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(54) Title: FOCUS SCANNING APPARATUS

(57) Abstract: Disclosed is a handheld scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object using confocal pattern projection techniques. Specific embodiments are given for intraoral scanning and scanning of the

Focus scanning apparatus

The present invention relates to an apparatus and a method for optical 3D scanning of surfaces. The principle of the apparatus and method according to the invention may be applied in various contexts. One specific embodiment of the invention is particularly suited for intraoral scanning, i.e. direct scanning of teeth and surrounding soft-tissue in the oral cavity. Other dental related embodiments of the invention are suited for scanning dental impressions, gypsum models, wax bites, dental prosthetics and abutments. Another embodiment of the invention is suited for scanning of the interior and exterior part of a human ear or ear channel impressions. The invention may find use within scanning of the 3D structure of skin in dermatological or cosmetic / cosmetological applications, scanning of jewelry or wax models of whole jewelry or part of jewelry, scanning of industrial parts and even time resolved 3D scanning, such as time resolved 3D scanning of moving industrial parts.

Background of the invention

The invention relates to three dimensional (3D) scanning of the surface geometry of objects. Scanning an object surface in 3 dimensions is a well known field of study and the methods for scanning can be divided into contact and non-contact methods. An example of contact measurements methods are Coordinate Measurement Machines (CMM), which measures by letting a tactile probe trace the surface. The advantages include great precision, but the process is slow and a CMM is large and expensive. Non-contact measurement methods include x-ray and optical probes.

Confocal microscopy is an optical imaging technique used to increase micrograph contrast and/or to reconstruct three-dimensional images by using a spatial pinhole to eliminate out-of-focus light or flare in specimens that are thicker than the focal plane.

A confocal microscope uses point illumination and a pinhole in an optically conjugate plane in front of the detector to eliminate out-of-focus information. Only the light within the focal plane can be detected. As only one point is illuminated at a time in confocal microscopy, 2D imaging requires raster scanning and 3D imaging requires raster scanning in a range of focus planes.

In WO 00/08415 the principle of confocal microscopy is applied by illuminating the surface with a plurality of illuminated spots. By varying the focal plane in-focus spot-specific positions of the surface can be determined. However, determination of the surface structure is limited to the parts of the surface that are illuminated by a spot.

WO 2003/060587 relates to optically sectioning of a specimen in microscopy wherein the specimen is illuminated with an illumination pattern. Focus positions of the image plane are determined by characterizing an oscillatory component of the pattern. However, the focal plane can only be adjusted by moving the specimen and the optical system relative to each other, i.e. closer to or further away from each other. Thus, controlled variation of the focal plane requires a controlled spatial relation between the specimen and the optical system, which is fulfilled in a microscope. However, such a controlled spatial relation is not applicable to e.g. a hand held scanner.

US2007/0109559 A1 describes a focus scanner where distances are found from the focus lens positions at which maximum reflective intensity of light beams incident on the object being scanned is observed. In contrast to the invention disclosed here, this prior art exploits no pre-determined measure of the illumination pattern and exploits no contrast detection, and therefore, the signal-to-noise ratio is sub-optimal.

In WO 2008/125605, means for generating a time-variant pattern composed of alternating split images are described. This document describes a scanning method to obtain an optical section of a scan object by means of two different illumination profiles, e.g. two patterns of opposite phases. These two images are used to extract the optical section, and the method is limited to acquisition of images from only two different illumination profiles. Furthermore, the method relies on a predetermined calibration that determines the phase offset between the two illumination profiles.

Summary of the invention

Thus, an object of the invention is to provide a scanner which may be integrated in a manageable housing, such as a handheld housing. Further objects of the invention are: discriminate out-of-focus information and provide a fast scanning time.

This is achieved by a method and a scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:

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

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

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