



US 20090087050A1

(19) **United States**

(12) **Patent Application Publication**  
**Gandyra**

(10) **Pub. No.: US 2009/0087050 A1**

(43) **Pub. Date: Apr. 2, 2009**

(54) **DEVICE FOR DETERMINING THE 3D COORDINATES OF AN OBJECT, IN PARTICULAR OF A TOOTH**

(30) **Foreign Application Priority Data**

Aug. 16, 2007 (DE) ..... 102007038721.2  
Dec. 14, 2007 (DE) ..... 102007060263.6

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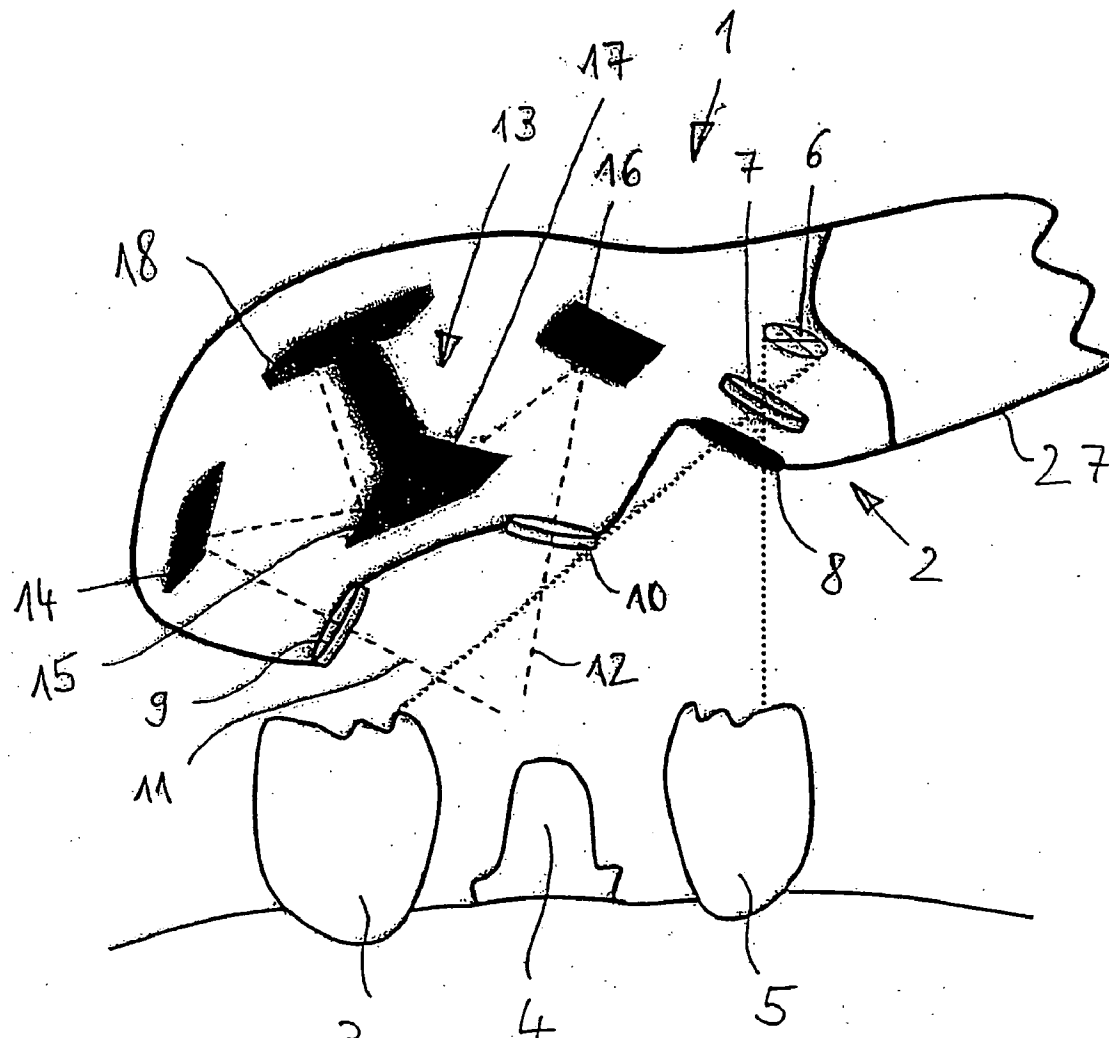
**Publication Classification**

(51) **Int. Cl.**  
**G06K 9/00** (2006.01)  
**G06K 9/20** (2006.01)

(52) **U.S. Cl.** ..... **382/128; 382/312**

(57) **ABSTRACT**

A scanner is used for scanning an object (3, 4, 5), in particular a tooth or a plurality of teeth or a dental cast. The scanner (1) comprises a projector (2) for projecting a pattern (7) onto the object (3, 4, 5) and a camera which comprises a recording optics and an image sensor (18). To improve such scanner, the recording optics comprises a first imaging optics (9) and a second imaging optics (10).



(21) Appl. No.: **12/228,917**

(22) Filed: **Aug. 18, 2008**

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Fig. 1

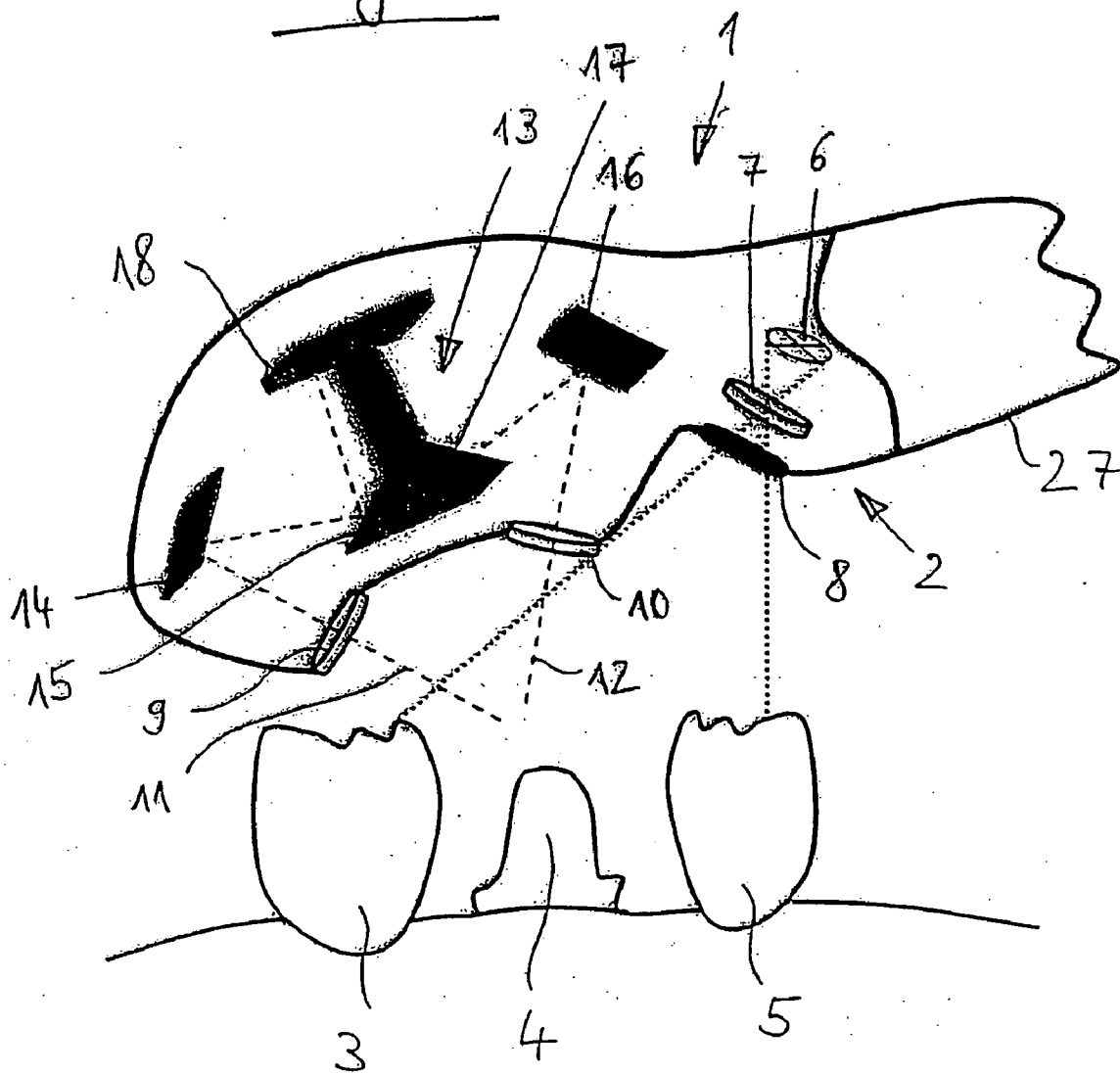


Fig. 2

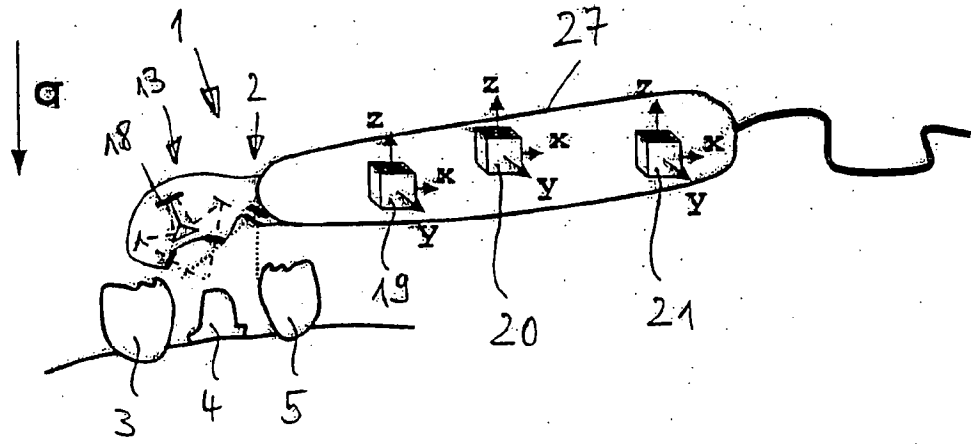
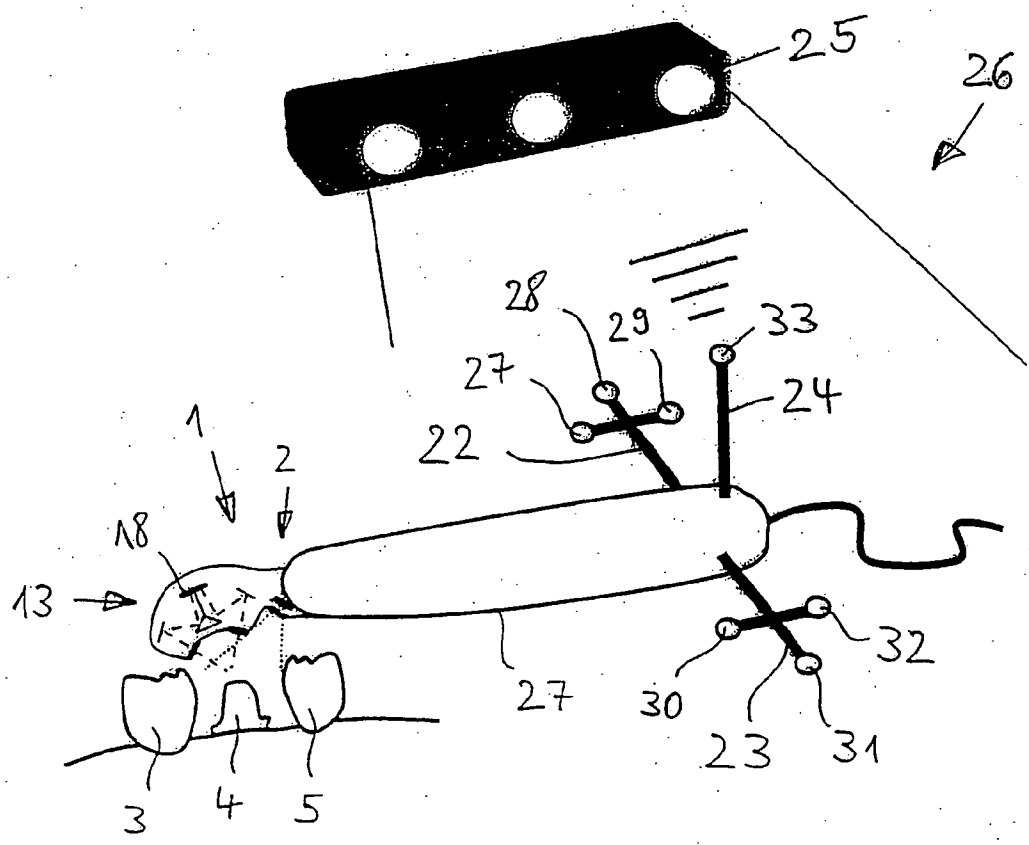


Fig. 3



**DEVICE FOR DETERMINING THE 3D  
COORDINATES OF AN OBJECT, IN  
PARTICULAR OF A TOOTH**

**[0001]** This invention relates to a scanner for scanning an object, in particular a tooth or a plurality of teeth or a dental cast, and a device for determining the 3D coordinates of an object, in particular of a tooth or a plurality of teeth or a dental cast.

**[0002]** Devices and methods for determining the 3D coordinates of an object are known already. EP 299 490 B2 describes a method for making a dental prosthesis, in which contour lines on the ground tooth and its surroundings are produced, the lines are detected with an optoelectronic means, in particular a video camera, the detected values are entered in a computer, and the three-dimensional structure of the tooth and the dental prosthesis is calculated. By means of the structure thus calculated, the dental prosthesis can be fabricated.

**[0003]** However, the detection of the 3D coordinates of objects located in regions which are hard to reach, i.e. in particular of teeth in the oral cavity of a patient, involves certain difficulties.

**[0004]** Proceeding therefrom, it is the object underlying the invention to propose an improved scanner for scanning an object, in particular a tooth, and an improved device for determining the 3D coordinates of an object, in particular of a tooth.

**[0005]** In accordance with the invention, this object is solved by a scanner with the features of claim 1. The scanner is used for scanning an object, in particular one or more teeth, wherein one or more or all teeth can be prepared. The term of preparing on the one hand comprises the dental preparation, i.e. for instance grinding the stump of a tooth, and on the other hand the preparation which is necessary for scanning a tooth with an optical measurement technique, for instance spraying white spray onto the region to be scanned.

**[0006]** The scanner comprises a projector for projecting a pattern onto the object and a camera which comprises a recording optics and an image sensor, in particular a CCD sensor or a CMOS sensor. In accordance with the invention, the recording optics comprises a first imaging optics and a second imaging optics. In this way, a stereoscopic pair is produced by the scanner. The imaging optics can be located at a distance from each other. The optical axes of the imaging optics can be arranged at an angle with respect to each other. Preferably, they are arranged at such an angle with respect to each other that they are directed towards a corresponding region of the object or tooth. As a result, the region of the object or tooth thus is observed with two cameras.

**[0007]** The scanner of the invention in particular can constitute a miniaturized scanner. It is particularly useful for scanning teeth in the mouth of a patient. It is, however, also particularly useful for other applications in which the objects to be scanned are hard to reach. In particular, the scanner of the invention can be used for intra-ear scanning, for endoscopic digitization and/or in hard-to-reach cavities and/or channels of machines and/or apparatuses.

**[0008]** Advantageous developments are described in the sub-claims.

**[0009]** Preferably, the recording optics comprises a beam

images onto the image sensor. In doing so, the images from the imaging optics can each be projected onto different regions of the image sensor.

**[0010]** It is possible to provide further imaging optics. In particular, two more imaging optics can be provided, so that a total of four imaging optics are present. Each image can be projected onto a separate quarter of the image sensor.

**[0011]** It is furthermore possible to provide further image sensors. In particular, one image sensor can be present for each imaging optics.

**[0012]** By taking a picture, a particular region of the object or tooth can be covered. To be able to cover the entire object or the entire tooth or several or all teeth and possibly also the surroundings thereof, a plurality of pictures can be taken sequentially. The individual shots can be combined to a total object representation.

**[0013]** For this purpose, the scanner is moved around the object, in order to cover several or all regions of the object. Since the scanner makes each individual shot in its coordinate system, the movement of the scanner advantageously should be detected, so as to be able to combine the individual shots as detailed and accurate as possible. This procedure is referred to as "registering" or "matching".

**[0014]** In accordance with an advantageous development, the scanner includes one or more sensors for detecting the location and orientation of the scanner. In this way, a tracking system can be formed for the scanner.

**[0015]** For detecting the location and orientation of the scanner, 6D data preferably are supplied by the sensor(s). The 6D data consist of three translational data and three rotational data. As a result, both the translation and the rotation of the scanner are detected completely. In this way, a tracking system is formed for the scanner.

**[0016]** In accordance with another advantageous development, the scanner includes one or more acceleration sensors. The scanner movement can be detected by the acceleration sensors, and the location of the scanner can be determined thereby. It is possible to detect the location of the scanner by the acceleration sensors.

**[0017]** In accordance with another advantageous development, the scanner includes one or more gyrometers. The rotations, i.e. the orientation, of the scanner can be detected by the gyrometers.

**[0018]** The 6D information corresponds to the six degrees of freedom, which must be defined to unambiguously define a body, namely the scanner, in space in terms of its location (position) and orientation (rotation). The 6D information of the scanner is defined by three translatory components and three rotary components.

**[0019]** The temporal integration of an acceleration sensor supplies a velocity. The further temporal integration thereof supplies a path component. Proceeding therefrom, three acceleration sensors can be used. Sensors which determine all three translatory components at the same time are, however, also available.

**[0020]** The same is true for gyrometers, which detect the rotary accelerations, whose temporal integration two times over supplies an angle of rotation. It is possible to use three gyrometers, in order to obtain the three spatial angles of rotation of the scanner. However, there are also gyrometers which supply all three spatial angles of rotation.

[0022] Instead or in addition, markers for a tracking system can be provided on the scanner. The markers for the tracking system can be one or more active markers. In particular, infrared markers can be used, which are triggered time-sequentially. However, the markers for the tracking system can also be one or more passive markers. In particular, the passive markers can be coded and/or non-coded, reflecting and/or non-reflecting markers. The markers can have different patterns.

[0023] The markers present on the scanner initially are surveyed. Hence, the position of the markers on the scanner is known. The markers then are tracked by a tracking camera. By means of the tracking system, the location and rotary position of the scanner can be covered in the different shots. In this way, possibilities for combining the different individual shots of the scanner are improved or created.

[0024] In a device for determining the 3D coordinates of an object, in particular of a tooth, the object underlying the invention is solved by the features of claim 12. The device comprises an inventive scanner for scanning the object or tooth and an evaluation means, in particular a computer, especially a PC including the associated software, for determining the 3D coordinates of the object from the pictures taken by the scanner.

[0025] Preferably, the device in accordance with the invention comprises a tracking system for determining the location and orientation of the scanner. The tracking system can be formed in that the scanner includes one or more sensors for detecting the location and orientation of the scanner. In particular, the tracking system can be formed in that the scanner includes acceleration sensors and/or gyrometers. It is possible that the data of the sensor(s) for detecting the location and orientation of the scanner and/or of the acceleration sensors and/or of the gyrometer(s), in particular the 6D data thereof, are calculated back onto the location and rotary position of the scanner by temporal integration. Instead or in addition, however, another tracking system can also be used, in particular an infrared tracking system.

[0026] Embodiments of the invention will be explained in detail below with reference to the attached drawing, in which:

[0027] FIG. 1 shows a scanner for scanning a group of teeth in a schematic view,

[0028] FIG. 2 shows the scanner of FIG. 1, which additionally includes acceleration sensors, and

[0029] FIG. 3 shows the scanner of FIG. 1 with infrared markers for an infrared tracking system.

[0030] FIG. 1 shows a scanner 1 which includes a projector 2 for projecting a pattern onto the teeth 3, 4, 5. The tooth 4 is ground, the adjacent teeth 3, 5 are not ground and form the surroundings of the ground tooth 4. The projector 2 comprises a light source 6, a pattern transparency 7 and a projection optics 8. The light source 6 can be a light bulb or an LED. Instead of the pattern transparency 7 a transmitted-light LCD can also be used, which can be activated for forming a pattern. The pattern can, however, also be projected by means of a DMD or LCOS method.

[0031] In the scanner 1, a first imaging optics 9 and a second imaging optics 10 furthermore are provided, which are spaced from each other and whose optical axes 11, 12 form an angle with respect to each other. The distances of the imaging optics 9, 10 and the directions of the optical axes 11,

[0032] The scanner 1 furthermore comprises a beam splitter 13. In the optical path from the imaging optics 9 to the beam splitter 13 a first mirror 14 is provided, which reflects the light which comes from the first tooth 4 and is projected by the first imaging optics 9 onto the first mirror 15 of the beam splitter 13. Correspondingly, a second mirror 16 is provided in the optical path of the second imaging optics 10, which reflects the light coming from the ground tooth 4 and projected by the second imaging optics 10 to the second mirror surface 17 of the beam splitter 13. From the mirror surfaces 15, 17 of the beam splitter 13, the light is reflected to a CCD sensor 18. The image from the first imaging optics 9 is projected onto the left half of the CCD sensor 18, the image from the second imaging optics 10 is projected onto the right half of the CCD sensor 18. The images from the imaging optics 9, 10 are supplied to the beam splitter 13, which projects the same onto different regions of the CCD sensor 18. In this way, a stereoscopic pair is produced on the CCD sensor 18, which can be evaluated by a software present on a PC. The CCD sensor 18 can constitute a divided CCD chip.

[0033] The scanner shown in FIG. 2 corresponds to the scanner shown in FIG. 1, so that the components explained above will not be described again. The scanner as shown in FIG. 2 additionally includes sensors for detecting the location and orientation of the scanner 3. These sensors are three acceleration sensors 19, 20, 21, which each supply data in x-, y- and z-direction, from which 6D data can be derived. These acceleration data can be integrated temporally, so that the position in space and the rotary position of the scanner can be determined therefrom. The acceleration sensors 19, 20 are disposed in the handle 27 of the scanner 1.

[0034] FIG. 3 shows the scanner 1 of FIG. 1 or 2 with cantilevers 22, 23, 24, at whose ends infrared markers 27, 28, 29; 30, 31, 32; 33, in particular infrared diodes, are provided, which supply data for an infrared tracking camera 25. The infrared markers 27-33 emit infrared beams, which are received by the infrared tracking camera. The tracking system 26, which consists of the markers 27-33 and the camera 25, can determine therefrom the location and orientation of the hand-guided scanner 1.

[0035] The method can be performed such that the infrared diodes 27-33 light up one after the other. This is time-sequentially detected by the tracking camera 25 (which can be a 3-line camera), from which the distance can be determined. The interconnection of the infrared markers 27-33 is unambiguously defined by its calibration. As a result, location and orientation in space can be calculated. The more markers can be evaluated, the more precisely can location and orientation be determined (some markers for instance are concealed during the measurement).

[0036] By means of the invention, a meteorological method can be performed, which is based on the evaluation of stereoscopic pairs. In the method, an object is observed with two cameras. With suitable algorithms, the same features can be found and correlated in both images. In calibrated systems, i.e. when the location and orientation of both cameras are known, a distance value and hence a 3D coordinate—in the coordinate system of the scanner—can be calculated for each object point, which can be observed in both cameras. The recording optics is equipped with a beam splitter. In this way, the scanner can be miniaturized. The object to be scanned, in particular a dental preparation or an object in a hard-to-reach

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