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[Continued on next page]

(54) Title: INTRAORAL 3D SCANNER

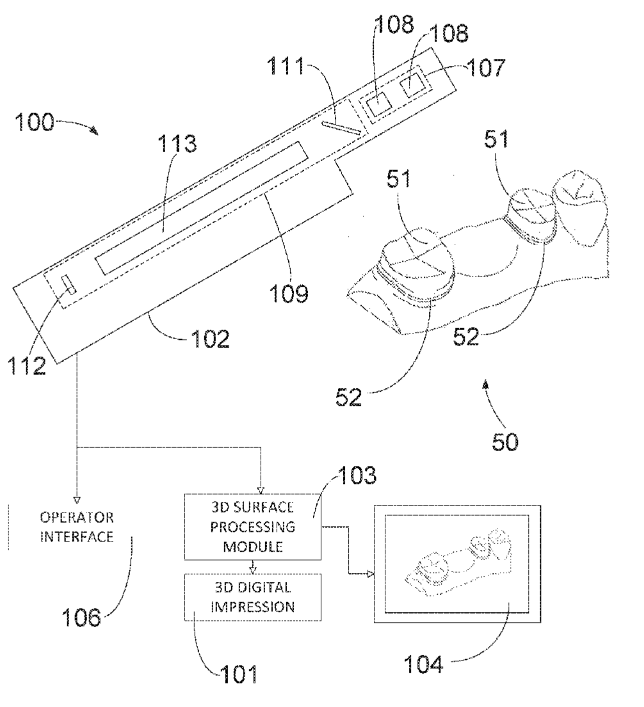

FIG. 7

(57) Abstract: An intraoral 3D scanner is used for scanning a dentition for generating a 3D digital impression. The 3D scanner including an illumination module for visible light illumination and infrared illumination of a dentition; an acquisition module for acquiring digital images of the dentition illuminated by said illumination module; and a 3D surface processing module for processing said digital images to generate a 3D digital impression of the dentition.

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

INTRAORAL 3D SCANNER

Field of the Invention

The invention relates to intraoral 3D scanners.

Background of the Invention

Dental crown procedures involve removing some original tooth structure to leave a prepared tooth. Such removal is assisted by the use of gingival retraction cord which is gently inserted below a patient's gum line into his gingival sulcus to primarily push gum tissue away from the tooth to be prepared. In an adult, the height of a gumline from the bottom of a gingival sulcus is typically about 1000 microns. The removed original tooth structure leaves a prepared tooth with a margin which is necessarily beneath the gumline to ensure gum tissue covers a lowermost crown surface of a crown intended to be cemented on the prepared tooth. Thereafter, a dental impression is made of the patient's dentition for subsequent preparation of a cast. The cast is then employed for preparing a crown outside the patient's mouth for cementing on the prepared tooth at a subsequent dental appointment.

More recently, non-contact intraoral 3D scanners are employed for preparing a 3D digital impression of a patient's dentition instead of a conventional impression. The intraoral 3D scanners employ different 3D scanning technologies including *inter alia* stereoscopic vision as disclosed in US Patent Application Publication No. US 2012/0218389, pattern projection as disclosed in US 7,724,932 to Densys et al, confocal imaging as disclosed in US Patent Application Publication No. US 2010/0208275, and others.

Such non-contact intraoral 3D scanners are commercially available from *inter alia* Carestream Dental, Inc., 3shape, a.Ttron3D, Sirona, ZFX, and alike. Particular models include *inter alia* Carestream Dental CS 3500 Intraoral Scanner, ATron bluescan-I Intraoral Scanner, ZFX Intrascan intraoral scanner, Sirona Omnicam, and others.

During removal of original tooth structure to leave a prepared tooth, fresh blood, coagulated blood and saliva accumulate in a patient's gingival sulcus and often reach the gumline. Accordingly, the blood saliva mixture typically overlies a margin and therefore prevents the preparation of a dental impression correctly imprinting same. Similarly, intraoral 3D scanners scan the top surface of the blood saliva mixture and not the submerged margin of the prepared tooth. Digital impressions are as accurate as conventional impressions as discussed in Clinical Oral Investigation. 2013 Sep; 17 (7):1759-64. doi: 10.1007/s00784-012-0864-4. Epub 2012 Oct 21.

The inability to correctly imprint or scan a margin leads to the need to estimate a margin during the preparation or a cast which in turn affects the accuracy of fabrication of a crown. This can lead to additional dental work during the fitting of a crown. More problematically, a badly fitted crown has a separation between a crown and gum tissue which can lead to dental caries particularly under a gumline.

Dental bridge preparation is similar to dental crown preparation but more complicated due to a bridge being longer than a crown and based on more than one tooth. Accordingly, dental bridge preparation requires more extensive use of gingival dental cord which further complicates imprinting or scanning the margin of each prepared tooth.

Infrared intraoral scanning is employed for detection of dental caries and cracks above a gumline for displaying them as patches of interest contrasted with respect to their surrounding tooth structures. Such infrared intraoral scanning for dental caries and crack detection purposes is disclosed *inter alia* in US Patent No. 8,556,625 to Lovely which employs probing wavelengths of between 800 nm and 1000 nm, US Patent Application Publication No. US 2011/0110575 to Banumathi et al. which employs probing wavelengths of 650 nm, and US Patent No. 6,584,341 to Mandelis et al.

The present invention is directed towards intraoral 3D scanners which can scan a margin of a prepared tooth for use in a wide range of dental procedures including *inter alia* crown preparation, bridge preparation, and the like.

Summary of the Invention

The present invention is directed to non-contact intraoral 3D scanners to generate 3D digital impressions of dentitions after a dental procedure to prepare at least one prepared tooth with a margin. In contradistinction to presently generated 3D digital impressions, the 3D digital impressions generated by intraoral 3D scanners of the present invention include margin information of margins submerged under blood saliva mixtures accumulated in a gingival sulcus arising from a dental procedure.

The present invention is based on the understanding that infrared illumination can penetrate blood typically to about 1mm to 1.5mm depth which is typically sufficient to scan a submerged margin of a prepared tooth. However, it is known that infrared light scattered from a 3D object is more diffused than visible light scattered from a 3D object such that some details which can be seen under visible light cannot be seen under infrared illumination. Accordingly, the intraoral 3D scanners of the present invention acquire 3D point cloud information of a prepared tooth from both visible light scanning and infrared scanning to generate a 3D digital impression of a dentition both above and below the top surface of a blood saliva mixture.

3D digital impressions can be generated by visible light only scanning to generate visible light only 3D point cloud information and infrared only scanning to generate infrared only 3D point cloud information and then combining the visible light only 3D point cloud information and the infrared only 3D point cloud information. Alternatively, 3D digital impressions can be generated by combined visible light and infrared scanning to generate combined and/or merged visible light and infrared 3D point cloud information.

The present invention can be embodied in newly designed intraoral 3D scanners. Additionally, commercially deployed intraoral 3D scanners can be upgraded to include infrared illumination and scanning to supplement their present visible light illumination and scanning. Some commercially employed intraoral 3D scanners include digital camera modules with digital components which are responsive to infrared illumination as well as visible light. Accordingly, such upgrading requires the provision of infrared illumination and software to combine 3D point cloud information from infrared scanning with 3D point cloud information from visible light scanning. The present invention is technologically agnostic in the sense that it can be implemented with different scanning technologies for scanning a dentition to generate a 3D digital impression.

It is envisaged that the ability to scan margins of prepared teeth and therefore generate 3D digital impressions which are more accurate than conventional impressions will lead to more widespread use of intraoral 3D scanners of the present invention than the present level of use of conventional intraoral 3D scanners and supersede the use of conventional impressions.

Brief Description of Drawings

In order to understand the invention and to see how it can be carried out in practice, preferred embodiments will now be described, by way of non-limiting examples only, with reference to the accompanying drawings in which similar parts are likewise numbered, and in which:

Fig. 1 is a schematic diagram showing a correctly fitting crown cemented on a prepared tooth and an encircled gumline region of interest;

Fig. 2 is an enlarged view of Figure 1's gumline region of interest;

Fig. 3 is a schematic diagram showing a full tooth with a gingival retraction cord in place in a gingival sulcus and intended removal of original tooth structure to leave the prepared tooth ready for obtaining an impression;

Fig. 4 is an enlarged view of Figure 3's gumline region of interest;

Fig. 5 is a schematic diagram showing an incorrectly fitted crown cemented on the prepared tooth and the same gumline region of interest;

Fig. 6 is an enlarged view of Figure 5's gumline region of interest;

Fig. 7 is a combined pictorial view and block diagram of an intraoral 3D scanner in accordance with the present invention for generating a 3D digital impression of a dentition;

Fig. 8 is a top level flow chart of the operation of the intraoral 3D scanner for generating a 3D digital impression of a dentition;

Fig. 9 is a perspective view of a 3D object partially submerged in a blood saliva mixture for scanning by the intraoral 3D scanner;

Fig. 10 is a graph showing timing sequences for visible light only scanning and infrared only scanning of the 3D object;

Fig 11 is a perspective view of the 3D object scanned under visible light only illumination;

Fig. 12 is a perspective view of the 3D object scanned under infrared only illumination; and

Fig. 13 is a graph showing timing sequences for combined visible light and infrared scanning of the 3D object.

Detailed Description of the Drawings

Figures 1 and 2 show a prepared tooth 10 in gum tissue 11 having an non-retracted gumline 12 and a correctly fitted crown 13 cemented on the prepared tooth 10 by a cement layer 14. The prepared tooth 10 has a margin 16 sufficiently below the gumline 12 such that the crown 13's lowermost crown surface 17 is also below the gumline 12 to prevent dental caries from colonizing on the tooth and the like.

Figures 3 and 4 show the manner of preparing the prepared tooth 10 by removal of original tooth structure 18 from a full tooth 19 as assisted by the placement of gingival retraction cord 21 around the full tooth 19 into its gingival sulcus 22 to push gum tissue way from the full tooth 19 such that the retracted gumline 23 is below the unretracted gumline 12 in Figures 1 and 2. The dashed line 24 indicates the original tooth structure 18 to be removed to leave the prepared tooth 10 from the full tooth 19. The retracted gumline 23 is still above the margin 16. Preparation of the prepared tooth 10 leads to a blood saliva mixture 26 accumulating in the gingival sulcus 22 and filling same to reach the retracted gumline 23 and thereby submerging the margin 16 which leads to difficulties in preparing both a conventional impression and a digital impression.

Figures 5 and 6 show an incorrectly fitted crown 27 cemented on the prepared tooth 10 and having a lowermost crown surface 28 above the unretracted gumline 12 to leave some of the cement layer 14 exposed which can lead to dental caries.

Figure 7 shows a non-contact intraoral 3D scanner 100 according to an embodiment of the invention for scanning a dentition 50 to generate a 3D digital impression 101. The dentition 50 includes two spaced apart prepared teeth 51 for undergoing a dental bridge procedure. Each prepared tooth 51 has a margin 52.

The intraoral 3D scanner 100 includes a handheld probe 102 for insertion into a patient's mouth for scanning purposes. The handheld probe 102 is connected to a 3D surface processing module 103 and a display monitor 104 for displaying the 3D digital impression in real time during scanning. The 3D surface processing module 103 and the display monitor 104 can be implemented as a conventional computer system. The intraoral 3D scanner 100 includes an operator interface 106 for operating same. The operator interface 106 can include manual operated controls on the handheld scanner 102 and display menus for enabling user operated functions.

The handheld probe 102 includes the following modules: An illumination module 107 for illuminating the dentition 50 with visible light illumination and/or infrared illumination. The visible light illumination is typically 420 nm illumination. The infrared illumination is typically 950 nm illumination. The illumination module 107 preferably includes individual LEDs 108 for the different illuminations. An acquisition module 109 for acquiring an incoming visible light stream of digital images of the dentition 50 illuminated under visible light illumination from the visible light illumination module 107 and an incoming infrared stream of digital images of the dentition

50 illuminated under infrared illumination from the infrared illumination module 108.

The operator interface 106 includes manual operated controls, for example, a brightness control for controlling the brightness of the visible light illumination module 107, a brightness control for controlling the brightness of the infrared illumination module 108, and the like.

The acquisition module 109 is a conventional acquisition module for acquiring digital images of the dentition 50. The digital images may include 3D data for generating a 3D point cloud for each digital image. The acquisition module 109 includes a single flat mirror 111 for reflecting images of the dentition 50, a digital camera module 112 for generating digital images from reflected images, and an optical system 113 for projecting reflected images from the mirror 111 to the digital camera module 112. The digital camera module 112 includes digital components which are sensitive to both visible light and infrared illumination. Suitable digital components include *inter alia* CMV4000 CMOS image sensor commercially available from Cmosis, Antwerp, Belgium www.cmosis.com.

Figure 8 is a top level flow chart of the operation of the intraoral 3D scanner 100 to generate a 3D digital impression 101 of a dentition 50. Scanning of a dentition 50 to generate a 3D digital impression can be achieved by two different modes of operation of the intraoral 3D scanner 100 as follows. Initial visible light only scanning and infrared only scanning for subsequent combining of visible light only 3D point cloud information and infrared only 3D point cloud information. Or, combined visible light and infrared illumination in a single scan. The processing unit 103 can display a real time 3D digital impression of the dentition 50 on the display monitor 104. The processing unit 103 preferably shows a visual indication on the real time 3D digital impression image whether a section of the dentition 50 requires additional re scanning, if any. An operator preferably operates the intraoral 3D scanner 100 to obtain sufficient 3D point cloud information of the dentition 50 to generate the 3D digital impression 101 in a single scan of the dentition 50.

Figure 9 shows a 3D object partially submerged in a blood saliva mixture for scanning by the intraoral 3D scanner 100 to simulate *in situ* scanning of a dentition 50 to generate a 3D digital impression 101. The 3D object 130 has a stepped configuration including three lower minor steps 131, 132 and 133, three upper major steps 134, 136 and 137 and an uppermost turret 138. The 3D object 130 is partially submerged in an open topped receptacle 139 containing a blood saliva mixture 141 to cover the minor step 133. The blood saliva mixture 141 has an uppermost mixture surface 142.

Figure 10 shows a timing sequence of the frame synchronization signal 150 for capturing digital images of the 3D object 130, a timing sequence 151 for visible light only illumination of the 3D object 130 and a timing sequence 152 for infrared only illumination of the 3D object 130. The timing sequence 152 is staggered with respect to the timing sequence 151 such that the intraoral 3D scanner 100 acquires alternate visible light only 3D digital images and infrared only 3D digital images of the 3D object 130. The processing unit 103 processes the visible light only 3D digital images and the infrared only 3D digital images of the 3D object 130 to generate corresponding visible light only 3D point cloud information and infrared only 3D point cloud information. The processing unit 103 combines the visible light only 3D point cloud information and the infrared only 3D point cloud information to generate the 3D digital file of the 3D object.

An operator can preferably determine the scan ratio of visible light scanning to infrared scanning depending on a dental procedure at hand. For example, in the case of a minor accumulation of a blood saliva mixture in a gingival sulcus, an operator may select a higher scan ratio of visible light only scanning to infrared only scanning. Conversely, in the case of a major accumulation of a blood saliva mixture in a gingival sulcus, an operator may select a higher scan ratio of infrared only scanning to visible light only scanning compared to the former case of a minor accumulation of a blood saliva mixture.

The 3D surface processing module 103 preferably provides a visual indication on the real time 3D digital impression image whether a section of the dentition 50 requires additional visual light scanning or infrared scanning.

Figure 11 shows scanning the 3D object 130 under 420 nm visible light illumination successfully acquires a digital image of the 3D object 130 above the mixture surface 142 but not below. In other words, the intraoral 3D scanner 100 successfully acquires a digital image of the three upper major steps 134, 136, and 137 and the uppermost turret 138 but not the three lower minor steps 131, 132 and 133.

Figure 12 shows scanning the 3D object 130 under 950 nm infrared illumination successfully acquires a digital image of the entire 3D object 130 both above and below the mixture surface 142. However, the digital image acquired under 950 nm infrared illumination is of a reduced resolution compared to the digital image acquired under 420 nm visible light illumination.

Figure 13 shows a timing sequence: frame synchronization signal 160 for capturing digital images of the 3D object 130, a timing sequence 161 for visible light only illumination of the 3D object 130 and a timing sequence 162 for infrared only illumination of the 3D object 130. The timing sequences 161 and 162 has some overlap as opposed to the timing sequences 151 and 152 for combined visible light and infrared scanning of the 3D object 130. Accordingly, the acquisition module 109 acquires combined visible light and infrared digital images of the 3D object 130 similar to Figure 12 in the sense they include the entire 3D object 130 both above and below the mixture surface 142.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications, and other applications of the invention can be made within the scope of the appended claims.

CLAIMS:

1. An intraoral 3D scanner for scanning a dentition for generating a 3D digital impression, the dentition possibly including a prepared tooth with a margin, the intraoral 3D scanner comprising:

an illumination module for visible light illumination and infrared illumination of the dentition;

an acquisition module for acquiring digital images of the dentition illuminated by said illumination module; and

a 3D surface processing module for processing said digital images to generate a 3D digital impression of the dentition.

2. The scanner according to claim 1 and operative to scan the dentition under visible light only illumination and infrared only illumination such that said processor unit combines visible light only 3D point cloud information and infrared only 3D point cloud information to generate the 3D digital impression of the dentition.

3. The scanner according to claim 1 and operative to scan the dentition under combined visible light and infrared illumination.

4. The scanner according to any one of claims 1 to 3, wherein said 3D surface processing module displays the 3D digital impression of the dentition in real time on a display monitor during scanning of the dentition and provides a visual indication on said real time 3D digital impression of a section of the dentition requiring additional scanning, if any.

5. The scanner according to any one of claims 1 or 4, and comprising a means, preferably selectable by an operator, for changing a scan ratio of visible light scanning to infrared scanning.

6. The scanner according to claim 5, wherein changing the scan ratio comprises providing more visible light, preferably at a higher rate, than infrared illumination.

7. The scanner according to claim 5, wherein changing the scan ratio comprises providing less visible light, preferably at a lower rate, than infrared illumination.

8. A method for intraoral 3D scanning comprising the steps of:

providing a 3D scanner comprising an illumination module and an acquisition module,

illuminating with the illumination module a dentition with visible light illumination and infrared illumination, and

acquiring with the acquisition module digital images of the dentition illuminated by the illumination module.

9. The method of claim 8, wherein the scanner further comprising a 3D surface processing module for processing said digital images to generate a 3D digital impression of the dentition.

10. The method of claim 8 or 9, wherein the scanner being operative to scan under visible light only illumination and infrared only illumination.

11. The method of claim 10 when dependent on claim 9, wherein the processor unit being adapted to combine visible light only 3D point cloud information with infrared only 3D point cloud information.

12. The method of claim 8 or 9, wherein the scanner being operative to scan under combined visible light and infrared illumination.

13. The method according to any one of claims 8 or 12, and comprising a means, preferably selectable by an operator, for changing a scan ratio of visible light scanning to infrared scanning.

14. The method of claim 13, wherein changing the scan ratio comprises providing more visible light, preferably at a higher rate, than infrared illumination.

15. The method of claim 13, wherein changing the scan ratio comprises providing less visible light, preferably at a lower rate, than infrared illumination.

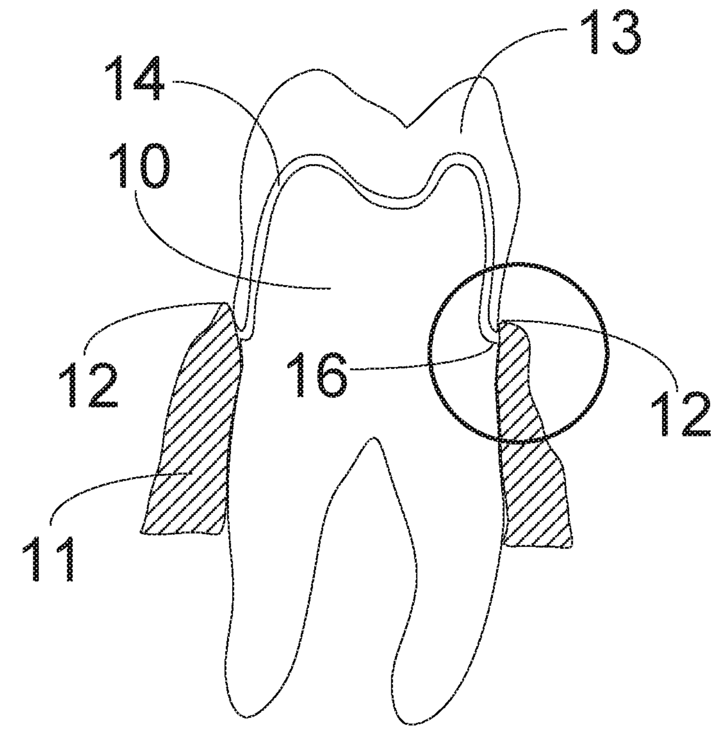


FIG. 1

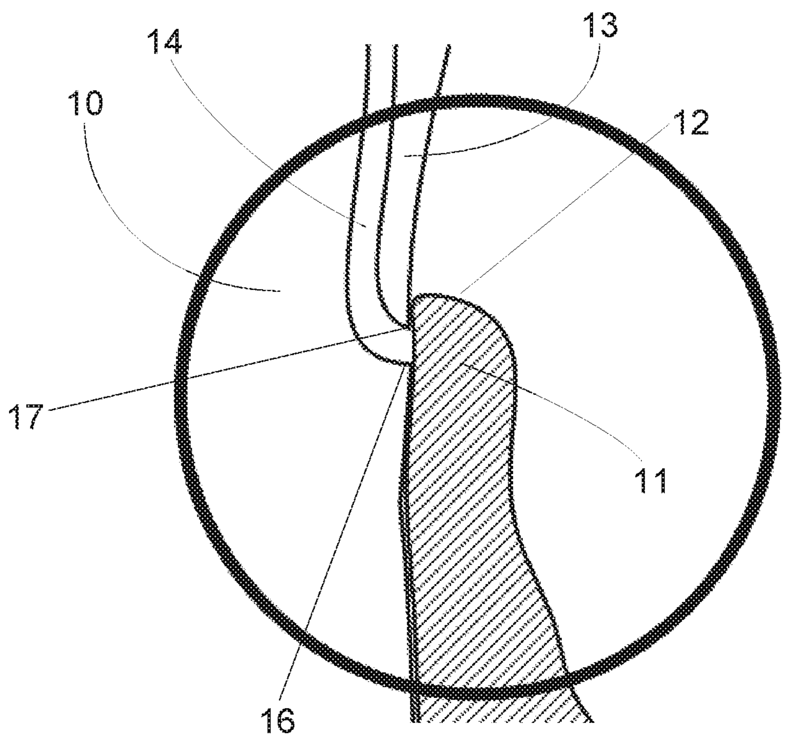


FIG. 2

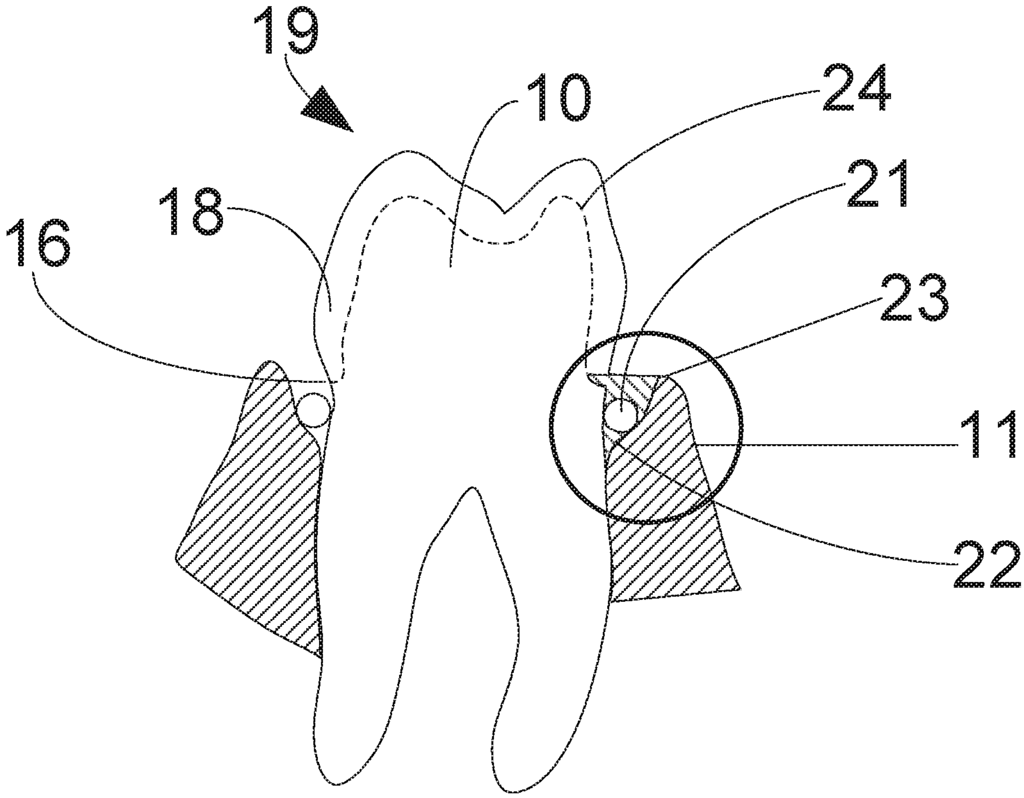


FIG. 3

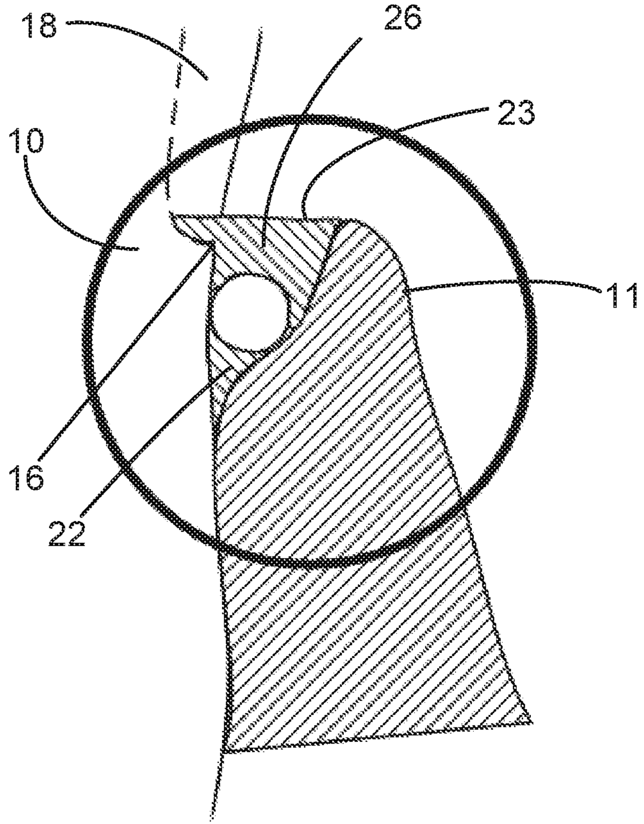


FIG. 4

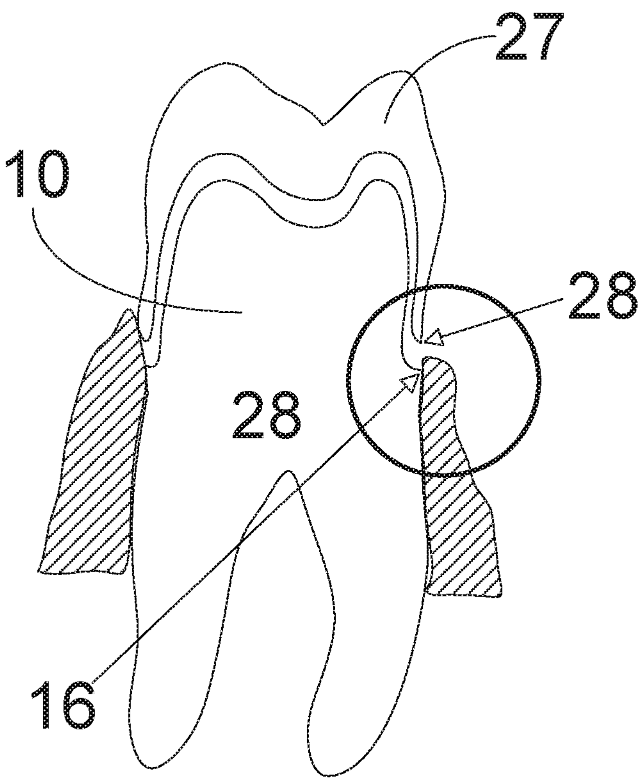


FIG. 5

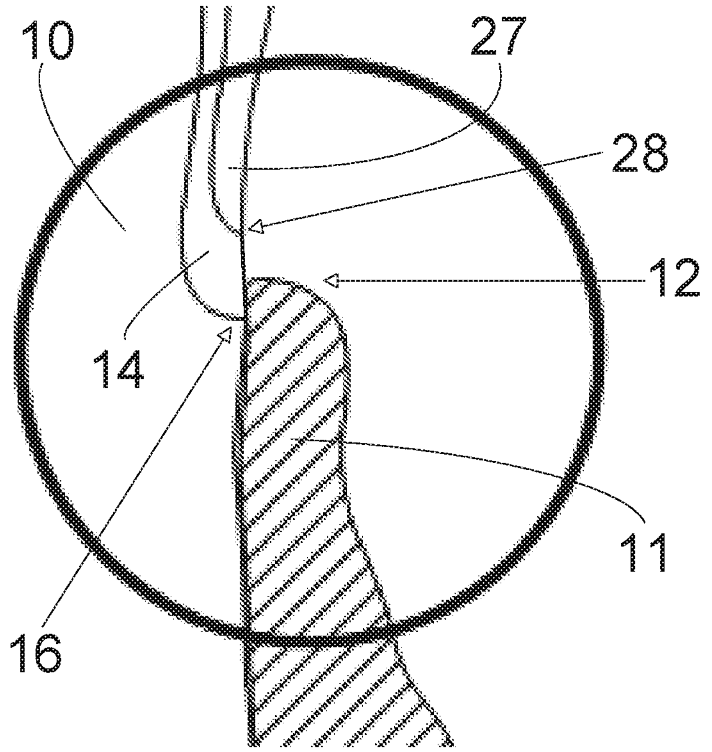
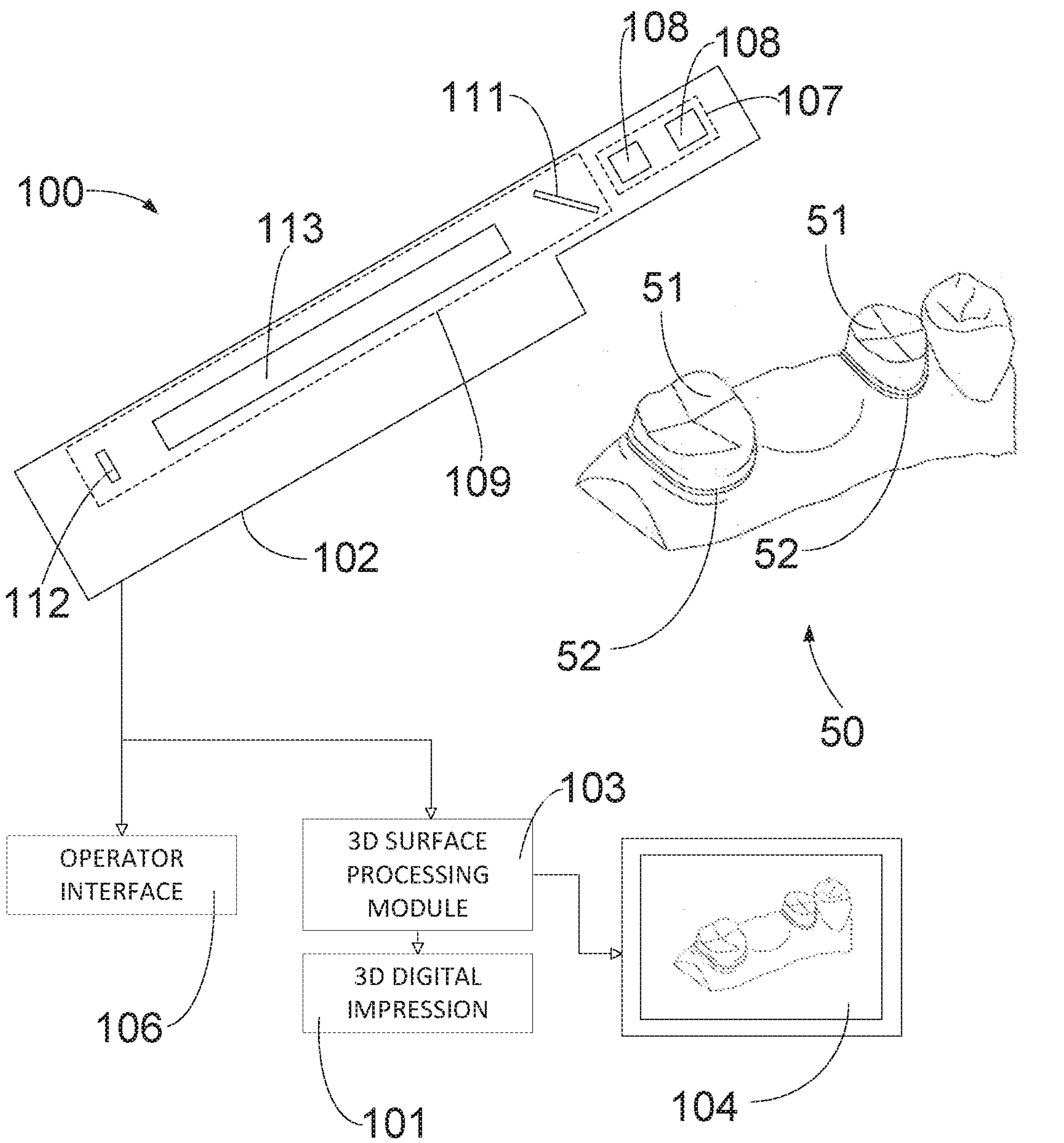


FIG. 6


108
108
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107
100
113
51
51
109
102
112
52
52
50
103
OPERATOR
INTERFACE
3D SURFACE
PROCESSING
MODULE
3D DIGITAL
IMPRESSION
106
101
104

FIG. 7

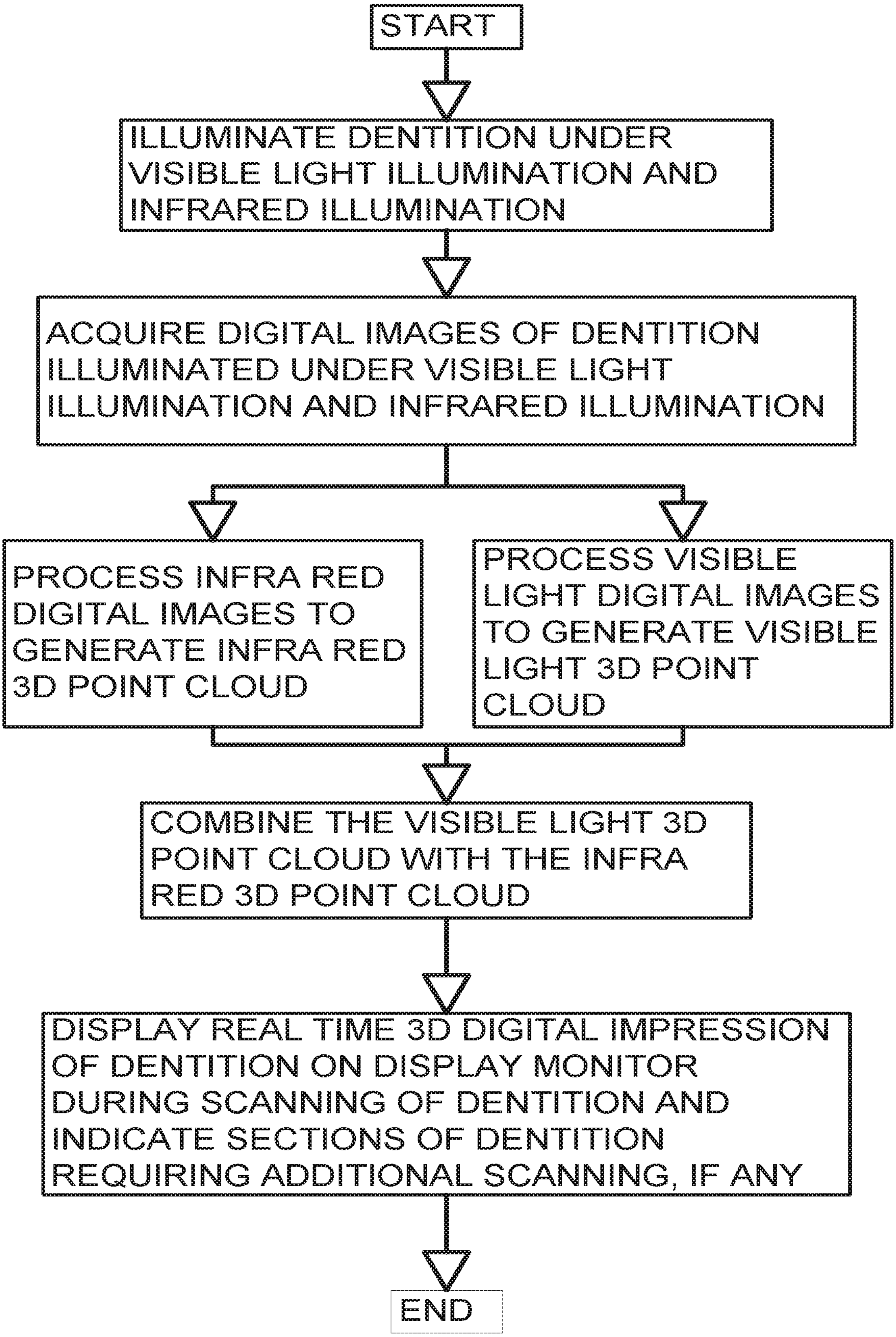
START
ILLUMINATE DENTITION UNDER VISIBLE LIGHT ILLUMINATION AND INFRARED ILLUMINATION
ACQUIRE DIGITAL IMAGES OF DENTITION ILLUMINATED UNDER VISIBLE LIGHT ILLUMINATION AND INFRARED ILLUMINATION
PROCESS INFRA RED DIGITAL IMAGES TO GENERATE INFRA RED 3D POINT CLOUD
PROCESS VISIBLE LIGHT DIGITAL IMAGES TO GENERATE VISIBLE LIGHT 3D POINT CLOUD
COMBINE THE VISIBLE LIGHT 3D POINT CLOUD WITH THE INFRA RED 3D POINT CLOUD
DISPLAY REAL TIME 3D DIGITAL IMPRESSION OF DENTITION ON DISPLAY MONITOR DURING SCANNING OF DENTITION AND INDICATE SECTIONS OF DENTITION REQUIRING ADDITIONAL SCANNING, IF ANY
END

FIG. 8

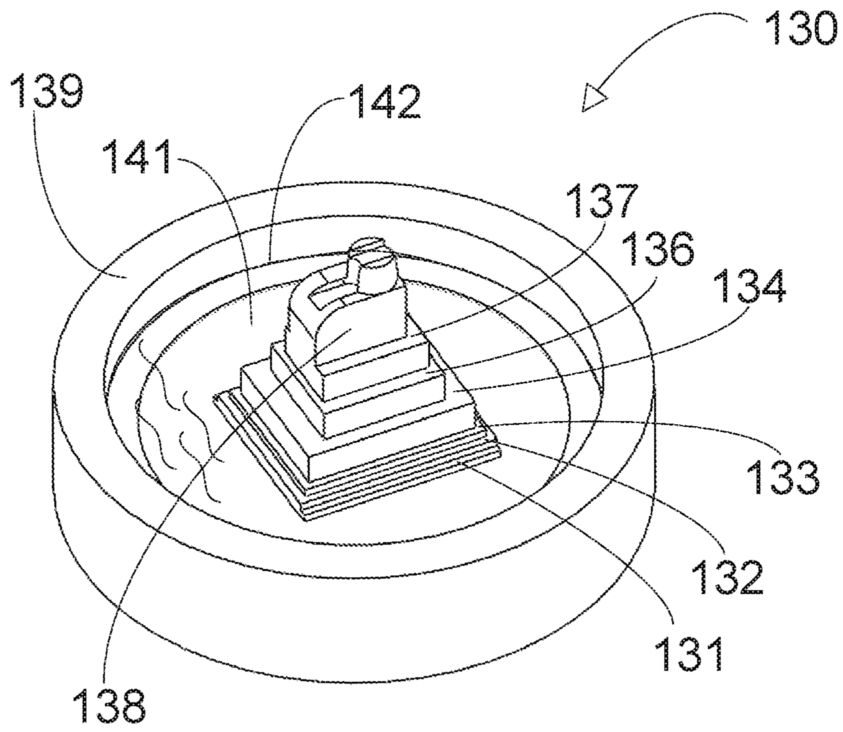

FIG. 9

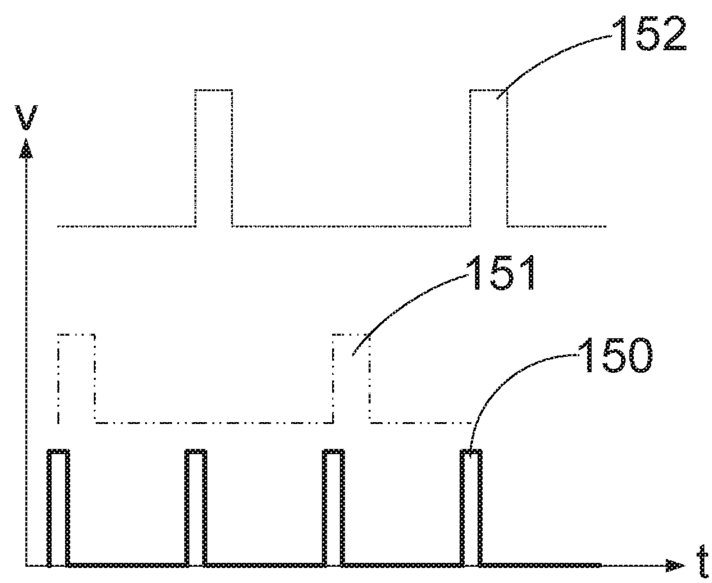

FIG. 10

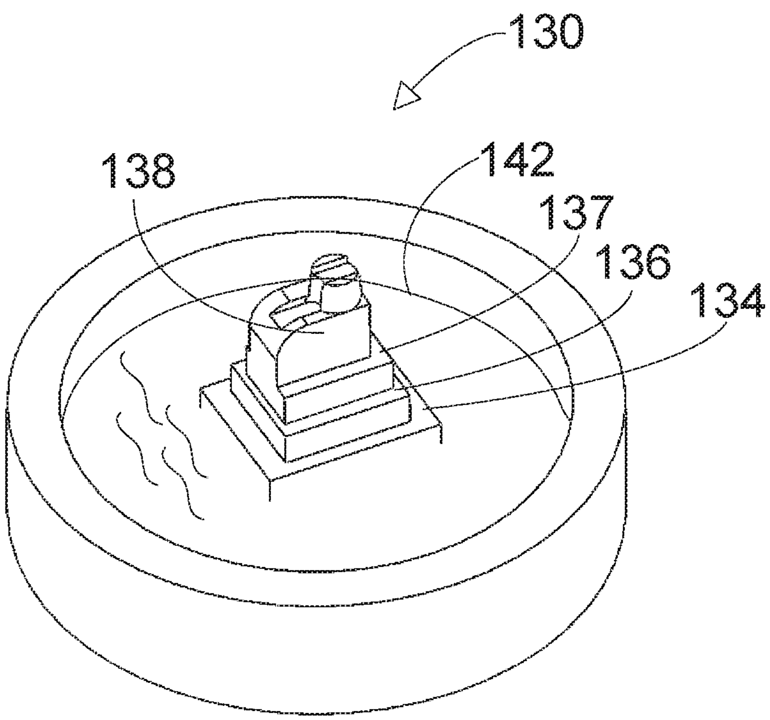
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FIG. 11

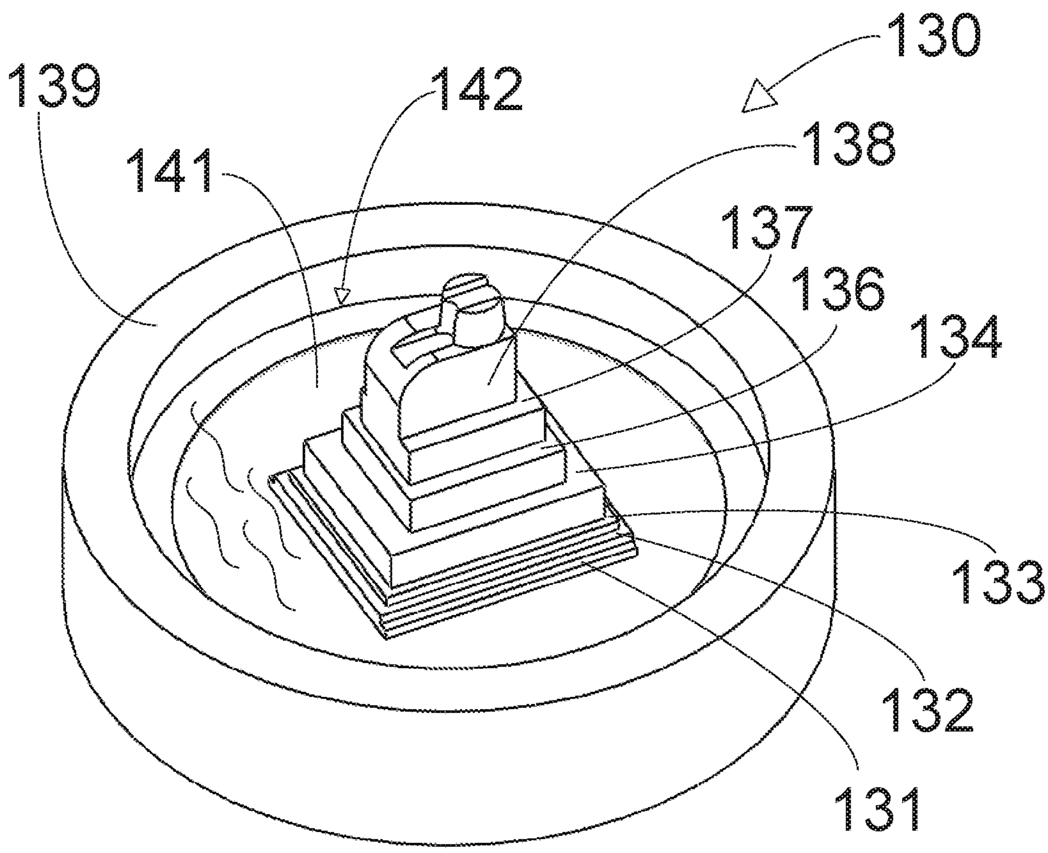
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FIG. 12

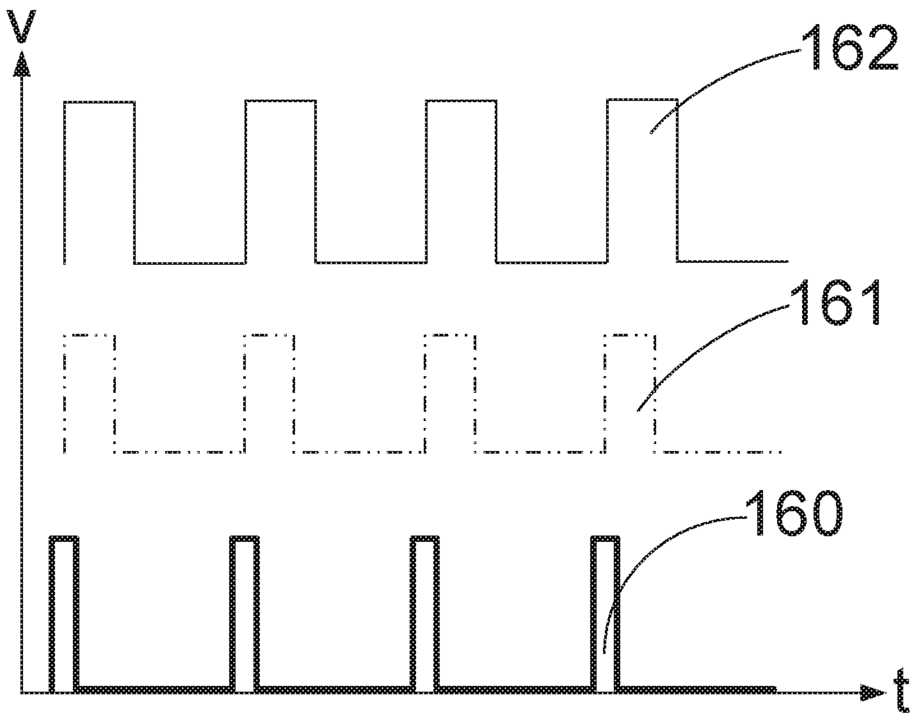

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IL2015/051125

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61C9/00
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)
A61C A61B

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

Electronic data base consulted during the international search (name of data base and, where 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	US 2007/134615 A1 (LOVELY PETER S [US]) 14 June 2007 (2007-06-14) paragraph [0002] paragraph [0008] paragraph [0067] paragraph [0082] - paragraph [0092] figures 11-13 -----	1-7
X	US 2005/090749 A1 (RUBBERT RUDGER [DE]) 28 April 2005 (2005-04-28) paragraph [0036] - paragraph [0038] paragraph [0050] - paragraph [0074] figure 1 -----	1-7
X	JP 2009 014728 A (J MORITA TOKYO MFG CORP) 22 January 2009 (2009-01-22) paragraph [0004] paragraph [0025] -----	1-7
	-/--	

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

[X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2016	11/05/2016

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	Fortune, Bruce

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 40 34 007 A1 (SIEMENS AG [DE]) 30 April 1992 (1992-04-30) column 2, line 35 - columns 3-18 figure -----	1-7
A	JP H08 71092 A (LION CORP) 19 March 1996 (1996-03-19) the whole document -----	1-7

2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2015/051125

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

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

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

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

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

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

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

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

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

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

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

1-7

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-7

   An intraoral 3D scanner for scanning a dentition for generating a 3D digital impression.

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2. claims: 8-15

   A method for intraoral 3D scanning.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IL2015/051125

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