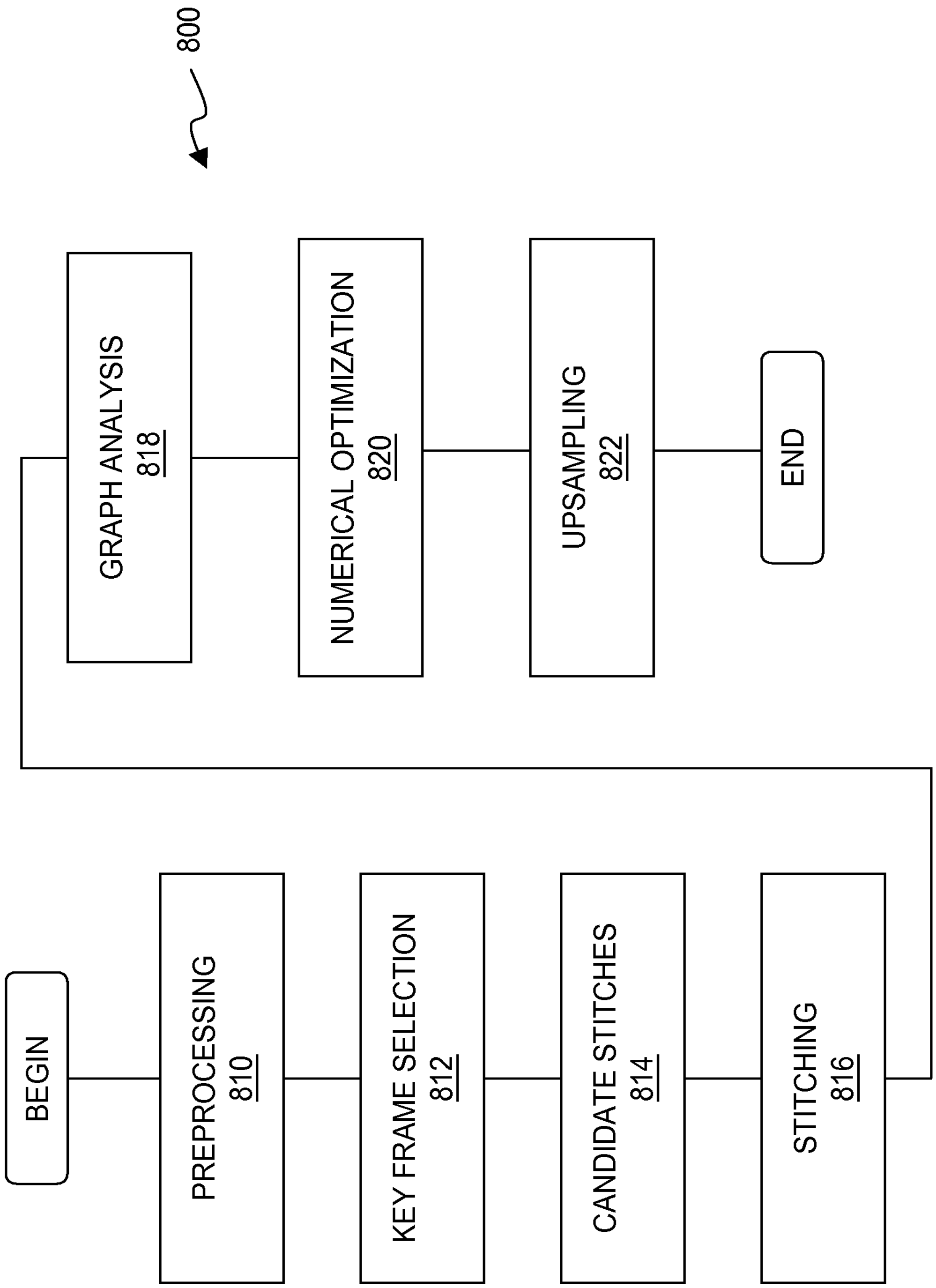
OBTAIN THREE-DIMENSIONAL MEASUREMENTS FROM IMAGE DATA 712
CONSTRUCT 3D MODEL FROM THREE-DIMENSIONAL MEASUREMENTS 714
PROJECT MEASURED 2D IMAGE FROM ONE CHANNEL ONTO 3D MODEL 716
BACKPROJECT MEASUREMENT FROM 3D MODEL TO ANOTHER CHANNEL 718
REFINE 3D MEASUREMENT TO MINIMIZE ERROR BETWEEN BACKPROJECTED 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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KEY FRAME SELECTION 812
CANDIDATE STITCHES 814
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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"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)

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JUNG, Yun Seok
Telephone No 82-42-481-8123

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	

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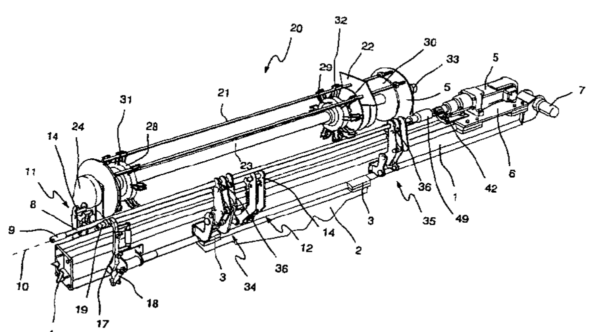
(54) **Title:** ARRANGEMENT FOR FIXING ROCK BOLTS DURING ROCK REINFORCEMENT



(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, **characterised 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.

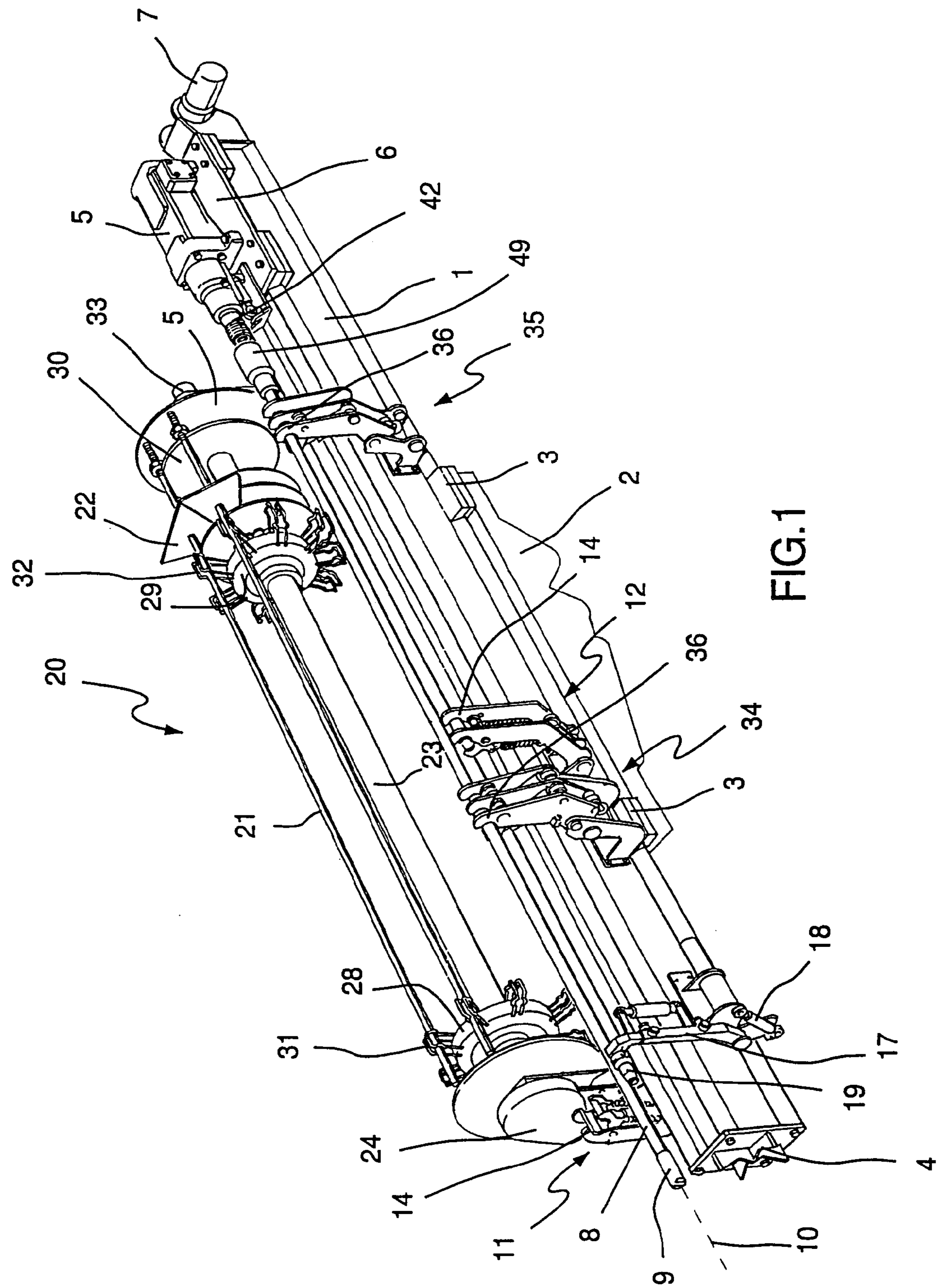

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FIG.1

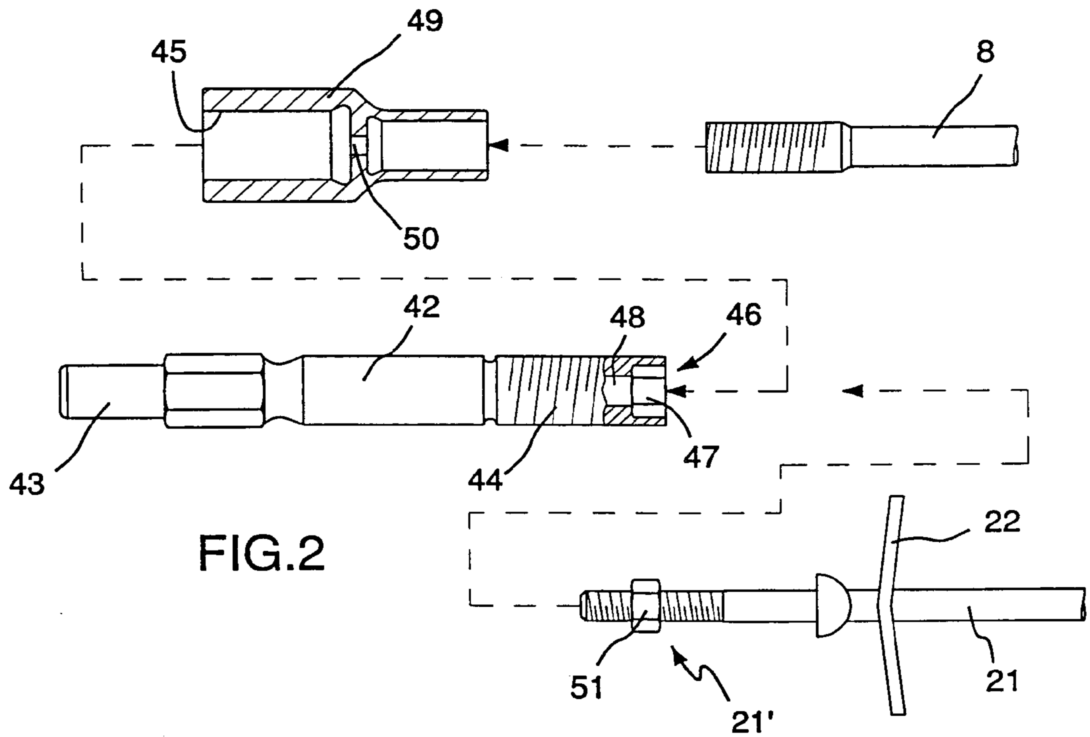

FIG.2

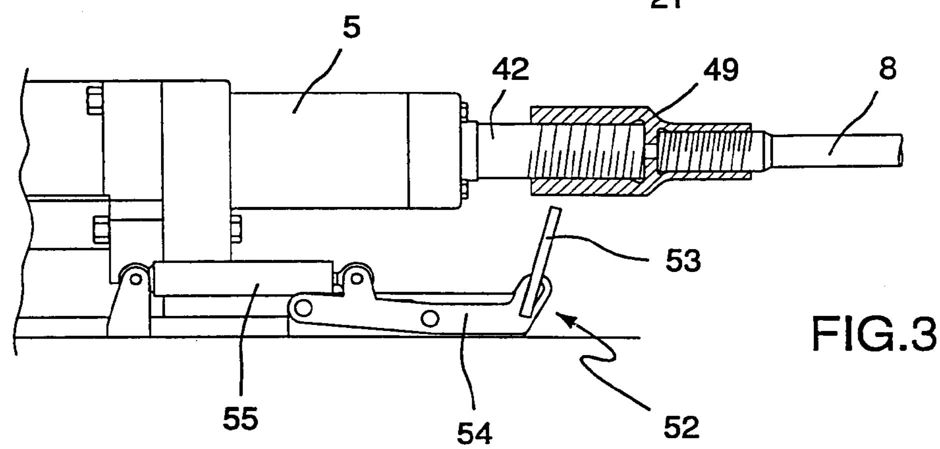

FIG.3

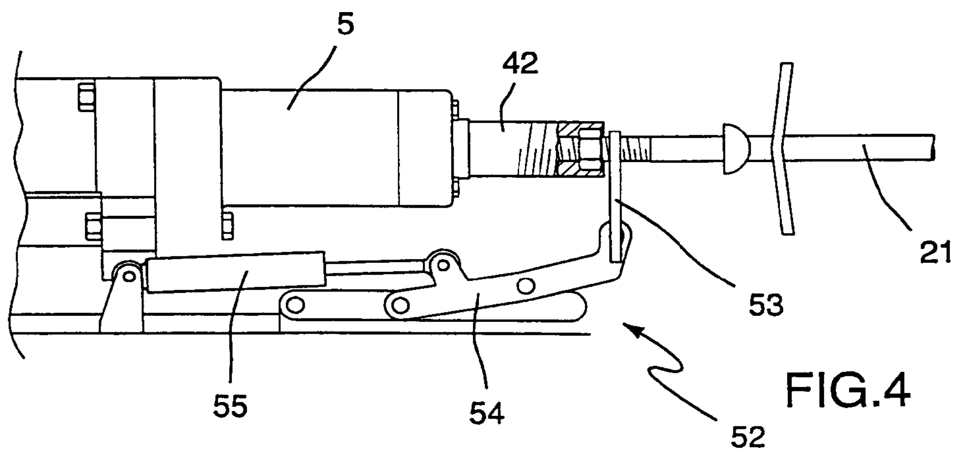

FIG.4

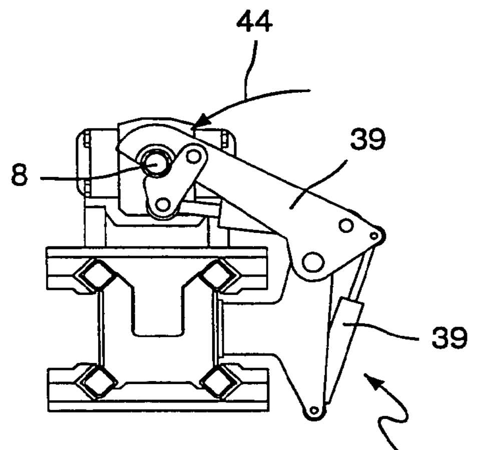

FIG.5

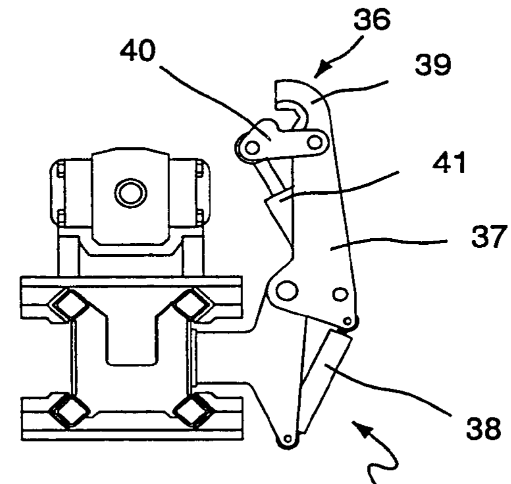

FIG.6

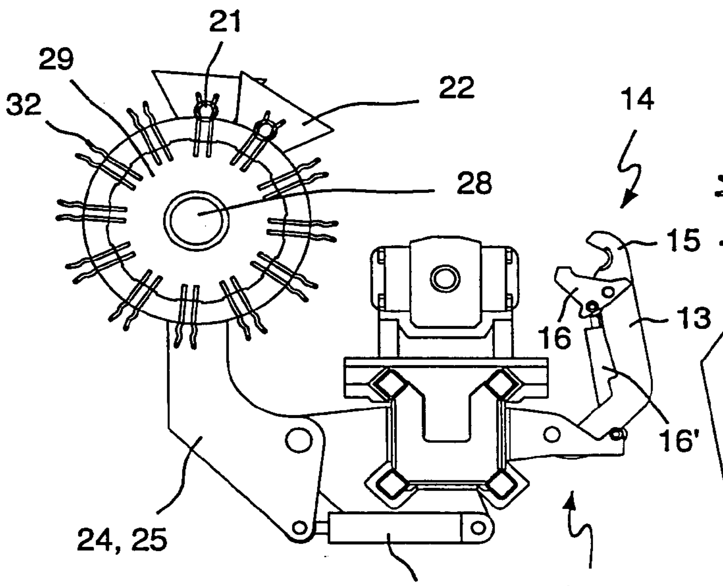

FIG.7

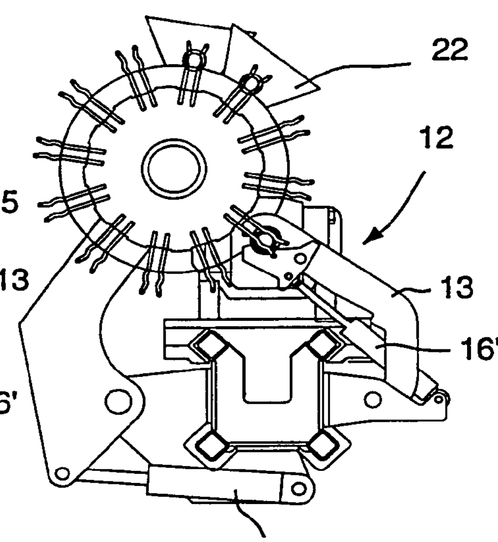

FIG.8

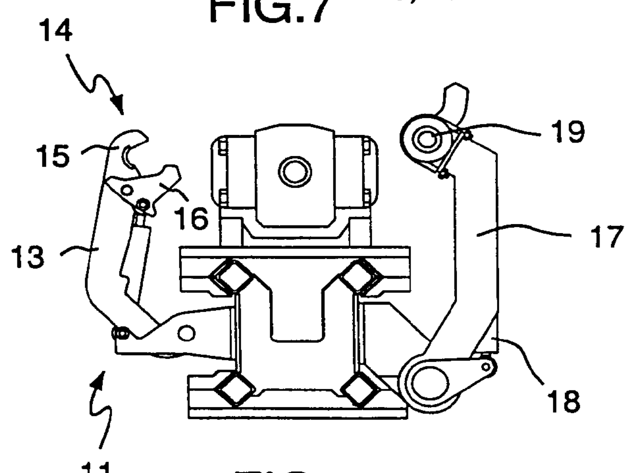

FIG.9

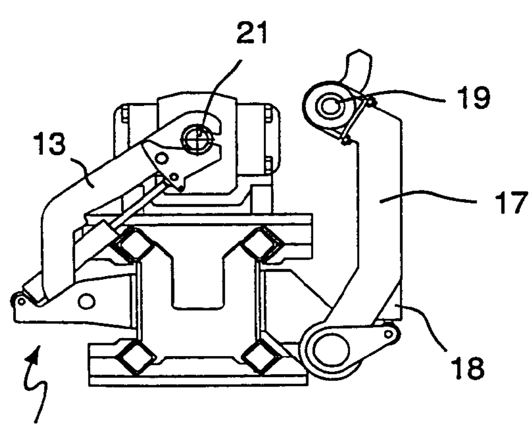

FIG.10

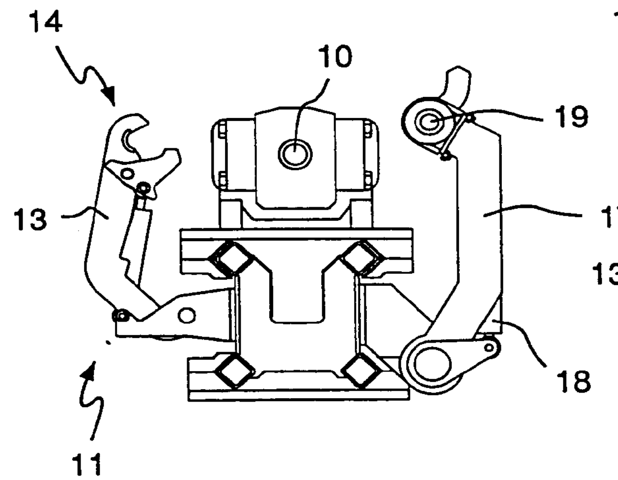

FIG.11

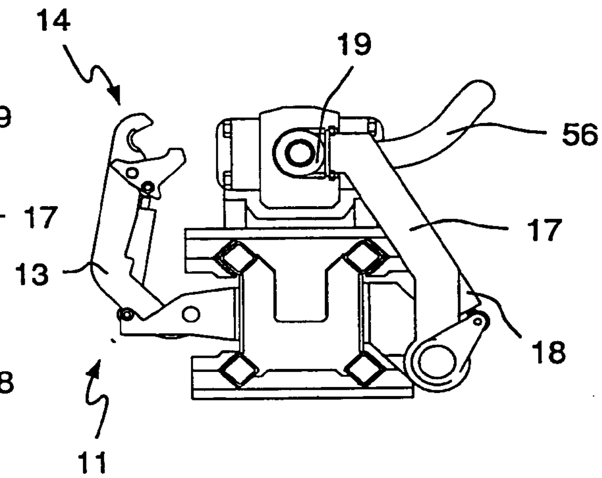

FIG.12

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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"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
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

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International application No.
PCT/SE 00/01541

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
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				US	4832536	A	23/05/89
EP	0130969	A2	09/01/85	SE	0130969	T3	
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				AT	384860	B	25/01/88
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				AU	2972484	A	17/01/85
				CS	273315	B	12/03/91
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				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

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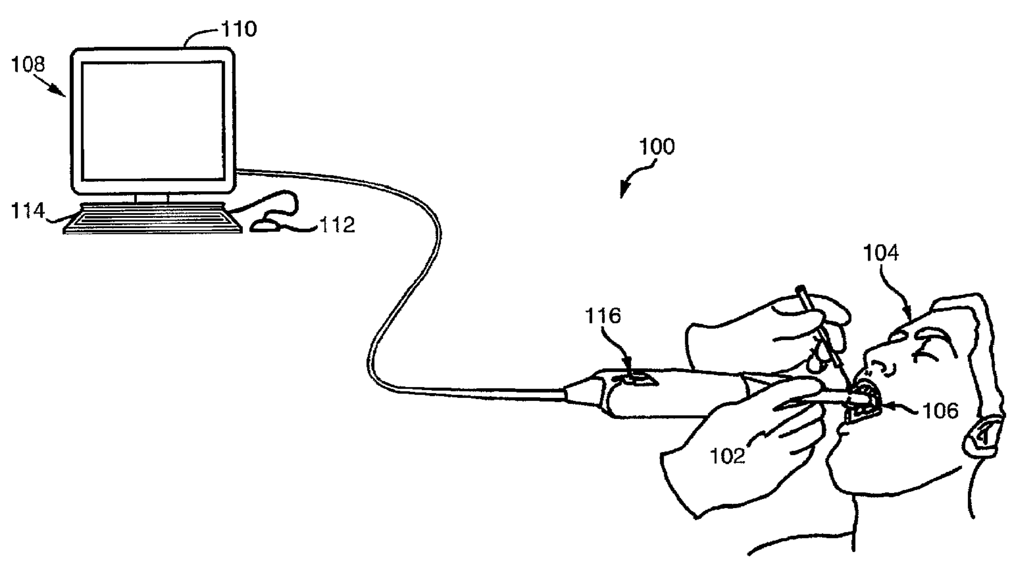
(54) **Title: DIGITAL DENTISTRY**



(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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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 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 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

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.

9 1. 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.

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 119, 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.

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.

3 16. The system of claim 3 15, wherein the user input affects rotational orientation of the visualization on the display.

3 17. 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.

32 1. 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.

331. 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.

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.

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.

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.

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.

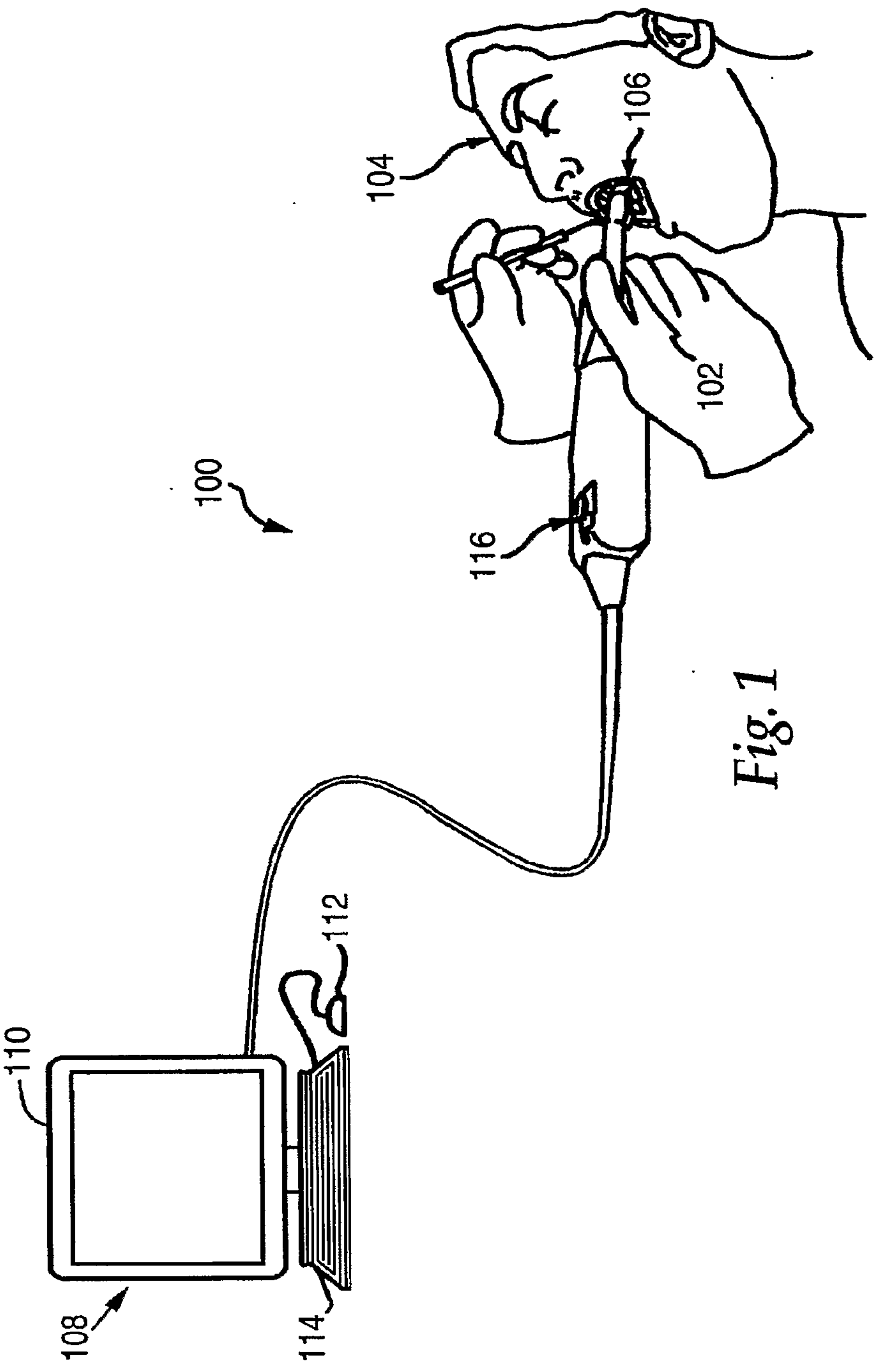


Fig. 1

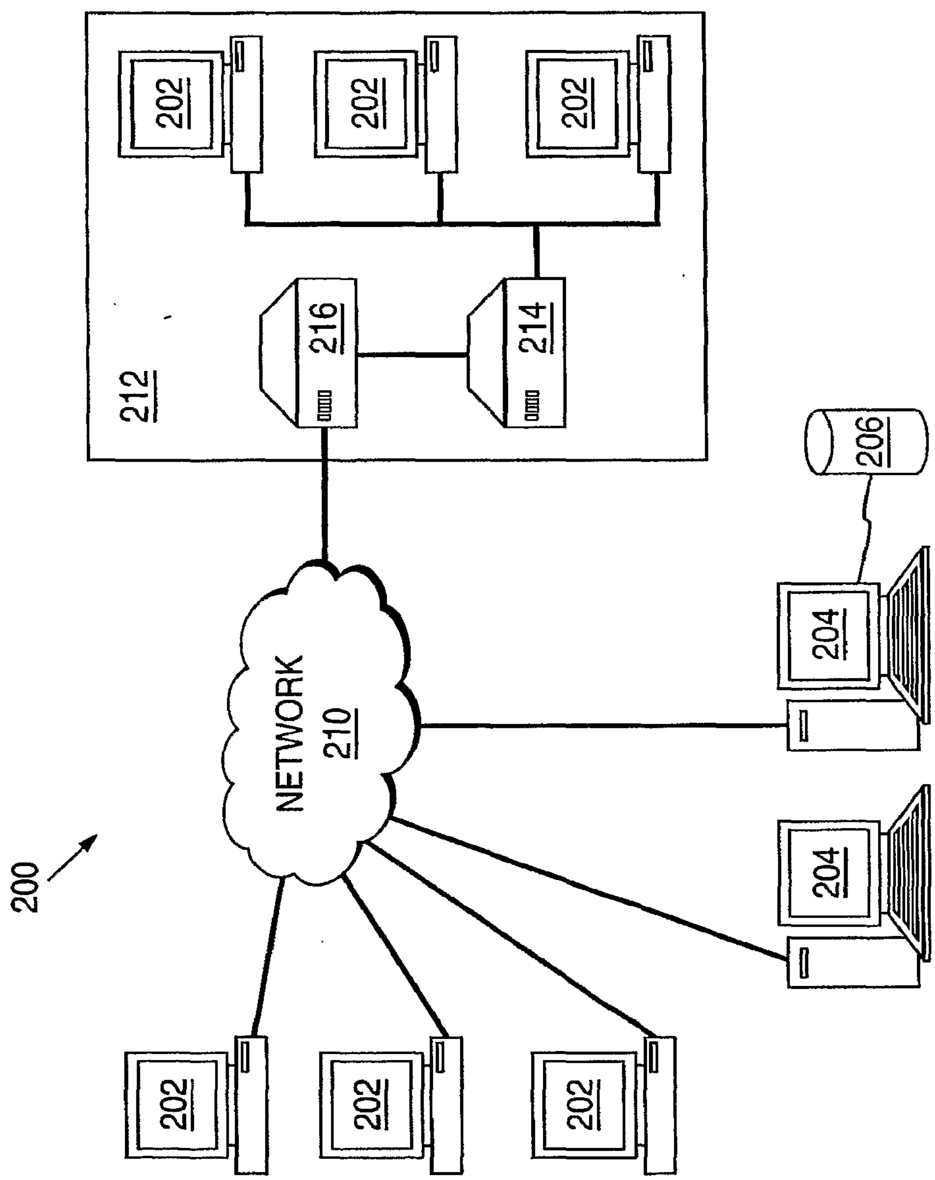


Fig. 2

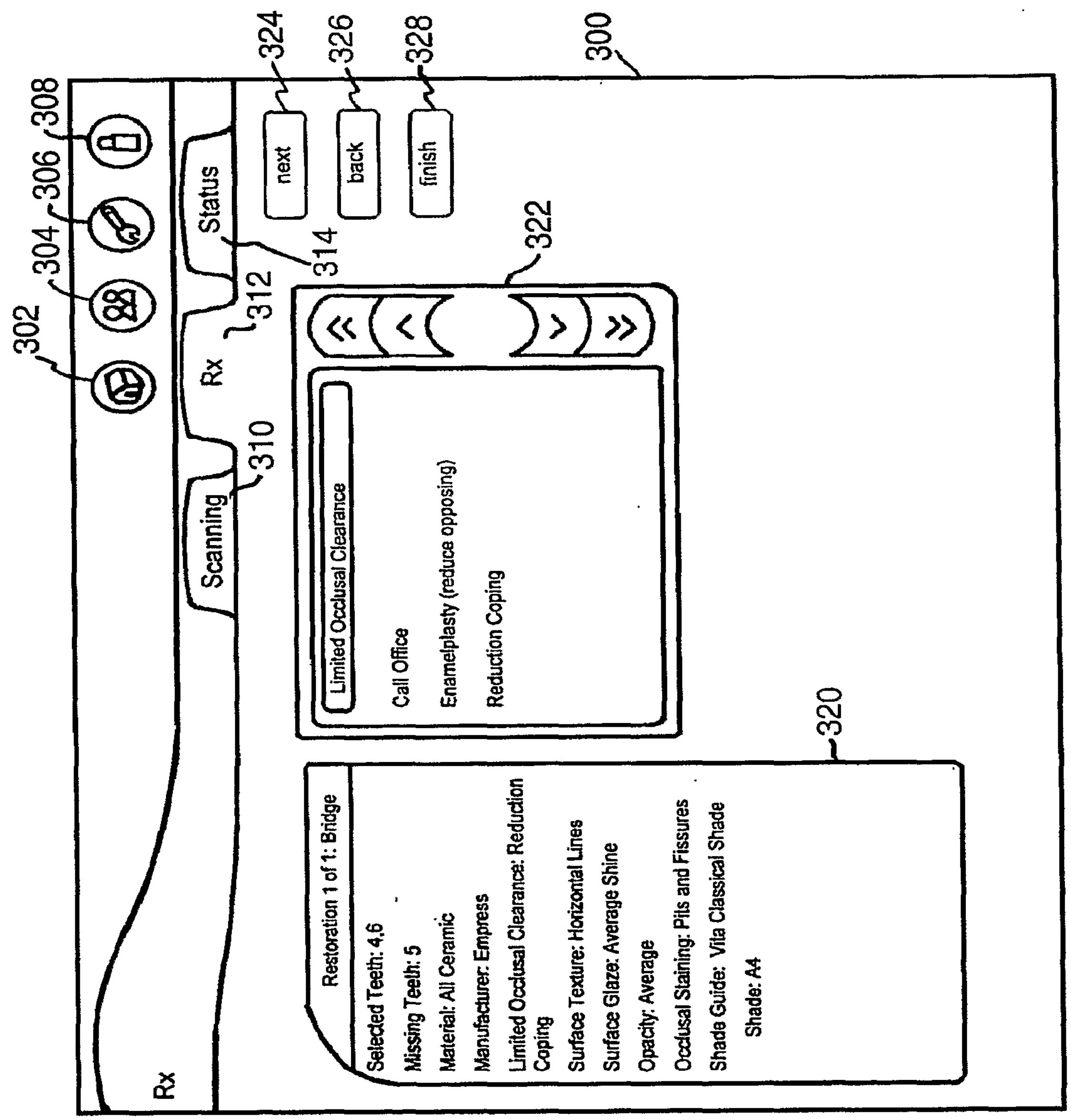
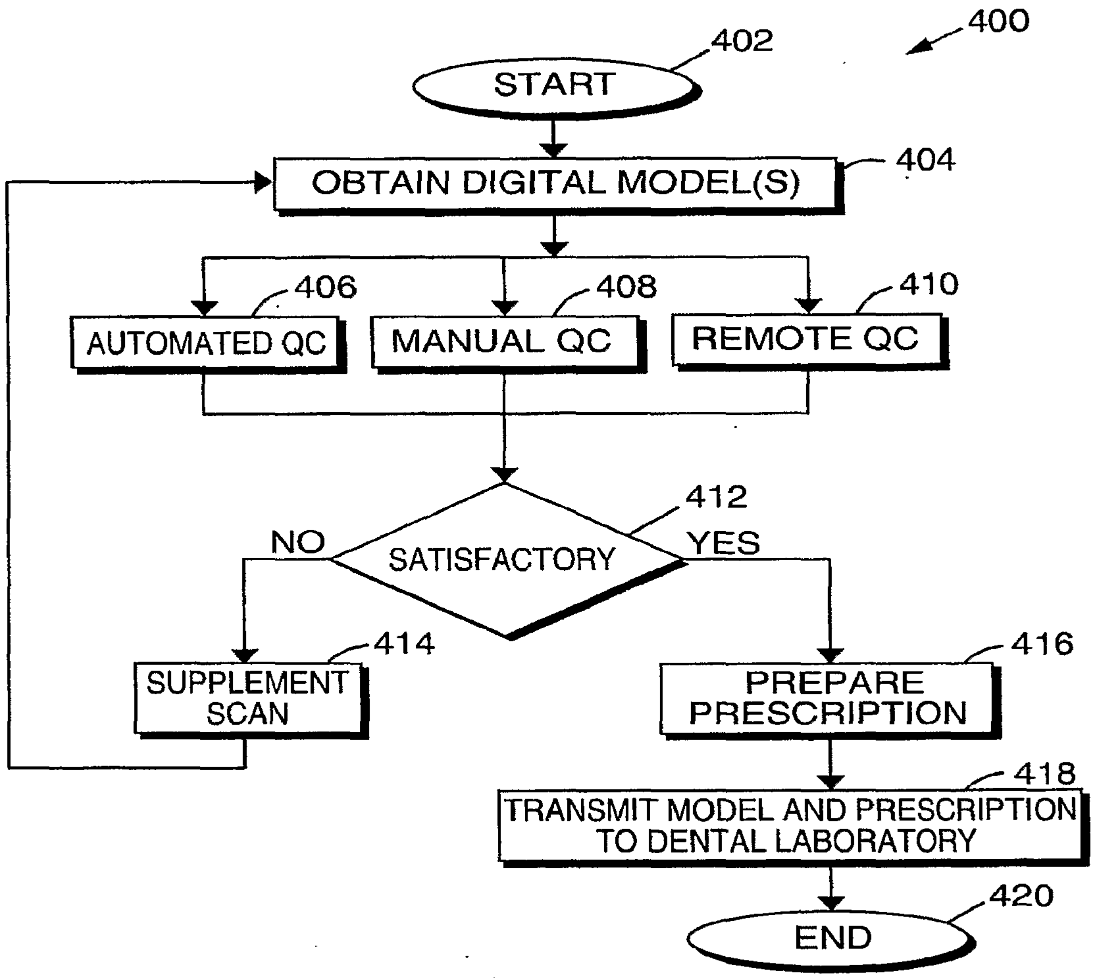

302
304
306
308
Rx
Scanning
Rx
Status
310
312
314
next
back
finish
324
326
328
300
322
Limited Occlusal Clearance
Call Office
Enamelplasty (reduce opposing)
Reduction Coping
320
Restoration 1 of 1: Bridge
Selected Teeth: 4,6
Missing Teeth: 5
Material: All Ceramic
Manufacturer: Empress
Limited Occlusal 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

Fig. 3



400
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

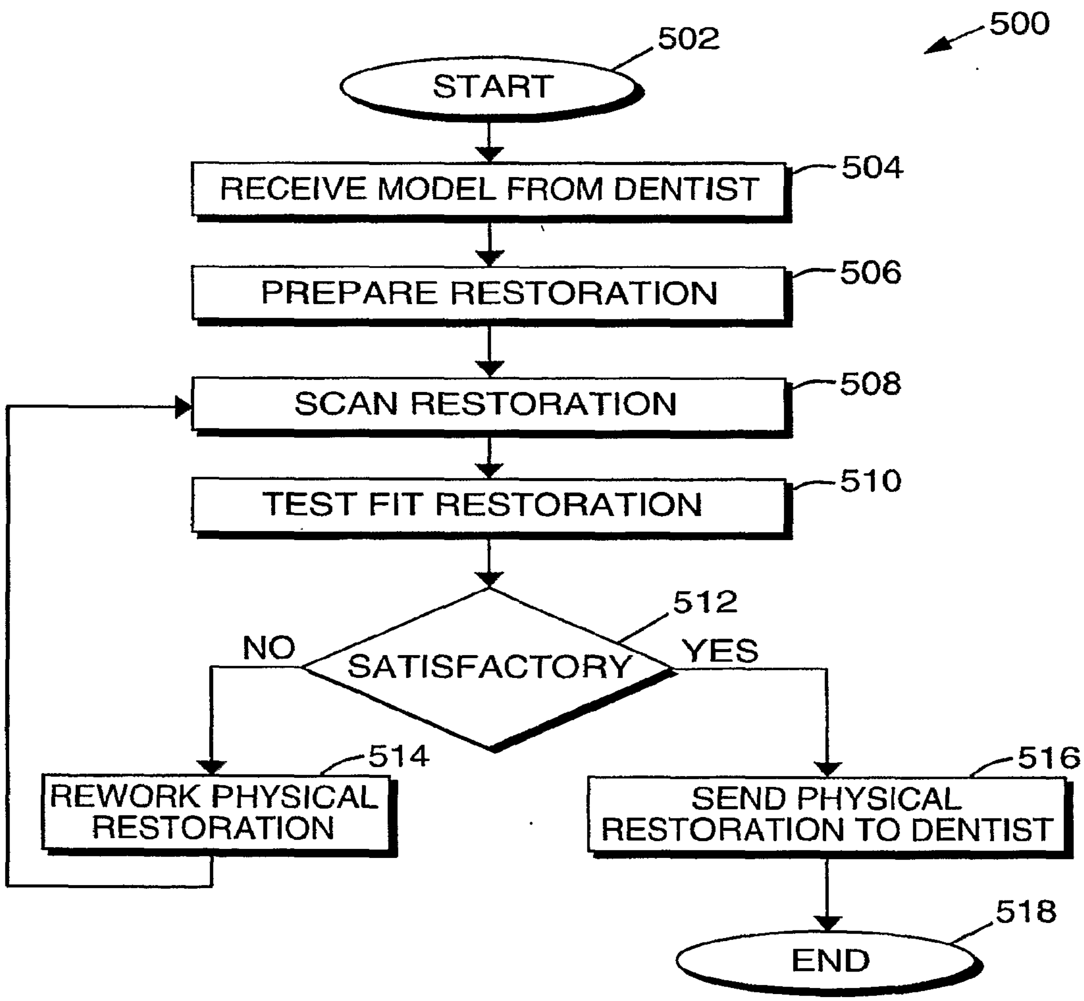

500
502
START
RECEIVE MODEL FROM DENTIST
504
PREPARE RESTORATION
506
SCAN RESTORATION
508
TEST FIT RESTORATION
510
512
NO
SATISFACTORY
YES
514
REWORK PHYSICAL RESTORATION
516
SEND PHYSICAL RESTORATION TO DENTIST
518
END

Fig. 5

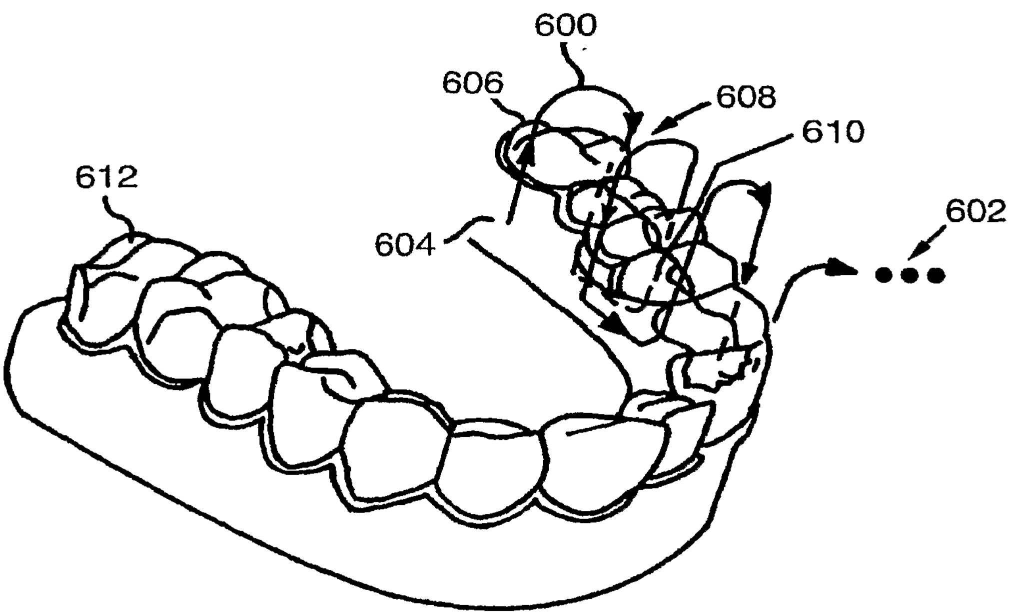


Fig. 6

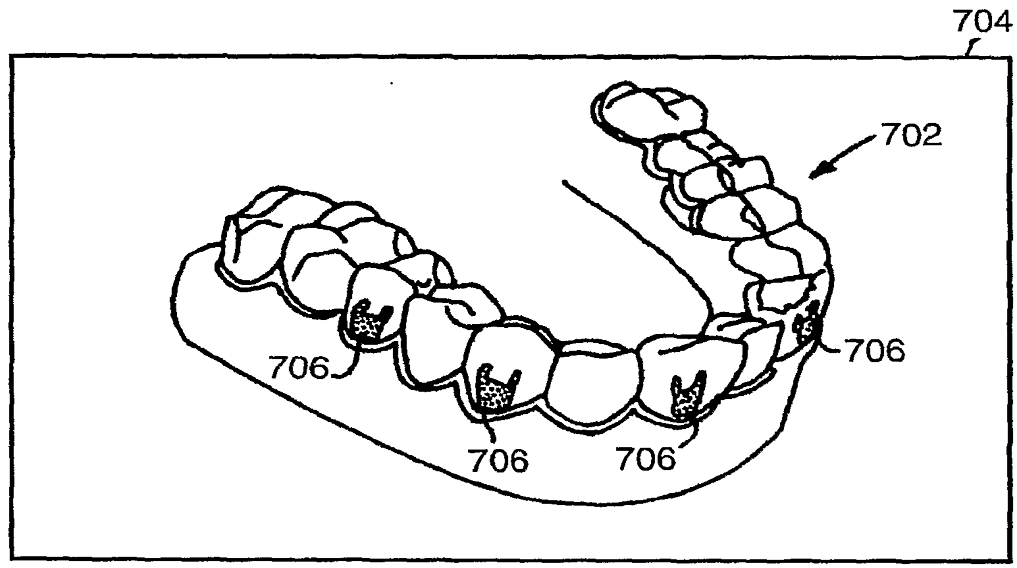


Fig. 7A

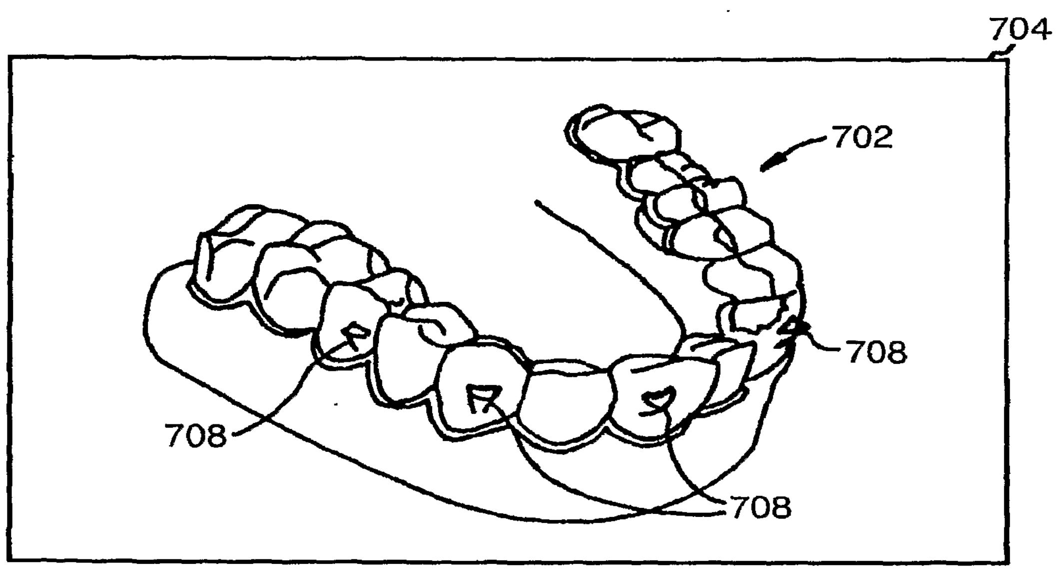


Fig. 7B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/001547

A. CLASSIFICATION OF SUBJECT MATTER

G06Q 10/00(2006.01)i

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)
"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
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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Facsimile No 82-42-472-7140

Authorized officer
KOO, Young Hoi
Telephone No 82-42-481-8376

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No
PCT/US2007/001547

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		EP1711120A1	18.10.2006
		W02005079695A1	01.09.2005

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61/508,314 15 July 2011 (15.07.2011) US

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(74) Agent: **MÜNZER, Marc**; Guardian IP Consulting I/S, Diplomvej, Building 381, DK-2800 Kgs. Lyngby (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, 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.

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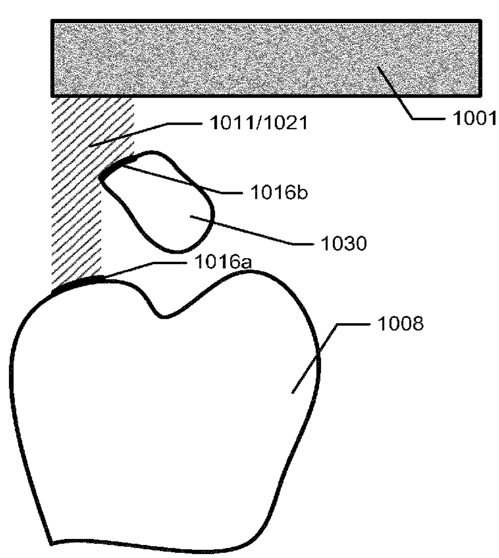
Published:
— *with international search report (Art. 21(3))*

(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.

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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

registration/alignment of subscans, two subscans of the same surface may incorrectly look like two different surfaces.
The near threshold distance may be such as 0.01 mm, 0.05 mm, 0.09 mm, 0.10 mm, 0.15 mm, 0.20 mm etc.

In some embodiments a far threshold distance is defined, which determines a distance from the captured surface, where the volume outside the far threshold distance is not included in the excluded volume of a representation.

Thus the volume outside the far threshold distance is not included in the first excluded volume of the first 3D representation, and the volume outside the far threshold distance is not included in the second excluded volume of the second 3D representation.

According to this embodiment any acquired data or surface or surface points of the first or second representation, which is/are present or located outside the far threshold distance, is not used to determine or define the first or second excluded volume, respectively.

It is an advantage because a surface or surface points from a movable object or from another part of the tooth surface can actually be present outside the far threshold distance without being detected by the scanner, due to the geometry and optical properties of the scanner. The light rays from the scanner head may be transmitted in any directions and with any angle or inclination from a normal plane of the scanner head, and therefore a light ray can be transmitted from the scanner head to a point which is placed behind the movable object or the other part of the tooth surface, when the movable object or the other part of the tooth surface is present partly in front of the scanner head.

Thus the volume outside the far threshold distance is not included in the excluded volume, because in the volume outside the far threshold distance a surface can be present even though no surface is detected by the scanner.

The far threshold distance defines or determines a distance from the captured surface, where the volume or region within the far threshold distance is included in the excluded volume.

Thus if utilizing or applying the far threshold distance, the excluded volume for a representation will be smaller than if not applying the far threshold distance, and therefore less volume can be excluded.
However, the advantage of applying a far threshold distance is that only volumes which can truly be excluded, will be excluded, meaning that the general scan data will have a higher quality.

Thus even though no surface or surface points has/have been detected in a volume or region between the scanner and the tooth surface, the whole region cannot be defined as excluded volume, because the light rays from and to the scanner may travel with inclined angles relative to a normal of the scan head, which means that the scanner can detect a point on the tooth surface even though another part of the tooth is actually placed, at least partly, between the detected tooth surface and the scanner. Therefore a far threshold distance is defined, and no data detected outside this far threshold distance from the tooth surface is used to define the excluded volume of a representation. Only data detected inside the far threshold distance is used to define the excluded volume, because only within this distance can one be certain that the data detected actually corresponds to the real physical situation.

The scanner may detect that no surface is present in the volume or region outside the far threshold distance between the tooth surface and the scanner, but this data or information cannot be used to define the excluded volume of the representation, because there may actually be a movable object or another part of the tooth surface in this region or volume which the scanner overlooks because of its inclined light rays.

Furthermore, the scanner may overlook a surface part even though the surface part is in the scan volume. This can be caused by that the surface part is outside the focus region of the scanner, for example if the surface part is too close to the opening of the scanner head and/or scanner body, as the focus region may begin some distance from the scanner head and/or scanner body. Alternatively and/or additionally this can be caused by the lightning conditions, which may not be optimal for the given material of the surface, whereby the surface is not properly illuminated and thus can become invisible for the scanner. Thus in any case the scanner may overlook or look through the surface part. Hereby a volume in space may erroneously be excluded, since the scanner detects that no surface is present, and therefore a surface portion captured in this excluded volume in another 3D representation or scan would be disregarded. For avoiding that this happens, which would be unfavorably if the surface part was a true tooth surface, the far threshold distance can be defined, such that the excluded volume becomes smaller, such that only volume which really can be excluded is excluded.

It is an advantage that real surface points of a tooth are not erroneously disregarded, whereby fewer holes, i.e. regions with no scan data, are created in the scans. Thus the excluded volume is reduced by means of the far threshold distance for avoiding that too much surface information is incorrectly disregarded.

The light rays from the scan head of the scanner may spread or scatter or disperse in any directions.

Even if an object, such as a movable object, is arranged between the scan head and the surface of a rigid object, e.g. a tooth, the scanner may still capture a surface point on the tooth surface which is present or hidden “under” the object, because of the angled or inclined light rays. A surface point or area may just have to be visible for one or a small number of light rays from and/or to the scanner in order for that surface point or area to be detected.

Since the far threshold distance determines a distance from the captured surface in a representation, where any acquired data or surface or surface points, which is/are present or located outside the far threshold distance, is not used to define the excluded volume of the representation, any acquired data or surface or surface points in the volume between the far threshold distance and the scan head is not included in the definition of the excluded volume.

The actual distance of the far threshold may depend or be calculated based on the optics of the scanner. The far threshold distance may be a fixed number, such as about 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, or 100 mm. Alternatively, the far threshold distance may be a percentage or a fraction of the length of the scan volume, such as about 20%, 25%, 30%, 35%, 40%, 45%, or 50% of the length of the scan volume, or such as ½, 1/3, ¼, 1/5 of the length of the scan volume.

The far threshold distance may be based on a determination of how far a distance from a detected point of the surface it is possible to scan, i.e. how much of the surface around a detected point that is visible for the scanner. If the visible distance in one direction from a surface point is short, then the far threshold distance will be smaller than if the distance in all directions from a surface point is long.

In some embodiments the first representation of at least part of a surface is a first subscan of at least part of the location, and the second representation of at least part of the surface is a second subscan of at least part of the location.

In some embodiments the first representation of at least part of a surface is a provisional virtual 3D model comprising the subscans of the location acquired already, and the second representation of at least part of the surface is a second subscan of at least part of the location.

In some embodiments acquired subscans of the location are adapted to be added to the provisional virtual 3D model concurrently with the acquisition of the subscans.

In some embodiments the provisional virtual 3D model is termed as the virtual 3D model, when the scanning of the rigid object is finished.

In some embodiments the method comprises:
- providing a third 3D representation of at least part of a surface by scanning at least part of the location;
- determine for the third 3D representation a third 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 third 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 third excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the third 3D representation is located in space in the first excluded volume and/or in the second excluded volume, the

portion of the surface in the third 3D representation is disregarded in the generation of the virtual 3D model.

In some embodiments the provisional virtual 3D model comprises the first representation of at least part of the surface and the second representation of at least part of the surface, and where the third representation of at least part of the surface is added to the provisional virtual 3D model.
Thus the timewise first acquired representation, which is not necessarily the first representation, and the timewise second acquired representation, which is not necessarily the second representation, may be combined to create the provisional virtual 3D model, and each time a new representation is acquired or provided, the new representation may be added to the provisional virtual 3D model, whereby the provisional virtual 3D model grows for each added representation.

In some embodiments the virtual 3D model is used for virtually designing a restoration for one or more of the patient's teeth.

Thus the purpose of scanning is to obtain a virtual 3D model of the patient's teeth. If the patient should have a restoration, e.g. a crown, a bridge, a denture, a partial removable etc., the restoration can be digitally or virtually designed on or relative to the 3D virtual model.

In some embodiments the virtual 3D model is used for virtually planning and designing an orthodontic treatment for the patient.

In some embodiments the relative motion of the scanner and the rigid object is determined.

In some embodiments the relative motion of the scanner and the rigid object is determined by means of motion sensors.

If the scanner used for acquiring the sub-scans is a handheld scanner, then the relative position, orientation or motion of scanner and the object which is scanned must be known. The relative position, orientation and motion of the scanner can be determined by means of position, orientation and/or motion sensors. However, if these sensors are not accurate enough for the purpose, the precise relative position of scanner and object can be determined by comparing the obtained 3D surfaces in the sub-scans, such as by means of alignment/registration.

A motion sensor is a device that can perform motion measurement, such as an accelerometer. Furthermore the motion sensor may be defined as a device which works as a position and orientation sensor as well.

A position sensor is a device that permits position measurement. It can be an absolute position sensor or a relative position sensor, also denoted displacement sensor. Position sensors can be linear or angular.

An orientation sensor is a device that can perform orientation measurement, such as a gyrosscope.

In some embodiments the relative motion of the scanner and the rigid object is determined by registering/aligning the first representation and the second representation.

In some embodiments the first representation and the second representation are aligned/registered before the first excluded volume and the second excluded volume are determined.

Thus after the first and the second representation are provided, they may be aligned/registered, and after this, the first and second excluded volume may be determined, and then it is detected whether a portion of the surface in the first 3D representation or in the second 3D representation is located in space in the second excluded volume or in the first excluded volume, respectively, such that such portion of the surface in the representation is disregarded in the generation of the virtual 3D model.

Alignment or registration may comprise bringing the 3D representations or subscans together in a common reference system, and then merging them to create the virtual 3D model or a provisional virtual 3D model. For each representation or subscan which is aligned/registered to the provisional virtual 3D model, the model grows and finally it becomes the virtual 3D model of the object.

In some embodiments the relative motion of the scanner and the rigid object determined by means of the motions sensors is verified and potentially adjusted by registering/aligning the first representation and the second representation.

In some embodiments motion sensors are used for an initial determination of the relative motion of the scanner and the rigid object, and where registering/aligning is used for the final determination of the relative motion of the scanner and the rigid object.
Thus in practice the motion sensors may be used as a first guess for the motion, and based on this the alignment/registration may be used for testing the determined motion and/or determining the precise motion or adjusting the determined motion.

In some embodiments the optical system of the scanner is telecentric.
A telecentric system is an optical system that provides imaging in such a way that the chief rays are parallel to the optical axis of said optical system. In a telecentric system out-of-focus points have substantially same magnification as in-focus points. This may provide an advantage in the data processing. A perfectly telecentric optical system may be difficult to achieve, however an optical system which is substantially telecentric or near telecentric may be provided by careful optical design. Thus, when referring to a telecentric optical system it is to be understood that it may be only near telecentric.

As the chief rays in a telecentric optical system are parallel to the optical axis, the scan volume becomes rectangular or cylindrical.

In some embodiments the optical system of the scanner is perspective. If the optical system is a perspective system, the chief rays are angled relative to the optical axis, and the scan volume thus becomes cone shaped. Note that the scan volume is typically a 3D shape.

In some embodiments a mirror in a scan head of the scanner provides that the light rays from the light source in the scanner are transmitted with an angle relative to the opening of the scan head.

The scan volume may be defined not as rectangular but rather as resembling a parallelogram. The light reflected back from a point on the surface may be projected as rays forming a cone or as parallel rays.

In some embodiments the 3D scanner is a hand-held scanner. The 3D scanner may for example be a hand-held intraoral scanner.

In some embodiments the scanner is a pinhole scanner. A pinhole scanner comprises a pinhole camera having a single small aperture. The size of the aperture may be such as 1/100 or less of the distance between it and the projected image. Furthermore, the pinhole size may be determined by the formula $d=2\sqrt{(2f\lambda)}$, where d is pinhole diameter, f is focal length, i.e. the distance from pinhole to image plane, and λ is the wavelength of light. It is an advantage to use the present method for detecting a movable object in a location in a pinhole scanner, since determining the first excluded volume and the second excluded volume is very fast, easy and accurate due to the pinhole setup, where the camera and the light source/projected pattern, respectively, of the scanner are well-defined points in space relative to the captured surface.

Furthermore, if the scanner is a pinhole scanner, the excluded volume may be bigger, compared to if the scanner is not a pinhole scanner. The reason for this is because no far threshold distance can or should be defined when using a pinhole scanner, since no volume between the scanner and the captured tooth surface may not be included in the excluded volume due to the geometry and optical properties of the scanner. The pinhole scanner cannot overlook a surface or surface points from e.g. a movable object due to its geometry and optical properties.

In some embodiments the scanner comprises an aperture, and the size of the aperture is less than 1/100 of the distance between it and the projected image.
This size of aperture corresponds to a pinhole scanner.

In some embodiments the scanner comprises an aperture, and the size of the aperture is more than 1/100 of the distance between it and the projected image.
This size of aperture corresponds to a scanner which is not a pinhole scanner.

Further aspects

According to another aspect of the invention, disclosed is a method for detecting movable objects in the mouth of a patient, when scanning the patient's set of teeth in the mouth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the teeth;
- providing a second 3D representation of at least part of the surface by scanning at least part of the teeth;
- 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.

According to another aspect of the invention, 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 representation of at least part of a surface by scanning the rigid object;
- determining a first scan volume in space related to the first representation of at least part of the surface;
- providing a second representation of at least part of the surface by scanning the rigid object;
- determining a second scan volume in space related to the second representation of at least part of the surface;
- if there is a common scan volume, where the first scan volume and the second scan volume are overlapping, then:

- determine whether there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface; and
- if there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface, then exclude the volume region by disregarding in the generation of the virtual 3D model any surface portion in the second representation or in the first representation, respectively, which is detected in the excluded volume region, since a surface portion detected in the excluded volume region represents a movable object which is not part of the rigid object.

According to another aspect of the invention, 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 surface by scanning the rigid object;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the rigid object;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the rigid object.

According to another aspect of the invention, disclosed is a method for detecting a movable object in the mouth of the patient, when scanning the patient's set of teeth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first surface by scanning the set of teeth;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the set of teeth;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the set of teeth.

According to another aspect of the invention, disclosed is a method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, where the virtual 3D model is made up of the already acquired subscans of the surface of the set of teeth, and where new subscans are adapted to be added to the 3D virtual model, when they are acquired, wherein the method comprises:

- acquiring at least a first subscan of at least a first surface of part of the set of teeth, where the at least first subscan is defined as the 3D virtual model;
- acquiring a first subscan of a first surface of part of the set of teeth;
- determining a first scan volume of the first subscan;

- determining a scan volume of the virtual 3D model;
- if the first scan volume of the first subscan and the scan volume of the virtual 3D model are at least partly overlapping in a common scan volume; then:
    - calculate whether at least a portion of the first surface lies within the common scan volume;
    - calculate whether at least a portion of the surface of the virtual 3D model lies within the common scan volume, and
    - determine whether at least a portion of a surface is present in the overlapping volume only in one subscan and not the other subscan/3D virtual model;
    - if at least a portion of a surface is present in only one subscan, then disregard the portion of the surface in the overlapping volume which is closest to the focusing optics of the scanner, since the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

According to another aspect of the invention, disclosed is s method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

a) providing a first subscan of a first surface of part of the set of teeth;
b) calculating a first scan volume of the first subscan;
c) providing a second subscan of a second surface of part of the set of teeth;
d) calculating a second scan volume of the second subscan; and
e) if the first scan volume and the second scan volume are at least partly overlapping in a common scan volume; then:

f) calculate whether at least a portion of the first surface lies within the common scan volume;

g) calculate whether at least a portion of the second surface lies within the common scan volume, and

h) if at least a portion of the first surface or at least a portion of the second surface lie within the common scan volume, and the portion of the first surface or the portion of the second surface is located in space between the scanner and at least a portion of the second surface or at least a portion of the first surface, respectively;

then the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

In some embodiments the method above further comprises:

- providing a third subscan of a third surface of part of the set of teeth;
- calculating a third scan volume of the third subscan;
- if the third scan volume is at least partly overlapping with the first scan volume and/or with the second scan volume in a common scan volume; then repeat steps f) - h) for the third subscan with respect to the first subscan and/or the second subscan.

Further embodiments are disclosed in the following sections:

Focus scanning and motion determination

In some embodiments the 3D scanning comprises the steps of:

- 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 a camera comprising an array of sensor elements,
- imaging on the camera at least part of the transmitted light returned from the object to the camera by means of an optical system,
- varying the position of the focus plane on the object by means of focusing optics,
- 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 sequence of focus plane positions, or
  - each of a plurality of groups of the sensor elements for a sequence of focus plane positions.

There may be for example more than 200 focus plane images, such as 225 focus plane images, in a sequence of focus plane images used in generating a 3D surface. The focus plane images are 2D images.

Image sensor(s), photo sensor and the like can be used for acquiring images in the scanner. By scanning is generally meant optical scanning or imaging using laser light, white light etc.

In some embodiments a sequence of focus plane images are depth images captured along the direction of the optical axis.

In some embodiments at least a part of the object is in focus in at least one of the focus plane images in a sequence of focus plane images.

In some embodiments the time period between acquisition of each focus plane image is fixed/predetermined/known.

Each focus plane image may be acquired a certain time period after the previous focus plane image was acquired. The focus optics may move between the acquisition of each image, and thus each focus plane image may be acquired in a different distance from the object than the previous focus plane images.

One cycle of focus plane image capture may be from when the focus optics is in position P until the focus optics is again in position P. This cycle may be denoted a sweep. There may such as 15 sweeps per second.

A number of 3D surfaces or sub-scans may then be combined to create a full scan of the object for generating a 3D model of the object.

In some embodiments determining the relative motion of the scanner during the acquisition of the sequence of focus plane images is performed by analysis of the sequence in itself.

Motion detection by means of hardware

In some embodiments determining the relative motion of the scanner during the acquisition of the sequence of focus plane images is performed by sensors in and/or on the scanner and/or by sensors on the object and/or by sensors in the room where the scanner and the object are located.

The motion sensors may be small sensor such as microelectromechanical systems (MEMS) motion sensors. The motion sensors may measure all motion in 3D, i.e., both translations and rotations for the three principal coordinate axes. The benefits are:

- Motion sensors can detect motion, also vibrations and/or shaking. Scans such affected can e.g. be corrected by use of the compensation techniques described.

- 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.
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.

In some embodiments the motion is determined by means of a texture image sensor having a depth of focus which is larger than the depth of focus of the focusing optics.

In some embodiments the motion is determined by determining the position and orientation of one or more of the sensors.

In some embodiments the motion is determined by means of one or more physical components arranged in the handheld scanner.

In some embodiments the motion is determined by means of 3D position sensors.

In some embodiments the motion is determined by means of optical tracking. The optical tracking may comprise LED(s) and camera(s), where the LED(s) may flash and the flashing can be detected by the camera(s).

In some embodiments the motion is determined by means of one or more gyroscopes.
A gyroscope is a device for measuring or maintaining orientation, based on the principles of conservation of angular momentum. A mechanical gyroscope is essentially a spinning wheel or disk whose axle is free to take any orientation. The gyroscopes used to determine the orientation of the sensor may be mechanical gyroscopes, electronic, microchip-packaged MEMS gyroscope devices, solid state ring lasers, fibre optic gyroscopes, quantum gyroscope and/or the like.

In some embodiments the motion is determined by means of one or more accelerometers.

In some embodiments the motion is determined by means of one or more magnetometers.

In some embodiments the motion is determined by means of one or more electromagnetic coils.

In some embodiments the motion is determined by means of a computerized measurement arm.
The measurement arm may for instance be from FARO Technologies. There may be goniometers in the measurement arm for measuring the movements of the arm.

In some embodiments the motion is determined by means of one or more axes on which the sensor is configured to move.

An example of an axes based system is a coordinate measuring machine (CMM), which is a device for measuring the physical geometrical characteristics of an object. This machine may be computer controlled. A typical CMM is composed of three axes, X, Y and Z, and these axes are orthogonal to each other in a typical three dimensional coordinate system. Each axis has a scale system that indicates the location of that axis. Measurements may be defined by a probe attached to the third moving axis of this machine, and the machine will read the input from the touch probe. Probes may be mechanical, optical, laser, or white light, among others.

In some embodiments the axes on which the sensor is configured to move are translational and / or rotational axes.

For each focus plane image that is acquired there is six degrees of freedom of the sensor, e.g. the handheld scanner, since the scanner is a rigid body which can perform motion in a three dimensional space, where the motion can be translation in three perpendicular axes, x, y, z, which is movement forward/backward, up/down, left/right, and this is combined with rotation about the three perpendicular axes. Thus the motion has six degrees of freedom as the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes.

3D modeling

3D modeling is the process of developing a mathematical, wireframe representation of any three-dimensional object, called a 3D model, via specialized software. Models may be created automatically, e.g. 3D models may be created using multiple approaches, such as use of NURBS curves to generate accurate and smooth surface patches, polygonal mesh modeling which is a manipulation of faceted geometry, or polygonal mesh subdivision which is advanced tessellation of polygons, resulting in smooth surfaces similar to NURBS models.

Obtaining a three dimensional representation of the surface of an object by scanning the object in a 3D scanner can be denoted 3D modeling, which is the process of developing a mathematical representation of the three-dimensional surface of the object via specialized software. The product is called a 3D model. A 3D model represents the 3D object using a collection of points in 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc. The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the object.
3D scanners collect distance information about surfaces within its field of view. The “picture” produced by a 3D scanner may describe the distance to a surface at each point in the picture.
For most situations, a single a scan or sub-scan will not produce a complete model of the object. Multiple sub-scans, such as 5, 10, 12, 15, 20, 30, 40, 50, 60, 70, 80, 90 or in some cases even hundreds, from many different directions may be required to obtain information about all sides of the object. These sub-scans are brought in a common reference system, a process that may be called alignment or registration, and then merged to create a complete model.

3D scanners may be fixed or stationary desktop scanners into which for example a dental impression, an ear canal impression or a casted gypsum model of teeth can be placed for scanning. 3D scanners may also be handheld intraoral scanners for scanning a patient directly in the mouth or handheld or fixed ear scanners for scanning a patient directly in the ear.

Thus a 3D scanner may be a handheld scanner where scanner and object are not arranged stationary relative to each other and where the relative motion may be unlimited, a desktop scanner where the object and the scanning means, e.g. light source and camera, are arranged stationary relative to each other, a stationary scanner where the object for example can move relative to the stationary scanner etc.

A triangulation 3D laser scanner uses laser light to probe the environment or object. A triangulation laser shines a laser on the object and exploits a camera to look for the location of the laser dot. Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view. This technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle. A laser stripe, instead of a single laser dot, may be used and is then swept across the object to speed up the acquisition process.

Structured-light 3D scanners project a pattern of light on the object and look at the deformation of the pattern on the object. The pattern may be one dimensional or two dimensional. An example of a one dimensional pattern is a line. The line is projected onto the object using e.g. an LCD projector or a sweeping laser. A camera, offset slightly from the pattern projector, looks at the shape of the line and uses a technique similar to triangulation to calculate the distance of every point on the line. In the case of a single-line pattern, the line is swept across the field of view to gather distance information one strip at a time.

An example of a two-dimensional pattern is a grid or a line stripe pattern. A camera is used to look at the deformation of the pattern, and an algorithm is used to calculate the distance at each point in the pattern. Algorithms for multistripe laser triangulation may be used.

Confocal scanning or focus scanning may also be used, where in-focus images are acquired at different depth to reconstruct the 3D model.

Iterative Closest Point (ICP) is an algorithm employed to minimize the difference between two clouds of points. ICP can be used to reconstruct 2D or 3D surfaces from different scans or sub-scans. The algorithm is conceptually simple and is commonly used in real-time. It iteratively revises the transformation, i.e. translation and rotation, needed to minimize the distance between the points of two raw scans or sub-scans. The inputs are: points from two raw scans or sub-scans, initial estimation of the transformation, criteria for stopping the iteration. The output is: refined transformation. Essentially the algorithm steps are:

1. Associate points by the nearest neighbor criteria.
2. Estimate transformation parameters using a mean square cost function.
3. Transform the points using the estimated parameters.
4. Iterate, i.e. re-associate the points and so on.

Aligning/registration

In some embodiments the motion between at least two subsequent 3D surfaces are determined by aligning/registering the at least two subsequent 3D surfaces.

This may be performed by means of the method of iterative closest point (ICP) or similar methods. The method of Iterative Closest Point (ICP) can be used for aligning, and it is employed to minimize the difference between two clouds of points. ICP can be used to reconstruct 2D or 3D surfaces from different scan. ICP iteratively revises the transformation, i.e. translation or rotation, needed to minimize the distance between the points of two raw scans or subscans. The input for ICP may be points from two raw scans or subscans, initial estimation of the transformation, and criteria for stopping the iteration. The output will thus be a refined transformation.

The alignment may be performed in two steps, where the first step is a subscan to subscan alignment, and the second step is a subscan to provisional virtual 3D model (combined model) alignment. The start guess for the alignment may be determined by using the gyroscopes, estimated speed of the scanner etc.

Additionally and/or alternatively, the method of least squares fit can be used in alignment.

In some embodiments aligning/registering is performed by selecting corresponding points on the at least two 3D surfaces, and minimizing the distance between the at least two 3D surfaces.
Corresponding points may the closest points on two surfaces, or point determined by a normal vector from a point on the other surface etc
The distance may be minimized with regards to translation and rotation.

In some embodiments aligning/registration is continued in an iterative process to obtain an improved motion estimation.

In some embodiments the sensor position of each sequence is determined based on the alignment.

In some embodiments aligning comprises aligning the coordinate systems of at least two 3D surfaces.

In some embodiments aligning comprises aligning by means of matching / comparing one or more specific features, such as one or more specific features common to the at least two 3D surfaces, such as the margin line.

In some embodiments aligning comprises aligning by means of matching / comparing one or more peripheral features of the at least two 3D surfaces.

In some embodiments aligning comprises registration of the at least two 3D surfaces.

In some embodiments aligning comprises applying a predefined criterion for maximum allowed error in the registration.

In some embodiments the motion compensation comprises reconstructing a self-consistent surface model and motion and/or rotation of the scanner relative to the object from two or more scans of the object where two successive scans overlap at least partially.

Focus scanning

The 3D scanner may be used for providing a 3D surface registration of objects using light as a non-contact probing agent. The light may be 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. The invention 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 the present invention.

In some embodiments the signals from the array of sensor elements are light intensity.

One embodiment of the invention 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 returned from the object to the camera. In the preferred embodiment of the invention 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, preferably along the same optical axis, however along opposite optical paths.

In the preferred embodiment of the invention an optical system provides an imaging of the pattern onto the object being probed and from the object being probed to the camera. Preferably, the focus plane is adjusted in such a way that the image of the pattern on the probed object is shifted along the optical axis, preferably 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.

Generally we consider the case where the light incident on the object is reflected diffusively and/or specularly from the object's surface. But it is understood that the scanning apparatus and method are not limited to this situation. They are also applicable to e.g. the situation where the incident light penetrates the surface and is reflected and/or scattered and/or gives rise to fluorescence and/or phosphorescence in the object. Inner surfaces in a sufficiently translucent object may also be illuminated by the illumination pattern and be imaged onto the camera. In this case a volumetric scanning is possible. Some planktic organisms are examples of such objects.

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 of the invention 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 of the invention 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.

The scanner preferably comprises at least one beam splitter located in the optical path. For example, an image of the object may be formed in the camera by means of a beam splitter. Exemplary uses of beam splitters are illustrated in the figures.

In a preferred embodiment of the invention light is transmitted in an optical system comprising a lens system. This lens system may transmit the pattern towards the object and images light reflected from the object to the camera.

In a telecentric optical system, out-of-focus points have the same magnification as in-focus points. Telecentric projection can therefore significantly ease the data mapping of acquired 2D images to 3D images. Thus, in a preferred embodiment of the invention the optical system is substantially telecentric in the space of the probed object. The optical system may also be telecentric in the space of the pattern and camera.

The present invention relates to different aspects including the method described above and in the following, and corresponding methods, devices, apparatuses, systems, 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 system 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 system comprises:

- means for providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- means for providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- means for determining for the first 3D representation a first excluded volume in space where no surface can be present;
- means for determining for the second 3D representation a second excluded volume in space where no surface can be present;
- means for disregarding the portion of the surface in the first 3D representation in the generation of the virtual 3D model, if a portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or
- means for disregarding the portion of the surface in the second 3D representation in the generation of the virtual 3D model, if a portion of the surface in the second 3D representation is located in space in the first excluded volume.

Furthermore, the invention relates to a computer program product comprising program code means for causing a data processing system to perform the method according to any of the embodiments, 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:

Fig. 1 shows an example of a flowchart of the 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.

Fig. 2 shows an example of a scan head of an intraoral 3D scanner scanning a set of teeth.

Fig. 3 shows an example of a handheld 3D scanner.

Fig. 4 shows an example of a section of teeth in the mouth which can be covered in a sub-scan.

Fig. 5 shows an example of how the different sub-scans generating 3D surfaces are distributed across a set of teeth.

Fig. 6 shows an example of registering/aligning representations of 3D surfaces and compensating for motion in a 3D surface.

Fig. 7 shows an example of a 3D surface where overlapping sub-scans are indicated.

Fig. 8 shows an example of excluded volume.

Fig. 9 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where no movable object is present.

Fig. 10 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in part of the first representation.

Fig. 11 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in the second representation.

Fig. 12 shows an example of acquiring a first and a second representation of the surface of an object, e.g. a tooth, where a movable object is captured in the first representation.

Fig. 13 shows an example of acquiring a first and a second representation of a surface of an object, where no movable object is present.

Fig. 14 shows an example of acquiring a first and a second representation of a surface of an object, where a movable object of the second representation is present in the excluded volume of the first representation.

Fig. 15 shows an example of acquiring a first and a second representation of a surface of an object, where a possible movable object is present in the second representation, but not in the excluded volume of the first representation.

Fig. 16 shows an example of a near threshold distance defining how far from the representation possible movable objects are disregarded in the generation of the virtual 3D model.

Fig. 17 shows an example of how the excluded volume is determined.

Fig. 18 shows examples of how movable objects can look in subscans.

Fig. 19 shows an example of a pinhole scanner.

Fig. 20 shows examples of the principle of a far threshold distance from the captured surface defining a volume which is not included in the excluded volume of a representation.

Detailed description

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 shows an example of a flowchart of the 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.
In step 101 a first 3D representation of at least part of a surface is provided by scanning at least part of the location.
In step 102 a second 3D representation of at least part of the surface is provided by scanning at least part of the location.
In step 103 a first excluded volume in space where no surface can be present is determined for the first 3D representation.
In step 104 a second excluded volume in space where no surface can be present is determined for the second 3D representation.
In step 105 a portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, if the portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or a portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, if the

portion of the surface in the second 3D representation is located in space in the first excluded volume.

Fig. 2 shows an example of a scan head of an intraoral 3D scanner scanning a set of teeth.
An intraoral handheld 3D scanner (not shown) comprising a scan head 207 is scanning a tooth 208. The scanning is performed by transmitting light rays on the tooth 208. The light rays forms a scan volume 211, which is cone shaped in this example.
The length 203 of the scan volume 211, i.e. the distance from the opening 202 of the scan head to the end of the scan volume may be for example about 5 mm, 10 mm, 15 mm, 16 mm, 17 mm, 18 mm, 19 mm, 20 mm, 25 mm, 30 mm.
The scan volume may be about 20 mm x 20 mm.

Fig. 3 shows an example of a handheld 3D scanner.
The handheld scanner 301 comprises a light source 302 for emitting light, a beam splitter 304, movable focus optic 305, such as lenses, an image sensor 306, and a tip or probe 307 for scanning an object 308. In this example the object 308 is teeth in an intra oral cavity.

The scanner comprises a scan head or tip or probe 307 which can be entered into a cavity for scanning an object 308. The light from the light source 302 travels back and forth through the optical system. During this passage the optical system images the object 308 being scanned onto the image sensor 306. The movable focus optics comprises a focusing element which can be adjusted to shift the focal imaging plane on the probed object 308. 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 and/or folding optics 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 onto the object being probed and from the object being probed to the image sensor, e.g. 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. 3 is the axis defined by a straight line through the light source, optics and the lenses in the optical system. This also corresponds to the longitudinal axis of the scanner illustrated in fig. 3. The optical path is the path of the light from the light source to the object and back to the camera. The optical path may change direction, e.g. by means of beam splitter and folding optic.

The focus element is adjusted in such a way that the image on the scanned object is shifted along the optical axis, for example in equal steps from one end of the scanning region to the other. A pattern may be imaged on the object, and 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 a 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 may be determined by finding the plane corresponding to an extremum in the correlation measure for each sensor in the image sensor array or each group of sensor in the image sensor array when recording the correlation measure for a range of different focus positions. Preferably one would move the focus position in equal steps from one end of the scanning region to the other. The distance from one end of the scanning region to the other may be such as 5 mm, 10 mm, 15 mm, 16 mm, 20 mm, 25 mm, 30 mm etc.

Fig. 4 shows an example of a section of teeth in the mouth which can be covered in a sub-scan.

In fig. 4a) the teeth 408 are seen in a top view, and in fig. 4b) the teeth 408 are seen in a perspective view.
An example of the scan volume 411 for one sequence of focus plane images is indicated by the transparent box. The scan volume may be such as 17x15x20 mm, where the 15 mm may be the “height” of the scan volume corresponding to the distance the focus optics can move.

Fig. 5 shows an example of how the different sub-scans generating 3D surfaces is distributed across a set of teeth.
Four sub-scans 512 are indicated on the figure. Each sub-scan provides a 3D surface of the scanned teeth. The 3D surfaces may be partly overlapping, whereby a motion of the scanner performed during the acquisition of the sub-scans can be determined by comparing the overlapping parts of two or more 3D surfaces.

Fig. 6 shows an example of registering/aligning representations of 3D surfaces and compensating for motion in a 3D surface.
Fig. 6a) shows a 3D surface 616, which for example may be generated from a number of focus plane images.
Fig. 6b) shows another 3D surface 617, which may have been generated in a subsequent sequence of focus plane images.
Fig. 6c) shows the two 3D surface 616, 617 are attempted to be aligned/registered. Since the two 3D surfaces 616, 617 have 3D points which correspond to the same area of a tooth, it is possible to perform the registration/alignment by ICP, by comparing the corresponding points in the two 3D surfaces etc.
Fig. 6d) shows the resulting 3D surface 618 when the two 3D surfaces 616, 617 have been merged together.
Fig 6e) shows that based on the resulting 3D surface 618 the relative motion performed by the scanner during the acquisition of the sub-scans or focus plane images generating 3D surface 616 and 617 can be determined, and

based on this determined motion the resulting 3D surface 618 can be corrected to a final “correct” 3D surface 619.

Fig. 7 shows an example of a 3D surface where overlapping sub-scans are indicated.
A number of 3D representations or sub-scans are indicated by the numbers 1-11 and the subdivision markers 712 on a 3D surface 713. The subdivision markers 712 for sub-scans 1, 3, 5, 7, 9, and 11 are with dotted lines, and the subdivision markers for sub-scan 2, 4, 6, 8, 10 are marked with full lines. The sub-scans are all overlapping with the same distance, but the overlapping distance may be different for each pair of subscans. As typically a dentist will hold the scanner and move it across the teeth of the patient, the overlapping distance depends on how fast the dentist moves the scanner and the time frame between the acquisition of each scan, so if the time frame is constant, and the dentist does not move the scanner exactly with a constant speed, the overlapping distance will not be the same for all subscans.

Fig. 8 shows an example of excluded volume.
The excluded volume 821 is the volume in space where no surface can be present. At least a part of the excluded volume 821 may correspond to the scan volume 811 of a 3D representation, since the space between the scan head 807 or the focusing optics of the 3D scanner and the captured surface 816 must be an empty space, unless a transparent object, which is not detectable by the 3D scanner, was located in the scan volume. Furthermore the volume of the scan head 807 and the 3D scanner 801 may be defined as an excluded volume 823, since the scanner and scan head occupies their own volume in space, whereby no surface can be present there. Furthermore, the tooth 808 which is being scanned also occupies a volume in space, but since the surface 816 of the tooth 808 is being captured by the scanner, it is not considered what is “behind” the surface 816.

Fig. 9 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where no movable object is present.

Fig. 9a) shows an example of scanning the tooth 908 using a 3D scanner 901 for acquiring a first 3D representation 916 of the surface of the tooth 908. A first scan volume 911 in space is related to the first representation, and a first excluded volume 921 corresponds to the first scan volume 911.

Fig. 9b) shows an example of scanning the tooth 908 using a 3D scanner 901 for acquiring a second 3D representation 917 of the surface of the tooth 908. A second scan volume 912 in space is related to the second representation, and a second excluded volume 922 corresponds to the second scan volume 912. The second representation is acquired with a different angle between scanner and tooth than the first representation.

No surface portion of the first representation 916 lies in the second excluded volume 922, and no surface portion of the second representation 917 lies in the first excluded volume 921, so no surface portion(s) are disregarded in the generation of the virtual 3D model in this case.

Fig. 10 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in part of the first representation.

Fig. 10a) shows an example of scanning the tooth 1008 using a 3D scanner 1001 for acquiring a first 3D representation 1016 of the surface of the tooth 1008. A movable object 1030 is present, and a part 1016b of the first representation 1016 comprises the surface of the movable object 1030. The part 1016a of the first representation 1016 comprises the surface of the tooth. A first scan volume 1011 in space is related to the first representation, and a first excluded volume 1021 corresponds to the first scan volume 1011.

Fig. 10b) shows an example of scanning the tooth 1008 using a 3D scanner 1001 for acquiring a second 3D representation 1017 of the surface of the tooth 1008. A second scan volume 1012 in space is related to the second

representation, and a second excluded volume 1022 corresponds to the second scan volume 1012. The second representation is acquired with a different angle between scanner and tooth than the first representation.
Since the surface portion 1016b of the first representation 1016 lies in the second excluded volume 1022, this surface portion 1016b is disregarded in the generation of the virtual 3D model.

Fig. 11 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in the second representation.
Fig. 11a) shows an example of scanning the tooth 1108 using a 3D scanner 1101 for acquiring a first 3D representation 1116 of the surface of the tooth 1108. A first scan volume 1111 in space is related to the first representation, and a first excluded volume 1121 corresponds to the first scan volume 1111.
Fig. 11b) shows an example of scanning the tooth 1108 using a 3D scanner 1101 for acquiring a second 3D representation 1117 of the surface of the tooth 1108. A movable object 1130 is present, and the second representation 1117 comprises the surface of the movable object 1130. A second scan volume 1112 in space is related to the second representation, and a second excluded volume 1122 corresponds to the second scan volume 1112. The second representation is acquired with a different angle between scanner and tooth than the first representation.
Since the surface of the second representation 1117 lies in the first excluded volume 1121, the surface of the second representation 1117 is disregarded in the generation of the virtual 3D model.
The figures in fig. 11 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 12 shows an example of acquiring a first and a second representation of the surface of an object, e.g. a tooth, where a movable object is captured in the first representation.

Fig. 12a) shows a first 3D representation 1216 comprising two parts, part 1216a and part 1216b. The first scan volume 1211 is indicated by the vertical lines. The first excluded volume 1221 corresponds to the first scan volume.
Fig. 12b) shows a second 3D representation 1217. The second scan volume 1212 is indicated by the vetical lines. The second excluded volume 1222 corresponds to the second scan volume.
The part 1216a of the first representation 1216 corresponds to the first part of the second representation 1217, whereas the part 1216b of the second representation 1216 does not correspond to the second part of the second representation 1217.
The part 1216b of the first representation 1216 lies in the second excluded volume 1222, and the part 1216b is therefore disregarded in the generation of the virtual 3D model
Fig. 12c) shows the resulting 3D representation 1219, which corresponds to the second representation.
The figures in fig. 12 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 13 shows an example of acquiring a first and a second representation of a surface of an object, where no movable object is present.
Fig. 13a) shows an example of acquiring a first 3D representation 1316 of a surface of an object (not shown). A first scan volume 1311 in space is related to the first representation. The first scan volume 1311 is indicated by dotted vertical lines. A first excluded volume 1321 corresponds to the first scan volume 1311.
Fig. 13b) shows an example of acquiring a second 3D representation 1317 of a surface of an object (not shown). A second scan volume 1312 in space is related to the second representation. The second scan volume 1312 is indicated by dotted vertical lines. A second excluded volume 1322 corresponds to the second scan volume 1312.

The second representation is acquired with a different angle between scanner and tooth than the first representation. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 13c) shows an example where the first representation 1316 and the second representation 1317 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location.

Fig. 13d) shows an example where the overlapping common scan volume 1340 of the first representation 1316 and the second representation 1317 is indicated as a shaded area. If a surface portion of one of the representations is located in the overlapping common scan volume 1340, then this corresponds to that the surface portion is located in the excluded volume of the other representation. However, in this case, no surface portion of the first representation 1316 or of the second representation 1317 lies in the overlapping common scan volume 1340, so no surface portion(s) are disregarded in the generation of the virtual 3D model in this case.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 13e) shows an example of the resulting virtual 3D surface 1319.

The figures in fig. 13 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 14 shows an example of acquiring a first and a second representation of a surface of an object, where a movable object of the second representation is present in the excluded volume of the first representation.

Fig. 14a) shows an example of acquiring a first 3D representation 1416 of a surface of an object (not shown). A first scan volume 1411 in space is related to the first representation. The first scan volume 1411 is indicated by dotted vertical lines. A first excluded volume 1421 corresponds to the first scan volume 1411.

Fig. 14b) shows an example of acquiring a second 3D representation 1417 of a surface of an object (not shown). A second scan volume 1412 in space is related to the second representation. The second scan volume 1412 is indicated by dotted vertical lines. A second excluded volume 1422 corresponds to the second scan volume 1412. The second 3D representation 1417 comprises two parts 1417a and 1417b. The part 1417b is located between the part 1417a and the scanner (not shown), which is arranged somewhere at the end of the scan volume.

The second representation is acquired with a different angle between scanner and tooth than the first representation. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 14c) shows an example where the first representation 1416 and the second representation 1417 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location. Some of the part 1417a of the second representation is aligned/registered with the first representation. The part 1417b cannot be aligned/registered with the first representation 1416, since there is no corresponding surface portions between the surface 1416 and the surface 1417b.

Fig. 14d) shows an example where the overlapping common scan volume 1440 of the first representation 1416 and the second representation 1417 is indicated as a shaded area. The surface portion 1417b of the second representation is located in the overlapping common scan volume 1440, and the surface portion 1417b of the second representation 1417 is therefore located in the excluded volume 1421 of the first representation 1416, and part 1417b must therefore be a movable object, which is only present in the second representation.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 14e) shows an example of the resulting virtual 3D surface 1419, where the surface portion 1417b is disregarded in the generation of the virtual 3D model, so the virtual 3D model comprises the first representation 1416 and the part 1417a of the second representation 1417.

The figures in fig. 14 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 15 shows an example of acquiring a first and a second representation of a surface of an object, where a possible movable object is present in the second representation, but not in the excluded volume of the first representation.

Fig. 15a) shows an example of acquiring a first 3D representation 1516 of a surface of an object (not shown). A first scan volume 1511 in space is related to the first representation. The first scan volume 1511 is indicated by dotted vertical lines. A first excluded volume 1521 corresponds to the first scan volume 1511.

Fig. 15b) shows an example of acquiring a second 3D representation 1517 of a surface of an object (not shown). A second scan volume 1512 in space is related to the second representation. The second scan volume 1512 is indicated by dotted vertical lines. A second excluded volume 1522 corresponds to the second scan volume 1512. The second 3D representation 1517 comprises two parts 1517a and 1517b. The part 1517b is located between the part 1517a and the scanner (not shown), which is arranged somewhere at the end of the scan volume.

The second representation 1517 is acquired with a different angle between scanner and tooth than the first representation 1516. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 15c) shows an example where the first representation 1516 and the second representation 1517 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location. Some of the part 1517a of the second representation is aligned/registered with the first representation 1516. The part 1517b cannot be aligned/registered with the first representation 1516, since there is no corresponding surface portions between the surface 1516 and the surface 1517b.

Fig. 15d) shows an example where the overlapping common scan volume 1540 of the first representation 1516 and the second representation 1517 is indicated as a shaded area. The surface portion 1517b of the second representation is not located in the overlapping common scan volume 1540, and the surface portion 1517b of the second representation 1517 is therefore not located in the excluded volume 1521 of the first representation 1516.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 15e) shows an example of the resulting virtual 3D surface 1519, where the surface portion 1517b is not disregarded in the generation of the virtual

3D model, so the virtual 3D model comprises the first representation 1516 and both parts, 1517a and 1517b, of the second representation 1517.

Even though the surface portion 1517b probably is the representation of a movable object, at least this would be assumed if the object in this case is a tooth, since a tooth is unlikely to have a protrusion like the part 1517b of the representation shows, the surface portion 1517b cannot be disregarded yet, because the surface portion 1517b is not found to be located in any excluded volume from any representation yet. But when the scanning of the object's surface continues, there will probably be acquired a third representation which has an overlapping common scan volume with the second representation, and if the surface portion 1517b is located in the excluded volume of the third representation, then the surface portion 1517b can be disregarded from the virtual 3D model.

The figures in fig. 15 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 16 shows an example of a threshold distance defining how far from the representation or captured surface possible movable objects are disregarded in the generation of the virtual 3D model.

A near threshold distance 1650 is defined, which determines a distance from the captured surface 1616 in a first representation, where a surface portion in the second representation (not shown) which is located within the near threshold distance 1650 from the captured surface 1616 and which is located in space in the first excluded volume 1611 is not disregarded in 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.

Reference numeral 1607 is the scan head of the scanner 1601, and reference numeral 1608 is the volume of the tooth.

The fig. 20 is shown in 2D, but it is understood that the figure represents 3D figures.

Fig. 17 shows an example of how the excluded volume is determined. The space may be quantized in a 3D volume grid 1760. The distance 1762 between the corners 1761 in the 3D grid 1760 may be equidistant. The single cells 1763 in the grid each comprises eight corners 1761, and when each of the eight corners 1761 has been covered by a representation, then this cell 1763 is marked as seen. Thus if all eight corners 1761 of a cell 1763 is in the scan volume of a representation, then this cell 1763 may be marked as excluded volume. There may be such as ten, hundred, thousands or millions of cells in the space of a representation.

Fig. 18 shows examples of how movable objects can look in subscans. Fig. 18a) shows a subscan where the tip of a finger 1870 has been captured in the subscan.

Fig. 18b) shows an example where a dental instrument 1871 has been captured in the subscan.

Fig. 19 shows an example of a pinhole scanner.

The pinhole scanner 1980 comprises a camera 1982 and a light source 1981, e.g. comprising a pattern (not shown). The light source 1981 transmits light rays 1983 to the surface 1916 from a small aperture, i.e. all the light rays 1983 transmitted to the surface 1961 are transmitted from a point. Light rays 1984 are reflected back from the surface 1961 and received by the camera 1982 through a small aperture.

Due to the pinhole setup, the point of light transmitted to the surface from the light source is well defined and the point of received light from the surface is also well defined.

Thus the excluded volume for a representation of the surface is defined by the volume in space that the light rays 1983 and 1984 span, and this volume is well defined due to the pinhole setup.

Fig. 20 shows examples of the principle of a far threshold distance from the captured surface defining a volume which is not included in the excluded volume of a representation.

The light rays 2052 (shown in dotted lines) from the scan head 2007 of the scanner 2001 may spread or scatter or disperse in any directions as seen in fig. 20a), where a number of the light rays are illustrated. It is understood that only some of all the light rays are shown here. The surface area on the tooth surface where the light rays impinge has reference numeral 2016.

In fig. 20b) it is shown that even if an object 2072, such as a movable object, is arranged between the scan head 2007 and the surface 2016 of a tooth, the scanner 2001 may still capture a surface point 2053 on the tooth surface 2016 which is present or hidden “under” the object 2072, because of the angled or inclined light rays 2052. A surface point 2053 needs just be visible for one light ray from the scanner in order for that surface point to be detected.

Fig. 20c) shows an example of the far threshold distance 2051, which determines a distance from the captured surface 2016 in a representation, where any acquired data or surface or surface points, which is/are present or located outside the far threshold distance 2051, is not included in the excluded volume for the representation. Thus any acquired data or surface or surface points in the volume 2054 between the far threshold distance 2051 and the scan head 2007 is not used in defining the excluded volume of the representation.

Fig. 20d) shows an example where defining the far threshold distance is an advantage for avoiding that real tooth surface parts are erroneously disregarded.

The scanner 2001 should in principle capture all surface parts, 2016 and 2017, present in the scan volume, but in some cases the scanner cannot capture all surface parts in the scan volume. This may happen for example because the surface part is present outside the focus region of the scanner 2001 or of the scan head 2007 or because of poor lightning conditions for the surface part. In such cases the surface part 2017 may not be captured and registered, and an excluded volume would be determined in the space region where the surface part 2017 of the tooth surface is actually present. By defining the far threshold distance 2051 less of the scan volume is excluded, and thereby it can be avoided that a real surface part 2017 is erroneously disregarded.

The actual distance of the threshold may depend or be calculated based on the optics of the scanner. The far threshold distance may be a fixed number, such as about 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, or 100 mm. Alternatively, the far threshold distance may be a percentage or a fraction of the length of the scan volume, such as about 20%, 25%, 30%, 35%, 40%, 45%, or 50% of the length of the scan volume, or such as ½, 1/3, ¼, 1/5 of the length of the scan volume.

The far threshold distance may be based on a determination of how far a distance from a detected point of the surface it is possible to scan, i.e. how much of the surface around a detected point that is visible for the scanner. If the visible distance in one direction from a surface point is short, then the far threshold distance will be smaller than if the distance in all directions from a surface point is long.

The figures in fig. 20 are shown in 2D, but it is understood that the figures represent 3D figures.

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.

A claim may refer to any of the preceding claims, and “any” is understood to mean “any one or more” of the preceding claims.

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 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.

2. The method according to any one or more of the preceding claims, wherein the rigid object is a patient's set of teeth, and the location is the mouth of the patient.

3. The method according to any one or more of the preceding claims, wherein 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.

4. The method according to any one or more of the preceding claims, wherein 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.

5. The method according to any one or more of the preceding claims, wherein the movable object is a finger, such as the dentist's finger or the dental assistant's finger.

6. The method according to any one or more of the preceding claims, wherein the 3D scanner is a scanner configured for acquiring scans of an object's surface for generating a virtual 3D model of the object.

7. The method according to any one or more of the preceding claims, wherein 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.

8. The method according to any one or more of the preceding claims, wherein 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.

9. The method according to any one or more of the preceding claims, wherein the first part of the surface and the second part of the surface are at least partially overlapping.

10. The method according to any one or more of the preceding claims, wherein the surface is a surface in the location.

11. The method according to any one or more of the preceding claims, wherein 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.

12. The method according to any one or more of the preceding claims, wherein 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.

13. The method according to any one or more of the preceding claims, wherein the scan volume is defined by the focusing optics in the 3D scanner and the distance to the surface which is captured.

14. The method according to any one or more of the preceding claims, wherein 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.

15. The method according to any one or more of the preceding claims, wherein 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.

16. The method according to any one or more of the preceding claims, wherein the first excluded volume and second excluded volume in space

where no surface can be present corresponds to the first scan volume and the second scan volume, respectively.

17. The method according to any one or more of the preceding claims, wherein the volume of the 3D scanner itself is defined as an excluded volume.

18. The method according to any one or more of the preceding claims, wherein the volume of the 3D scanner itself is comprised in the first excluded volume and in the second excluded volume.

19. The method according to any one or more of the preceding claims, wherein 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.

20. The method according to any one or more of the preceding claims, wherein a far threshold distance is defined, which determines a distance from the captured surface, where the volume outside the far threshold distance is not included in the excluded volume of a representation.

21. The method according to any one or more of the preceding claims, wherein the first representation of at least part of a surface is a first subscan of at least part of the location, and the second representation of at least part of the surface is a second subscan of at least part of the location.

22. The method according to any one or more of the preceding claims, wherein the first representation of at least part of a surface is a provisional virtual 3D model comprising the subscans of the location acquired already, and the second representation of at least part of the surface is a second subscan of at least part of the location.

23. The method according to any one or more of the preceding claims, wherein acquired subscans of the location are adapted to be added to the provisional virtual 3D model concurrently with the acquisition of the subscans.

24. The method according to any one or more of the preceding claims, wherein the provisional virtual 3D model is termed as the virtual 3D model, when the scanning of the rigid object is finished.

25. The method according to any one or more of the preceding claims, wherein the method comprises:

- providing a third 3D representation of at least part of a surface by scanning at least part of the location;
- determine for the third 3D representation a third 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 third 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 third excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the third 3D representation is located in space in the first excluded volume and/or in the second excluded volume, the

portion of the surface in the third 3D representation is disregarded in the generation of the virtual 3D model.

26. The method according to any one or more of the preceding claims, wherein the provisional virtual 3D model comprises the first representation of at least part of the surface and the second representation of at least part of the surface, and where the third representation of at least part of the surface is added to the provisional virtual 3D model.

27. The method according to any one or more of the preceding claims, wherein the virtual 3D model is used for virtually designing a restoration for one or more of the patient's teeth.

28. The method according to any one or more of the preceding claims, wherein the virtual 3D model is used for virtually planning and designing an orthodontic treatment for the patient.

29. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined.

30. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined by means of motion sensors.

31. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined by registering/aligning the first representation and the second representation.

32. The method according to any one or more of the preceding claims, wherein the first representation and the second representation are

aligned/registered before the first excluded volume and the second excluded volume are determined.

33. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object determined by means of the motions sensors is verified and potentially adjusted by registering/aligning the first representation and the second representation.

34. The method according to any one or more of the preceding claims, wherein motion sensors are used for an initial determination of the relative motion of the scanner and the rigid object, and where registering/aligning is used for the final determination of the relative motion of the scanner and the rigid object.

35. The method according to any one or more of the preceding claims, wherein the optical system of the scanner is telecentric.

36. The method according to any one or more of the preceding claims, wherein the optical system of the scanner is perspective.

37. The method according to any one or more of the preceding claims, wherein a mirror in a scan head of the scanner provides that the light rays from the light source in the scanner are transmitted with an angle relative to the opening of the scan head.

38. The method according to any one or more of the preceding claims, wherein the 3D scanner is a hand-held scanner.

39. The method according to any one or more of the preceding claims, wherein the scanner is a pinhole scanner.

40. The method according to any one or more of the preceding claims, wherein the scanner comprises an aperture, and where the size of the aperture is less than 1/100 of the distance between it and the projected image.

41. The method according to any one or more of the preceding claims, wherein the scanner comprises an aperture, and where the size of the aperture is more than 1/100 of the distance between it and the projected image.

42. A method for detecting movable objects in the mouth of a patient, when scanning the patient's set of teeth in the mouth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the teeth;
- providing a second 3D representation of at least part of the surface by scanning at least part of the teeth;
- 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.

43. 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 representation of at least part of a surface by scanning the rigid object;
- determining a first scan volume in space related to the first representation of at least part of the surface;
- providing a second representation of at least part of the surface by scanning the rigid object;
- determining a second scan volume in space related to the second representation of at least part of the surface;
- if there is a common scan volume, where the first scan volume and the second scan volume are overlapping, then:
    - determine whether there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface; and
    - if there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface, then exclude the volume region by disregarding in the generation of the virtual 3D model any surface portion in the second representation or in the first representation, respectively, which is detected in the excluded volume region, since a surface portion detected in the excluded volume region represents a movable object which is not part of the rigid object.

44. 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 surface by scanning the rigid object;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the rigid object;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the rigid object.

45. A method for detecting a movable object in the mouth of the patient, when scanning the patient's set of teeth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first surface by scanning the set of teeth;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the set of teeth;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the set of teeth.

46. A method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, where the virtual 3D model is made up of the already acquired subscans of the surface of the set of teeth, and where new subscans are adapted to be added to the 3D virtual model, when they are acquired, wherein the method comprises:

- acquiring at least a first subscan of at least a first surface of part of the set of teeth, where the at least first subscan is defined as the 3D virtual model;
- acquiring a first subscan of a first surface of part of the set of teeth;
- determining a first scan volume of the first subscan;
- determining a scan volume of the virtual 3D model;
- if the first scan volume of the first subscan and the scan volume of the virtual 3D model are at least partly overlapping in a common scan volume; then:
  - calculate whether at least a portion of the first surface lies within the common scan volume;
  - calculate whether at least a portion of the surface of the virtual 3D model lies within the common scan volume, and
  - determine whether at least a portion of a surface is present in the overlapping volume only in one subscan and not the other subscan/3D virtual model;
  - if at least a portion of a surface is present in only one subscan, then disregard the portion of the surface in the overlapping volume which is closest to the focusing optics of the scanner, since the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

47. A method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

a) providing a first subscan of a first surface of part of the set of teeth;

b) calculating a first scan volume of the first subscan;

c) providing a second subscan of a second surface of part of the set of teeth;

d) calculating a second scan volume of the second subscan; and

e) if the first scan volume and the second scan volume are at least partly overlapping in a common scan volume; then:

f) calculate whether at least a portion of the first surface lies within the common scan volume;

g) calculate whether at least a portion of the second surface lies within the common scan volume, and

h) if at least a portion of the first surface or at least a portion of the second surface lie within the common scan volume, and the portion of the first surface or the portion of the second surface is located in space between the scanner and at least a portion of the second surface or at least a portion of the first surface, respectively;

then the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

48. The method according to the previous claims, wherein the method further comprises:

- providing a third subscan of a third surface of part of the set of teeth;
- calculating a third scan volume of the third subscan;
- if the third scan volume is at least partly overlapping with the first scan volume and/or with the second scan volume in a common scan volume; then

repeat steps f) - h) for the third subscan with respect to the first subscan and/or the second subscan.

49. A computer program product comprising program code means for causing a data processing system to perform the method of any one or more of the preceding claims, when said program code means are executed on the data processing system.

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

51. A system 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 system comprises:

- means for providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- means for providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- means for determining for the first 3D representation a first excluded volume in space where no surface can be present;
- means for determining for the second 3D representation a second excluded volume in space where no surface can be present;
- means for disregarding the portion of the surface in the first 3D representation in the generation of the virtual 3D model, if a portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or
- means for disregarding the portion of the surface in the second 3D representation in the generation of the virtual 3D model, if a portion of the

surface in the second 3D representation is located in space in the first excluded volume.

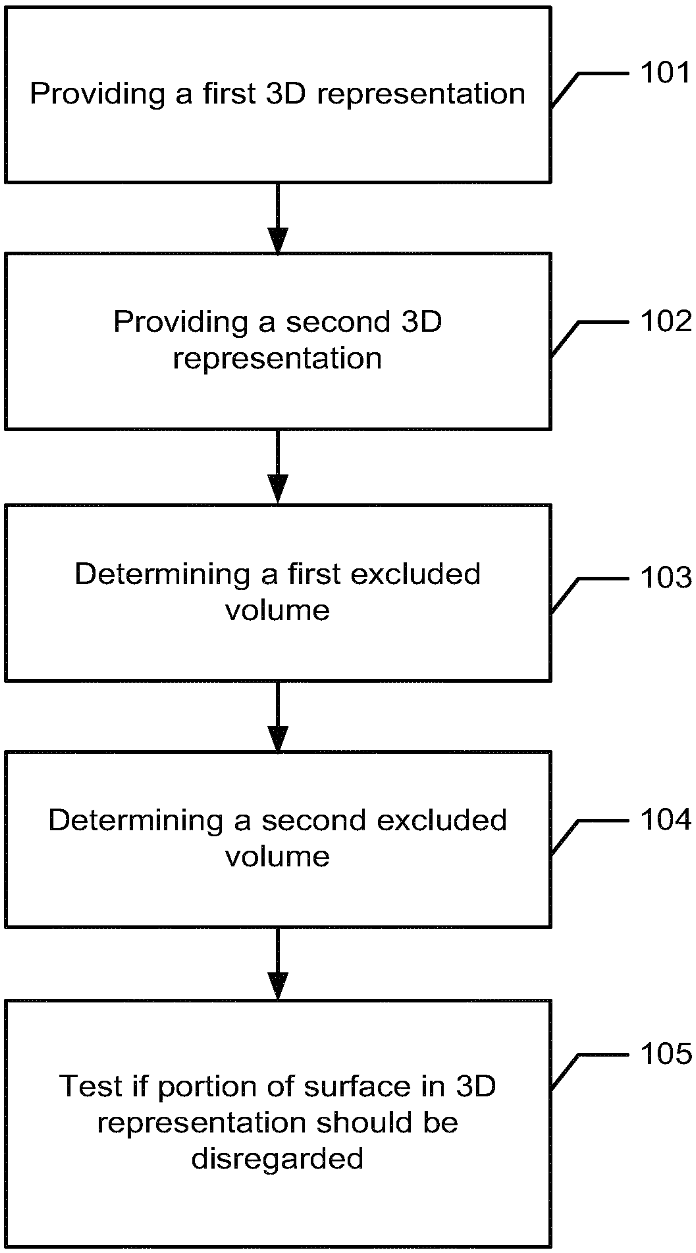

Providing a first 3D representation
101
Providing a second 3D representation
102
Determining a first excluded volume
103
Determining a second excluded volume
104
Test if portion of surface in 3D representation should be disregarded
105

Fig. 1

2/19

Fig. 2

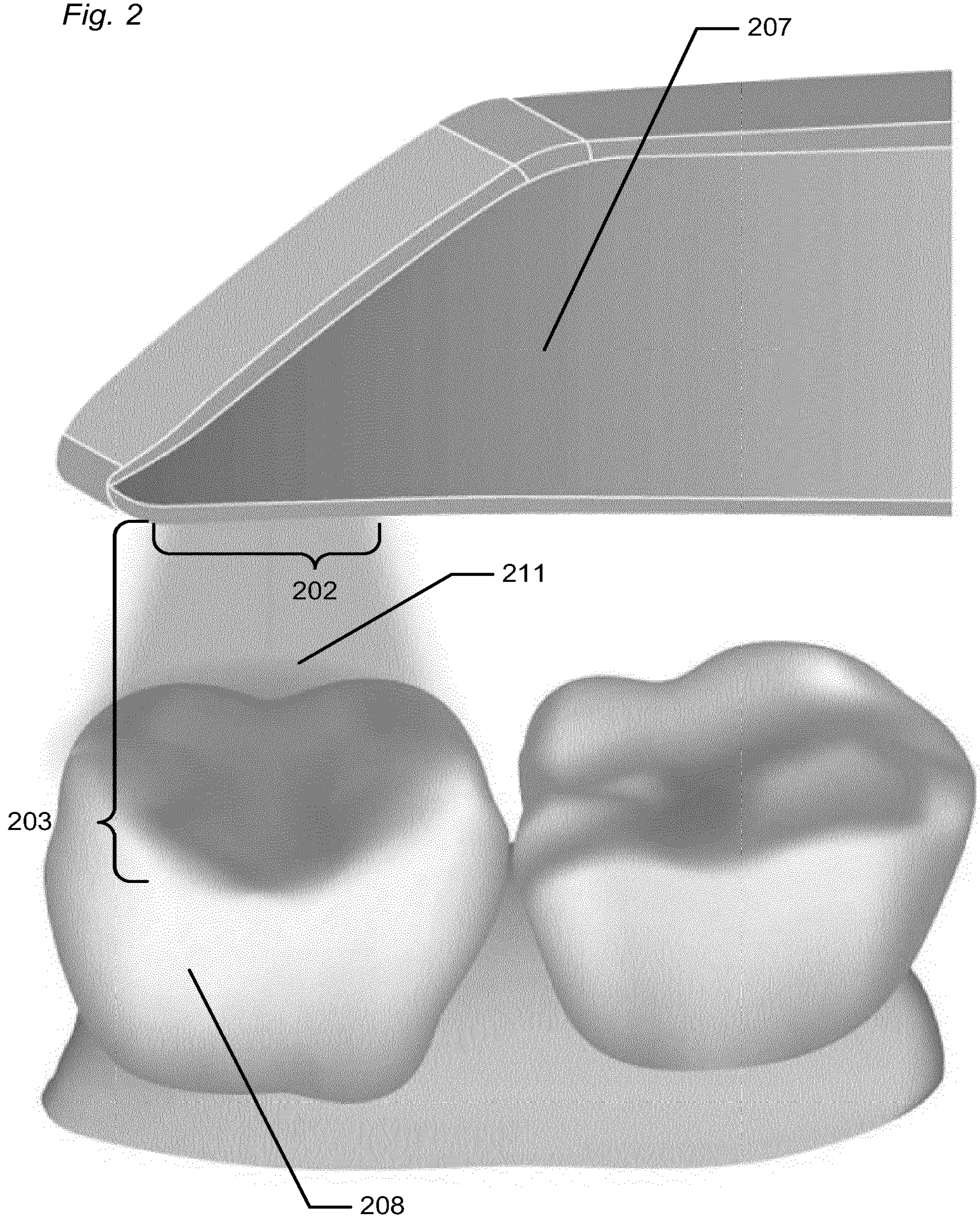


Fig. 3

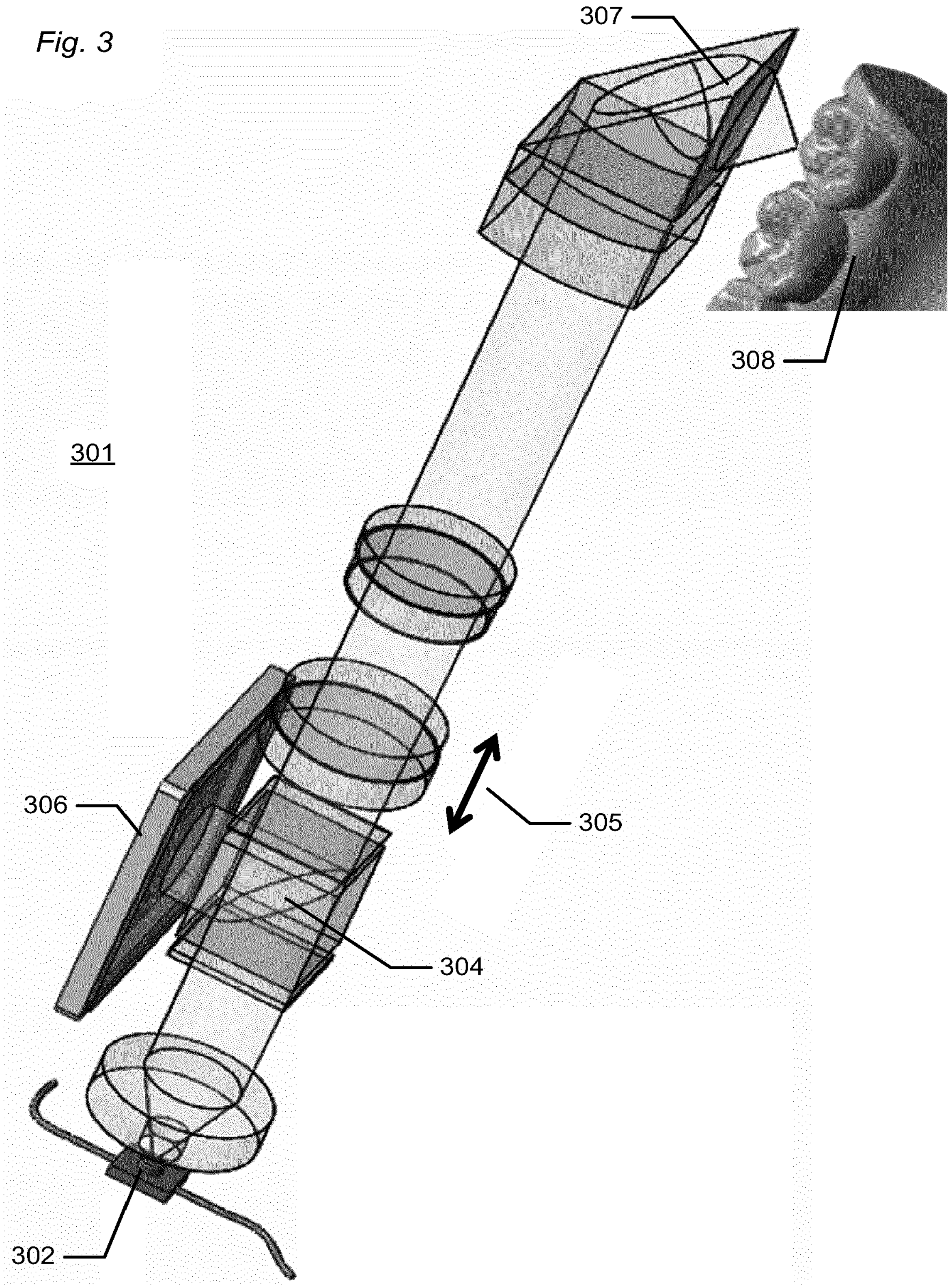


Fig. 4

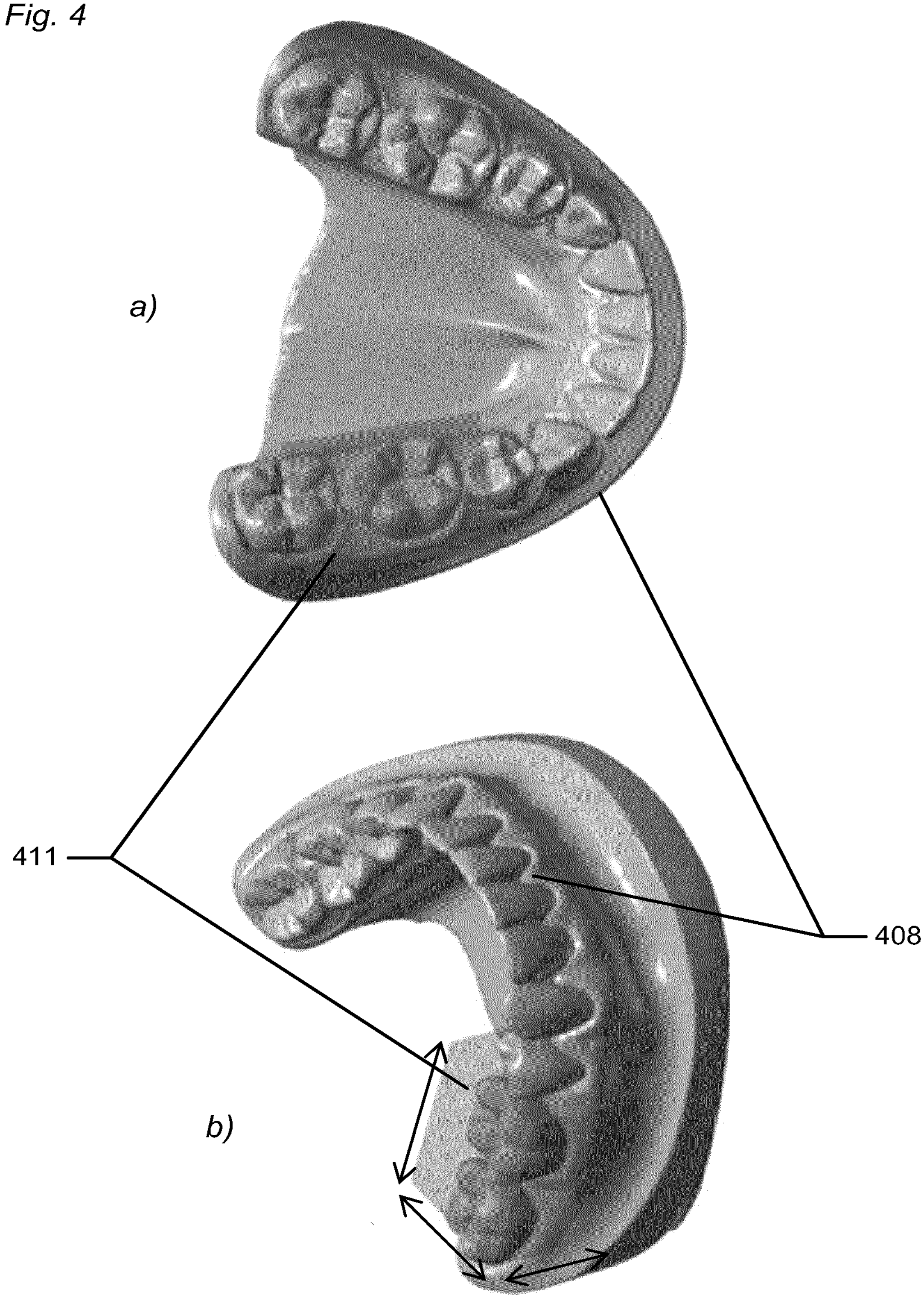
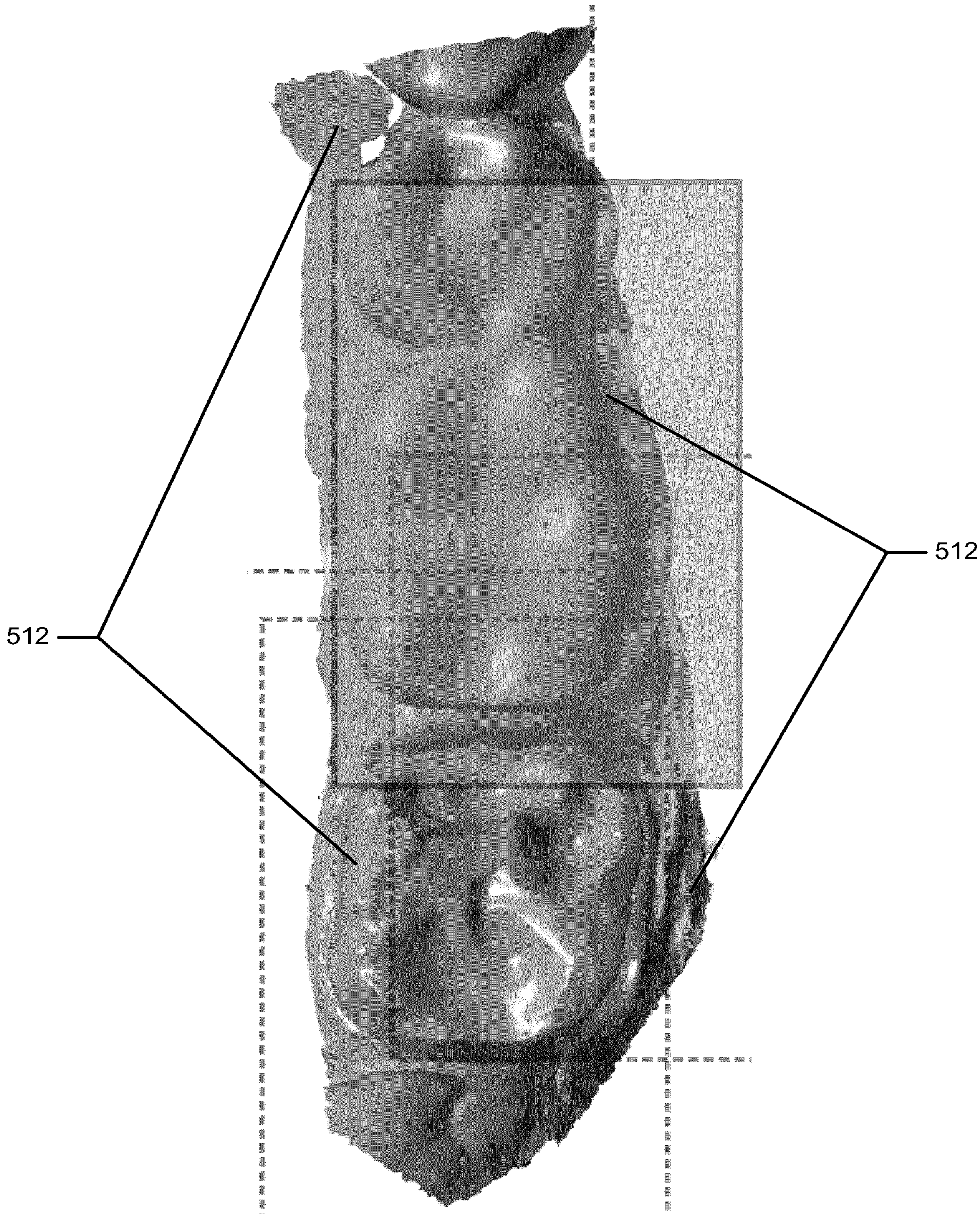


Fig. 5



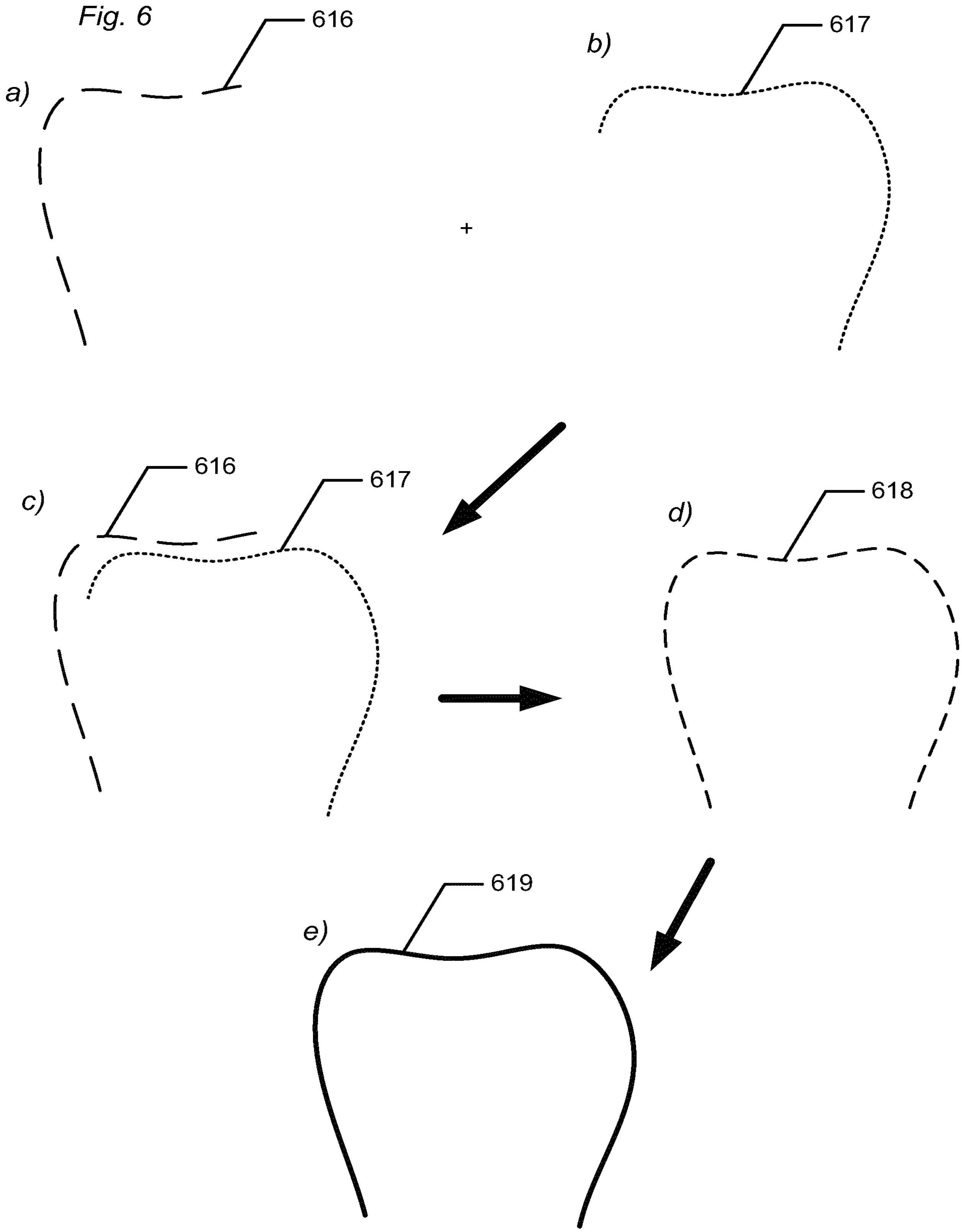


Fig. 6
a)
616
b)
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c)
616
617
d)
618
e)
619

Fig. 7

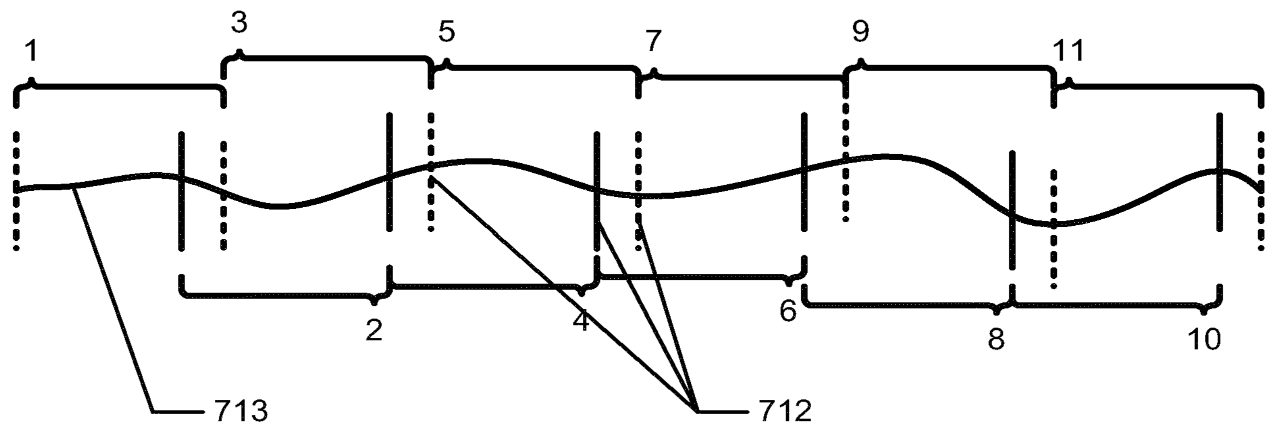
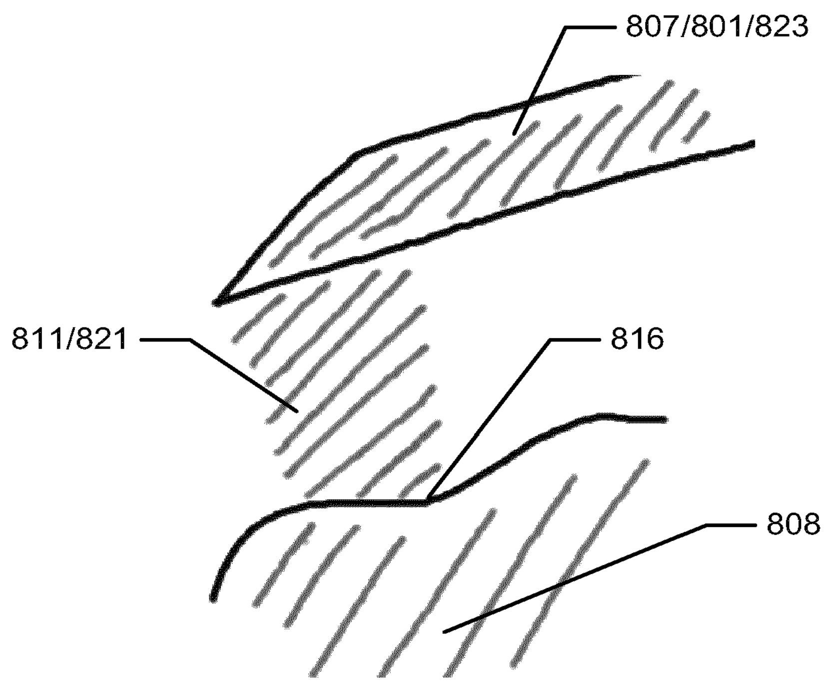


Fig. 8



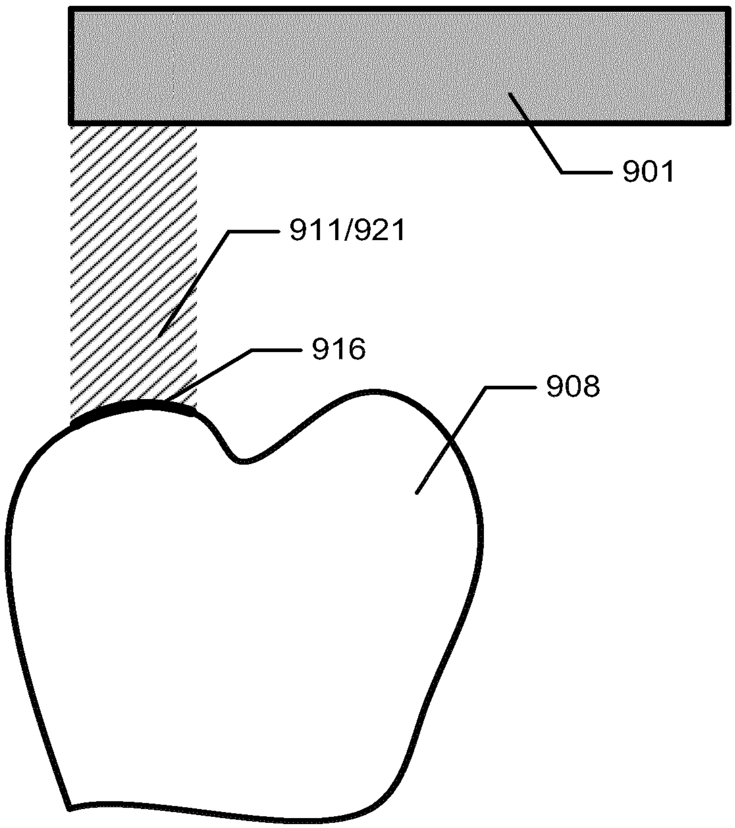


Fig. 9a)

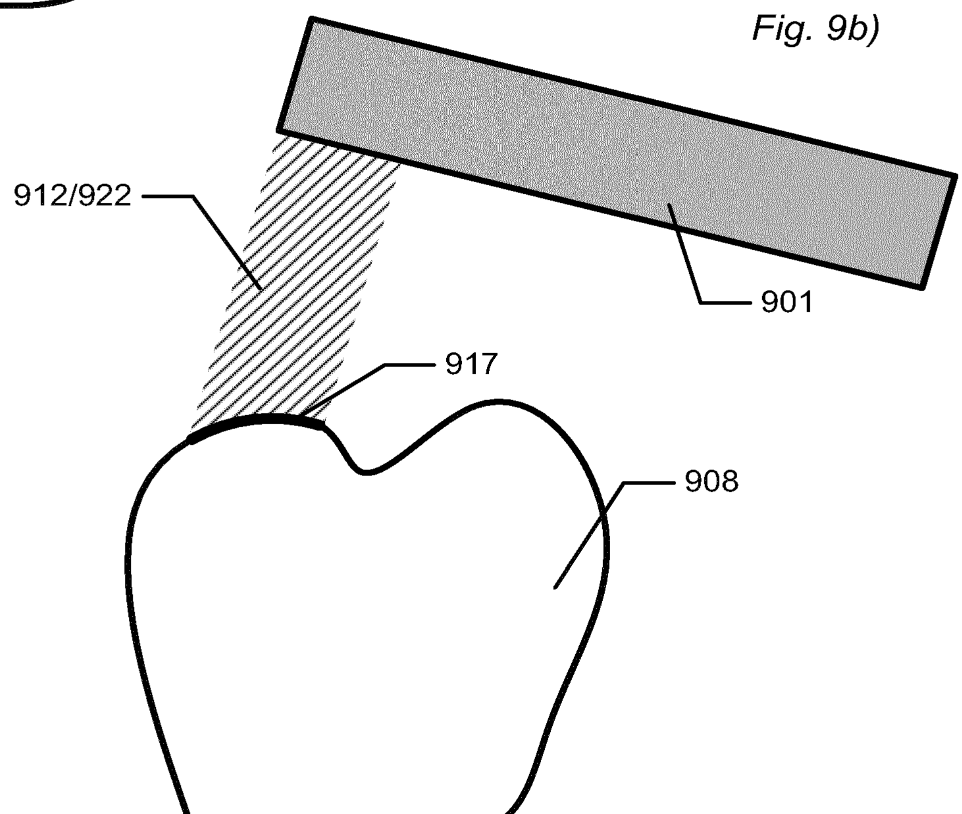


Fig. 9b)

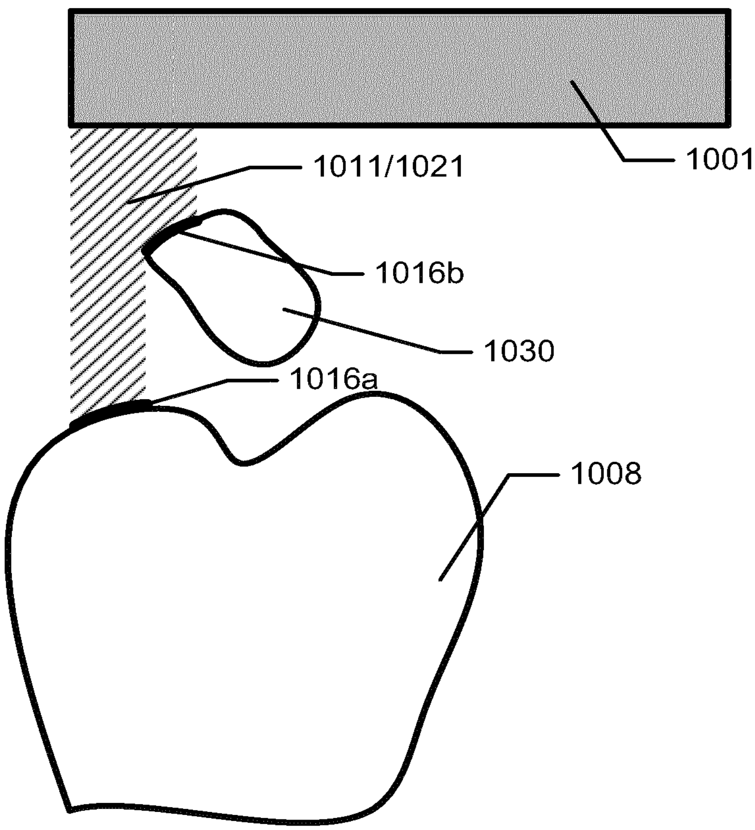


Fig. 10a)

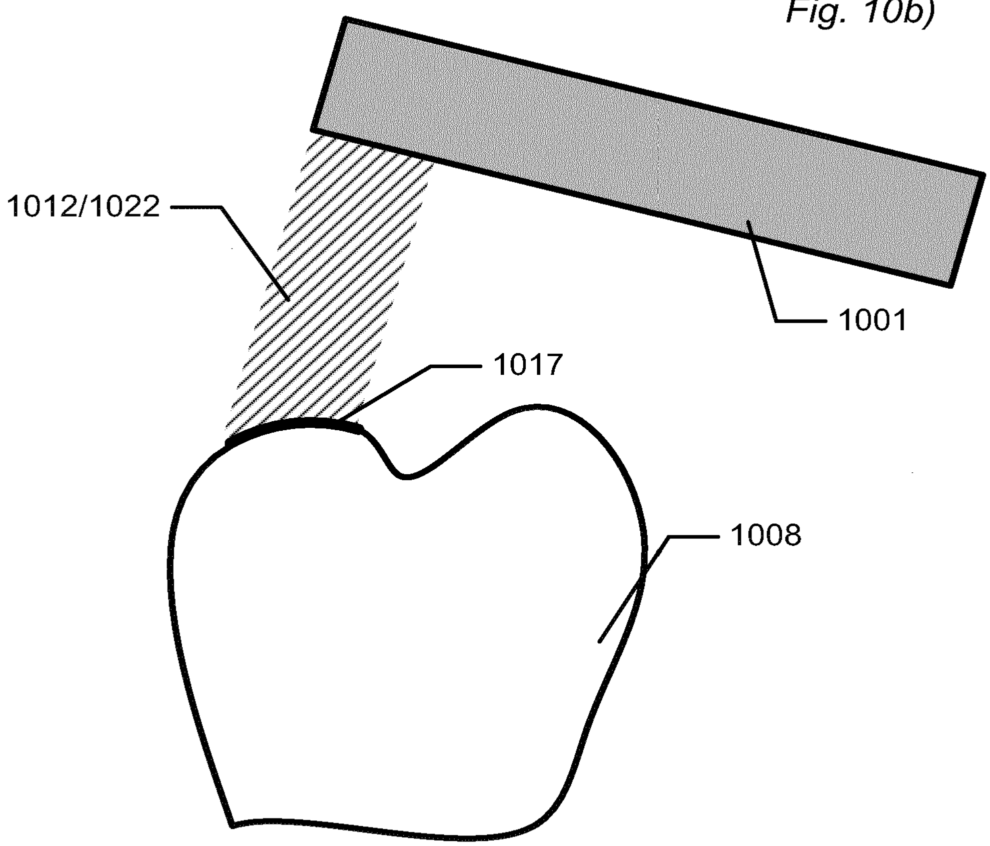


Fig. 10b)

Fig. 11a)

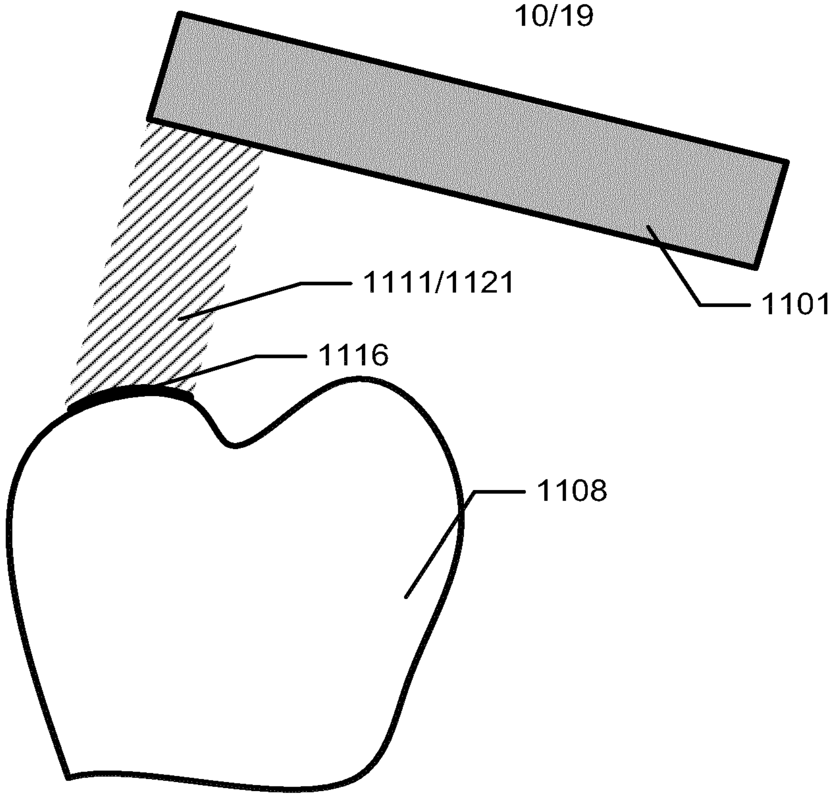


Fig. 11b)

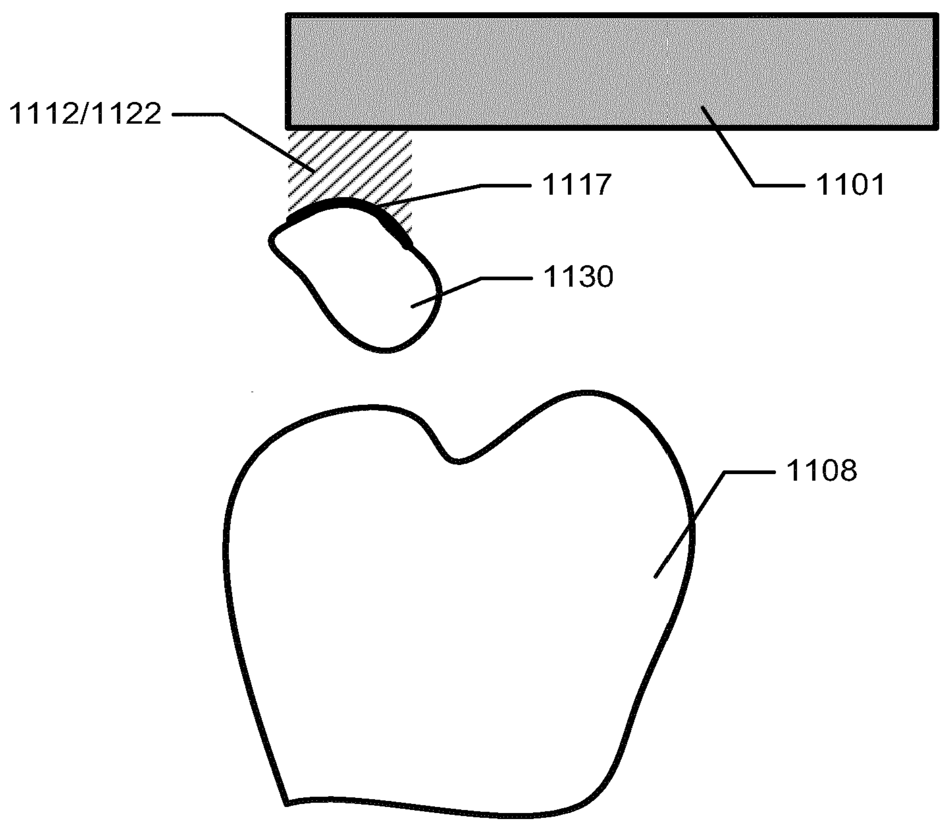
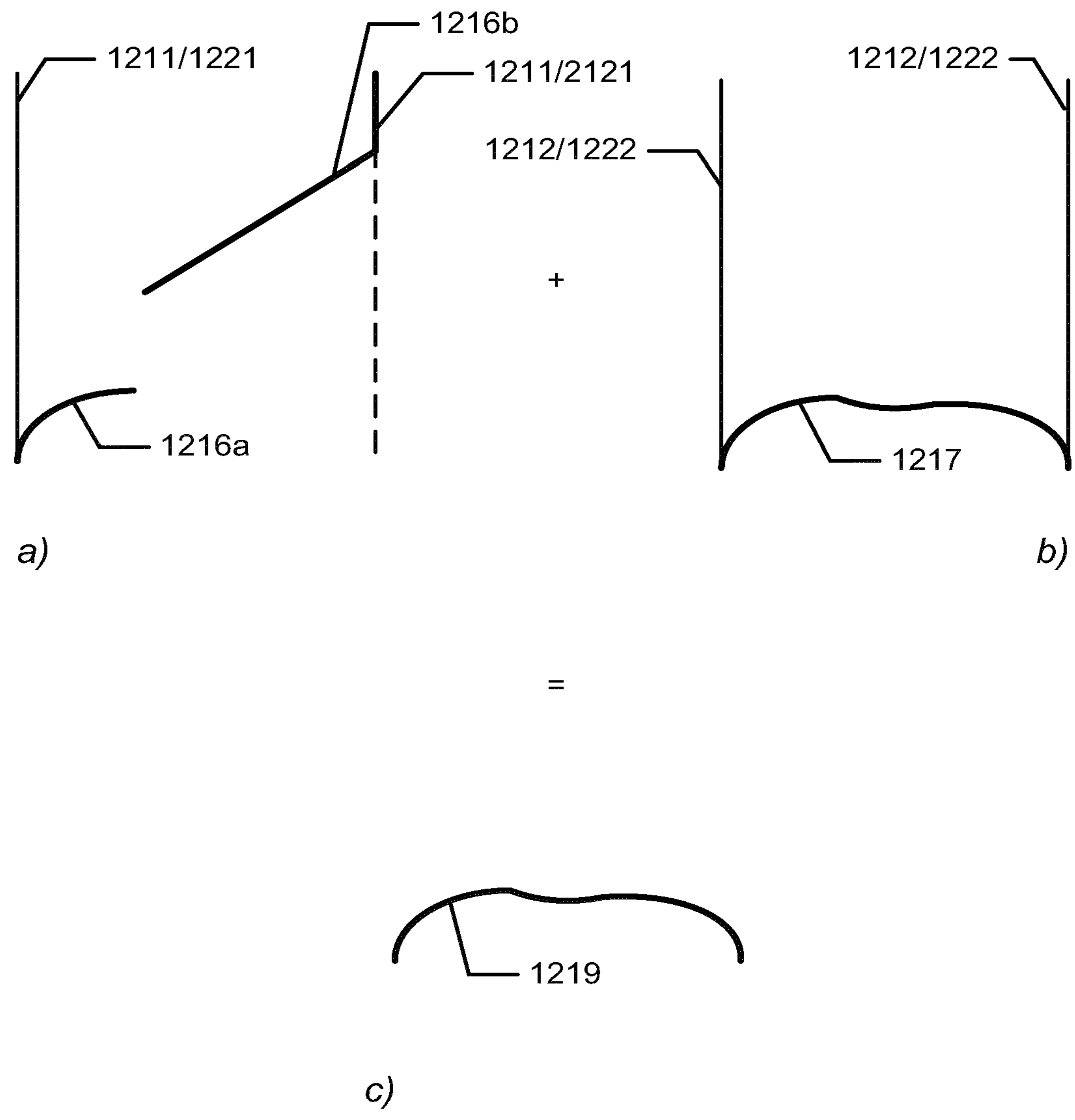


Fig. 12


1216b
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a)
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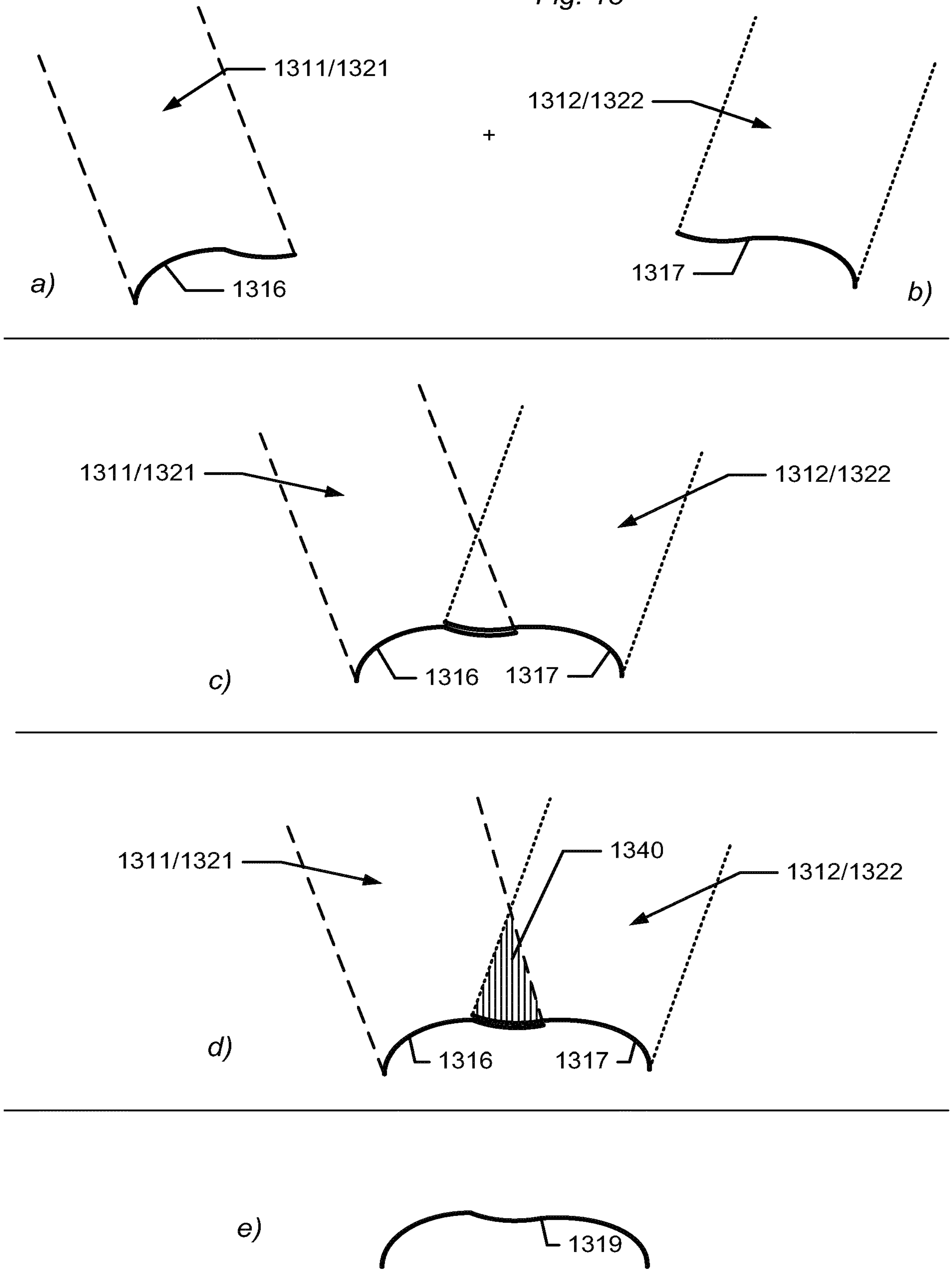
c)

Fig. 13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d)
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e)
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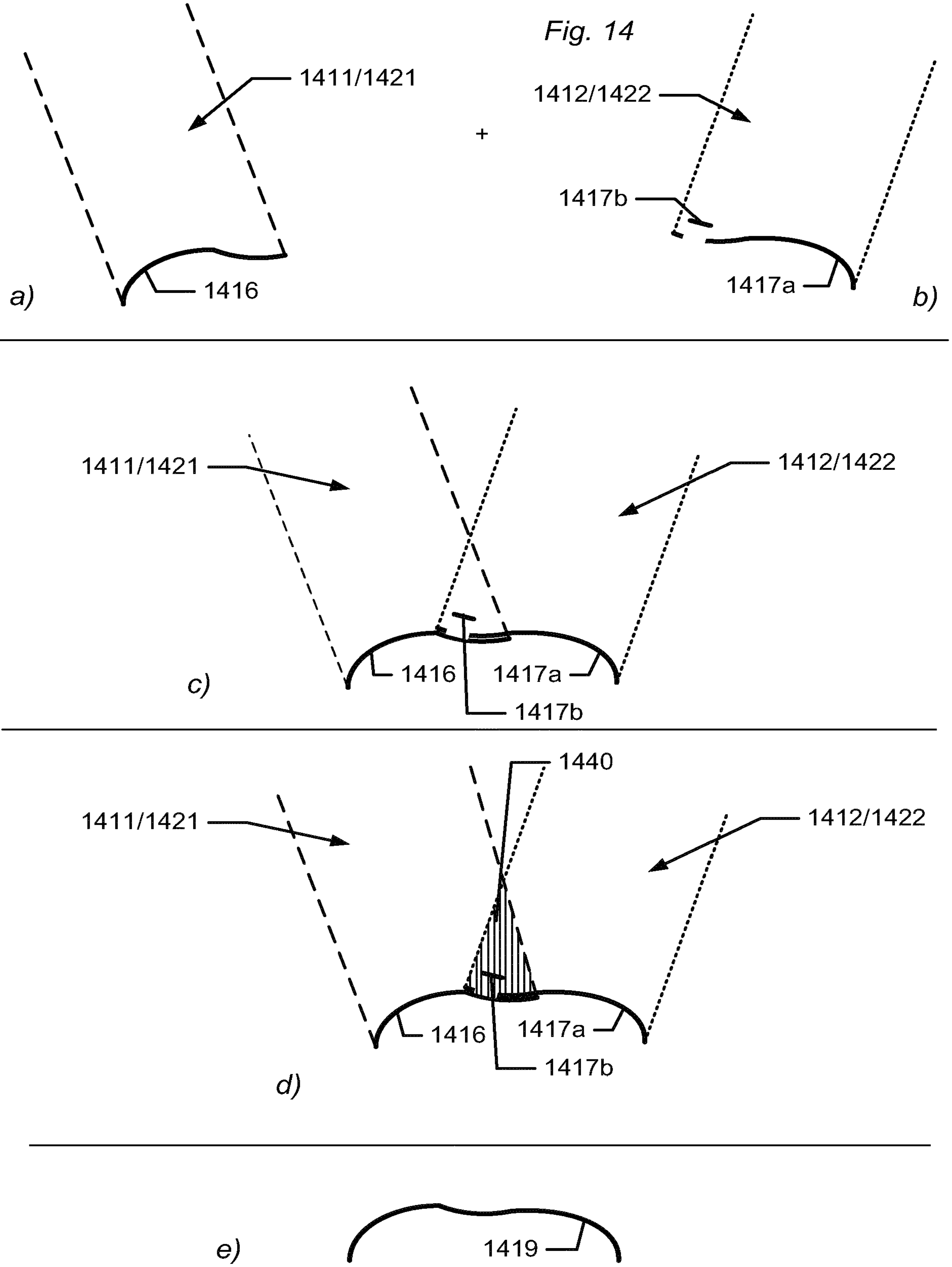
Fig. 14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1417a
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1411/1421
1412/1422
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1417a
1417b
d)
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e)

Fig. 15

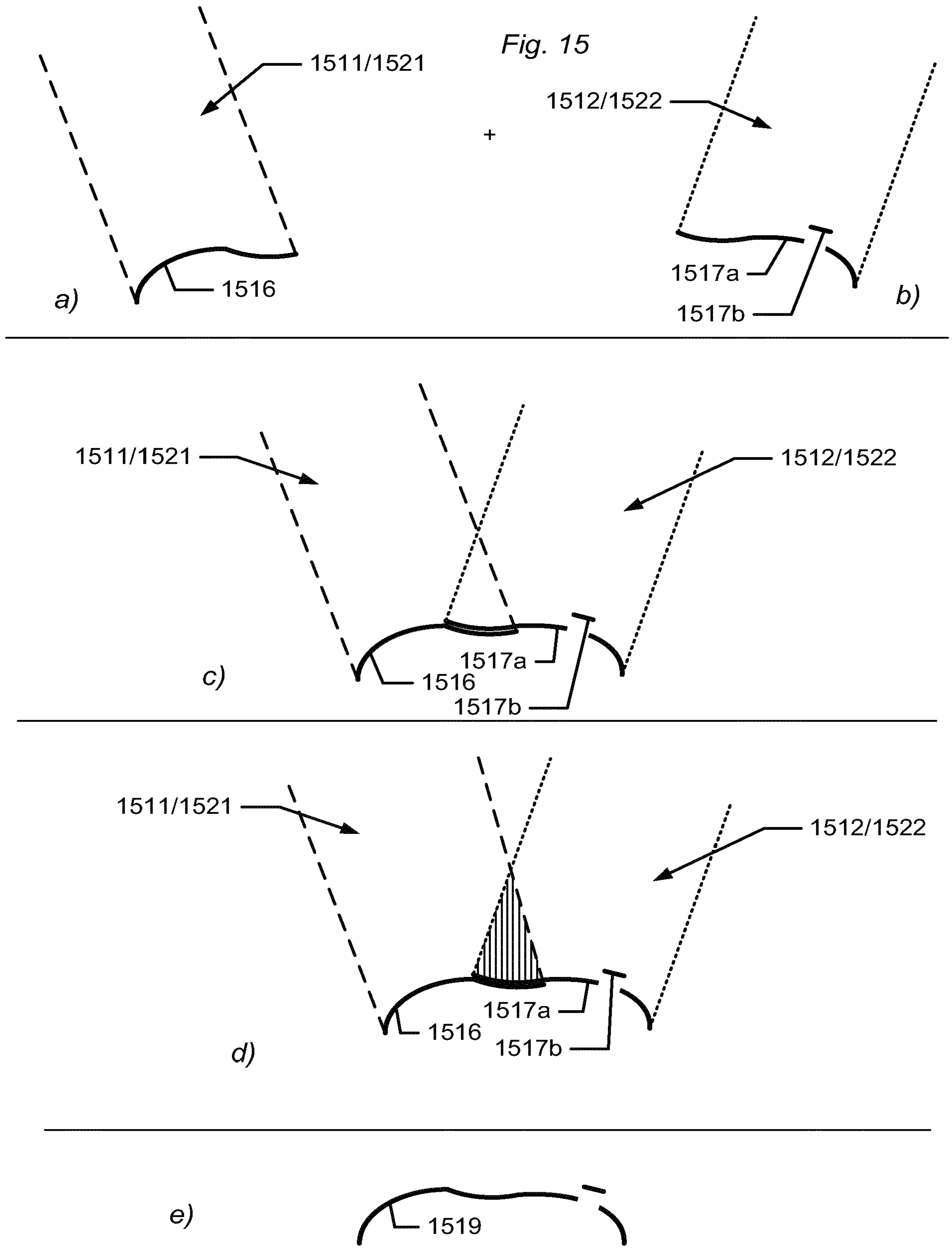

Fig. 16

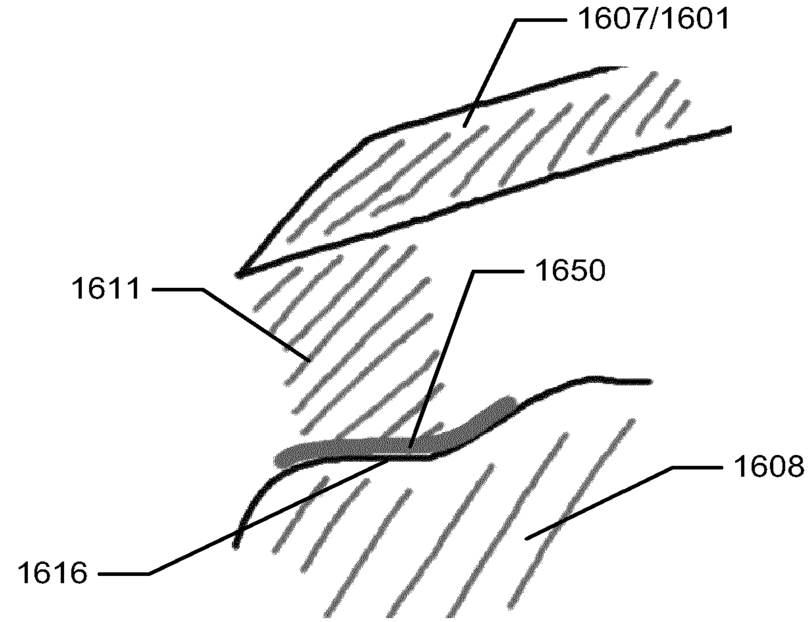
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Fig. 17

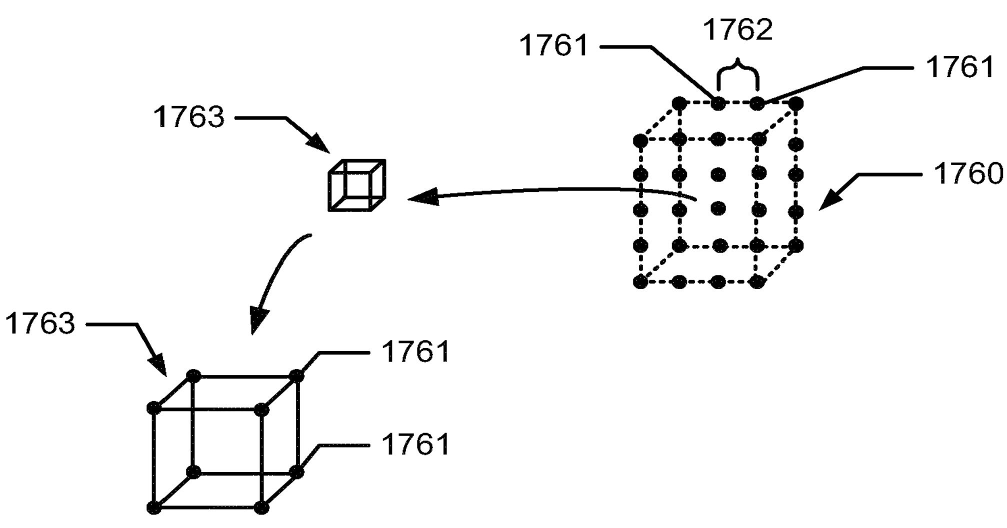
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Fig. 18a)

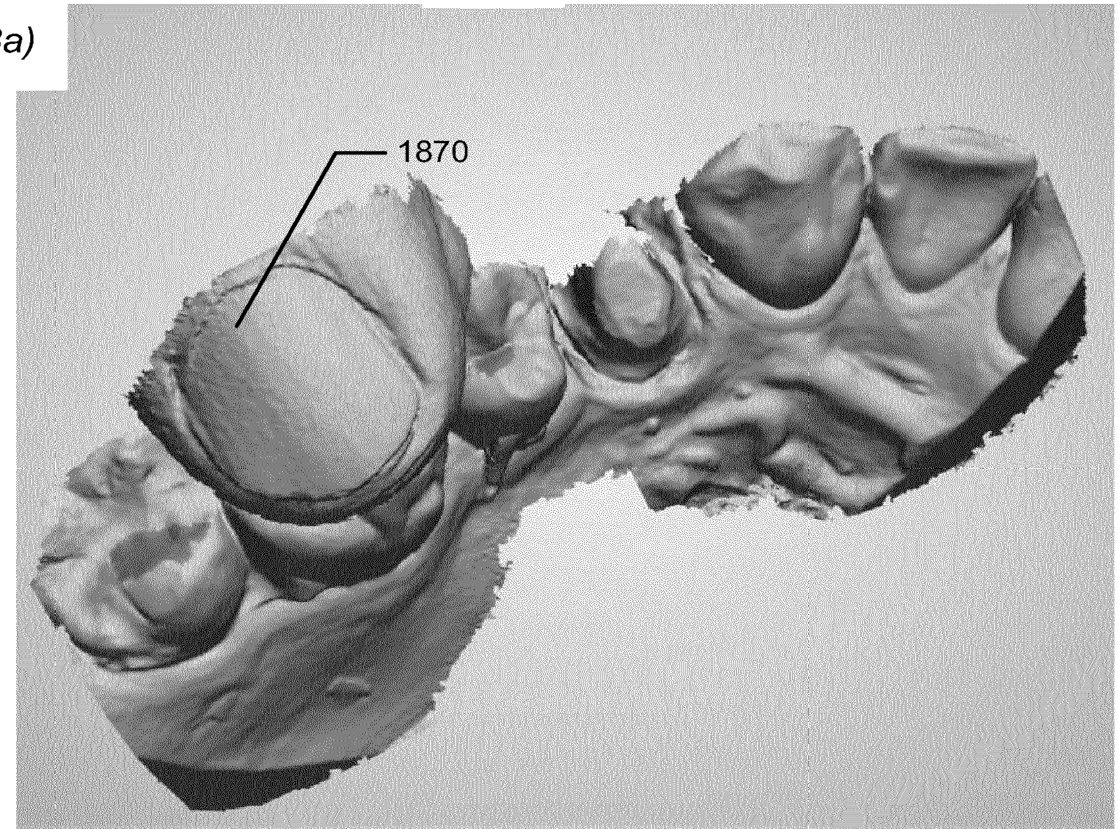
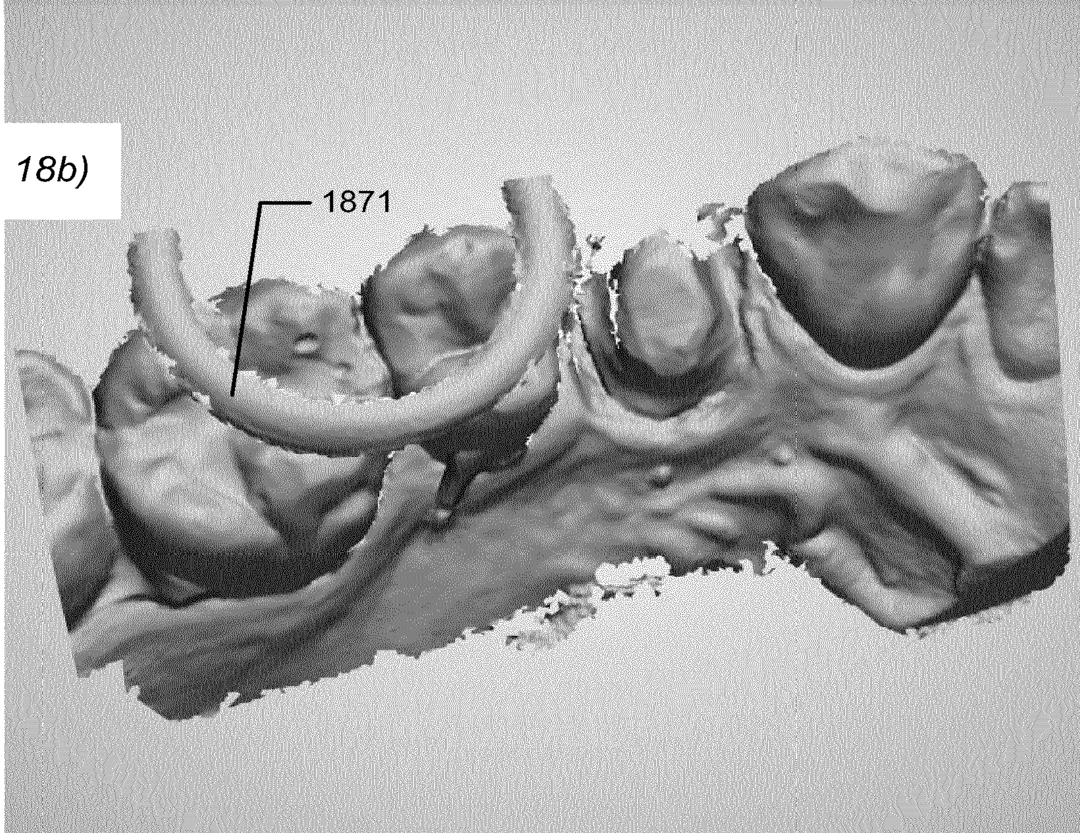


Fig. 18b)



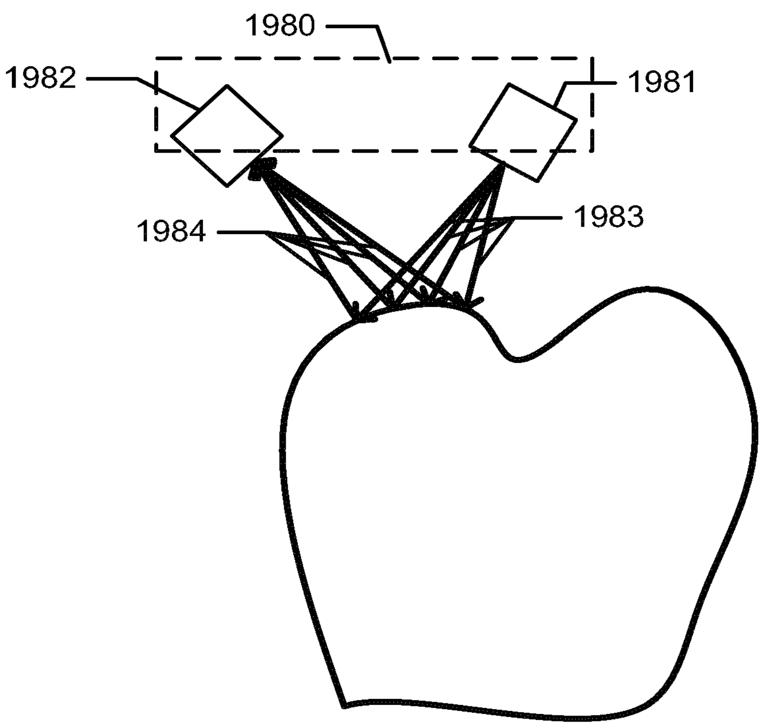


Fig. 19

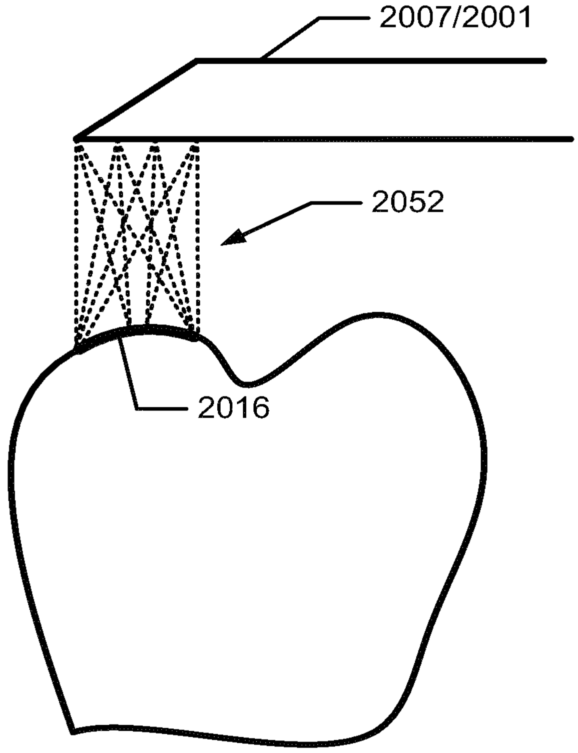


Fig. 20a)

Fig. 20b)

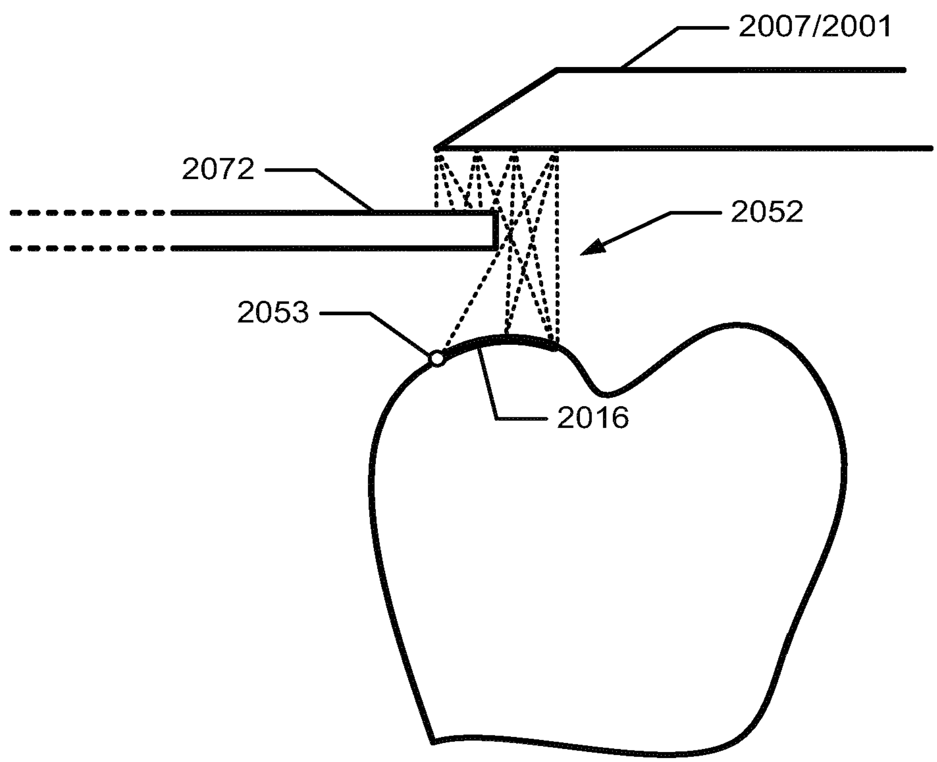


Fig. 20c)

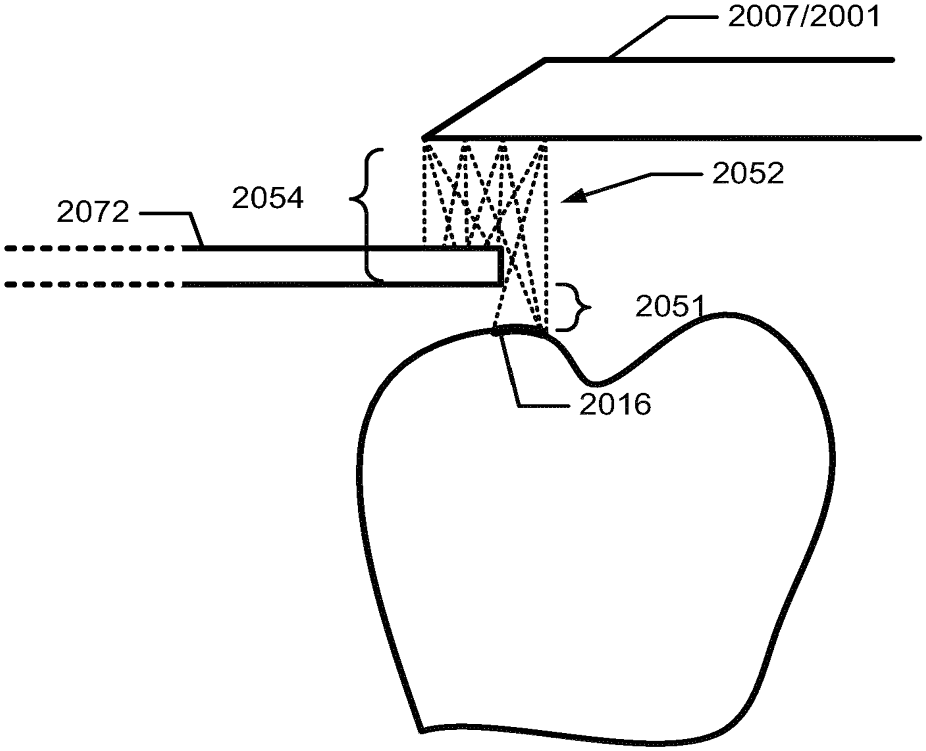
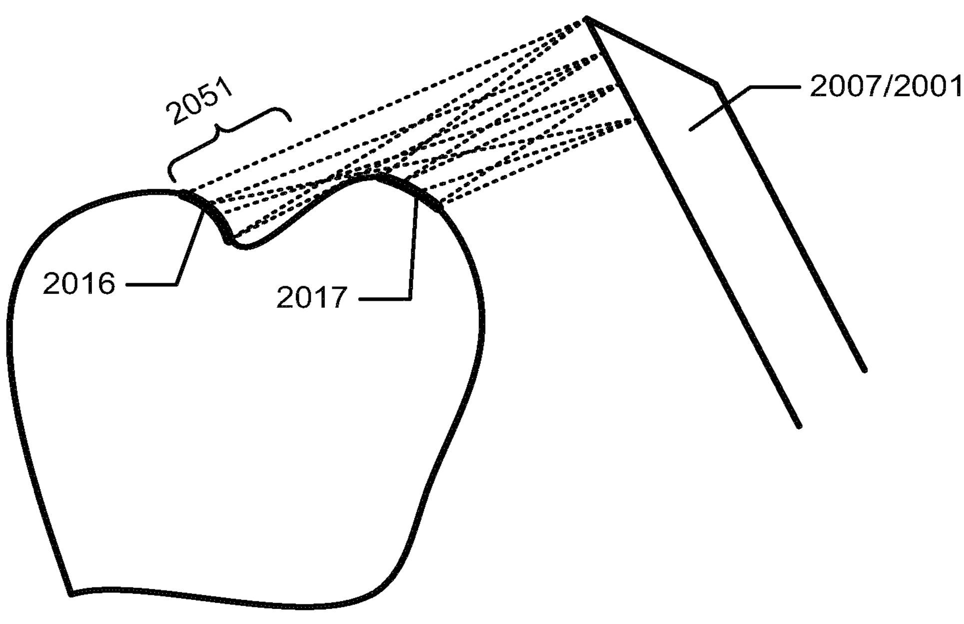


Fig. 20d)



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/063687

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T7/00
ADD.

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)
G06T G06K A61B A61C

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MEHL A ET AL: "Accuracy testing of a new intraoral 3D camera", INTERNATIONAL JOURNAL OF COMPUTERIZED DENTISTRY, QUINTESSENCE, NEW MALDEN, GB, vol. 12, no. 1, 1 January 2009 (2009-01-01), pages 11-28, XP009162619, ISSN: 1463-4201 the whole document -----	1-51

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

[ ] See patent family annex.

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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

"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
13 September 2012	21/09/2012

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	Borotschnig, Hermann

3

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ZHIGANG ZHU ET AL: "Content-Based 3D Mosaic Representation for Video of Dynamic 3D Scenes", APPLIED IMAGERY AND PATTERN RECOGNITION WORKSHOP, 2005. PROCEEDINGS. 3 4TH WASHINGTON, DC, USA 19-21 OCT. 2005, PISCATAWAY, NJ, USA,IEEE, 19 October 2005 (2005-10-19), pages 198-203, XP010905628, DOI: 10.1109/AIPR.2005.25 ISBN: 978-0-7695-2479-5 the whole document -----	1-51
A	THOMAS POLLARD ET AL: "Change Detection in a 3-d World", CVPR '07. IEEE CONFERENCE ON COMPUTER VISION AND PATTERN RECOGNITION; 18-23 JUNE 2007; MINNEAPOLIS, MN, USA, IEEE, PISCATAWAY, NJ, USA, 1 June 2007 (2007-06-01), pages 1-6, XP031114330, ISBN: 978-1-4244-1179-5 the whole document -----	1-51
A	YAMANY S M ET AL: "Free-form surface registration using surface signatures", COMPUTER VISION, 1999. THE PROCEEDINGS OF THE SEVENTH IEEE INTERNATION AL CONFERENCE ON KERKYRA, GREECE 20-27 SEPT. 1999, LOS ALAMITOS, CA, USA,IEEE COMPUT. SOC, US, vol. 2, 20 September 1999 (1999-09-20), pages 1098-1104, XP010350539, ISBN: 978-0-7695-0164-2 the whole document -----	1-51
T	Silvia Logozzo ET AL: "A Comparative Analysis Of Intraoral 3d Digital Scanners For Restorative Dentistry", The Internet Journal of Medical Technology, 1 January 2011 (2011-01-01), pages 1-12, XP55037945, DOI: 10.5580/1b90 Retrieved from the Internet: URL:http://www.ispub.com/journal/the-internet-journal-of-medical-technology/volume-5-number-1/a-comparative-analysis-of-intraoral-3d-digital-scanners-for-restorative-dentistry.html [retrieved on 2012-09-12] the whole document -----	1-51

3