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Application Number: 16526281

Document Date: 07/30/2019

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		
<p>The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.</p> <p>This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.</p>			

Secrecy Order 37 CFR 5.2:

☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
--------------------------	---

Inventor Information:

Inventor	1				Remove
Legal Name					
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Henrik		ØJELUND		
Residence Information (Select One) US Residency ☒ Non US Residency Active US Military Service					
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Postal Code	DK-2800	Country ⁱ	DK		

Inventor	2				Remove
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Inventor	3				Remove
Legal Name					

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Prefix	Given Name	Middle Name	Family Name	Suffix
	Karl-Josef		HOLLENBECK	
Residence Information (Select One) US Residency ☒ Non US Residency Active US Military Service				
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Address 2				
City	København Ø	State/Province		
Postal Code	DK-2100	Country ⁱ	DK	
All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button. Add				

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).			
☐ An Address is being provided for the correspondence information of this application.			
Customer Number	21839		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		
Attorney Docket Number	0079124-000266	Small Entity Status Claimed	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	5	Suggested Figure for Publication (if any)	2a

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country ⁱ

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Publication Information:

☐	Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐	Request Not to Publish. I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.			
Please Select One:			
☒	Customer Number	☐	Limited Recognition (37 CFR 11.9)
Customer Number	21839		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Patented	Remove			
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
	reissued of	13991513	2013-06-04	9329675	2016-05-03
Prior Application Status	Pending	Remove			
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)		
13991513	a 371 of international	PCT/DK2011/050461	2011-12-05		
Prior Application Status	Expired	Remove			
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)		
PCT/DK2011/050461	Claims benefit of provisional	61420138	2010-12-06		
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.					Add

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)ⁱ the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ⁱ (if applicable)	Remove
PA 2010 01104	DK	2010-12-06		

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant	1	Remove
<p>If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.</p> <p style="text-align: right;">Clear</p>		
☒ Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.		Person who shows sufficient proprietary interest
If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:		
<div style="border: 1px solid black; height: 20px; width: 100%;"></div>		
Name of the Deceased or Legally Incapacitated Inventor: <div style="border: 1px solid black; height: 20px; width: 100%;"></div>		
If the Applicant is an Organization check here. ☒		
Organization Name	3Shape A/S	
Mailing Address Information For Applicant:		
Address 1	Holmens Kanal 7, 4. sal	
Address 2		
City	Copenhagen K	State/Province
Country	DK	Postal Code
Phone Number		Fax Number
Email Address		
Additional Applicant Data may be generated within this form by selecting the Add button. Add		

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

Assignee	1		
Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.			
			<input type="button" value="Remove"/>
If the Assignee or Non-Applicant Assignee is an Organization check here.			☒
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Mailing Address Information For Assignee including Non-Applicant Assignee:			
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Address 2			
City	Copenhagen K	State/Province	
Country i	DK	Postal Code	DK-1060
Phone Number		Fax Number	
Email Address			
Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.			<input type="button" value="Add"/>

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). However, if this Application Data Sheet is submitted with the **INITIAL** filing of the application and either box A or B is **not** checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Stephany G. Small/		Date (YYYY-MM-DD)	2019-07-30
First Name	Stephany G.	Last Name	Small	Registration Number
				69,532
Additional Signature may be generated within this form by selecting the Add button.				<input type="button" value="Add"/>

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000266
		Application Number	
Title of Invention	SYSTEM WITH 3D USER INTERFACE INTEGRATION		

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
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9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

1/5

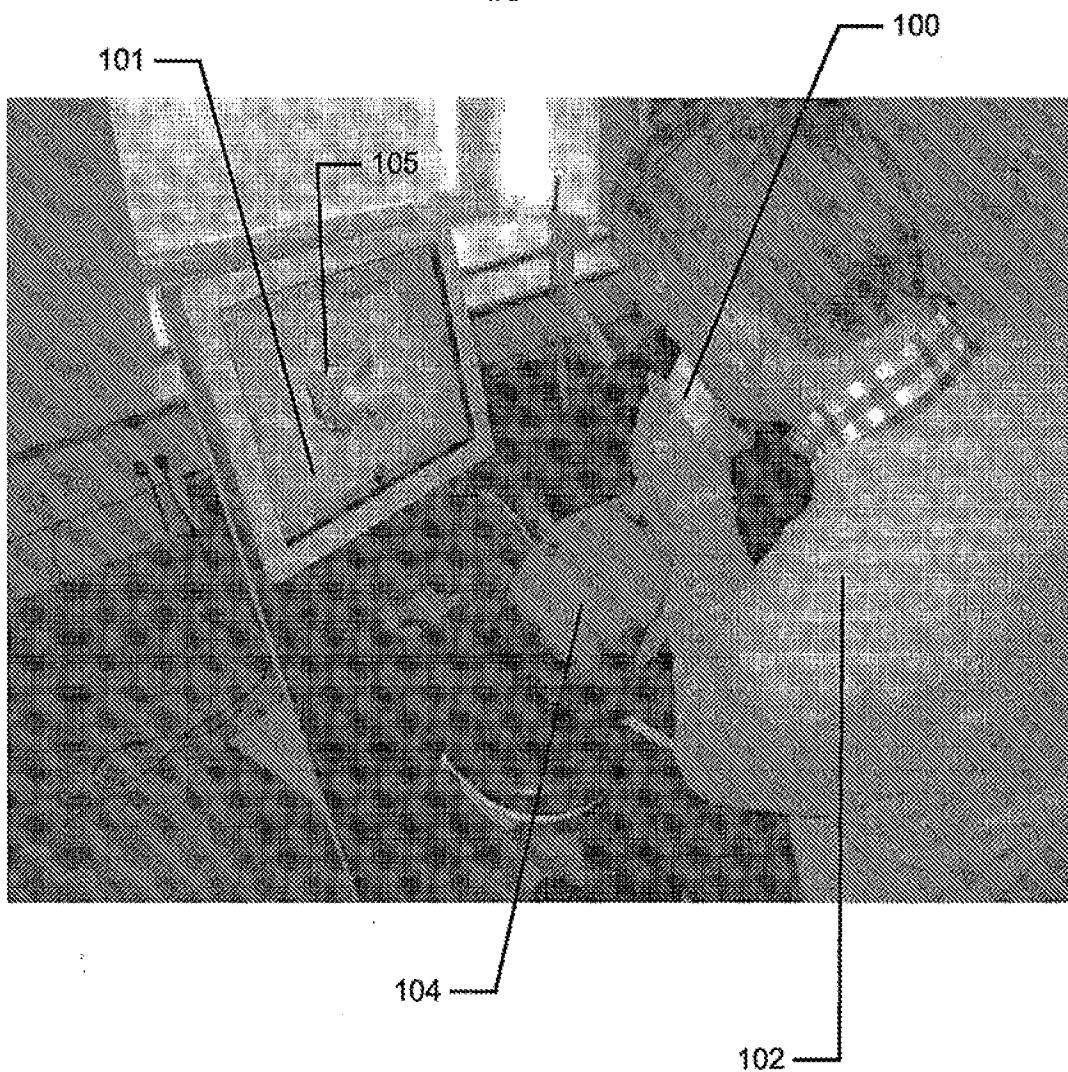


Fig. 1

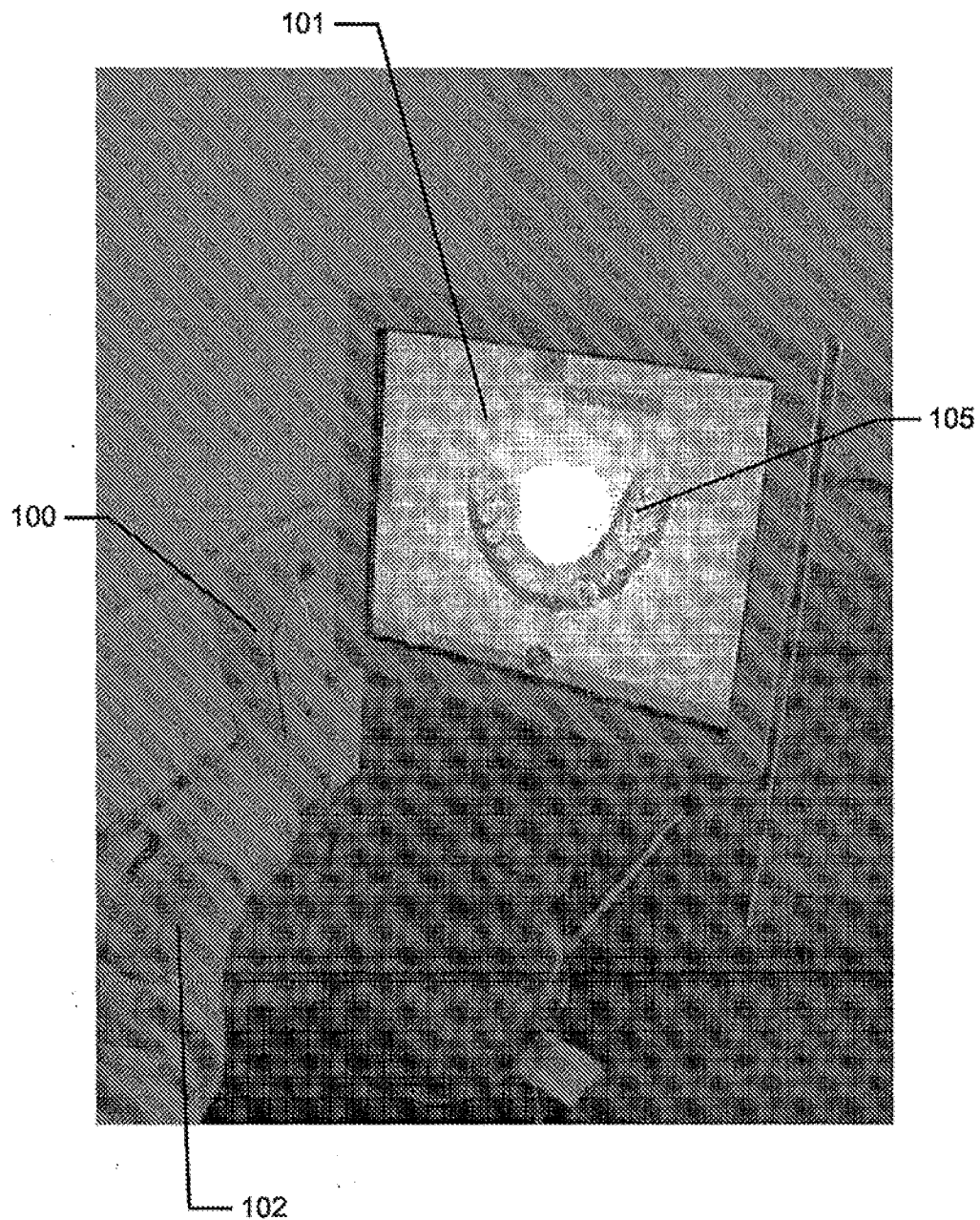


Fig. 2a)

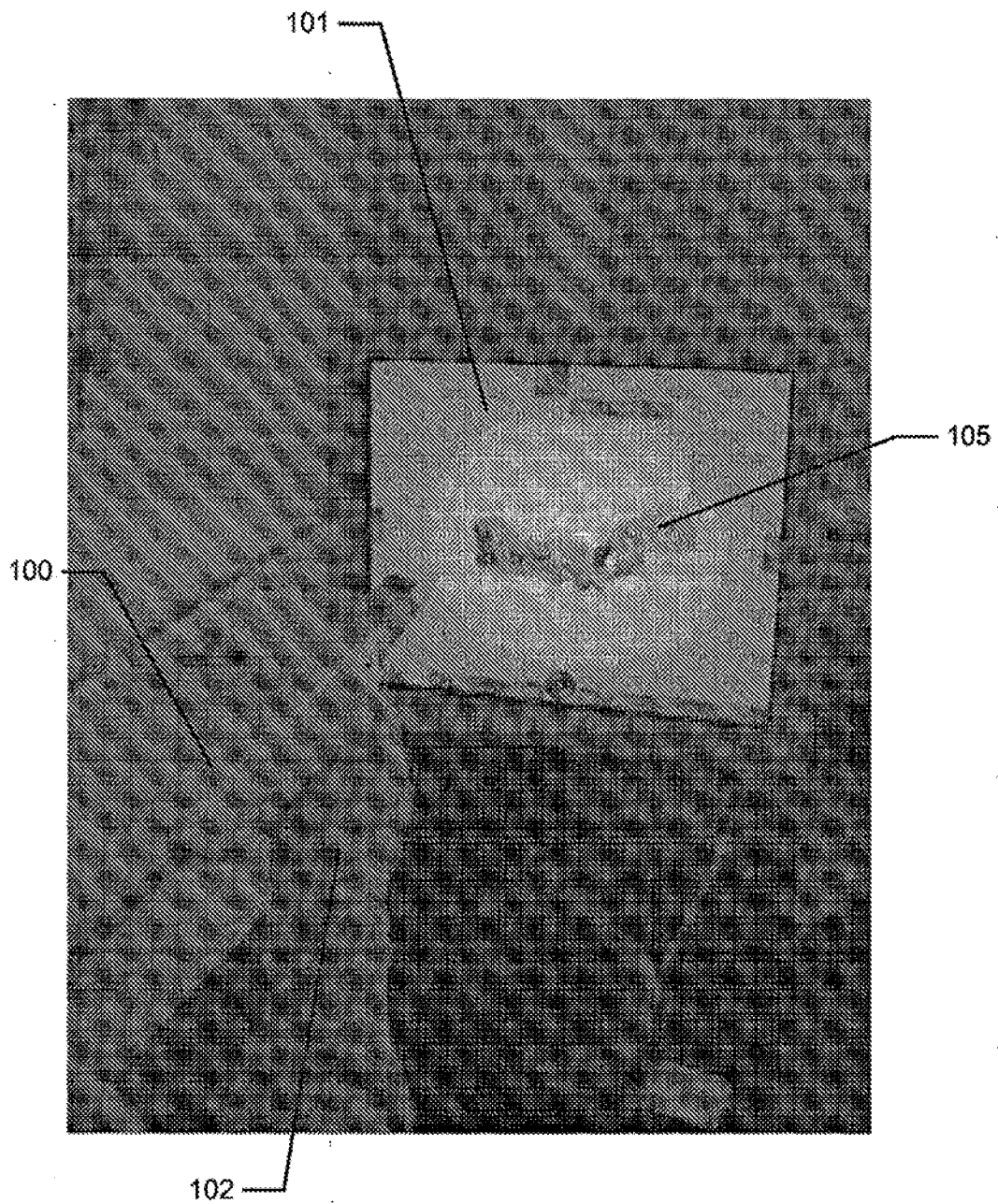


Fig. 2b)

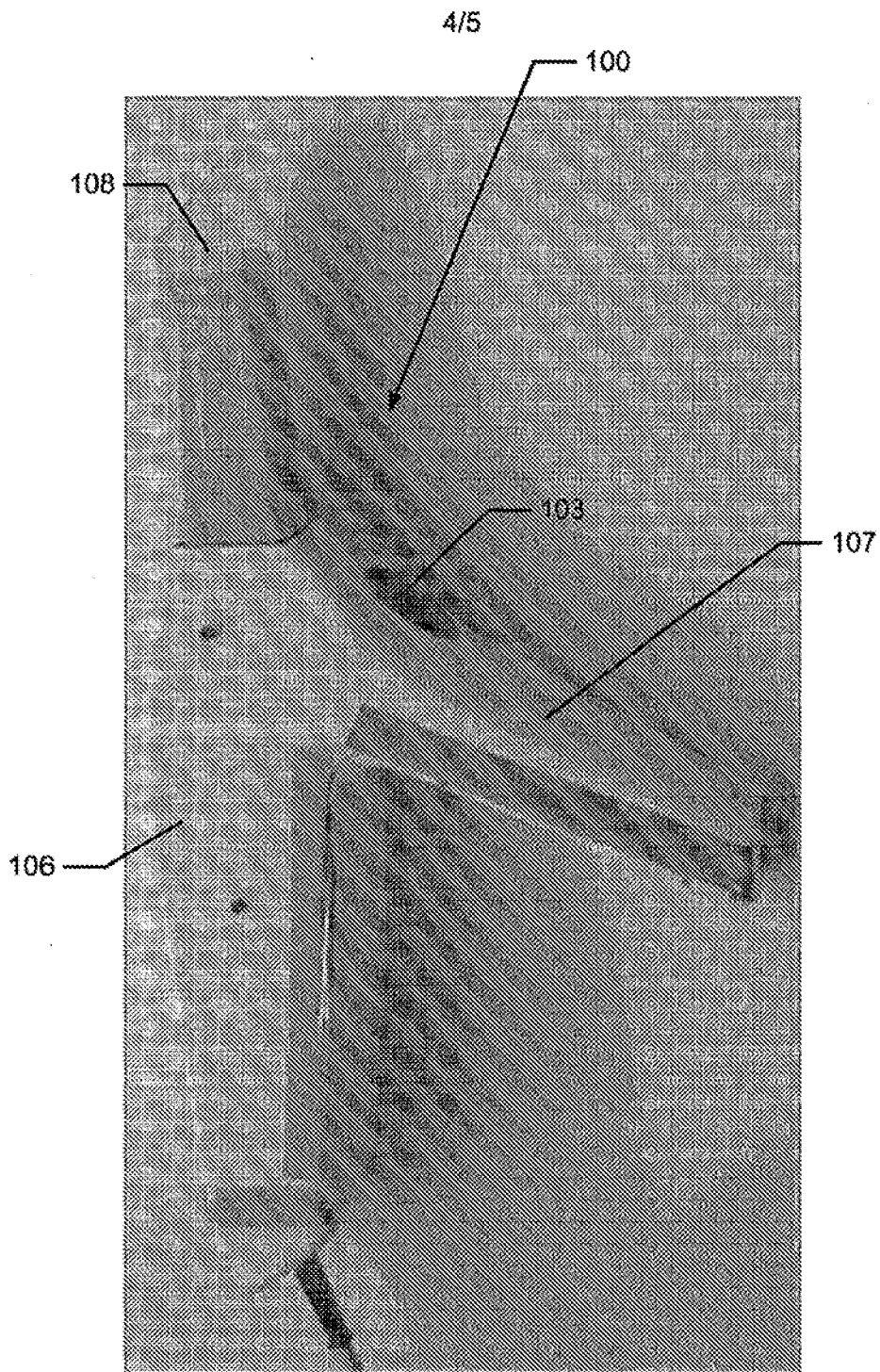
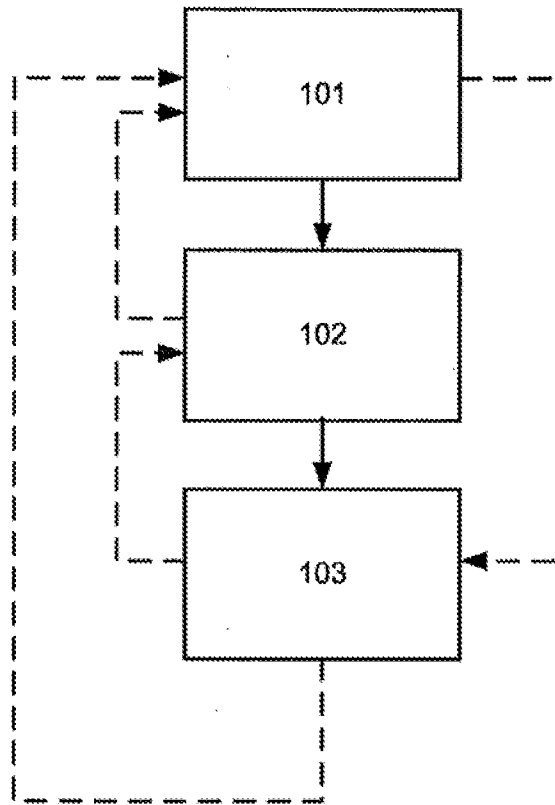


Fig. 3

*Fig. 4*

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of)
Henrik ÖJELUND, et al.) **MAIL STOP: REISSUE**
Reissue of U.S. Patent No. 9,329,675:)
Issued: May 3, 2016)
For: SYSTEM WITH 3D USER INTERFACE)
INTEGRATION)

GENERAL AUTHORIZATION FOR PETITIONS
FOR EXTENSIONS OF TIME AND PAYMENT OF FEES

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In accordance with 37 C.F.R. § 1.136(a)(3), the U.S. Patent and Trademark Office is hereby provided with a general authorization to treat any concurrent or future reply requiring a petition for an extension of time for its timely submission as containing a request therefor for the appropriate length of time.

The Commissioner is hereby authorized to charge any appropriate fees under 37 C.F.R. § 1.17 that may be required by this paper, or any other submissions in this application, and to credit any overpayment, to Deposit Account No. 02-4800.

Respectfully submitted,

BUCHANAN INGERSOLL & ROONEY PC

Date: July 30, 2019

By: /Stephany G. Small/
Stephany G. Small
Registration No. 69,532

Customer No. 21839
703 836 6620

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This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11, 1.14 and 41.6. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTD-9199 and select option 2.



US009329675B2

(12) **United States Patent**
Öjelund et al.

(10) **Patent No.:** **US 9,329,675 B2**
(45) **Date of Patent:** **May 3, 2016**

(54) **SYSTEM WITH 3D USER INTERFACE
INTEGRATION**

(75) Inventors: **Henrik Öjelund**, Lyngby (DK); **David
Fischer**, Stenløse (DK); **Karl-Josef
Hollenbeck**, København Ø (DK)

(73) Assignee: **3SHAPE A/S**, Copenhagen K (DK)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 249 days.

(21) Appl. No.: **13/991,513**

(22) PCT Filed: **Dec. 5, 2011**

(86) PCT No.: **PCT/DK2011/050461**

§ 371 (c)(1),

(2), (4) Date: **Jun. 4, 2013**

(87) PCT Pub. No.: **WO2012/076013**

PCT Pub. Date: **Jun. 14, 2012**

(65) **Prior Publication Data**

US 2013/0257718 A1 Oct. 3, 2013

Related U.S. Application Data

(60) Provisional application No. 61/420,138, filed on Dec.
6, 2010.

(30) **Foreign Application Priority Data**

Dec. 6, 2010 (DK) 2010 01104

(51) **Int. Cl.**

G06F 3/01 (2006.01)

A61C 9/00 (2006.01)

G01B 11/24 (2006.01)

(52) **U.S. CL.**

CPC : **G06F 3/01** (2013.01); **A61C 9/004** (2013.01);
G01B 11/24 (2013.01)

(58) **Field of Classification Search**

CPC combination set(s) only.

See application file for complete search history.

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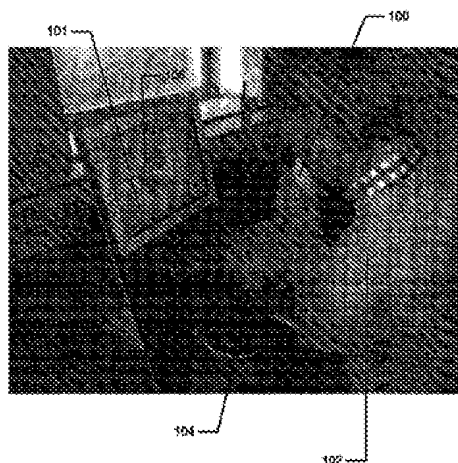
Primary Examiner — Van Chow

(74) *Attorney, Agent, or Firm* — Buchanan Ingersoll &
Rooney PC

(57) **ABSTRACT**

Disclosed is a system comprising a handheld device and at least one display. The handheld device is adapted for performing at least one action in a physical 3D environment; wherein the at least one display is adapted for visually representing the physical 3D environment; and where the handheld device is adapted for remotely controlling the view with which the 3D environment is represented on the display.

19 Claims, 5 Drawing Sheets



(56)

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Sebastian Vogt et al., "An AR System With Intuitive User Interface for Manipulation and Visualization of 3D Medical Data", Stud. Health Technol. Inform., Medicine Meets Virtual Reality 12, 2004, vol. 98, pp. 397-403.

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Second Office Action issued in corresponding Chinese Patent Application No. 201180066956.6, dated Nov. 18, 2015, with English translation (27 pages).

* cited by examiner

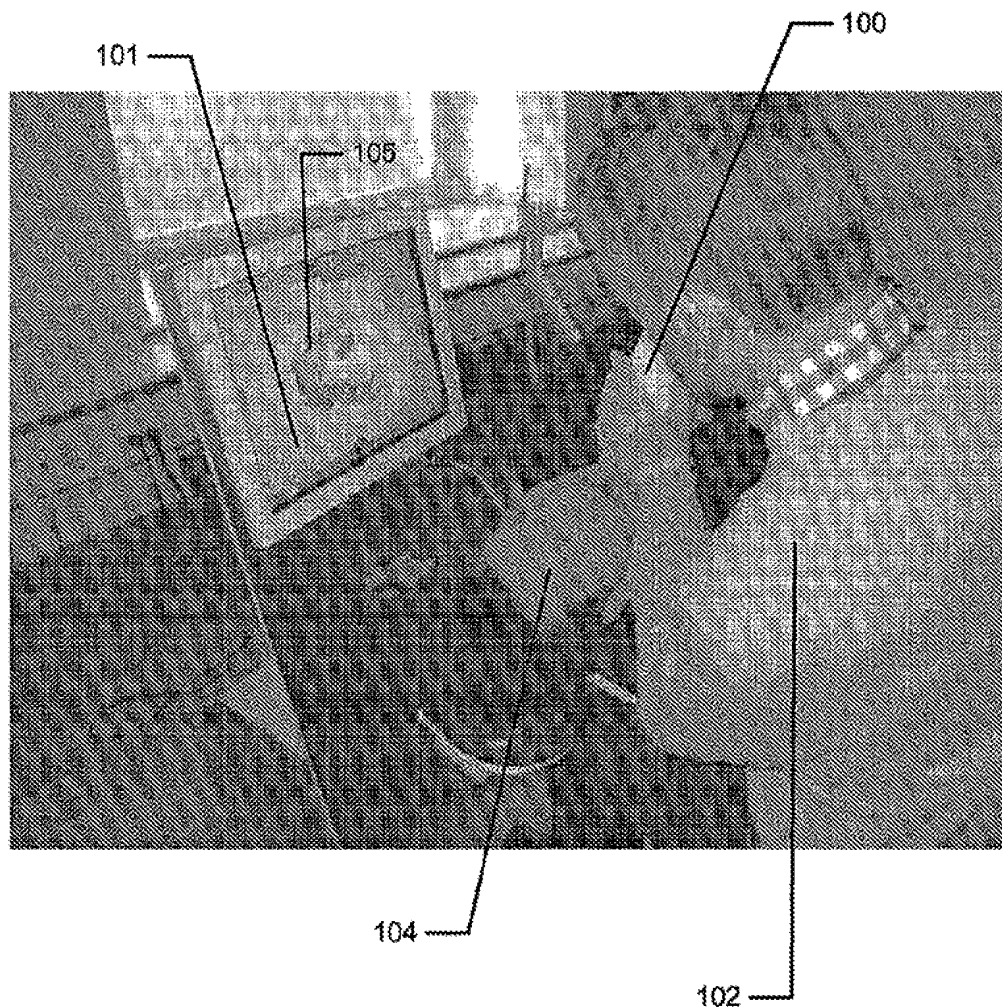


Fig. 1

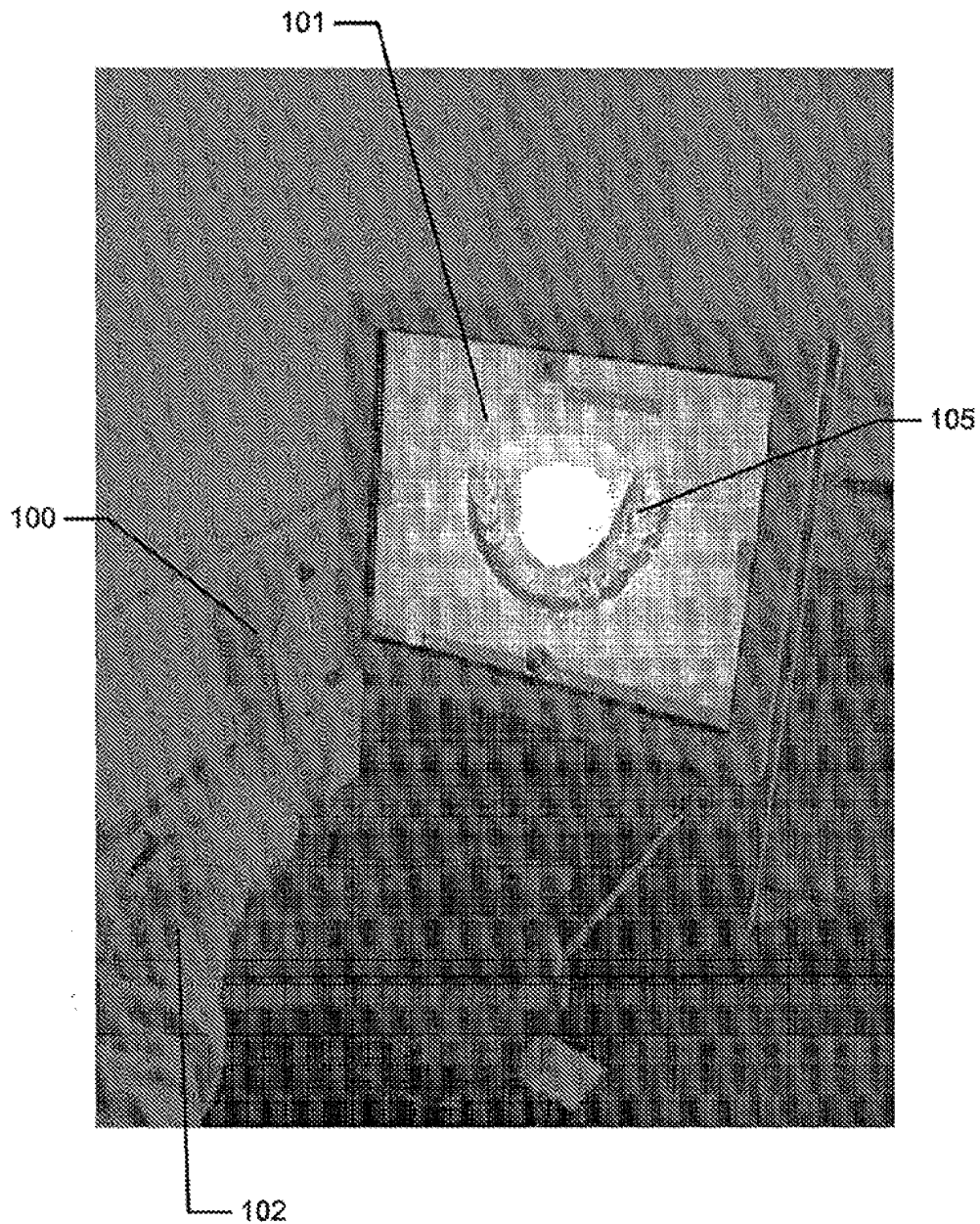


Fig. 2a)

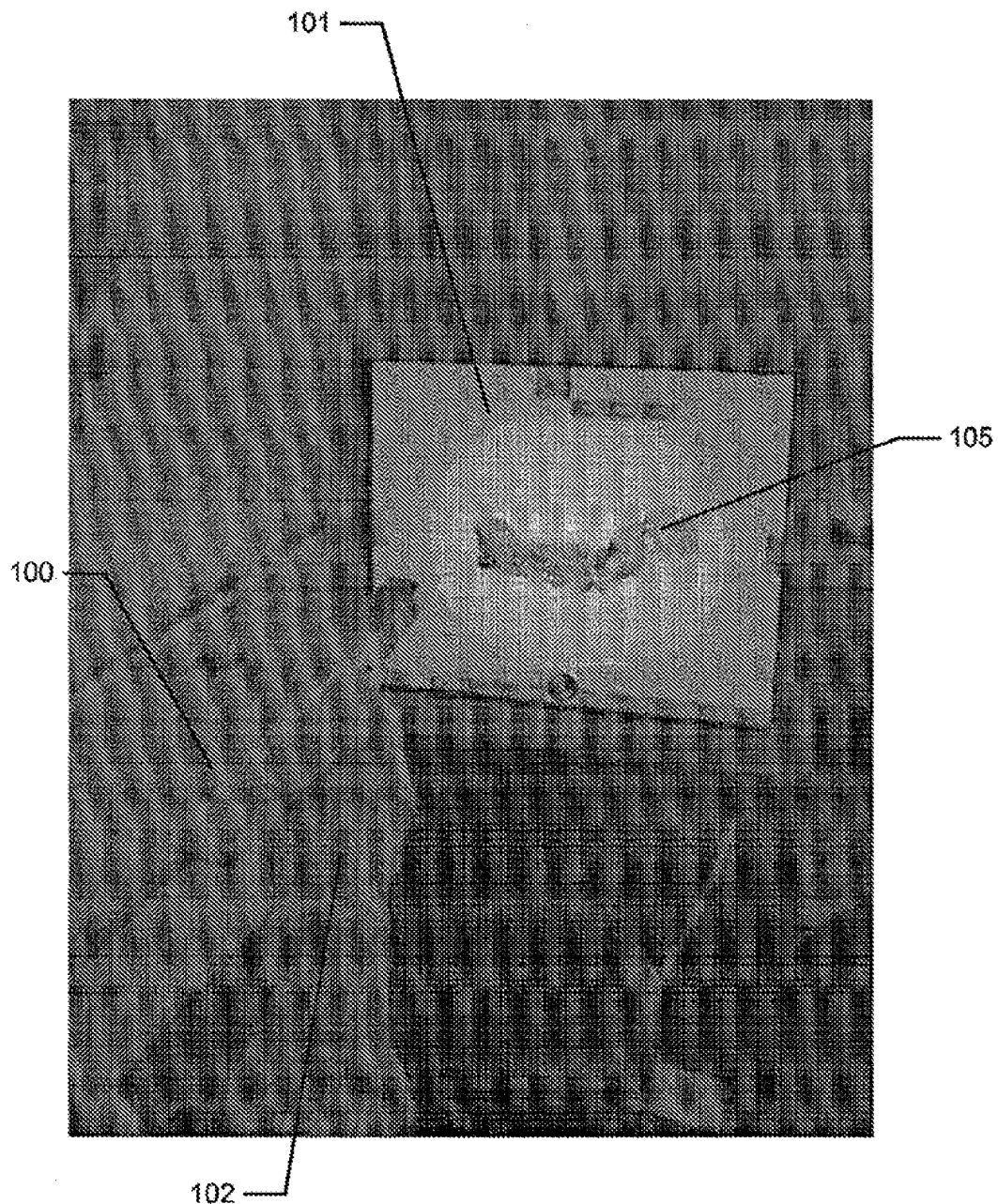


Fig. 2b)

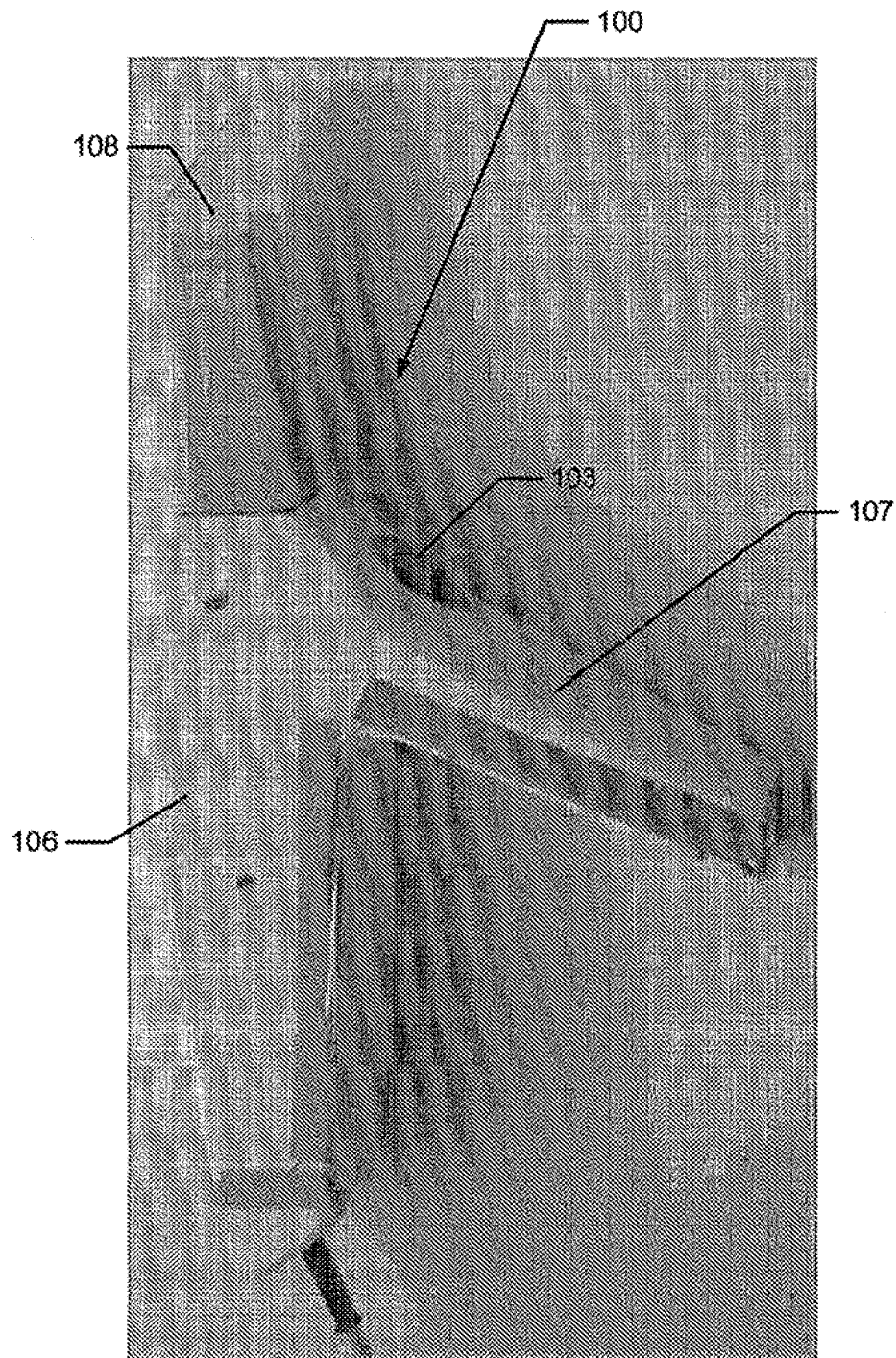
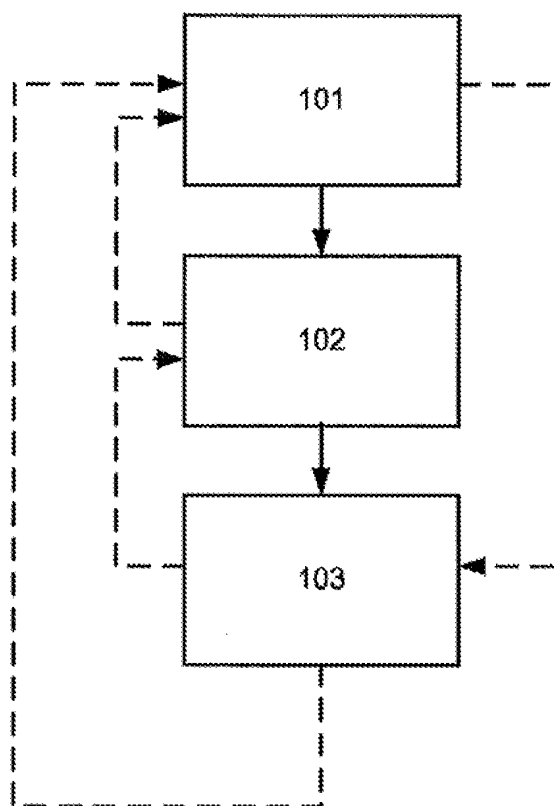


Fig. 3

*Fig. 4*

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SYSTEM WITH 3D USER INTERFACE INTEGRATION

FIELD OF THE INVENTION

This invention generally relates to a method and a system comprising a handheld device and at least one display.

BACKGROUND OF THE INVENTION

3D visualization is important in many fields of industry and medicine, where 3D information is becoming more and more predominant.

Displaying and inspecting 3D information is inherently difficult. To fully understand a 3D object or entire environment on a screen, the user should generally be able to rotate the object or scene, such that many or preferentially all surfaces are displayed. This is true even for 3D displays, e.g. stereoscopic or holographic, where from a given viewing position and with a given viewing angle, the user will only see some surfaces of an arbitrary 3D environment. Often, the user will also want to zoom into details or zoom out for an overview.

Various user interaction devices are in use for software that displays 3D data; these devices are: 3D mice, space balls, and touch screens. The operation of these current interaction devices requires physically touching them.

Physically touching a user-interaction device can be a disadvantage in medical applications due to risks of cross-contamination between patients or between patient and operator, or in industrial applications in dirty environments.

Several non-touch user interfaces for 3D data viewing in medical applications have been described in the literature. Vogt et al (2004) describe a touchless interactive system for in-situ visualization of 3D medical imaging data. The user interface is based on tracking of reflective markers, where a camera is mounted on the physician's head. Graetzel et al (2004) describe a touchless system that interprets hand gestures as mouse actions. It is based on stereo vision and intended for use in minimally invasive surgery.

It remains a problem to improve systems that require user interfaces for view control, which for example can be used for clinical purposes.

SUMMARY

Disclosed is a system comprising a handheld device and at least one display, where the handheld device is adapted for performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and where the handheld device is adapted for remotely controlling the view with which said 3D environment is represented on the display.

The system may be adapted for switching between performing the at least one action in the physical 3D environment, and remotely controlling the view with which the 3D environment is represented on the display.

The system disclosed here performs the integration of 3D user interface functionality with any other handheld device with other operating functionality, such that the operator ideally only touches this latter device that is intended to be touched. A particular example of such a handheld device is one that records some 3D geometry, for example a handheld 3D scanner.

The handheld device is a multi-purpose device, such as a dual-purpose or two-purpose device, i.e. a device both for performing actions in the physical 3D environment, such as

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measuring and manipulating, and for remotely controlling the view of the 3D environment on the display.

Geometrically, a view is determined by the virtual observer's/camera's position and orientation relative to the 3D environment or its visual representation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor.

The virtual observer's and the 3D environment's position and orientation are always relative to each other. In terms of user experience in software systems with 3D input devices, the user may feel that for example, he/she is moving the 3D environment while remaining stationary himself/herself, but there is always an equivalent movement of the virtual observer/camera that gives the same results on the display. Often, descriptions of 3D software systems use the expression "pan" to indicate an apparent translational movement of the 3D environment, "rotate" to indicate a rotational movement of the 3D environment, and "zoom" to indicate a change in magnification factor.

Graphically, a view can represent a 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

All of the touch-less prior art systems are 3D user interface devices only. In many prior art applications, the operator using such user interface device will also hold and work with another device that really is the central device in the overall application, e.g. a medical instrument.

It is thus an advantage of the present system that the 3D user-interface functionality is integrated in the central device, which is used for performing some kind of action.

In some embodiments the handheld device is adapted for remotely controlling the magnification with which the 3D environment is represented on the display.

In some embodiments the handheld device is adapted for changing the rendering of the 3D environment on the display.

In some embodiments the view is defined as viewing angle and/or viewing position.

In some embodiments the at least one action comprises one or more of the actions of:

- measuring,
- recording,
- scanning,
- manipulating,
- modifying.

In some embodiments the 3D environment comprises one or more 3D objects.

In some embodiments the handheld device is adapted to be held in one hand by an operator.

In some embodiments the display is adapted to represent the 3D environment from multiple views.

In some embodiments the display is adapted to represent the 3D environment from different viewing angles and/or viewing positions.

In some embodiments the view of the 3D environment in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

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In some embodiments the magnification represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

In some embodiments the handheld device is adapted to record the 3D geometry of the 3D environment.

Thus the handheld device may be an intraoral dental scanner, which records the 3D geometry of a patient's teeth. The operator may move the scanner along the teeth of the patient for capturing the 3D geometry of the relevant teeth, e.g. all teeth. The scanner may comprise motion sensors for taking the movement of the scanner into account while creating the 3D model of the scanned teeth.

The 3D model of the teeth may be shown on a display, and the display may for example be a PC screen and/or the like.

The user interface functionality may comprise incorporating motion sensors in the scanner to provide that the user can determine the view on the screen by moving the scanner. Pointing the scanner down can provide that the scanned teeth are shown given a downward viewing angle. Holding the scanner in a horizontal position can provide that the viewing angle is likewise horizontal.

In some embodiments the handheld device comprises at least one user-interface element. A user-interface element is an element which the user may manipulate in order to activate a function on the user interface of the software. Typically the use interface is graphically presented on the display of the system.

The handheld device may furthermore be provided with an actuator, which switches the handheld device between performing the at least one action and remotely controlling the view. By providing such a manual switching function that enables the operator to switch between performing the at least one action and remotely controlling the view, the operator may easily control what is performed.

Such an actuator can for example be in the form of a button, switch or contact. In other embodiments it could be a touch sensitive surface or element.

In another embodiment the actuator could be a motion sensor provided in the handheld device that function as the actuator when it registers a specific type of movement, for example if the operator shakes the handheld device. Examples of such motion sensors will be described herein with respect to the user-interface element, however, the person skilled in the art will be based on the disclosure herein understand that such motion sensors may also be used as actuators as discussed.

For example, the handheld device can in one embodiment be an intra-oral 3D scanner used by a dentist. The scanner is set to be performing the action of scanning a dental area when the actuator is in one position. When the actuator is switched into a second position the handheld is set to control the view with which the 3D environment is represented on the display. This could for example be that when the dentist have scanned a part of or the complete desired area of an dental arch he can activate the actuator which then allows the dentist to remotely control the view of the 3D representation of the scanned area on the display by using the handheld device.

For example, the actuator could be a button. When the button is pressed quickly the handheld device is prepared for scanning, i.e. it is set for performing at least one action, the scanning procedure, in the physical 3D environment. The scanning is stopped when the button is pressed quickly a second time.

While the scanning is performed a virtual 3D representation is visually built on the display.

The user can now press and hold the button. This will put the handheld in a controller mode, where the handheld device

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is adapted for remotely controlling the view with which the 3D environment, such as scanned teeth, is represented on the display. While holding the button pressed the system will use signals from a motion sensor in the handheld device to determine how to present the view of the virtual 3D environment. Thus, if the user turns or otherwise moves the hand that holds the handheld device the view of the virtual 3D environment on the display will change accordingly.

Thus, the dentist may use the same handheld device for both scanning an area and subsequently verifying that the scan has been executed correctly without having to move away from the patient or touching any other equipment than already present in his hands.

In one embodiment the user-interface element is the same as the actuator, or where several user-interface elements are present at least one also functions as an actuator.

The system may be equipped with a button as an additional element providing the user-interface functionality.

In an example the handheld device is a handheld intraoral scanner, and the display is a computer screen. The operator or user may be a dentist, an assistant and/or the like. The operation functionality of the device may be to record some intraoral 3D geometry, and the user interface functionality may be to rotate, pan, and zoom the scanned data on the computer screen.

In some embodiments the at least one user-interface element is at least one motion sensor.

Thus the integration of the user interface functionality in the device may be provided by motion sensors, which can be accelerometers inside the scanner, whose readings determine the orientation of the display on the screen of the 3D model of the teeth acquired by the scanner. Additional functionality, e.g. to start/stop scanning, may be provided by a button. The button may be located where the operator's or user's index finger can reach it conveniently.

Prior art intraoral scanners use a touch screen, a trackball, or a mouse to determine the view in the display. These prior art user interface devices can be inconvenient, awkward and difficult to use, and they can be labor-intensive, and thus costly to sterilize or disinfect. An intraoral scanner should always be disinfected between scanning different patients, because the scanner is in and may come in contact with the mouth or other parts of the patient being scanned.

The operator or user, e.g. dentist, may use one hand or both hands to hold the intraoral scanner while scanning, and the scanner may be light enough and comfortable to be held with just one hand for a longer time while scanning.

The device can also be held with one or two hands, while using the device as remote control for e.g. changing the view in the display. It is an advantage of the touchless user interface functionality that in clinical situations, the operator can maintain both hands clean, disinfected, or even sterile.

An advantage of the system is that it allows an iterative process of working in a 3D environment without releasing the handheld device during said process. For the above intraoral scanning system example, the operator, e.g. dentist, can record some teeth surface geometry with a handheld device that is an intraoral scanner, inspect coverage of the surface recording by using that same handheld device to move, e.g. rotate, the recorded surface on the display, e.g. a computer screen, detect possible gaps or holes in the coverage of the scanned teeth, and then for example arrange the scanner in the region where the gaps were located and continue recording teeth surface geometry there. Over this entire iterative cycle, which can be repeated more than once, such as as many times

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as required for obtaining a desired scan coverage of the teeth, the dentist does not have to lay the handheld intraoral scanner out of his or her hands.

In some embodiments, the 3D user interface functionality is exploited in a separate location than the operation functionality. For the above intraoral scanning system example, the scanning operation is performed in the oral cavity of the patient, while the user interface functionality is more flexibly exploited when the scanner is outside the patient's mouth. The key characteristic and advantage of the system, again, is that the dentist can exploit the dual and integrated functionality, that is operation and user interface, of the scanner without laying it out of his or her hands.

The above intraoral scanning system is an example of an embodiment. Other examples for operation functionality or performing actions could be drilling, welding, grinding, cutting, soldering, photographing, filming, measuring, executing some surgical procedure etc.

The display of the system can be a 2D computer screen, a 3D display that projects stereoscopic image pairs, a volumetric display creating a 3D effect, such as a swept-volume display, a static volume display, a parallax barrier display, a holographic display etc. Even with a 3D display, the operator has only one viewing position and viewing angle relative to the 3D environment at a time. The operator can move his/her head to assume another viewing position and/or viewing angle physically, but generally, it may be more convenient to use the handheld device with its built-in user interface functionality, e.g. the remote controlling, to change the viewing position and/or viewing angle represented in the display.

In some embodiments the system comprises multiple displays, or one or more displays that are divided into regions. For example, several sub-windows on a PC screen can represent different views of the 3D environment. The handheld device can be used to change the view in all of them, or only some of them.

In some embodiments the user interface functionality comprises the use of gestures.

Gestures made by e.g. the operator can be used to change, shift or toggle between sub-windows, and the user-interface functionality can be limited to an active sub-window or one of several displays.

In some embodiments the gestures are adapted to be detected by the at least one motion sensor. Gestures can alternatively and/or additionally be detected by range sensors or other sensors that record body motion.

The operator does not have to constantly watch the at least one display of the system. In many applications, the operator will shift between viewing and possible manipulating the display and performing another operation with the handheld device. Thus it is an advantage that the operator does not have to touch other user interface devices. However, in some cases it may not be possible for the operator to fully avoid touching other devices, and in these cases it is an advantage that fewer touches are required compared to a system where a handheld device does not provide any user interface functionality at all.

In some embodiments the at least one display is arranged separate from the handheld device.

In some embodiments the at least one display is defined as a first display, and where the system further comprises a second display.

In some embodiments the second display is arranged on the handheld device.

In some embodiments the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

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In some embodiments the second display indicates where the handheld device is positioned relative to the 3D environment.

In some embodiments the first display and/or the second display provides instructions for the operator.

The display(s) can be arranged in multiple ways. For example, they can be mounted on a wall, placed on some sort of stand or a cart, placed on a rack or desk, or other.

In some embodiments at least one display is mounted on the device itself. It can be advantageous to have a display on the device itself because with such an arrangement, the operator's eyes need not focus alternately between different distances. In some cases, the operating functionality may require a close look at the device and the vicinity of the 3D environment it operates in, and this may be at a distance at most as far away as the operator's hand. Especially in crowded environments such as dentist's clinics, surgical operation theatres, or industrial workplaces, it may be difficult to place an external display closely to the device.

In some embodiments visual information is provided to the operator on one or more means other than the first display.

In some embodiments audible information to the operator is provided to the operator.

Thus in some embodiments, the system provides additional information to the operator. In some embodiments, the system includes other visual clues shown on means other than the display(s), such as LEDs on the device. In some embodiments, the system provides audible information to the operator, for example by different sounds and/or by speech.

Said information provided to the operator can comprise instructions for use, warnings, and the like.

The information can aid with improving the action performance or operation functionality of the device, for example by indicating how well an action or operation is being performed, and/or instructions to the operator aimed at improving the ease of the action or operation and/or the quality of the action or operation's results. For example, a LED can change in color and/or flashing frequency. In a scanner, the information can relate to how well the scanned 3D environment is in focus and/or to scan quality and/or to scan coverage. The information can comprise instructions on how best to position the scanner such as to attain good scan quality and/or scan coverage. The instructions can be used for planning and/or performing bracket placement. The instructions can be in the form of a messenger system to the operator.

In some embodiments, some 3D user interface functionality is provided by at least one motion sensor built into the device. Examples of motion sensors are accelerometers, gyros, and magnetometers and/or the like. These sensors can sense rotations, lateral motion, and/or combinations thereof. Other motion sensors use infrared sensing. For example, at least one infrared sensor can be mounted on the device and at least one infrared emitter can be mounted in the surroundings of the device. Conversely, the at least one emitter can be mounted on the device, and the at least one sensors in the surroundings. Yet another possibility is to use infrared reflector(s) on the device and both sensor(s) and emitter(s) on the surroundings, or again conversely. Thus motion can be sensed by a variety of principles.

Through proper signal processing, some sensors can recognize additional operator actions; for example gestures such as taps, waving, or shaking of the handheld device. Thus, these gestures can also be exploited in the 3D user interface functionality.

In some embodiments the handheld device comprises at least two motion sensors providing sensor fusion. Sensor fusion can be used to achieve a better motion signal from for

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example raw gyro, accelerometer, and/or magnetometer data. Sensor fusion can be implemented in ICs such as the InvenSense MPU 3000.

In some embodiments the handheld device comprises at least one user-interface element other than the at least one motion sensor.

In some embodiments the at least one other user-interface element is a touch-sensitive element.

In some embodiments the at least one other user-interface element is a button.

In some embodiments the at least one other user-interface element is a scroll-wheel.

In some embodiments, user interface functionality is provided through additional elements on the device. Thus these additional elements can for example be buttons, scroll wheels, touch-sensitive fields, proximity sensors and/or the like.

The additional user interface elements can be exploited or utilized in a workflow suitable for the field of application of the device. The workflow may be implemented in some user software application that may also control the display and thus the view represented thereon. A given interface element can supply multiple user inputs to the software. For example, a button can provide both a single click and a double click. For example, a double click can mean to advance to a subsequent step in a workflow. For the example of intraoral scanning, three steps within the workflow can be to scan the lower mouth, the upper mouth, and the bite. A touch-sensitive field can provide strokes in multiple directions each with a different effect, etc. Providing multiple user inputs from a user interface elements is advantageous because the number of user interface elements on the device can be reduced relative to a situation where each user interface element only provides one user input.

The motion sensors can also be exploited in a workflow. For example, lifting the device, which can be sensed by an accelerometer, can represent some type of user input, for example to start some action. In a device that is a scanner, it may start scanning. Conversely, placing the device back in some sort of holder, which can be sensed by an accelerometer as no acceleration occur over some period of time, can stop said action.

If the action performed by the device is some kind of recording, for example scanning, for example 3D scanning, the results of the recording can also be exploited as user inputs, possibly along with user inputs from other user interface elements. For example, with a 3D scanner with a limited depth of field, it may be possible to detect whether any objects within the 3D environments are present in the volume corresponding to this depth of field by detecting whether any 3D points are recorded. User inputs can depend on such detected presence. For example, a button click on an intraoral scanner can provide a different user input depending on whether the scanner is in the mouth, where teeth are detectable, or significantly away from and outside the mouth. Also the effect of motion sensor signals can be interpreted differently for either situation. For example, the scanner may only change the view represented on the display when it is outside the mouth.

In some embodiments the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

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In some embodiments the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

In some embodiments the view of the 3D environment comprises rendering of texture and/or shading.

In some embodiments the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

Thus in some embodiments the user interface functionality comprises changing the view with which the 3D environment is displayed. Changes in view can comprise changes in viewing angle, viewing position, magnification and/or the like. A change in viewing angle can naturally be effected by rotating the device. Rotation is naturally sensed by the aid of gyros and/or relative to gravity sensed by an accelerometer. Zooming, i.e. a change in magnification, can for example be achieved by pushing the handheld device forward and backward, respectively. A translational change of the viewing position, i.e., panning, can for example be achieved by pushing the handheld device up/down and/or sideways.

In some embodiments the user interface functionality comprises selecting or choosing items on a display or any other functionality provided by graphical user interfaces in computers known in the art. The operator may perform the selection. The Lava C.O.S scanner marketed by 3M ESPE has additional buttons on the handheld device, but it is not possible to manipulate the view by these. Their only purpose is to allow navigation through a menu system, and to start/stop scanning.

In some embodiments the user interface functionality comprises manipulating the 3D environment displayed on the screen. For example, the operator may effect deformations or change the position or orientation of objects in the 3D environment. Thus, in some embodiments the user interface functionality comprises virtual user interface functionality, which can be that the 3D data are manipulated, but the physical 3D environment in which the device operates may not be manipulated.

In some embodiments the handheld device is an intraoral scanner and/or an in-the-ear scanner. If the scanner comprises a tip, this tip may be exchanged whereby the scanner can become suitable for scanning in the mouth or in the ear. Since the ear is a smaller cavity than the mouth, the tip for fitting into an ear may be smaller than a tip for fitting in the mouth.

In some embodiments the handheld device is a surgical instrument. In some embodiments, the surgical instrument comprises at least one motion sensor, which is built-in in the instrument.

In some embodiments the handheld device is a mechanical tool. In some embodiments, the tool has at least one motion sensor built in. In other embodiments, other user-interface elements are built in as well, for example buttons, scroll wheels, touch-sensitive fields, or proximity sensors.

In some embodiment the 3D geometry of the 3D environment is known a-priori or a 3D representation of the environment is known a priori, i.e. before the actions (s) are performed. For example in surgery, a CT scan may have been taken before the surgical procedure. The handheld device in this example could be a surgical instrument that a physician needs to apply in the proper 3D position. To make sure this proper position is reached, it could be beneficial to view the 3D environment from multiple perspectives interactively, i.e. without having to release the surgical instrument.

An advantage of the system, also in the above surgery example, is the ability of the handheld device to record the 3D environment at least partially, typically in a 3D field-of-view that is smaller than the volume represented in the a-priori

data. The 3D data recorded by the handheld device can be registered in real time with the a-priori data, such that the position and orientation of the device can be detected.

In some embodiments the 3D geometry comprises a 3D surface of the environment.

In some embodiments the 3D geometry comprises a 3D volumetric representation of the environment.

Thus the 3D environment can be displayed as volumetric data, or as surface, or a combination thereof. Volumetric data are typically represented by voxels. Voxels can comprise multiple scalar values. Surface data are typically represented as meshed, such as triangulated meshes, or point clouds.

The scanning may be performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

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

In particular, disclosed herein is a method of interaction between a handheld device and at least one display, where the method comprises the steps of:

- performing at least one action in a physical 3D environment by means of the handheld device;
- visually representing the physical 3D environment by the at least one display; and
- remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

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.

According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment from multiple perspectives, where said device is adapted to be held in one hand by an operator, and where the perspective represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment in multiple views, where said device is adapted to be held in one hand by an operator, where the view represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device, and where the device has at least one touch-sensitive user interface element.

The motion of the operator's hand is typically determined by a motion sensor arranged in the handheld device.

DEFINITIONS

3D geometry: A constellation of matter or its virtual representation in a three-dimensional space.

3D environment: A constellation of physical objects each having a 3D geometry in a three-dimensional space.

View: The way a 3D environment is represented on a display. Geometrically, a view is determined by the virtual observer's/camera's position and orientation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor. Graphically, a view can show the 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

Functionality: A Purpose or Intended Use.

Performing action(s) or operating functionality: Actions or functionality that includes some type of interaction with a 3D environment, such as measuring, modifying, manipulating, recording, touching, sensing, scanning, moving, transforming, cutting, welding, chemically treating, cleaning, etc. The term "operating" is thus not directed to surgical procedures, but operating may comprise surgical procedures.

User Interface Functionality: Functionality for interaction between a human user and a machine with a display.

Handheld device: An object that has at least one functionality and that is held by a human operator's hand or both hands while performing this at least one functionality.

3D scanner: A device that analyzes a real-world object or 3D environment to collect data on its shape and possibly its appearance.

Coverage of scan: The degree to which a physical surface is represented by recorded data after a scanning operation.

Motion sensor: A sensor detecting motion. Motion can be detected by: sound (acoustic sensors), opacity (optical and infrared sensors and video image processors), geomagnetism (magnetic sensors, magnetometers), reflection of transmitted energy (infrared laser radar, ultrasonic sensors, and microwave radar sensors), electromagnetic induction (inductive-loop detectors), and vibration (triboelectric, seismic, and inertia-switch sensors). MEMS accelerometers, gyros, and magnetometers are examples of motions sensors.

Workflow: a sequence of tasks implemented in software.

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 the system comprising a handheld device and a display.

FIG. 2 shows an example of user interface functionality in the form of remote controlling using the handheld device.

FIG. 3 shows an example of the handheld device.

FIG. 4 shows an example of a flow-chart of a method of interaction between a handheld device and a display.

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.

FIG. 1 shows an example of the system comprising a handheld device and a display. The handheld device 100 is in this

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example an intraoral dental scanner, which records the 3D geometry of the patient's teeth. The operator 102 moves the scanner along the teeth of the patient 104 for capturing the 3D geometry of the relevant teeth, e.g. all teeth. The scanner comprises motion sensors (not visible) for taken the movement of the scanner into account while creating the 3D model 105 of the scanned teeth. The display 101 is in this example a PC screen displaying the data recorded by the scanner.

FIG. 2 shows an example of user interface functionality in the form of remote controlling using the handheld device. The motion sensors (not shown) in the handheld device 100, e.g. scanner, provide that the user 102 can determine the view shown on the display 101, e.g. screen, by moving the handheld device 100.

FIG. 2a) shows that pointing the device 100 down can provide that the 3D model 105 of the scanned teeth is shown from a downward viewing angle.

FIG. 2b) shows that holding the scanner in a horizontal position can provide that the viewing angle is likewise horizontally from the front, such that the 3D model 105 of the scanned teeth is shown from the front.

FIG. 3 shows an example of the handheld device.

The handheld device 100 is in this example an intraoral scanner with a pistol-grip. The scanner comprises a housing 106 comprising the pistol-grip part 107, and a tip 108 adapted for insertion in the mouth of the patient. In this example the scanner also is equipped with a button 103 which is an additional element providing user-interface functionality.

The example system as shown in FIG. 1, FIG. 2 and FIG. 3 comprises a device 100 which is a handheld intraoral scanner and a display 101 which is a computer screen. The operator 102 may be a dentist, an assistant and/or the like. In an example, the action performance or operation functionality of the device 100 is to record some intraoral 3D geometry, and the user interface functionality is to rotate, pan, and zoom the 3D model 105 of the scanned data on the computer screen 101. The integration of the user interface functionality in the device 100 is provided by motion sensors (not visible), which can be accelerometers inside the scanner 100, whose readings determine the orientation, as seen in FIGS. 2a and 2b, of the display on the screen of the 3D model 105 of the teeth acquired by the scanner 100. Additional functionality, e.g. to start/stop scanning, may be provided by the button 103 as seen in FIG. 3. In the example system, the button 103 is located where the user's index finger can reach it conveniently.

In FIG. 1 the dentist 102 uses two hands to hold the intraoral scanner 100 while scanning, but it is understood that the scanner 100 can also be held with one hand while scanning. The device 100 can also be held with one or two hands, while changing the perspective of the 3D model 105 in the display 101. The example shown in FIG. 1 thus illustrates the advantage of the touchless user interface functionality, because in many clinical situations, the operator 102 should maintain both hands clean, disinfected, or even sterile.

The 3D user interface functionality may be exploited in a separate location than the operation functionality. For the above intraoral scanning system example, the scanning operation is performed in the oral cavity of the patient, see FIG. 1, while the user interface functionality is more flexibly exploited when the scanner is outside the patient's mouth, see FIGS. 2 and 3.

FIG. 4 shows an example of a flow-chart of a method of interaction between a handheld device and a display.

In step 101 at least one action in a physical 3D environment is performed by means of the handheld device. This action may be the scanning of teeth as shown in FIG. 1.

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In step 102 the physical 3D environment is visually represented by the at least one display. This may be the display of the 3D model of the scanned teeth as seen in FIG. 1.

In step 103 the view of the represented 3D environment shown on the display is remotely controlled on the display by means of the handheld device. This may be the control of the viewing angle of the 3D model as seen in FIG. 2.

All the steps of the method may be repeated one or more times. The order in which the steps are performed may be different than the order described above, which is indicated by the dotted lines in the figure. If one or more of the steps are performed more times, the order of the steps may also be different.

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

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

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

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

LITERATURE

- C. Graetzl, T. Fong, S. Grange, and C. Baur. A Non-Contact Mouse for Surgeon-Computer Interaction. *Technology and Health Care*, 12(3), 2004.
- Vogt S., Khamene A., Niemann H., Sauer F., An AR system with intuitive user interface for manipulation and visualization of 3D medical data. *Stud. Health Technol. Inform.* 2004; 98, pp. 397-403.

EMBODIMENTS

The following embodiments relates to one aspect of the system as disclosed by the description herein.

1. A system comprising a handheld device and at least one display, where the handheld device is adapted for performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and where the handheld device is adapted for remotely controlling the view with which the 3D environment is represented on the display.

2. The system according to any one or more of the preceding embodiments, wherein the view is defined as viewing angle and/or viewing position.

3. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted for

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remotely controlling the magnification with which the 3D environment is represented on the display.

4. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted for changing the rendering of the 3D environment on the display.

5. The system according to any one or more of the preceding embodiments, wherein the at least one action comprises one or more of:

measuring,
recording,
scanning,
manipulating, and/or
modifying.

6. The system according to any one or more of the preceding embodiments, wherein the 3D environment comprises one or more 3D objects.

7. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to be held in one hand by an operator.

8. The system according to any one or more of the preceding embodiments, wherein the display is adapted to represent the 3D environment from multiple views.

9. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

10. The system according to any one or more of the preceding embodiments, wherein the magnification represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

11. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

12. The system according to any one or more of the preceding embodiments, wherein the 3D geometry of the 3D environment is known a-priori.

13. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least one user-interface element.

14. The system according to any one or more of the preceding embodiments, wherein the at least one user-interface element is at least one motion sensor.

15. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least two motion sensors providing sensor fusion.

16. The system according to any one or more of the preceding embodiments, wherein the user interface functionality comprises the use of gestures.

17. The system according to any one or more of the preceding embodiments, wherein the gestures are detected by the at least one motion sensor.

18. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least one user-interface element other than the at least one motion sensor.

19. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a touch-sensitive element.

20. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a button.

21. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a scroll wheel.

22. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted

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to change a viewing angle with which the 3D environment is represented on the at least one display.

23. The system according to any of the preceding embodiments, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

24. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

25. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

26. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment comprises rendering of texture and/or shading.

27. The system according to any one or more of the preceding embodiments, wherein the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

28. The system according to any one or more of the preceding embodiments, wherein the 3D geometry comprises a 3D surface of the environment.

29. The system according to any one or more of the preceding embodiments, wherein the 3D geometry comprises a 3D volumetric representation of the environment.

30. The system according to any one or more of the preceding embodiments, wherein the handheld device is an intra-oral 3D scanner.

31. The system according to any one or more of the preceding embodiments, wherein the handheld device is a surgical instrument.

32. The system according to any one or more of the preceding embodiments, wherein the handheld device is a mechanical tool.

33. The system according to any one or more of the preceding embodiments, wherein the handheld device is an intra-oral 3D scanner.

34. The system according to any one or more of the preceding embodiments, wherein the at least one display is arranged separate from the handheld device.

35. The system according to any one or more of the preceding embodiments, wherein the at least one display is arranged on a cart.

36. The system according to any one or more of the preceding embodiments, wherein the at least one display is defined as a first display, and where the system further comprises a second display.

37. The system according to any one or more of the preceding embodiments, wherein the second display is arranged on the handheld device.

38. The system according to any one or more of the preceding embodiments, wherein the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

39. The system according to any one or more of the preceding embodiments, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.

40. The system according to any one or more of the preceding embodiments, wherein the first display and/or the second display provides instructions for the operator.

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41. The system according to any one or more of the preceding embodiments, wherein visual information is provided to the operator on one or more means other than the first display.

42. The system according to any one or more of the preceding embodiments, wherein audible information to the operator is provided to the operator.

43. The system according to any one or more of the preceding embodiments, wherein the scanning is performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

44. A method of interaction between a handheld device and at least one display, where the method comprises the steps of: performing at least one action in a physical 3D environment by means of the handheld device; visually representing the physical 3D environment by the at least one display; and remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

45. 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 embodiments, when said program code means are executed on the data processing system.

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

The invention claimed is:

1. A scanning system for scanning a 3D environment, the scanning system comprising:

a handheld device including an optical scanner, wherein the 3D environment to be scanned is selected by pointing the optical scanner at the 3D environment; and at least one display remotely connected to the handheld device,

wherein the handheld device is adapted for performing at least one scanning action in a physical 3D environment, and the at least one display is adapted for visually representing the physical 3D environment; and the handheld device includes a user interface for remotely controlling the display to adjust the view with which the 3D environment is represented on the display.

2. A system according to claim 1, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

3. A system according to claim 1, wherein the user interface includes means for manually switching between performing the at least one scanning action and remotely controlling the view.

4. The system according to claim 1, wherein the handheld device comprises at least one motion sensor.

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5. The system according to claim 4, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the at least one motion sensor.

6. The system according to claim 4, wherein functionality of the user interface comprises a use of gestures.

7. The system according to claim 6, wherein the gestures are detected by the at least one motion sensor.

8. The system according to claim 4, wherein the user-interface is other than the at least one motion sensor.

9. The system according to claim 1, wherein the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

10. The system according to claim 1, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

11. The system according to claim 1, wherein the handheld device is an intra-oral 3D scanner.

12. The system according to claim 1, wherein the handheld device includes a surgical instrument.

13. The system according to claim 1, wherein the handheld device includes a mechanical tool.

14. The system according to claim 1, wherein the handheld device is an in-ear 3D scanner.

15. The system according to claim 1, wherein the at least one display is defined as a first display, and where the system further comprises a second display.

16. The system according to claim 15, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.

17. The system according to claim 15, wherein the first display and/or the second display provides instructions for the operator.

18. The system according to claim 1, wherein audible information is provided to the operator.

19. A system comprising:

a handheld device and at least one display; wherein the handheld device is adapted for switching between performing at least one action in a physical 3D environment, wherein the at least one display is adapted for visually representing the physical 3D environment; and remotely controlling the display to adjust the view with which the 3D environment is represented on the display;

wherein the handheld device is an intra-oral 3D scanner and the at least one action performed in the physical 3D environment is scanning and that the view is remotely controlled by at least one motion sensor arranged in the handheld device, and wherein an actuator provided on the handheld device switches between performing the at least one action and remotely controlling the view.

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Application Number	Unassigned
Filing Date	July 30, 2019
First Named Inventor	Henrik ÖJELUND
Title	SYSTEM WITH 3D USER INTERFACE INTEGRATION
Art Unit	Unassigned
Examiner Name	Unassigned
Attorney Docket Number	0079124-000266

SIGNATURE of Applicant or Patent Practitioner

Signature	/Stephany G. Small/	Date	July 30, 2019
Name	Stephany G. Small	Telephone	703-836-6620
Registration Number	69,532		

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications.

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This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

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21839

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3Shape A/S

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- ☒ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
- ☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature

Date (Optional)

15 MAY 2012

Name

HETTE CARLSTEDT

Title

GENERAL COUNSEL

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STATEMENT UNDER 37 CFR 3.73(c)Applicant/Patent Owner: 3SHAPE A/SApplication No./Patent No.: 9,329,675Filed/Issue Date: May 3, 2016Titled: SYSTEM WITH 3D USER INTERFACE INTEGRATION3SHAPE A/S, a corporation

(Name of Assignee)

(Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. ☒ The assignee of the entire right, title, and interest.
2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):
- ☐ The extent (by percentage) of its ownership interest is _____%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.
- ☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (e.g., bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of options A or B below):

- A. ☒ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 031241, Frame 0837, or for which a copy thereof is attached.
- B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

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[Page 1 of 2]

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Exhibit 1002-page 36 of 1005

STATEMENT UNDER 37 CFR 3.73(c)

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☒ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Stephany G. Small/

July 30, 2019

Signature

Date

Stephany G. Small

69,532

Printed or Typed Name

Title or Registration Number

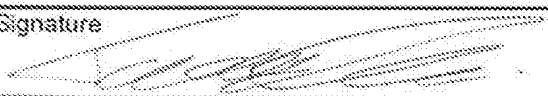
[Page 2 of 2]

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7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
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REISSUE APPLICATION: CONSENT OF ASSIGNEE; STATEMENT OF NON-ASSIGNMENT		Docket Number (Optional) 0079124-000266
This is part of the application for a reissue patent based on the original patent identified below.		
Name of Patentee(s) 3SHAPE A/S		
Patent Number 9,329,675	Date Patent Issued May 3, 2016	
Title of Invention SYSTEM WITH 3D USER INTERFACE INTEGRATION		
<p>1. ☒ Filed herein is a statement under 37 CFR 3.73(c). (Form PTO/AIA/96)</p> <p>2. ☐ Ownership of the patent is in the inventor(s), and no assignment of the patent is in effect.</p> <p>One of boxes 1 or 2 above must be checked. If multiple assignees, complete this form for each assignee. If box 2 is checked, skip the next entry and go directly to "Name of Assignee."</p> <p>The written consent of all assignees and inventors owning an undivided interest in the original patent is included in this application for reissue.</p> <p>The assignee(s) owning an undivided interest in said original patent is/are <u>3SHAPE A/S</u> and the assignee(s) consents to the accompanying application for reissue.</p>		
Name of assignee/inventor (if not assigned) 3SHAPE A/S		
Signature 	Date 25. 04. 2019	
Typed or printed name and title of person signing for assignee (if assigned) TAIS CLAUSEN, Co-CEO (3SHAPE A/S)		

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2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 216(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE		Docket Number (optional) 0079124-000266	
<p>I hereby declare that:</p> <p>The residence and mailing address of the inventor or joint inventors are stated below.</p> <p>Name of the Assignee:</p> <div style="border: 1px solid black; padding: 2px;">3SHAPE A/S</div> <p>I am authorized to act on behalf of the assignee (if the assignee is a juristic entity).</p> <p>The entire title to the patent identified below is vested in said assignee, or if there are multiple assignees/owners, all assignees/owners have executed a Reissue Application Declaration to account for the entire title of the patent identified below.</p>			
<p>Inventor Henrik OJELUND</p>			
Residence: City	State	Country	
Lyngby		DK	
<p>Mailing Address</p> <p>Kulevierparken 55</p>			
City	State	Zip	Country
Lyngby		DK-2800	DK
☒ Additional Inventors are named on separately numbered sheets attached hereto.			
Patent Number 9,329,675		Patent Issue Date May 3, 2016	
<p>I believe said inventor(s) to be the original inventor or original joint inventors of the subject matter which is described and claimed in said patent, for which a reissue patent is sought on the invention titled:</p> <div style="border: 1px solid black; padding: 10px; min-height: 40px;"> <p>SYSTEM WITH 3D USER INTERFACE INTEGRATION</p> </div> <p>the specification of which</p> <p>☒ is attached hereto.</p> <p>☐ was filed on _____ as reissue application number _____</p> <p>The above-identified application was made or authorized to be made by me.</p> <p>I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.</p> <p>I believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)</p> <p>☐ by reason of a defective specification or drawing.</p> <p>☒ by reason of the patentee claiming more or less than he had the right to claim in the patent.</p> <p>☐ by reason of other errors.</p>			

[Page 1 of 2]

This collection of information is required by 37 CFR 1.175. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1480, Alexandria, VA 22313-1480. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1480, Alexandria, VA 22313-1480.

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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE		Docket Number (Optional) 0079124-0002										
<p>At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, a claim that the application seeks to broaden must be identified and the box below must be checked:</p> <p>A claim is being added to correct an error wherein patent owner failed to previously present a narrower claim reciting that the at least one motion sensor is an accelerometer, gyro, or magnetometer. Claim 20 recites this subject matter.</p> <p style="text-align: center;">[Attach additional sheets, if needed.]</p> <p>☐ The application for the original patent was filed under 37 CFR 1.46 by the assignee of the entire interest.</p>												
<p>I hereby appoint:</p> <p>☒ Practitioners associated with Customer Number: 21839</p> <p style="text-align: center;">OR</p> <p>☐ Practitioner(s) named below:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%;">Name</th> <th style="width: 50%;">Registration Number</th> </tr> </thead> <tbody> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> <tr><td> </td><td> </td></tr> </tbody> </table>			Name	Registration Number								
Name	Registration Number											
<p>as my/our attorney(s) or agent(s) to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith.</p>												
<p>Correspondence Address: Direct all communications about the application to:</p> <p>☒ The address associated with Customer Number: 21839</p> <p style="text-align: center;">OR</p> <p>☐ Firm or Individual Name</p> <p>Address</p> <p>City State Zip </p> <p>Country </p> <p>Telephone Email </p>												
<p style="text-align: center;">WARNING:</p> <p>Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.</p>												
<p>Signature </p>		<p>Date (Optional) 30. 07. 2019</p>										
<p>Legal name of person signing Tais Clausen</p>												
<p>Address of Assignee 3Shape A/S, Holmens Kanal 7, 4. sal, Copenhagen K, DK-1050, DENMARK</p>												

Privacy Act Statement

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8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
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SUPPLEMENTAL SHEET FOR DECLARATION**ADDITIONAL INVENTOR(S)**

Supplemental Sheet (for PTO/AIA/08,09)

Page 3 of 3**Legal Name of Additional Joint Inventor, if any:**

(E.g., Given Name (first and middle (if any)) and Family Name or Surname)

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Signature

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Country DK

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(E.g., Given Name (first and middle (if any)) and Family Name or Surname)

Inventor's
Signature

Date (Optional)

Residence: City

State

Country

Mailing Address

City

State

Zip

Country

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 21 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of	)	
	)	
Henrik ÖJELUND et al.	)	MAIL STOP: REISSUE
	)	
Reissue of U.S. Patent No. 9,329,675	)	
	)	
Issued: May 3, 2016	)	
	)	
For: SYSTEM WITH 3D USER INTERFACE	)	
INTEGRATION	)	

PRELIMINARY AMENDMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

Prior to examination of the above-captioned patent application, kindly amend the application as follows:

AMENDMENTS TO THE CLAIMS:

The following listing of claims will replace all prior versions and listings of claims in this application.

LISTING OF CLAIMS:

1. (amended) A scanning system for scanning a 3D environment, the scanning system comprising:
a handheld device including an optical scanner, wherein the 3D environment to be scanned is selected by pointing the optical scanner at the 3D environment; and
at least one display remotely connected to the handheld device,
wherein the handheld device is adapted for performing at least one scanning action in a physical 3D environment, and the at least one display is adapted for visually representing the physical 3D environment; and
the handheld device includes a 3D user interface for remotely controlling the display to adjust the view with which the 3D environment is represented on the display,
wherein the handheld device comprises at least one motion sensor, and
wherein the at least one motion sensor is a sensor that directly detects motion.
2. (amended) [A] The scanning system according to claim 1, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

3. (amended) [A] The scanning system according to claim 1, wherein the handheld device includes an actuator [means] for manually switching between performing the at least one scanning action and remotely controlling the view.

Please cancel Claim 4.

5. (amended) The scanning system according to claim [4] 1, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the at least one motion sensor.
6. (amended) The scanning system according to claim [4] 1, wherein functionality of the 3D user interface comprises a use of gestures.
7. (amended) The scanning system according to claim 6, wherein the gestures are detected by the at least one motion sensor.
8. (amended) The scanning system according to claim [4] 1, wherein the [user-interface is other than the at least one motion sensor] handheld device further comprises at least one of an infrared sensor, a range sensor, or a proximity sensor.

9. (amended) The scanning system according to claim 1, wherein the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.
10. (amended) The scanning system according to claim 1, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.
11. (amended) The scanning system according to claim 1, wherein the handheld device is an intra-oral 3D scanner.
12. (amended) The scanning system according to claim 1, wherein the handheld device includes a surgical instrument.
13. (amended) The scanning system according to claim 1, wherein the handheld device includes a mechanical tool.
14. (amended) The scanning system according to claim 1, wherein the handheld device is an in-ear 3D scanner.
15. (amended) The scanning system according to claim 1, wherein the at least one display is defined as a first display, and where the system further comprises a second display.

16. (amended) The scanning system according to claim 15, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.
17. (amended) The scanning system according to claim 15, wherein the first display and/or the second display provides instructions for the operator.
18. (amended) The scanning system according to claim 1, wherein audible information is provided to the operator.
19. (amended) A system comprising:
a handheld device and at least one display;
wherein the handheld device is adapted for switching between performing at least one action in a physical 3D environment, wherein the at least one display is adapted for visually representing the physical 3D environment; and remotely controlling the display to adjust the view with which the 3D environment is represented on the display;
wherein the handheld device is an intra-oral 3D scanner and the at least one action performed in the physical 3D environment is scanning and that the view is remotely controlled by at least one motion sensor arranged in the handheld device, and wherein an actuator provided on the handheld device switches between performing the at least one action and remotely controlling

- the view, and wherein the at least one motion sensor is a sensor that directly detects motion.
20. (new) The scanning system according to claim 1, wherein the at least one motion sensor is an accelerometer, gyro, or magnetometer.
21. (new) The scanning system according to claim 1, wherein the at least one motion sensor is adapted for taking the movement of the scanner into account while performing the scanning.
22. (new) The scanning system according to claim 1, wherein the system comprises at least two motion sensors and wherein the at least two motion sensors provide sensor fusion.
23. (new) The scanning system according to claim 1, wherein the at least one motion sensor is the 3D user interface for remotely controlling the display, wherein the view on the display is determined by moving the handheld scanner.
24. (new) The scanning system according to claim 23, wherein moving the handheld scanner to point down causes the view on the display to be a downward viewing angle.

25. (new) The scanning system according to claim 1, wherein the handheld device further comprises a user-interface element
26. (new) The scanning system according to claim 25, wherein the user-interface element comprises a touch-sensitive element, a button, a scroll-wheel, or a proximity sensor.
27. (new) The scanning system according to claim 25, wherein the user-interface element provides more than one user input.
28. (new) The scanning system according to claim 25, wherein the at least one motion sensor and/or the user-interface element are utilized in a workflow.
29. (new) The system according to claim 19, wherein the handheld device is adapted to change a magnification factor of the view represented on the at least one display which is determined by the motion of the operator's hand holding the handheld device, through the use of the at least one motion sensor.
30. (new) The scanning system according to claim 1, wherein the at least one display is arranged on a cart.
31. (new) The scanning system according to claim 1, wherein the at least one display is divided into multiple regions.

32. (new) The system according to claim 19, wherein the handheld device further comprises a user interface element,
wherein switching to remotely controlling the view puts the handheld device into a controller mode,
wherein holding the user interface element and/or the actuator on the handheld device in conjunction with moving the handheld device determines the view of the 3D environment on the display in accordance with signals from the motion sensor.

33. (new) A scanning system for scanning a 3D environment, the scanning system comprising:
a handheld device including an optical scanner, wherein the 3D environment to be scanned is selected by pointing the optical scanner at the 3D environment; and
at least one display remotely connected to the handheld device,
wherein the handheld device is adapted for performing at least one scanning action in a physical 3D environment, and the at least one display is adapted for visually representing the physical 3D environment; and
wherein the handheld device includes at least one motion sensor for remotely controlling the display to adjust the view with which the 3D environment is represented on the display; and
wherein the at least one motion sensor is an accelerometer, gyro, or magnetometer.

34. (new) The scanning system according to claim 33, wherein the handheld device further comprises at least two user interface elements.

35. (new) The scanning system according to claim 34, wherein the at least two user interface elements comprises at least one button and a touch-sensitive element, and wherein the display is on a cart.

36. (new) The scanning system according to claim 35, wherein the at least one button and the touch-sensitive element provides more than one user input.

37. (new) The scanning system according to claim 36, wherein at least one of the user input provides for manually switching between performing the at least one scanning action and remotely controlling the view.

38. (new) The scanning system according to claim 37, wherein switching to remotely controlling the view puts the handheld device into a controller mode, wherein holding at least one user interface element on the handheld device in conjunction with moving the handheld device determines the view of the 3D environment on the display in accordance with signals from the motion sensor.

39. (new) The scanning system according to claim 37, wherein switching to remotely controlling the view puts the handheld device into a controller mode and wherein when in controller mode, moving the handheld device down results in showing the view of the 3D environment from a downward viewing angle on the display.

REMARKS

This communication is submitted in accordance with 37 C.F.R. § 1.173.

Status of Claims and Support for Claim Changes

This application for a narrowing reissue is being filed with original patent Claims 1-19, of which Claims 1-3, 5-19 are amended and Claim 4 is canceled herein, and new Claims 20-39 are added.

As of the filing of this reissue application, Claims 1-3, 5-39 are pending.

The following table lists the status of the claims as well as non-limiting, exemplary support for the claim amendments and the new claims.

Claim	Status/Support
1	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 1, lines 58-60; col. 6, lines 46-50; col. 9, lines 59-60; and col. 10, line 35.
2	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
3	Pending and Amended. Non-limiting, exemplary support found at original Claim 1; and col. 3, lines 28-31.
4	Canceled.
5	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
6	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 1, lines 58-60; and col. 5, lines 37-38 and 43-46.
7	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
8	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 5, lines 43-46; col. 6, lines 51-58; and col. 7, lines 14-17.
9	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
10	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
11	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
12	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.

13	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
14	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
15	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
16	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
17	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
18	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
19	Pending and Amended. Non-limiting, exemplary support found at col. 6, lines 46-50; col. 9, lines 59-60; and col. 10, line 35.
20	Pending and New. Non-limiting, exemplary support found at col. 6, lines 46-50.
21	Pending and New. Non-limiting, exemplary support found at col. 3, lines 10-12.
22	Pending and New. Non-limiting, exemplary support found at col. 6, line 65-col. 7, line 3.
23	Pending and New. Non-limiting, exemplary support found at original Claim 19; col. 3, lines 15-17; and col. 4, lines 6-8.
24	Pending and New. Non-limiting, exemplary support found at Fig. 2a; col. 3, lines 18-19; and col. 11, lines 9-17.
25	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-17.
26	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-17.
27	Pending and New. Non-limiting, exemplary support found at col. 7, lines 22-34.
28	Pending and New. Non-limiting, exemplary support found at col. 7, lines 18-34.
29	Pending and New. Non-limiting, exemplary support found at original Claim 10; col. 9, lines 45-60; and col. 13, lines 28-31.
30	Pending and New. Non-limiting, exemplary support found at col. 14, lines 45-47.
31	Pending and New. Non-limiting, exemplary support found at col. 14, lines 19-21.
32	Pending and New. Non-limiting, exemplary support found at original Claim 19; col. 3, line 66-col. 4, line 8; and col. 7, lines 4-17.
33	Pending and New. Non-limiting, exemplary support found at original Claims 1, 4, 19; col. 6, lines 46-50.
34	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-34.
35	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-34; and col. 14, lines 45-47.

36	Pending and New. Non-limiting, exemplary support found at col. 7, lines 22-34.
37	Pending and New. Non-limiting, exemplary support found at original Claims 3 and 19; and col. 3, lines 28-37.
38	Pending and New. Non-limiting, exemplary support found at col. 3, lines 15-17; and col. 3, line 66-col. 4, line 8.
39	Pending and New. Non-limiting, exemplary support found at Fig. 2a; col. 3, lines 15-19; col. 3, line 66-col. 4, line 8; and col. 11, lines 9-17.

Early and favorable action concerning this application is respectfully requested.

If there are any questions concerning this Preliminary Amendment Pursuant To 37 C.F.R. § 1.173, or the reissue application in general, the Examiner is respectfully requested to telephone the undersigned attorney so that prosecution of the application may be expedited.

The Director is hereby authorized to charge any appropriate fees under 37 C.F.R. §§ 1.16, 1.17 and 1.20(d) and 1.21 that may be required by this paper, and to credit any overpayment, to Deposit Account No. 02-4800.

Favorable consideration of the application in view of the foregoing amendments is respectfully requested. Should any questions arise in connection with this application, it is respectfully requested that the undersigned be contacted at the number indicated below.

Respectfully submitted,

BUCHANAN INGERSOLL & ROONEY PC

Date July 30, 2019

By: /Stephany G. Small/
Stephany G. Small, Ph.D.
Registration No. 69,532

Customer No. 21839
703 836 6620

Electronic Patent Application Fee Transmittal				
Application Number:				
Filing Date:				
Title of Invention:		SYSTEM WITH 3D USER INTERFACE INTEGRATION		
First Named Inventor/Applicant Name:		Henrik ÖJELUND		
Filer:		Stephany Gale Small/Sarah Noel		
Attorney Docket Number:		0079124-000266		
Filed as Large Entity				
Filing Fees for Reissue (Utility)				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
UTILITY REISSUE BASIC	1014	1	300	300
REISSUE OR REISSUE DESIGN CPA SEARCH FEE	1114	1	660	660
REISSUE OR REISSUE DESIGN CPA EXAM. FEE	1314	1	2200	2200
Pages:				
Claims:				
REISSUE CLAIMS IN EXCESS OF 20	1205	18	100	1800
Miscellaneous-Filing:				
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
Total in USD (\$)				4960

Electronic Acknowledgement Receipt

EFS ID:	36730210
Application Number:	16526281
International Application Number:	
Confirmation Number:	9657
Title of Invention:	SYSTEM WITH 3D USER INTERFACE INTEGRATION
First Named Inventor/Applicant Name:	Henrik ÖJELUND
Customer Number:	21839
Filer:	Stephany Gale Small/Sarah Noel
Filer Authorized By:	Stephany Gale Small
Attorney Docket Number:	0079124-000266
Receipt Date:	30-JUL-2019
Filing Date:	
Time Stamp:	15:24:14
Application Type:	Reissue (Utility)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$4960
RAM confirmation Number	E20197TF24585385
Deposit Account	024800
Authorized User	Sarah Noel

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

37 CFR 1.16 (National application filing, search, and examination fees)

37 CFR 1.17 (Patent application and reexamination processing fees)

Exhibit 1002 page 60 of 1005

0060

DENTAL IMAGING

37 CFR 1.19 (Document supply fees)
 37 CFR 1.20 (Post Issuance fees)
 37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Reissue Application	Transmittal_NewApp.pdf	506624	no	1
			e620035e4f07dc050cdf8be7117a57cf96912b9f		
Warnings:					
Information:					
2	Application Data Sheet	ADS.pdf	1822876	no	9
			c9ab8d609240dea77ad3fba0f4af33a89c468f3b		
Warnings:					
Information:					
3	Specification	US9329675B2.pdf	5728314	no	15
			f51402e5210c9c996e4c6390181cd4024e37c17f		
Warnings:					
Information:					
4	Drawings-only black and white line drawings	Figures.pdf	2163940	no	5
			cf1663a225f3b85d464cd7da28e559d421dd0c9c		
Warnings:					
Information:					
5	Authorization for Extension of Time all replies	Authorization.pdf	93782	no	1
			946a66368c01c202c3524d200cf036b05ae26445		
Warnings:					
Information:					
6	Fee Worksheet (SB06)	Fee_Transmittal.pdf	509522	no	1
			1be4efeaed6ed09ebb8bbe46cc8ea471aa2f16c4		
Warnings:					
Information:					

7	Power of Attorney	POA.pdf	560039	no	2
			a4bb7027969bb1c77137f106ec8c258e14a090d2		
Warnings:					
Information:					
8	Assignee showing of ownership per 37 CFR 3.73	373c_Statement.pdf	1538154	no	3
			c7930b7b99f8a5d07158a4e974c8e2c1a5254e17		
Warnings:					
Information:					
9	Consent of Assignee accompanying the declaration	Consent_Assignee.pdf	505763	no	2
			003a3b7153410d149e837ea949456079bc55b170		
Warnings:					
Information:					
10	Reissue dec filed in accordance with MPEP 1414	Declaration.pdf	1278463	no	4
			db7149cddfa5548ca8d73eb538c788f98fbc7e7d3		
Warnings:					
Information:					
11		Prelim.pdf	121821	yes	13
			c4be3a0f590a5624928d868f252fe0ee51a18326		
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Preliminary Amendment		1	1	
	Claims		2	10	
	Applicant Arguments/Remarks Made in an Amendment		11	13	
Warnings:					
Information:					
12	Fee Worksheet (SB06)	fee-info.pdf	37132	no	2
			d81b8ddc98e2064f15befa3c7ee0d2e01355d142		
Warnings:					
Exhibit 1002 page 62 of 100					

Information:	
Total Files Size (in bytes):	14866430
<p>This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.</p> <p><u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.</p> <p><u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.</p> <p><u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.</p>	

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875						Application or Docket Number 16/526,281			
APPLICATION AS FILED - PART I									
(Column 1)		(Column 2)		SMALL ENTITY		OR OTHER THAN SMALL ENTITY			
FOR	NUMBER FILED	NUMBER EXTRA	RATE(\$)	FEE(\$)		RATE(\$)	FEE(\$)		
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	300		
SEARCH FEE (37 CFR 1.16(k), (l), or (m))	N/A	N/A	N/A			N/A	660		
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	2200		
TOTAL CLAIMS (37 CFR 1.16(j))	38	minus 20 = *	18			x 100 =	1800		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3	minus 3 = *				x 460 =	0.00		
APPLICATION SIZE FEE (37 CFR 1.16(s))			If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))									
* If the difference in column 1 is less than zero, enter "0" in column 2.				TOTAL		TOTAL	4960		
APPLICATION AS AMENDED - PART II									
(Column 1)		(Column 2)		(Column 3)		SMALL ENTITY		OR OTHER THAN SMALL ENTITY	
AMENDMENT A	CLAIMS REMAINING AFTER AMENDMENT	HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE(\$)	ADDITIONAL FEE(\$)	RATE(\$)	ADDITIONAL FEE(\$)		
	Total (37 CFR 1.16(i))	*	Minus **	=	x =	x =	=		
	Independent (37 CFR 1.16(h))	*	Minus ***	=	x =	x =	=		
	Application Size Fee (37 CFR 1.16(s))								
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))								
				TOTAL ADD'L FEE		TOTAL ADD'L FEE			
AMENDMENT B	CLAIMS REMAINING AFTER AMENDMENT	HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE(\$)	ADDITIONAL FEE(\$)	RATE(\$)	ADDITIONAL FEE(\$)		
	Total (37 CFR 1.16(i))	*	Minus **	=	x =	x =	=		
	Independent (37 CFR 1.16(h))	*	Minus ***	=	x =	x =	=		
	Application Size Fee (37 CFR 1.16(s))								
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))								
				TOTAL ADD'L FEE		TOTAL ADD'L FEE			
* If the entry in column 1 is less than the entry in column 2, write "0" in column 3. ** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20". *** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3". The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.									



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www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
16/526,281	07/30/2019	2621	4960	0079124-000266	38	3

CONFIRMATION NO. 9657

FILING RECEIPT

21839
BUCHANAN, INGERSOLL & ROONEY PC
POST OFFICE BOX 1404
ALEXANDRIA, VA 22313-1404



Date Mailed: 08/15/2019

Receipt is acknowledged of this reissue patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

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Inventor(s)

Henrik ØJELUND, Lyngby, DENMARK;
David FISCHER, Stenløse, DENMARK;
Karl-Josef HOLLENBECK, København Ø, DENMARK;

Applicant(s)

3Shape A/S, Residence Not Provided, Assignee (with 37 CFR 1.172 Interest);

Assignment For Published Patent Application

3Shape A/S, Copenhagen K, DK

Power of Attorney: The patent practitioners associated with Customer Number 21839

Domestic Priority data as claimed by applicant

This application is a REI of 13/991,513 06/04/2013 PAT 9329675
which is a 371 of PCT/DK2011/050461 12/05/2011
which claims benefit of 61/420,138 12/06/2010

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see <http://www.uspto.gov> for more information.)
DENMARK PA 2010 01104 12/06/2010 No Access Code Provided

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

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If Required, Foreign Filing License Granted: 08/14/2019

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 16/526,281**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No
Title

SYSTEM WITH 3D USER INTERFACE INTEGRATION

Preliminary Class

345

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific

countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

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Title 35, United States Code, Section 184
Title 37, Code of Federal Regulations, 5.11 & 5.15

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
16/526,281	07/30/2019	3992	4960	0079124-000266	38	3

21839
BUCHANAN, INGERSOLL & ROONEY PC
POST OFFICE BOX 1404
ALEXANDRIA, VA 22313-1404

CONFIRMATION NO. 9657
CORRECTED FILING RECEIPT



Date Mailed: 08/20/2019

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Applicant(s)

3Shape A/S, Copenhagen K, DENMARK, Assignee (with 37 CFR 1.172 Interest);

Assignment For Published Patent Application

3Shape A/S, Copenhagen K, DK

Power of Attorney: The patent practitioners associated with Customer Number 21839

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DENMARK PA 2010 01104 12/06/2010 No Access Code Provided

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Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No
Title

SYSTEM WITH 3D USER INTERFACE INTEGRATION

Preliminary Class

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This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875				Application or Docket Number 16/526,281		Filing Date 07/30/2019		☐ To be Mailed		
ENTITY: ☒ LARGE ☐ SMALL ☐ MICRO										
APPLICATION AS FILED - PART I										
		(Column 1)	(Column 2)							
FOR		NUMBER FILED	NUMBER EXTRA	RATE (\$)		FEE (\$)				
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))		N/A	N/A	N/A						
☐ SEARCH FEE (37 CFR 1.16(k), (l), or (m))		N/A	N/A	N/A						
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))		N/A	N/A	N/A						
TOTAL CLAIMS (37 CFR 1.16(i))		minus 20 =	*	x \$100 =						
INDEPENDENT CLAIMS (37 CFR 1.16(h))		minus 3 =	*	x \$460 =						
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))		If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).								
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))										
* If the difference in column 1 is less than zero, enter "0" in column 2.				TOTAL						
APPLICATION AS AMENDED - PART II										
		(Column 1)	(Column 2)	(Column 3)						
AMENDMENT	10/28/2019	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE (\$)		ADDITIONAL FEE (\$)		
	Total (37 CFR 1.16(i))	* 43	Minus	** 38	= 5	x \$100 =		500		
	Independent (37 CFR 1.16(h))	* 3	Minus	*** 3	= 0	x \$460 =		0		
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))									
						TOTAL ADD'L FEE		500		
		(Column 1)	(Column 2)	(Column 3)						
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE (\$)		ADDITIONAL FEE (\$)		
	Total (37 CFR 1.16(i))	*	Minus	**	=	x \$0 =				
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x \$0 =				
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))									
						TOTAL ADD'L FEE				
* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.						LIE				
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".						/EFREM WARREN/				
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".										
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.										

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of	)	
	)	
Henrik ÖJELUND et al.	)	Group Art Unit: 3992
	)	
Reissue Application Serial No.: 16/526,281	)	Examiner: Peng KE
	)	
Filed: July 30, 2019	)	Confirmation No.: 9657
	)	
For: SYSTEM WITH 3D USER INTERFACE	)	
INTEGRATION	)	

SECOND PRELIMINARY AMENDMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

Prior to examination of the above-captioned patent application, kindly amend the application as follows:

AMENDMENTS TO THE CLAIMS:

The following listing of claims will replace all prior versions and listings of claims in this application.

LISTING OF CLAIMS:

1. (amended) A scanning system for scanning a 3D environment, the scanning system comprising:

a handheld device including an optical scanner, wherein the 3D environment to be scanned is selected by pointing the optical scanner at the 3D environment; and

at least one display remotely connected to the handheld device,

wherein the handheld device is adapted for performing at least one scanning action in a physical 3D environment, and the at least one display is adapted for visually representing the physical 3D environment; and

the handheld device includes a 3D user interface for remotely controlling the display to adjust the view with which the 3D environment is represented on the display,

wherein the handheld device comprises at least one motion sensor, and

wherein the at least one motion sensor is a sensor that directly detects motion.
2. (amended) [A] The scanning system according to claim 1, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

3. (amended) [A] The scanning system according to claim 1, wherein the handheld device includes an actuator [means] for manually switching between performing the at least one scanning action and remotely controlling the view.

Please cancel Claim 4.

5. (amended) The scanning system according to claim [4] 1, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the at least one motion sensor.
6. (amended) The scanning system according to claim [4] 1, wherein functionality of the 3D user interface comprises a use of gestures.
7. (amended) The scanning system according to claim 6, wherein the gestures are detected by the at least one motion sensor.
8. (amended) The scanning system according to claim [4] 1, wherein the [user-interface is other than the at least one motion sensor] handheld device further comprises at least one of an infrared sensor, a range sensor, or a proximity sensor.

9. (amended) The scanning system according to claim 1, wherein the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.
10. (amended) The scanning system according to claim 1, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.
11. (amended) The scanning system according to claim 1, wherein the handheld device is an intra-oral 3D scanner.
12. (amended) The scanning system according to claim 1, wherein the handheld device includes a surgical instrument.
13. (amended) The scanning system according to claim 1, wherein the handheld device includes a mechanical tool.
14. (amended) The scanning system according to claim 1, wherein the handheld device is an in-ear 3D scanner.

15. (amended) The scanning system according to claim 1, wherein the at least one display is defined as a first display, and where the system further comprises a second display.
16. (amended) The scanning system according to claim 15, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.
17. (amended) The scanning system according to claim 15, wherein the first display and/or the second display provides instructions for the operator.
18. (amended) The scanning system according to claim 1, wherein audible information is provided to the operator.
19. (amended) A system comprising:
a handheld device and at least one display;
wherein the handheld device is adapted for switching between performing at least one action in a physical 3D environment, wherein the at least one display is adapted for visually representing the physical 3D environment; and
remotely controlling the display to adjust the view with which the 3D environment is represented on the display;

wherein the handheld device is an intra-oral 3D scanner and the at least one action performed in the physical 3D environment is scanning and that the view is remotely controlled by at least one motion sensor arranged in the handheld device, and wherein an actuator provided on the handheld device switches between performing the at least one action and remotely controlling the view, and wherein the at least one motion sensor is a sensor that directly detects motion.

20. (new) The scanning system according to claim 1, wherein the at least one motion sensor is an accelerometer, gyro, or magnetometer.

21. (new) The scanning system according to claim 1, wherein the at least one motion sensor is adapted for taking the movement of the scanner into account while performing the scanning.

22. (new) The scanning system according to claim 1, wherein the system comprises at least two motion sensors and wherein the at least two motion sensors provide sensor fusion.

23. (new) The scanning system according to claim 1, wherein the at least one motion sensor is the 3D user interface for remotely controlling the display, wherein the view on the display is determined by moving the handheld scanner.

24. (new) The scanning system according to claim 23, wherein moving the handheld scanner to point down causes the view on the display to be a downward viewing angle.
25. (new) The scanning system according to claim 1, wherein the handheld device further comprises a user-interface element
26. (new) The scanning system according to claim 25, wherein the user-interface element comprises a touch-sensitive element, a button, a scroll-wheel, or a proximity sensor.
27. (new) The scanning system according to claim 25, wherein the user-interface element provides more than one user input.
28. (new) The scanning system according to claim 25, wherein the at least one motion sensor and/or the user-interface element are utilized in a workflow.
29. (new) The system according to claim 19, wherein the handheld device is adapted to change a magnification factor of the view represented on the at least one display which is determined by the motion of the operator's hand holding the handheld device, through the use of the at least one motion sensor.

30. (new) The scanning system according to claim 1, wherein the at least one display is arranged on a cart.
31. (new) The scanning system according to claim 1, wherein the at least one display is divided into multiple regions.
32. (new) The system according to claim 19, wherein the handheld device further comprises a user interface element,
wherein switching to remotely controlling the view puts the handheld device into a controller mode,
wherein holding the user interface element and/or the actuator on the handheld device in conjunction with moving the handheld device determines the view of the 3D environment on the display in accordance with signals from the motion sensor.
33. (new) A scanning system for scanning a 3D environment, the scanning system comprising:
a handheld device including an optical scanner, wherein the 3D environment to be scanned is selected by pointing the optical scanner at the 3D environment; and
at least one display remotely connected to the handheld device.

wherein the handheld device is adapted for performing at least one scanning action in a physical 3D environment, and the at least one display is adapted for visually representing the physical 3D environment; and

wherein the handheld device includes at least one motion sensor for remotely controlling the display to adjust the view with which the 3D environment is represented on the display; and

wherein the at least one motion sensor is an accelerometer, gyro, or magnetometer.

34. (new) The scanning system according to claim 33, wherein the handheld device further comprises at least two user interface elements.

35. (new) The scanning system according to claim 34, wherein the at least two user interface elements comprises at least one button and a touch-sensitive element, and wherein the display is on a cart.

36. (new) The scanning system according to claim 35, wherein the at least one button and the touch-sensitive element provides more than one user input.

37. (new) The scanning system according to claim 36, wherein at least one of the user input provides for manually switching between performing the at least one scanning action and remotely controlling the view.

38. (new) The scanning system according to claim 37, wherein switching to remotely controlling the view puts the handheld device into a controller mode, wherein holding at least one user interface element on the handheld device in conjunction with moving the handheld device determines the view of the 3D environment on the display in accordance with signals from the motion sensor.

39. (new) The scanning system according to claim 37, wherein switching to remotely controlling the view puts the handheld device into a controller mode and wherein when in controller mode, moving the handheld device down results in showing the view of the 3D environment from a downward viewing angle on the display.

40. (new) The scanning system according to claim 1, wherein the at least one display is a 3D display, whereby a 3D representation of the 3D environment is displayed on the 3D display; and wherein the handheld device is an intra-oral 3D scanner or an in-ear 3D scanner.

41. (new) The scanning system according to claim 40, wherein the 3D display is configured to project stereoscopic image pairs of the 3D representation.

42. (new) The scanning system according to claim 40, wherein the 3D display is volumetric display configured to create a 3D effect of the 3D representation.
43. (new) The system according to claim 19, wherein the at least one display is a 3D display, whereby a 3D representation of the 3D environment is displayed on the 3D display; and wherein the 3D display is configured to project stereoscopic image pairs of the 3D representation.
44. (new) The scanning system according to claim 33, wherein the at least one display is a 3D display, whereby a 3D representation of the 3D environment is displayed on the 3D display; wherein the handheld device is an intra-oral 3D scanner or an in-ear 3D scanner; and wherein the 3D display is configured to project stereoscopic image pairs of the 3D representation.

REMARKS

This communication is submitted in accordance with 37 C.F.R. § 1.173.

Status of Claims and Support for Claim Changes

This application for a narrowing reissue is being filed with original patent Claims 1-19, of which Claims 1-3, 5-19 are amended and Claim 4 is canceled, and new Claims 20-44 are added.

As of the filing of this second preliminary amendment, Claims 1-3, 5-44 are pending.

The following table lists the status of the claims as well as non-limiting, exemplary support for the claim amendments and the new claims.

Claim	Status/Support
1	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 1, lines 58-60; col. 6, lines 46-50; col. 9, lines 59-60; and col. 10, line 35.
2	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
3	Pending and Amended. Non-limiting, exemplary support found at original Claim 1; and col. 3, lines 28-31.
4	Canceled.
5	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
6	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 1, lines 58-60; and col. 5, lines 37-38 and 43-46.
7	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
8	Pending and Amended. Non-limiting, exemplary support found at original Claims 1 and 4; col. 5, lines 43-46; col. 6, lines 51-58; and col. 7, lines 14-17.
9	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
10	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.

11	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
12	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
13	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
14	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
15	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
16	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
17	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
18	Pending and Amended. Non-limiting, exemplary support found at original Claim 1.
19	Pending and Amended. Non-limiting, exemplary support found at col. 6, lines 46-50; col. 9, lines 59-60; and col. 10, line 35.
20	Pending and New. Non-limiting, exemplary support found at col. 6, lines 46-50.
21	Pending and New. Non-limiting, exemplary support found at col. 3, lines 10-12.
22	Pending and New. Non-limiting, exemplary support found at col. 6, line 65-col. 7, line 3.
23	Pending and New. Non-limiting, exemplary support found at original Claim 19; col. 3, lines 15-17; and col. 4, lines 6-8.
24	Pending and New. Non-limiting, exemplary support found at Fig. 2a; col. 3, lines 18-19; and col. 11, lines 9-17.
25	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-17.
26	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-17.
27	Pending and New. Non-limiting, exemplary support found at col. 7, lines 22-34.
28	Pending and New. Non-limiting, exemplary support found at col. 7, lines 18-34.
29	Pending and New. Non-limiting, exemplary support found at original Claim 10; col. 9, lines 45-60; and col. 13, lines 28-31.
30	Pending and New. Non-limiting, exemplary support found at col. 14, lines 45-47.
31	Pending and New. Non-limiting, exemplary support found at col. 14, lines 19-21.
32	Pending and New. Non-limiting, exemplary support found at original Claim

	19; col. 3, line 66-col. 4, line 8; and col. 7, lines 4-17.
33	Pending and New. Non-limiting, exemplary support found at original Claims 1, 4, 19; col. 6, lines 46-50.
34	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-34.
35	Pending and New. Non-limiting, exemplary support found at col. 7, lines 4-34; and col. 14, lines 45-47.
36	Pending and New. Non-limiting, exemplary support found at col. 7, lines 22-34.
37	Pending and New. Non-limiting, exemplary support found at original Claims 3 and 19; and col. 3, lines 28-37.
38	Pending and New. Non-limiting, exemplary support found at col. 3, lines 15-17; and col. 3, line 66-col. 4, line 8.
39	Pending and New. Non-limiting, exemplary support found at Fig. 2a; col. 3, lines 15-19; col. 3, line 66-col. 4, line 8; and col. 11, lines 9-17.
40	Pending and New. Non-limiting, exemplary support found at Fig. 1; col. 5, lines 19-30; col. 3, lines 6-12 and 47-48; col. 4, lines 47-48; col. 5, lines 14-15; and col. 8, lines 39-40.
41	Pending and New. Non-limiting, exemplary support found at col. 5, lines 19-30.
42	Pending and New. Non-limiting, exemplary support found at col. 5, lines 19-30.
43	Pending and New. Non-limiting, exemplary support found at col. 5, lines 19-30.
44	Pending and New. Non-limiting, exemplary support found at Fig. 1; col. 5, lines 19-30; col. 3, lines 6-12 and 47-48; col. 4, lines 47-48; col. 5, lines 14-15; and col. 8, lines 39-40.

Early and favorable action concerning this application is respectfully requested.

If there are any questions concerning this Second Preliminary Amendment Pursuant To 37 C.F.R. § 1.173, or the reissue application in general, the Examiner is respectfully requested to telephone the undersigned representative so that prosecution of the application may be expedited.

The Director is hereby authorized to charge any appropriate fees under 37 C.F.R. §§ 1.16, 1.17 and 1.20(d) and 1.21 that may be required by this paper, and to credit any overpayment, to Deposit Account No. 02-4800.

Favorable consideration of the application in view of the foregoing amendments is respectfully requested. Should any questions arise in connection with this application, it is respectfully requested that the undersigned be contacted at the number indicated below.

Respectfully submitted,

BUCHANAN INGERSOLL & ROONEY PC

Date October 28, 2019

By: /Stephany G. Small/
Stephany G. Small, Ph.D.
Registration No. 69,532

Customer No. 21839
703 836 6620

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	
Henrik ÖJELUND <i>et al.</i>	)	Group Art Unit: 3992
Reissue Application Serial No.: 16/526,281	)	Examiner: Peng KE
Filed: July 30, 2019	)	Confirmation No.: 9657
For: SYSTEM WITH 3D USER INTERFACE	)	
INTEGRATION	)	

FIRST INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

In accordance with the duty of disclosure as set forth in 37 C.F.R. § 1.56, the accompanying information is being submitted in accordance with 37 C.F.R. §§ 1.97 and 1.98.

To assist the Examiner, the documents are listed on the attached substitute for forms PTO/SB/08a and PTO/SB/08b. It is respectfully requested that an Examiner-initialed copy of this form be returned to the undersigned.

The documents are being submitted within three (3) months of the filing or entry of the national stage of this application or before the first Office Action on the merits, whichever is later. Because these documents are being filed within the time period set forth in 37 C.F.R. § 1.97(b), no fee or statement is required.

The Director is hereby authorized to charge any appropriate fees under 37 C.F.R. §§ 1.16, 1.17, and 1.21 that may be required by this paper, and to credit any overpayment, to Deposit Account No. 02-4800.

Respectfully submitted,
BUCHANAN INGERSOLL & ROONEY PC

Dated: October 28, 2019

By: /Stephany G. Small/
Stephany G. Small, Ph.D.
Registration No. 69,532

Customer No. 21839
BUCHANAN INGERSOLL & ROONEY PC
1737 King Street, Suite 500
Alexandria, Virginia 22314
(703) 836-6620

FIRST INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary)

Sheet **1** of **4**

Complete if Known

Application Number	16/526,281
Filing Date	July 30, 2019
First Named Inventor	Henrik ÖJELUND
Examiner Name	Peng KE
Attorney Docket Number	0079124-000266

U.S. PATENTS

Examiner Initials	Item No.	Patent Number	Kind Code (if known)	Name of Patentee or Applicant of Cited Document	Issue Date (MM-DD-YYYY)
	1.	9,329,675	B2	Öjelund <i>et al.</i> (IPR2018-00197, Ex. 1001) (IPR2018-00198, Ex. 1001)	05-03-2016
	2.	8,903,746	B2	Brennan <i>et al.</i> (IPR2018-00197, Ex. 1007) (IPR2018-00198, Ex. 1007)	12-02-2014
	3.	7,221,332	B2	Miller <i>et al.</i> (IPR2018-00197, Ex. 1013) (IPR2018-00198, Ex. 1013)	05-22-2007
	4.	5,377,011	A	Koch (IPR2018-00197, Ex. 1014) (IPR2018-00198, Ex. 1014)	12-27-1994
	5.	6,485,413	B1	Boppart <i>et al.</i> (IPR2018-00197, Ex. 1015) (IPR2018-00198, Ex. 1015)	11-26-2002
	6.	5,131,844	A	Marinaccio <i>et al.</i> (IPR2018-00197, Ex. 1020) (IPR2018-00198, Ex. 1020)	07-21-1992
	7.	6,592,371	B2	Durbin <i>et al.</i> (IPR2018-00197, Ex. 1021) (IPR2018-00198, Ex. 1021)	07-15-2003
	8.	5,722,412	A	Pflugrath <i>et al.</i> (IPR2018-00197, Ex. 1024) (IPR2018-00198, Ex. 1024)	03-03-1998
	9.	6,645,148	B2	Nguyen-Dinh <i>et al.</i> (IPR2018-00197, Ex. 1025) (IPR2018-00198, Ex. 1025)	11-11-2003
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	12.	7,213,214	B2	Baar <i>et al.</i> (IPR2018-00197, Ex. 1032) (IPR2018-00198, Ex. 1032)	05-01-2007
	13.	7,551,353	B2	Kim <i>et al.</i> (IPR2018-00197, Ex. 1034) (IPR2018-00198, Ex. 1034)	06-23-2009
	14.	7,813,591	B2	Paley <i>et al.</i> (IPR2018-00198, Ex. 2001)	10-12-2010
	15.	7,141,020	B2	Poland <i>et al.</i>	11-28-2006
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	17.	7,831,292	B2	Quaid <i>et al.</i>	11-09-2010
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	20.	6,135,961	A	Pflugrath <i>et al.</i>	10-24-2000

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Examiner Initials	Item No.	Document Number	Kind Code (if known)	Name of Patentee or Applicant of Cited Document	Publication Date (MM-DD-YYYY)
	21.	2007/0171220	A1	Kriveshko (IPR2018-00197, Ex. 1005) (IPR2018-00198, Ex. 1005)	07-26-2007
	22.	2006/0020204	A1	Serra <i>et al.</i> (IPR2018-00197, Ex. 1006) (IPR2018-00198, Ex. 1006)	01-26-2006
	23.	2006/0212260	A1	Kopelman <i>et al.</i> (IPR2018-00197, Ex. 1008) (IPR2018-00198, Ex. 1008)	09-21-2006

Examiner Signature

Date Considered

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with M.P.E.P. § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

Form Letters1

FIRST INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary)

Sheet	2	of	4	Attorney Docket Number	0079124-000266
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Complete if Known

Application Number	16/526,281
Filing Date	July 30, 2019
First Named Inventor	Henrik ÖJELUND
Examiner Name	Peng KE

24.	2007/0172112	A1	Paley <i>et al.</i>	(IPR2018-00197, Ex. 1009) (IPR2018-00198, Ex. 1009)	07-26-2007
25.	2012/0179035	A1	Boudier	(IPR2018-00197, Ex. 1010) (IPR2018-00198, Ex. 1010)	07-12-2012
26.	2009/0322676	A1	Kerr <i>et al.</i>	(IPR2018-00197, Ex. 1011) (IPR2018-00198, Ex. 1011)	12-31-2009
27.	2005/0237581	A1	Knighton <i>et al.</i>	(IPR2018-00197, Ex. 1026) (IPR2018-00198, Ex. 1026)	10-27-2005
28.	2006/0092133	A1	Touma <i>et al.</i>	(IPR2018-00197, Ex. 1028) (IPR2018-00198, Ex. 1028)	05-04-2006
29.	2010/0009308	A1	Wen <i>et al.</i>	(IPR2018-00197, Ex. 1031) (IPR2018-00198, Ex. 1031)	01-14-2010
30.	2003/0164952	A1	Deichmann <i>et al.</i>	(IPR2018-00197, Ex. 1033) (IPR2018-00198, Ex. 1033)	09-04-2003
31.	2009/0040175	A1	Xu <i>et al.</i>	(IPR2018-00197, Ex. 2001) (IPR2018-00198, Ex. 2003)	02-12-2009
32.	2009/0217207	A1	Kagermeier <i>et al.</i>		08-27-2009
33.	2003/0158482	A1	Poland <i>et al.</i>		08-21-2003
34.	2009/0061381	A1	Durbin <i>et al.</i>		03-05-2009
35.	2006/0146009	A1	Syrbe <i>et al.</i>		07-06-2006
36.	2004/0204787	A1	Kopelman <i>et al.</i>		10-14-2004
37.	2005/0057745	A1	Bontje		03-17-2005
38.	2006/0025684	A1	Quistgaard <i>et al.</i>		02-02-2006
39.	2014/0022352	A1	Fisker <i>et al.</i>	(IPR2018-00197, Ex. 1039)	01-23-2014

FOREIGN PATENT DOCUMENTS

Examiner Initials	Item No.	Country Code ¹ , Number, Kind Code	Publication Date (MM-DD-YYYY)	Name of Patentee or Applicant of Cited Document
	40.	WO 2010/064156 A1 (IPR2018-00197, Ex. 1012) (IPR2018-00198, Ex. 1012)	06-10-2010	Poland <i>et al.</i>
	41.	EP 2200332 A1 (IPR2018-00197 Ex. 1019) (IPR2018-00198, Ex. 1019)	06-23-2010	Thominet
	42.	WO 00/08415 A1 (IPR2018-00198, Ex. 1037)	02-17-2000	Babayoff <i>et al.</i>
	43.	WO 2010/145669 A1	12-23-2010	3Shape A/S <i>et al.</i>
	44.	WO 2011/120526 A1	10-06-2011	3Shape A/S <i>et al.</i>
	45.	WO 2004/066615 A1	08-05-2004	Nokia Corporation
	46.	CN 101513350 A with English Abstract	08-26-2009	Siemens AG
	47.	WO 2009/089126 A1	07-16-2009	3M Innovative Properties Company
	48.	WO 2001/011193 A1	01-27-2011	Dimensional Photonics International, Inc.
	49.	WO 2007/084727 A1	07-26-2007	3M Innovative Properties Company
	50.	WO 2013/010910 A1 (IPR2018-00197, Ex. 1040)	01-24-2013	3Shape A/S <i>et al.</i>

NON-PATENT LITERATURE DOCUMENTS

Examiner Initials	Item No.	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.
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Examiner Signature	Date Considered
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*EXAMINER: Initial if reference considered, whether or not citation is in conformance with M.P.E.P. § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

Form Letters I

FIRST INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary)

Sheet	3	of	4	Attorney Docket Number	0079124-000266
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Complete if Known

Application Number	16/526,281
Filing Date	July 30, 2019
First Named Inventor	Henrik ÖJELUND
Examiner Name	Peng KE

51.	Petition for Inter Partes Review of U.S. Patent 9,329,675, filed November 22, 2017 in IPR2018-00197.
52.	Patent Owner's Preliminary Response to the Petition for Inter Partes Review of U.S. Patent No. 9,329,675, filed March 3, 2018 in IPR2018-00197.
53.	Institution Decision entered May 30, 2018 in IPR2018-00197.
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Examiner Signature	Date Considered
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*EXAMINER: Initial if reference considered, whether or not citation is in conformance with M.P.E.P. § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to Applicant.

Form Letters I

FIRST INFORMATION DISCLOSURE STATEMENT BY APPLICANT (use as many sheets as necessary)			Complete if Known		
			Application Number	16/526,281	
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			First Named Inventor	Henrik ÖJELUND	
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(54) Title: ULTRASOUND ASSEMBLY AND SYSTEM COMPRISING INTERCHANGABLE TRANSDUCERS AND DISPLAYS

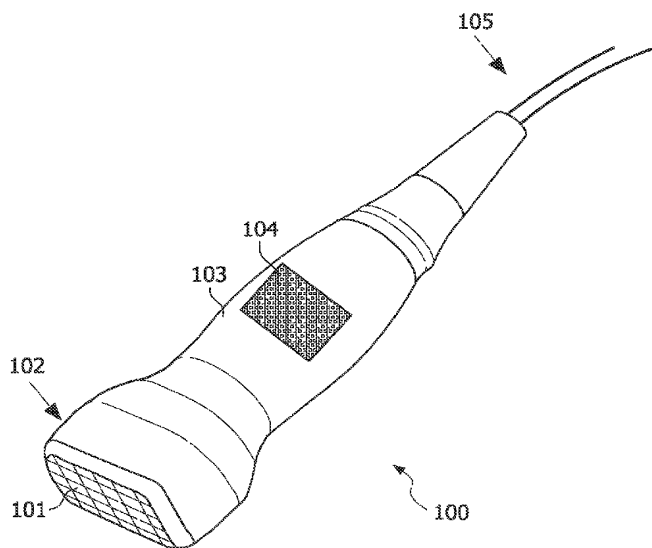


FIG. 1

(57) Abstract: An ultrasound assembly comprises a module having an input side and an output side; an ultrasound transducer comprising a micro-beamformer configured for attachment to and detachment from the input side of the module; and a display attached to the output side of the module. An ultrasound system is also described.

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5 **ULTRASOUND ASSEMBLY AND SYSTEM COMPRISING**
 INTERCHANGABLE TRANSDUCERS AND DISPLAYS

 BACKGROUND AND SUMMARY

10

 Acoustic waves (including, specifically, ultrasound waves) are useful in many scientific or technical fields, such as in medical diagnosis and medical procedures, non-destructive control of mechanical parts and underwater
15 imaging, etc. Acoustic waves allow diagnoses and visualizations which are complementary to optical observations, because acoustic waves can travel in media that are not transparent to electromagnetic waves.

 In one application, acoustic waves are employed by a
20 medical practitioner in the course of performing a medical procedure or to provide images of a particular anatomical region of a body. Often, an acoustic imaging apparatus is employed to provide images of an area of interest to the medical practitioner to facilitate successful performance
25 of the medical procedure.

 As should be appreciated by one having ordinary skill in the art, the acoustic imaging apparatus comprises an ultrasound transducer and signal processing electronics that capture the electrical signal from the acoustic
30 transducer and process the signal for display on one type of monitor or another. The monitor may then be viewed by the medical practitioner real-time, or may be stored/reproduced for later review, or both.

5 As is known, there are various types of transducers
that can be used to capture ultrasonic images. For
example, there are linear, curved linear and phased array
transducers, which may be used in ultrasound. These
transducers may have elements arranged in a one-dimensional
10 or a two-dimensional fashion, which can enable the
capturing of either a narrow slice of echo data, multiple
narrow slices of echo data in different orientations with
respect to each other, or a full volume set of echo data.
Each type of array has advantages, and depending on the
15 medical anatomy being imaged (due to different target
depths or imaging window accessibility) , a medical
practitioner may select one type of transducer over
another. As should be appreciated, in known systems this
results in duplicative transducer electronics, transducer
20 housings, and cables, and thus increases the overall
capital expenditure for the medical facility.

Furthermore, the arrangement of the medical equipment
in the imaging room can be challenging due to the placement
of the ultrasound system and its display, which the user
25 needs to look at during the scanning session. Storing and
using multiple transducer probes in the imaging room
exacerbates the problem of crowding the patient area with
cables and equipment.

In addition, in such known systems, the main
30 ultrasound system and its display are similarly problematic
for placement, since they are typically bulky and
relatively immobile. Traditional ultrasound scanners are
large, weighing up to several hundred pounds, and are
integrated with wheeled carts. Even newer "compact"

5 ultrasound display systems, typically mounted semi-permanently on smaller, lighter carts, must be transported to a practical location such that the display is visible to the sonographer but the cart is sufficiently out of the way of the medical procedure. This is a difficult compromise to
10 achieve, and often leads to awkward viewing angles or motions such as leaning across the patient by the medical practitioner to view the display.

What is needed, therefore, is an ultrasound assembly and system that overcomes at least the shortcomings of the
15 known assemblies and systems described above.

In accordance with a representative embodiment, an ultrasound assembly comprises a module having an input side and an output side; an ultrasound transducer comprising a micro-beamformer configured for attachment and detachment
20 from the input side of the module; and a display attached to the output side of the module.

In accordance with another representative embodiment, a system for ultrasound imaging comprises an ultrasound assembly. The ultrasound assembly comprises: a module
25 having an input side and an output side; a ultrasound transducer comprising a micro-beamformer configured for attachment and detachment from the input side of the module; and a display attached to the output side of the module .

BRIEF DESCRIPTION OF THE DRAWINGS

The present teachings are best understood from the following detailed description when read with the accompanying drawing figures. The features are not

5 necessarily drawn to scale. Wherever practical, like reference numerals refer to like features.

Fig. 1 is a perspective view of an ultrasound assembly in accordance with a representative embodiment.

10 Fig. 2 is a simplified schematic diagram of an ultrasound assembly in accordance with a representative embodiment .

Fig. 3 is a simplified block diagram of a system for ultrasound imaging in accordance with a representative embodiment .

15

DEFINED TERMINOLOGY

As used herein, the terms Λ_a or Λ_{an} , as used herein are defined as one or more than one.

20 In addition to their ordinary meanings, the terms ^substantial' or ^substantially' mean to with acceptable limits or degree to one having ordinary skill in the art.

In addition to their ordinary meanings, the term ^approximately' mean to within an acceptable limit or amount to one having ordinary skill in the art. For
25 example, ^approximately the same' means that one of ordinary skill in the art would consider the items being compared to be the same.

DETAILED DESCRIPTION

30 In the following detailed description, for purposes of explanation and not limitation, representative embodiments disclosing specific details are set forth in order to provide a thorough understanding of the present teachings.

5 Descriptions of known devices, materials and manufacturing
methods may be omitted so as to avoid obscuring the
description of the example embodiments. Nonetheless, such
devices, materials and methods that are within the purview
of one of ordinary skill in the art may be used in
10 accordance with the representative embodiments.

Fig. 1 is a perspective view of an ultrasound assembly
100 in accordance with a representative embodiment. The
assembly comprises a phased array transducer 102 having
transducer elements 101 in a forward portion thereof. The
15 transducer elements 101 are shown in a two-dimensional
array in the representative embodiment. As will become
clearer as the present description continues, the
transducer elements may be arranged in a linear array, or
in a curved linear array, or other transducer arrangement
20 within the purview of one having ordinary skill in the art.
It is noted that a lens covering the elements 101 is
normally included; but is not shown in the various Figs.

The transducer 102 is connected to an ultrasound (US)
module 103 in a detachable manner. The module 103
25 illustratively comprises a display 104 configured to
provide an ultrasound image (not shown) garnered from the
transducer 102. The display 104 is illustratively a small
form-factor liquid crystal display (LCD) device but may be
a display based on other technologies. For example, the
30 display 104 may be a small form-factor organic light
emitting diode (OLED) device to name only one alternative
to the LCD. Other types of displays based on known
technologies are contemplated.

5 Notably, because the assembly 100 is designed and
intended for hand-held use by a medical practitioner, the
display 104 is beneficially of a comparatively small form-
factor as mentioned above. It is contemplated that the
display 104 may be the only display of an ultrasound
10 system; or an auxiliary display used by the medical
practitioner during a medical procedure or test. As should
be appreciated by one having ordinary skill in the art, the
locating of the display 104 fosters simplicity and accuracy
during certain procedures and testing. Beneficially,
15 because the display 104 is on the module, the medical
practitioner can look to the location where he/she is
physically scanning and view the resultant image on the
display 104 without looking away at a remote display. For
instance, the display 104 could be attached to the back of
20 a transducer in a manner that it can be easily rotated and
tilted or can be located on the side of the module 103 in a
so-called "flip-out" style configuration (similar to a
consumer video camera) .

 Moreover, the display 104 may be detachable so as to
25 be positioned in a desired location separate from the body
of the transducer and module. Among other benefits, this
is useful in cases where another action is being effected
simultaneously, such as placement of a needle for a biopsy,
or insertion of a catheter in the body. The medical
30 practitioner would be able to hold the assembly 100 in one
hand, and guide the needle/catheter with the other using
the image on the display 104 to facilitate the process and
without having to look away to a remote monitor (not
shown) .

5 The module 103 may be connected to a system (not
shown) via connection 105. In representative embodiments,
the connection 105 may be a wireless connection configured
to operate under one of a variety of wireless protocols
provided under standards. Such protocols are known to one
10 having ordinary skill in the art and thus are not detailed
in order to avoid obscuring the description of the
representative embodiments. Notably, however, due to
issues of confidentiality related to medical information,
the selected protocol will likely have a competent level of
15 security to ensure compliance with medical information
confidentiality.

 Alternatively, the connection 105 is shown to be a
wired connection and may be compatible with one of a
variety of standards. Illustratively, the connection may be
20 a single differential serial pair such as universal serial
bus (USB) or low-voltage differential signaling (LVDS) .
However, it is contemplated that other types of connections
may be used.

 As alluded to above, the transducer 102 is detachably
25 mounted to the module 103. As described more fully herein,
by providing for selective attachment and detachment of the
transducer 102, a medical practitioner is accorded the
ability to select a different transducer type based on the
particular test/measurement undertaken; and without having
30 to select and stock an entirely different assembly. As
should be appreciated, this option beneficially allows the
medical facility to reduce its capital expenditure by
stocking one module for multiple types of transducers,

5 rather than having to stock a complete ultrasound assembly for each type of transducer.

Similarly, the display 104 is illustratively detachably mounted to module 103. As mentioned above, the display 104 may be detached for optimal placement in the field of view of the sonographer during the imaging session. The data connection between the display 104 and the module 103 may be wired, as with USB or similar high-speed serial interface, or wireless, as with an ultra-wideband (UWB) protocol promoted by the WiMedia Alliance. If wireless, the display 104 should include a provision to provide power, such as a battery or DC input connector for an AC adapter.

Taking advantage of the detachable feature of the display 104, the medical facility is afforded the ability to reduce their overall capital investment or increase their aggregate ultrasound scanner reliability, or "up time", by separately stocking detachable display units. The display units may then be combined at will with one or more ultrasound transducers and modules as the patient workload changes, or as display units occasionally fail.

In representative embodiments, the transducer 102 is magnetically connected to the module 103. Alternatively, the transducer 102 may be mechanically connected to the module 103, such as by latching mechanisms (not shown) or friction-fit (i.e., 'snap-on') mechanisms. As described more fully below, the transducer 102 is connected electrically to the module by an interface (not shown in Fig. 1), which is operative to provide electrical power to the transducer 102 and to pass electrical signals from the

5 transducer 102. Illustratively, the electrical-mechanical connection may comprise tabs (not shown) comprising copper with gold coating on a lower end (not shown) of the transducer 102 that mate to the electrical tabs (not shown) on the module 103 end. A skirt may be located around
10 either the transducer 102 or module 103 sides that align the module to the opposite end. The connected structure is sealed such that it is resistant to fluid ingress. For example, the electrical-mechanical connection of the transducer 102 to the module 103 can be made similarly as
15 described in US Patent 6,635,019, the disclosure of which is specifically incorporated herein by reference.

Notably however, and as described below, because of the microbeamformer placed in the transducer 102, the electrical connections needed to mate are much reduced
20 since less analogue signals are required thus allowing for simpler mechanical connections such as "snap-on" mechanism where the mechanical tolerance required is much less. The is much more practically achievable allowing for easy connect /disconnect modules where the wear and tear over
25 time would still allow a robust electrical connection.

Fig. 2 is a simplified schematic diagram of an ultrasound assembly 200 in accordance with a representative embodiment. The assembly 200 includes many common features to the assembly 100 described in connection with Fig. 1.
30 Such common features are often not duplicatively described, but may be further elaborated upon.

The transducer 102 comprises transducer elements 102 as noted above. The transducer elements 101 may be linear array or a phased array, or a combination thereof, such as

5 described in U.S. Patent 6,436,048. The beam from the
transducer elements 101 may also be steered as described in
U.S. Patent 7,037,264. As noted, the transducer elements
101 may be a curved linear (ID) array (CLA), such as
described in US Patent 6,540,682. These patents are
10 assigned to the present assignee and are all specifically
incorporated herein by reference.

The transducer 102 also comprises a microbeamformer
201. The microbeamformer 201 may be as described in U.S.
Patent 6,436,048. Echoes by the elements 101 of the
15 transducer 102 are partially beamformed by a micro-
beamformer 201. In a representative embodiment, the micro-
beamformer 201 contains circuitry which controls the
signals applied to groups of elements ("patches") of the
transducer elements 101 and effects some processing of the
20 echo signals received by elements of each group. Micro-
beamforming in the transducer 102 beneficially reduces the
number of conductors in the connection 105 between the
assembly 100 and the ultrasound system (not shown).
Additional details of the benefits derived from
25 microbeamforming may be found in commonly assigned U.S.
Pat. No. 5,997,479, the disclosure of which is specifically
incorporated herein by reference and in the ^A048 patent.

In addition to the benefits derived from dividing the
beamforming with a microbeamformer, the representative
30 embodiments foster additional benefits because the
microbeamformer 201 is co-located with the transducer
elements 101 within the transducer 102. For example,
superior electrical performance is realized because the
electronics of the microbeamformer 201 are proximal to the

5 elements 101, eliminating the need for complex interconnects, cabling, and the attendant signal distortions and power losses of long electrical connections .

Moreover, microbeamforming may be specifically matched
10 with the type of array of transducer elements 101, since the microbeamforming is physically combined with the elements 101. Moreover, because of the matching of the microbeamformer 201 to the particular type of sensor array different versions of the microbeamformer 201 can be
15 optimized for different sensor classes (e.g., sector, linear, CLA) and for different frequencies/impedances. Thus, rather than a generic microbeamformer that is configured to work acceptably with each of a number of transducer types, the present teachings allow for an
20 improved if not optimal match of microbeamformer to the type of transducer array of each individual transducer 102.

Illustratively, the microbeamformer 201 may be matched in dimensions to the layout of the acoustic elements of sensor array 101 and then may be mounted directly to the
25 sensor itself, saving space, simplifying the interconnection scheme between the microbeamformer 201 and the sensor, and reducing electrical noise and signal loss by minimizing signal trace lengths.

In addition, the microbeamformer 201 may be optimized
30 to respond to the resonant frequency range of the acoustic sensor elements and to apply beamforming delays that match said frequency range with sufficient resolution for high quality imaging, but not so much resolution as to waste circuit components. Similarly, the microbeamformer

5 circuitry may be optimized to match the characteristic impedance of the sensor elements 101.

As described above, the transducer 102 is connected to the module 103 via an interface 202; and the interface 202 comprises both a mechanical connection and an electrical connection. The mechanical connection enables attaching and detaching of the transducer 102 to the module 103 as described above. The electrical connection provides power to the transducer 102, in particular to its integrated microbeamformer; and signals from the microbeamformer 201 to the module 103 for further processing. The electrical mechanical connection can be made using a standard USB type latching connector or a custom mechanical latch type, snap fit, or magnetic type connection, such as described in co-pending US Patent Application Serial No. 60/941,427
10 entitled Wireless Ultrasound Probe Cable and filed on June 1, 2007. The disclosure of this application is specifically incorporated herein by reference.

The module 103 comprises a scan controller 203 and a main beamformer 204, such as described in U.S. Patent
25 6,436,048 or in U.S. Patent 7,037,264 for example. The module 103 may also comprise DSP circuitry 205 for the signal detection path in multiple modes (e.g., Greyscale, Flow, PW, CW) . In addition, the module 103 comprises a power supply 206 for powering the module 103, the
30 transducer 102 and the display component 104. It also comprises a memory 207 for storing acquired images user presets scan control and beamforming coefficients user programs .

5 The power supply 206 may be an AC/DC converter
operative to provide a desired DC voltage. Alternatively,
the power supply 206 may be a known type of battery. The
implementation of the latter provides certain benefits over
known devices. First, because no cable is needed for
10 power, the assembly 100 may be readily implemented
according to a wireless protocol providing ease of
portability and use. Moreover, a battery, which can be
rechargeable, can be recharged simultaneously with data
transfer over the same (wired) connection 105. For
15 example, a USB connection may be used to realize both data
and power for recharging.

The use of a battery also accords the benefit of
powering the display 104 in a local manner. Thus, the
display 104 does not require a remote power supply, and may
20 have its own battery. As such, the display 104 can be
compact and light. By contrast, a separate monitor or
external display such as on a personal digital assistant
(PDA) will require a power source and central processing
unit (CPU), which add to the complexity of the system and
25 reduce the ergonomic benefits derived from the self-
contained assembly 100.

Furthermore, the rendering and formatting of images
may be effected in the module 103, thus minimizing the need
for processing at the display 104. This reduces not only
30 the size and weight of the system, but also the cost of the
display 104. The display 104 is easily connected or
disconnected to the module 103 thus allowing for
flexibility in positioning for the user. Due to the few
electrical signals required, the mechanical - electrical

5 connection can be made to be simple since the alignment and tolerance of the electrical tabs easily achievable. The electrical tabs of the module (described above) can mate to the electrical tabs of the display 104, such as by a magnetic connection, a friction fit or some other type of
10 latching connection. This mechanical connection can allow for rotation and tilting of the display.

Fig. 3 is a simplified block diagram of a system 300 for ultrasound imaging in accordance with a representative embodiment. The system 300 comprises the assembly 100 and
15 a system monitor 301 connected by connection 105 as shown. The system 300 includes many common features and details to those described in connection with the representative embodiments of Figs. 1 and 2.

The system monitor 301 may be a stand-alone monitor
20 used by the medical practitioner using the assembly 100 and may be in lieu of or in addition to the display 104. Alternatively, the system monitor 300 may be a central unit (e.g., a server) of a medical facility that provides access to the images from the assembly in real-time or via memory.
25 Again, the link between the assembly 100 and the monitor 301 may be wired or wireless, as may the link from the monitor to other devices of a network connected thereto.

In view of this disclosure it is noted that the various ultrasound assemblies and systems ultrasound
30 imaging may comprise a variety of devices, components, software, hardware and firmware. Moreover, applications other than medical imaging may benefit from the present teachings. Further, the various devices, components, software, hardware, firmware and parameters are included by

5 way of example only and not in any limiting sense. In view
of this disclosure, those skilled in the art can implement
the present teachings in determining their own applications
and needed devices, components, software, hardware and
firmware to implement these applications, while remaining
10 within the scope of the appended claims.

5 Claims :

1. An ultrasound assembly, comprising:

a module having an input side and an output side;

10 a ultrasound transducer comprising a micro-beamformer configured for attachment and detachment from the input side of the module; and

a display attached to the output side of the module.

2. An ultrasound assembly as claimed in claim 1, wherein

15 the ultrasound transducer comprises a linear transducer array and the module is configured to receive input signals from the linear transducer array and to provide output signals to the display.

20 3. An ultrasound assembly as claimed in claim 1, wherein

the ultrasound transducer comprises a phased array transducer array and the module is configured to receive input signals from the phased array transducer array and to provide output signals to the display.

25 4. An ultrasound assembly as claimed in claim 1, wherein

the ultrasound transducer comprises a curved transducer array and the module is configured to receive input signals from the curved transducer array and to provide output
30 signals to the display.

5. An ultrasound assembly as claimed in claim 1, wherein

the module comprises a microcontroller and a memory and the

5 microcontroller is configured to acquire a transducer
parameter from the memory.

6. An ultrasound assembly as claimed in claim 5, wherein
the microcontroller is configured to receive data from the
10 transducer array after acquiring the transducer parameter.

7. An ultrasound assembly as claimed in claim 5, wherein
the microcontroller is configured to optimize calculating
configuration and scanning coefficients of the ultrasound
15 transducer.

8. An ultrasound assembly as claimed in claim 1, wherein
the display is disposed over the module.

20 9. An ultrasound assembly as claimed in claim 1, wherein
the module and the transducer are configured to
mechanically attach and detach from one another.

10. An ultrasound assembly as claimed in claim 1, wherein
25 the display is electrically connected to the assembly in a
wired manner.

11. An ultrasound assembly as claimed in claim 1, wherein
the module and the display are configured to magnetically
30 attach and detach from one another.

12. An ultrasound assembly as claimed in claim 1, wherein
the display is electrically connected to the assembly in a

5 wireless manner.

13. A system for ultrasound imaging, comprising:

an ultrasound assembly, comprising: a module having an
input side and an output side; an ultrasound transducer
10 comprising a micro-beamformer configured for attachment and
detachment from the input side of the module; and a display
attached to the output side of the module.

14. A system as claimed in claim 13, wherein the
15 ultrasound transducer comprises a linear transducer array
and the module is configured to receive input signals from
the linear transducer array and to provide output signals
to the display.

20 15. A system as claimed in claim 13, wherein the
ultrasound transducer comprises a phased array transducer
array and the module is configured to receive input signals
from the phased array transducer array and to provide
output signals to the display.

25 16. A system as claimed in claim 13, wherein the
ultrasound transducer comprises a curved transducer array
and the module is configured to receive input signals from
the curved transducer array and to provide output signals
30 to the display.

17. A system as claimed in claim 13, wherein the
ultrasound transducer comprises a memory and the module

5 comprises a microcontroller configured to acquire a
transducer parameter from the memory.

18. A system as claimed in claim 17, wherein the
microcontroller is configured to receive data from the
10 transducer array after acquiring the transducer parameter..

19. A system as claimed in claim 13, wherein the
microcontroller is configured to optimize calculating
configuration and scanning coefficients of the ultrasound
15 transducer.

20. A system as claimed in claim 13, wherein the display
is disposed over the module.

20 21. A system as claimed in claim 13, wherein the module
and the transducer are configured to mechanically attach
and detach from one another.

23. A system as claimed in claim 13, wherein the
25 mechanical attachment is by friction-fit.

23. A system as claimed in claim 13, further comprising
another display remote to the ultrasound assembly.

1/2

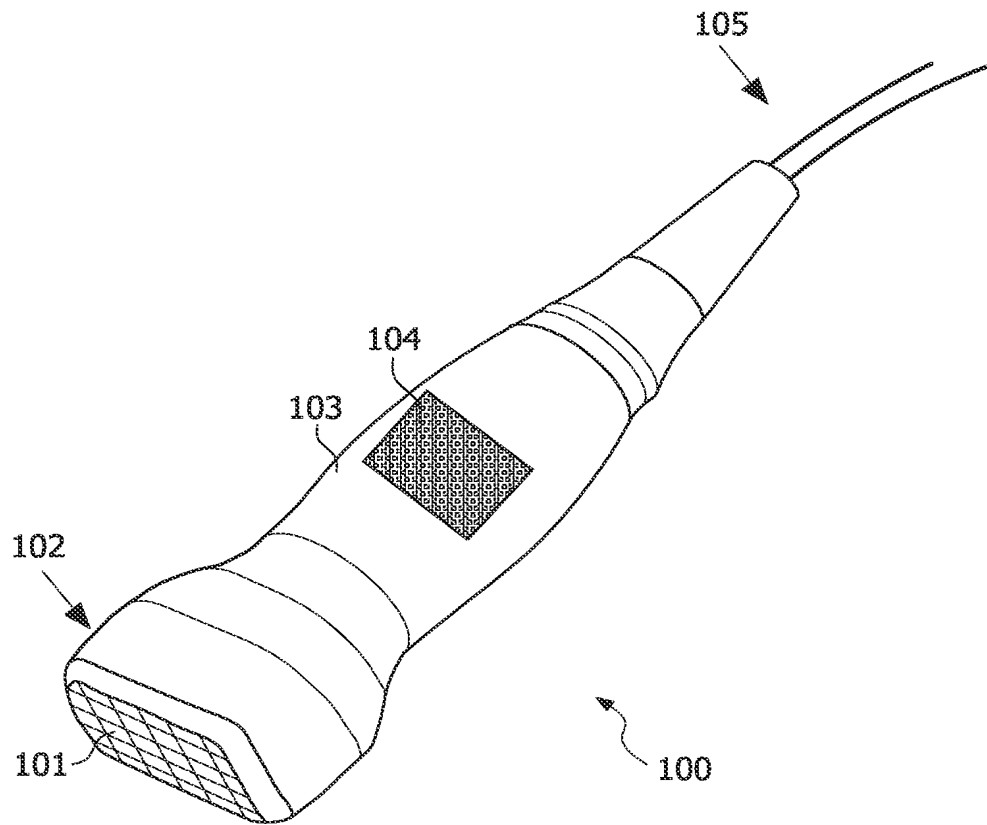


FIG. 1

2/2

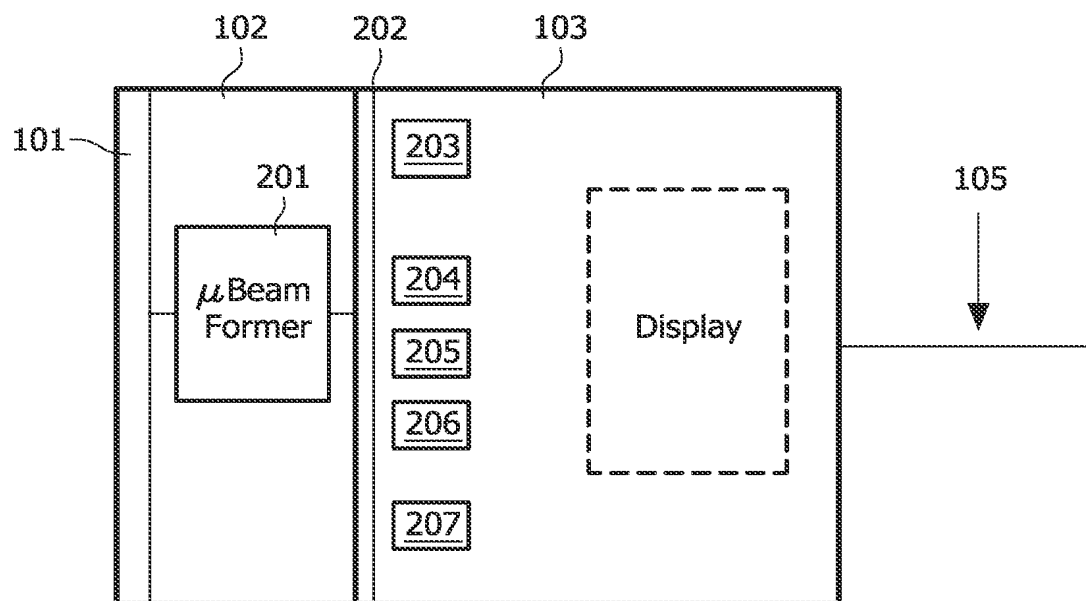


FIG. 2

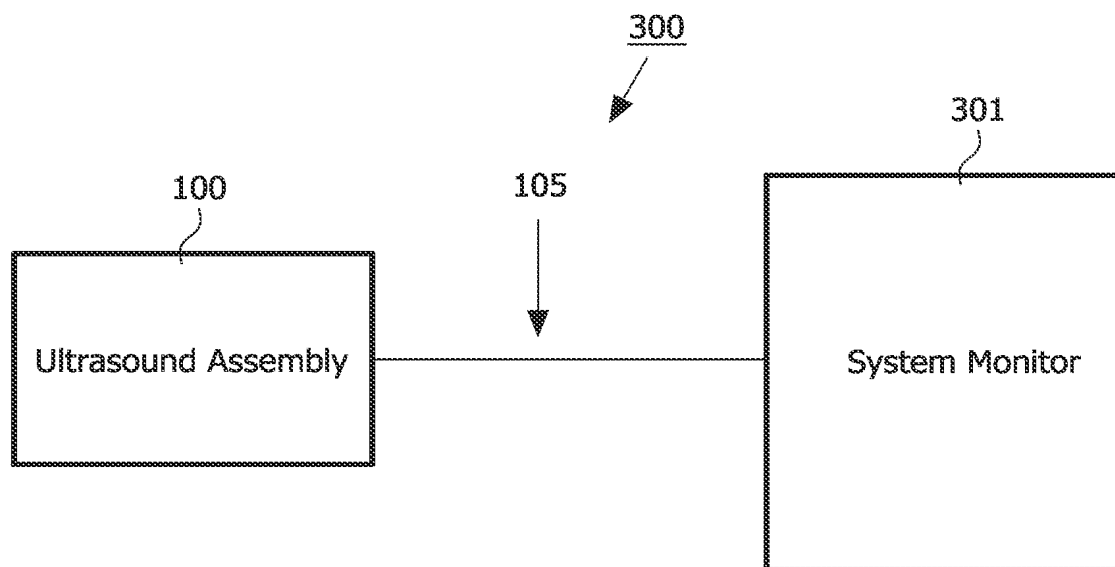


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2009/054999

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G01S7/521 G01S15/89

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)
 GOIS

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
X	US 2003/139664 A1 (HUNT ROBERT P [US] ET AL) 24 July 2003 (2003-07-24) figures 1,2A,3-5 paragraphs [0021], [0024], [0025] paragraphs [0030], [0031], [0035] paragraphs [0047], [0049] -----	1-23
X	US 2003/036702 A1 (DAVIDSEN RICHARD EDWARD [US]) 20 February 2003 (2003-02-20) abstract; figures 2,3 paragraphs [0023] - [0028] paragraphs [0030], [0034] ----- -/-	1-7, 9-19, 21-23



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 document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

9 February 2010

Date of mailing of the international search report

16/02/2010

Name and mailing address of the ISA/

European Patent Office, P B 5818 Patentlaan 2
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Authorized officer

Knoll, Bernhard

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/054999

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	<p>WO 01/13796 A1 (NOVASONICS INC [US]) 1 March 2001 (2001-03-01) figures 1,2,4,7,8 page 5, line 26 - line 30 line 3 - page 7, line 16 page 7, line 32 - page 8, line 6 page 10, line 19 - line 30 page 13, line 11 - line 23 page 14, line 27 - line 34 page 20, line 7 - page 21, line 23 -----</p>	1-23
A	<p>US 2007/262216 A1 (WANG DAVID [US]) 15 November 2007 (2007-11-15) the whole document -----</p>	11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2009/054999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003139664	A1	24-07-2003	NONE
US 2003036702	A1	20-02-2003	NONE
WO 0113796	A1	01-03-2001	AU 6910300 A 19-03-2001
		BR 0013436 A 30-04-2002	
		CA 2382227 A1 01-03-2001	
		CN 1376040 A 23-10-2002	
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		US 6251073 B1 26-06-2001	
		US 2002038088 A1 28-03-2002	
US 2007262216	A1	15-11-2007	NONE



(11) **EP 2 200 332 A1**

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(54) **Autostereoscopic display**

(57) An autostereoscopic display (1), in particular an autostereoscopic head-up display, is disclosed, comprising a pane (2), which is partly reflective and partly transmissive and a light source (3) for generation of an image consisting of a plurality of pixels (5,5a,5b), wherein for

each pixel (5,5a,5b) a left/right light beam (6a,6b) is guided from the light source (3) to the left/right eye of the viewer via the pane (2). According to the invention, said guiding of the light beams (6a,6b) to the eyes is achieved only by pure reflection at said pane (2) (ie. there is no diffraction).

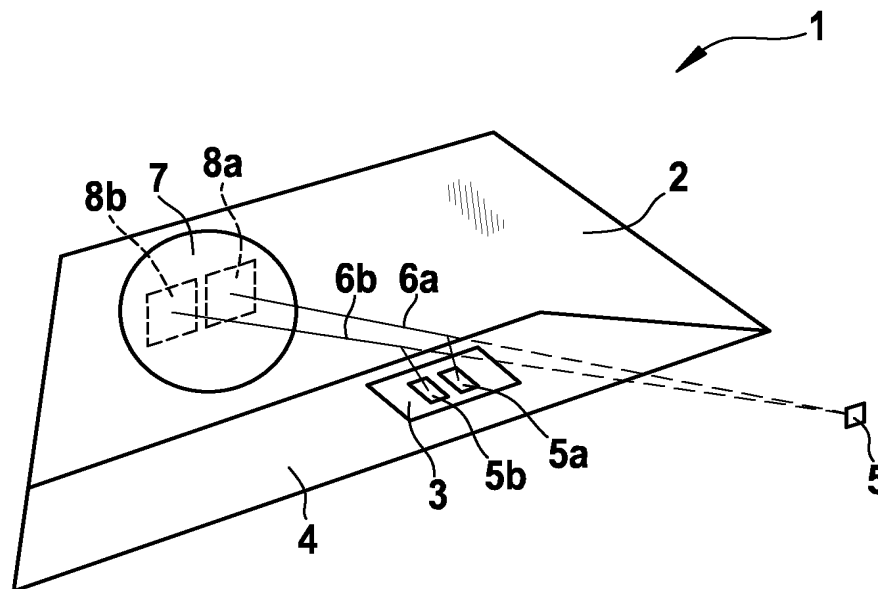


Fig. 1

EP 2 200 332 A1

Description

Technical Field

[0001] The invention relates to an autostereoscopic display. A autostereoscopic display is a device for displaying three-dimensional pictures without the need of additional equipment for the viewer, i.e. 3D-glasses such as anaglyphs, LCD-shutter glasses (LCD = Liquid Crystal Display), polarized glasses or prismatic glasses for example. In particular, the invention relates to head-up displays (HUD). A head-up display is any transparent display that presents data without requiring the user to look away from his or her usual viewpoint. Although they were initially developed for military aviation, HUDs are now used in commercial aircraft, automobiles, and other applications as well.

Prior Art

[0002] DE 101 35 342 C1 discloses a projection device having a projection unit and a relatively spaced projection surface, e.g. incorporated in the automobile dashboard, onto which an image is projected using a light beam for each image point. The projection surface has a beam widening device in front of a mirror reflecting the incident light beams to provide reflected beams converging in a planar viewing field in front of the automobile driver.

[0003] DE 101 31 720 A1 discloses a head-up display system for presentation of an object outside the vehicle to a person in the vehicle, comprising means for determination of the position of vehicle occupants and means for location corrected display of the object relative to the position.

[0004] Furthermore, US 5,198,895 A discloses a head-up display used in a cockpit with a space for the pilot having two subspaces where the pilot's eyes will be located during flight. The head-up display includes a video display device for emitting light representative of a pre-determined image, located in the cockpit and a second video display for emitting light representative of the pre-determined image located in the cockpit. An angularly selective holographic optic element diffraction grating is provided for reflecting light emitted from the first video display into the first subspace, but not into the second subspace. Light emitted from second video display device is reflected into the second subspace but not into the first subspace.

[0005] In addition, US 5,973,727 A discloses a refractive index modulator consisting of a liquid crystal layer, which is arranged near a glass plate so that the liquid crystal molecules are arranged to have a refractive index that is either less than or greater than that of the glass plate to produce either a total internal reflection of a beam at the glass plate or to transmit a light beam through the glass plate.

[0006] Furthermore, US 2004/0239835 A1 discloses a three-dimension display apparatus which includes a

liquid crystal display, a first polarizer on the rear surface of the liquid crystal display, a second polarizer on the front surface of the liquid crystal display, a liquid crystal polymer being on the second polarizer and including a chiral dopant and liquid crystal molecules. The liquid crystal polymer is divided into first regions through which incident light is not polarized and second regions through which the incident light is polarized at 90 degrees. A third polarizer on the liquid crystal polymer selectively transmits the incident light from the liquid crystal polymer.

[0007] Finally, EP 1 739 978 A2 discloses a three dimensional display device including an image display unit, which unit includes pixels having first sub-pixels corresponding to a left-eye image and second sub-pixels corresponding to a right-eye image. The three dimensional display device also includes a parallax barrier which is located proximately to the image display unit. The parallax barrier includes light interception portions and light transmission portions alternately and repeatedly arranged in a direction and also color filters arranged between the light interception portions and the light transmission portions, wherein the color filters control paths of lights from the pixels.

Object of the Invention

[0008] It is an object of the invention to provide an autostereoscopic display which is less complex and can be implemented with less technical effort. In particular, the object of the invention is to provide a head-up display which allows for a spatial impression.

Summary of the Invention

[0009] The object of the invention is achieved by a display according to claim 1, that is an autostereoscopic display, comprising

- a pane which is partly reflective and partly transmissive and
- a light source for generation of an image consisting of a plurality of pixels, wherein for each pixel a left/right light beam is guided from the light source to the left/right eye of the viewer via said pane,
- wherein said guiding of the light beams to the eyes is achieved only by pure reflection at said pane.

[0010] Advantageously, the guiding of the light beams at the pane (particularly a windscreen) is achieved only by pure reflection. That does not mean that there may be no transmissive part, that is to say parts of the light beams which cross the pane and do not reach the viewer's eyes. It means that the part, which reaches the viewer, is just reflected at the pane and not diffracted as it is the case in some prior art solutions, which use a diffraction grating in the windscreen.

[0011] A diffraction grating is an optical component with a regular pattern, which splits (diffracts) light into

several beams travelling in different directions. The directions of these beams depend on the spacing of the grating and the wavelength of the light so that the grating acts as a dispersive element.

[0012] As one can imagine, the use of such a grating, especially in a relatively large pane such as a windscreen which in addition often have complex shapes, requires complex machinery to produce the same. By contrast, the inventive display does not need additional diffractive means in the pane. Accordingly, such a display can be produced with less technical effort.

[0013] It is beneficial if the light beams are reflected at a surface being inclined in relation to the pane. For example, this embodiment can be used for cars, in which a light source is installed on the roof of the car which emits light beams to the viewer's eyes via the surface and the pane. Mounting the light source on the roof requires less space in the region of the dashboard of a car. Just the space for a reflecting surface, basically a small mirror, is needed there.

[0014] It is advantageous if the light source is designed as one out of the group: LED-display (Light Emitting Diode), LCD-display (Liquid Crystal Display) or OLED-display (Organic Light Emitting Diode). Such displays are easy available, reliable and low priced. They can be used for generation of pictures by definition. To provide a spatial impression of the picture, parallax barriers, which are known per se, have to be provided. Examples are micro lenses and transmissive slits separated by opaque barrier regions.

[0015] In an advantageous embodiment of the invention, the light source is designed as a single laser light source for both light beams. Lasers are suitable means for generating pictures as known from laser shows for example. In this embodiment, both eyes have to share one light source. This is cost saving but may lead to limitations in brightness of the image and the frame rate. The latter is particularly important for animated pictures or videos.

[0016] It is also advantageous if the light source is designed as one laser light source for each light beam. Here the left channel and the right channel are drawn by a left and a right laser. Using two lasers is more expensive but provides for brighter images and an increased frame rate. The latter is important for the generation of less 'nervous' pictures or videos.

[0017] In a further advantageous embodiment, the pixels are generated by modulation of a movable laser beam. Often so-called 'scanners' are used for the generation of laser based pictures. Scanners comprise two galvanometers, i.e. two mirrors perpendicular to each other and electromagnetically actuated. The first mirror deflects the laser beam in horizontal direction, and the second mirror deflects it in vertical direction. By blanking and mixing colors in combination with said deflection, single pixels on a surface can be illuminated in a desired color and a desired brightness. If just one laser or scanner is used, it generates the pictures for the left and the right

eye semi-parallel, wherein the projection of the image may be achieved interlaced, i.e. drawing the odd lines for the left eye and the even lines for the right eye and then vice versa, or picture by picture, i.e. drawing the complete picture for the left and the right eye in an alternating manner. If two lasers or scanners are used, the images are generated fully parallel. Using two lasers provides for an increased frame rate and thus for generation of less 'nervous' pictures.

[0018] In yet another preferred embodiment of the invention, the pixels are generated by modulation of a reflection of a laser beam. Here a laser beam, which may also stand still, is modulated by a reflective surface comprising pixels, whose reflective factor can be influenced. An example are very small mirrors, each representing one pixel and being electrically actuated, which can deflect the assigned part of the light beam past the viewer's eye so that the pixels appears dark. This provides just for black and white images but also more sophisticated modulations are imaginable.

[0019] It is beneficial if the reflection modulation is done at the pane. In this embodiment, the reflection modulator is attached to or part of the pane. Here, the light source may directly shine on the pane respectively windscreen, but one has to take care that said means (e.g. usually thin foils) do not influence the viewers perception of the world outside the car.

[0020] Furthermore, it is advantageous if the reflection modulation is done at said inclined surface. Here the problem of influencing the viewers perception (even when the display is switched off) is circumvented as the reflection modulator is attached to or built into said surface. Usually, the reflection modulator is mounted on a car's dashboard in this embodiment.

[0021] Furthermore, it is advantageous if a LCD-matrix is provided as reflection modulator. Such matrices are easy available, reliable and low priced. Basically, an LCD-matrix is a LCD-display without backlight. By contrast, the light for illuminating the pixels is generated in front of the matrix and a mirror is arranged behind the matrix. By darkening a LCD-pixel as known per se, light is no longer reflected. By means of an LCD-matrix also grayscale images can be generated quite easily. In the case of laser light being used, dedicated parallax barriers may be omitted as the laser beams for the left and the right channel can be guided to the viewer's eyes with high precession. However, one has to take care that the laser beam is widened a bit so that not a singular light point reaches the viewer's eyes but a beam having the size of, let us say the size of spectacles glass. In this sense, virtual glasses may be provided.

[0022] Finally, the display comprises means for detecting a position of the viewer, means for determining a desired position for the left/right light beam according to said position of the viewer and, means for adapting the left/right light beam to said desired position in a preferred embodiment. It may happen that the driver considerably moves his head in the line of sight and/or in a plane per-

pendicular to said line of sight during driving a car. Another reason for changing eye-positions are different users using the car. If the eyes of the viewer move out of the associated projecting areas, then the projecting areas are adapted to the current eye-position of the user in this embodiment. In this way, the viewer can see the projected image in any position and keeps on his 'virtual glasses' in this sense.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described and shown in the schematic Figures hereinafter.

Brief Description of the Drawings

[0023]

Figure 1 shows a first embodiment of the invention with an active display on a surface on a car's dashboard;

Figure 2 shows a second embodiment with a laser scanner projecting the image directly via the windscreen of a car;

Figure 3 shows a third embodiment with a laser scanner projecting an image via a surface on a car's dashboard;

Figure 4 shows a fourth embodiment with a reflection modulator in the windscreen of a car.

Description of Embodiments

[0024] In the Figs. the same elements and elements with the same function are referenced with the same reference sign if not stated otherwise.

[0025] Fig. 1 depicts a first embodiment of the invention and shows an autostereoscopic display 1, comprising a pane 2, which is a windscreen of a car in this case, a light source 3 being arranged on a surface 4, which surface 4 is inclined in relation to the pane 2. For the sake of brevity just one pixel 5 of the light source 3 is shown, which pixel 5 consists of a left pixel 5a and a right pixel 5b. In addition, a left and a right light beam 6a and 6b is shown being emitted by the pixels 5a and 5b. Finally, Fig. 1 shows a driver's head 7.

[0026] The function of the display 1 as shown in Fig. 1 is as follows:

[0027] The left pixel 5a and the right pixel 5b are illuminated with a particular color and a particular brightness as the image to be projected requires. Thus, a left and a right light beam 6a and 6b are emitted, reflected at the pane 2 and finally reach the driver's head 7. The driver receives the left pixel 5a with the left eye and the right pixel 5b with right eye and thus gets the impression of a pixel 5 hovering in front of or behind the pane 2. As can be seen, the angle of radiation for the beams 6a and 6b are chosen in such a way that the left and the right pixel 5a and 5b are visible in a particular left and right projecting areas 8a and 8b. Thus, small movements of the driver's

head do not influence his spatial impression of the image. However, if he moves out of the target area, the spatial impression of the image is lost. This behavior of the light beams 6a and 6b can be seen as a provision of 'virtual glasses'.

[0028] The light source 3 may be an (active, meaning back lighted) LCD-display, a LED display or an OLED display. The way how pixels are activated is known per se for these devices and not explained any further. Said displays, however, need parallax barriers, which are known per se. Examples are micro lenses and transmissive slits separated by opaque barrier regions

[0029] Fig. 2 is quite similar to Fig. 1, the only difference is that the light source 3 is designed as a laser scanner. In this embodiment one single laser is used for the image generation, however, also two lasers can be used as the case may be. Furthermore, it is assumed that the images for the left and the right eye are sequentially generated, that means one by one. First, the laser generates the left light beam 6a and draws the image pixel by pixel and line by line quite similar as the cathode ray tubes do. After the left image has been completed, the laser generates the right light beam 6b and draws the right image in a similar way. Usually, 25 frames per second are chosen to project flowing pictures. Accordingly, the single laser should be capable of providing 50 frames per second so that flowing pictures for both the left and the right eye can be generated. If the contents of the pictures does not change very fast, also considerably lower frame rates may be applicable. An example is the speedometer which owing to the physics of a car cannot change very fast. As a laser beam can be guided or directed very precisely and as such may act as a parallax barrier, a further parallax barrier is not required. However, as laser light is so directional, means for widening the beams 6a and 6b a bit should be provided so that the pixels 5a and 5b are not just visible in a singular position of the driver's head but in a particular projecting area 8a and 8b as has been explained for the embodiment of Fig. 1 already. Additionally, a variable step width for the vertical scanning lines can compensate the double image introduced by a windscreen. According to prior art, a windscreen with 'wedged PVB' (Polyvinylbutyral) is used for this reason, which is a special windscreen providing for ghost-free automotive head-up displays. However, by employing variable step widths for the scanning lines also a 'normal' windscreen can be used.

[0030] Fig. 3 shows a modification of the embodiment shown in Fig. 2. Here the light source 3, again a laser scanner, is arranged on the roof of the car and emits the light beams 6a and 6b downwards to a reflecting surface 4 arranged inclined to the pane 1. However, the principle is the same as the one of Fig. 2. There is just another reflecting plane. The reflecting surface 4 may be a simple mirror in this embodiment, why the pixels 5a and 5b have a rather symbolical meaning. This variant of the invention is advantageous if there is just limited space on the dashboard.

[0031] A next embodiment is a variation of the embodiments shown in the Figs. 1 and 3. Here again, a light source 3 is arranged on the roof of the car, but is a fixed laser source in this case. In addition, the surface 4 comprises a reflection modulator, e.g. a LCD-matrix which is arranged right above the reflective surface 4. In this example, a left and a right light beam 6a and 6b are emitted by two lasers and reach two separated areas on the reflecting surface 4. As known per se, the LCD-matrix provides for darkening dedicated pixels and thus for the generation of grayscale images. By contrast to the last examples, the pixels 5a and 5b are 'real' here. The light beams 6a and 6b, which are already modulated now, propagate to the pane 2 and are deflected to the viewer's eyes there as has already been explained hereinbefore. Alternatively, a single laser beam can be emitted by the light source 3 which is then separated in a left and a right light beam 6a and 6b at the reflective surface 4.

[0032] In a fourth embodiment as shown in Fig. 4, the reflection modulator, e.g. a LCD-matrix again, is arranged on or in the pane 2. In principle, this arrangement would also work without external light- provided the LCD-matrix comprises a parallax barrier - but to provide proper function also in twilight or during night, the matrix is again illuminated as has been explained hereinbefore. The light source 3, which may be a fixed laser again, can be arranged on the roof if there is a reflective surface 4 (e.g. a mirror) on the dashboard or directly on the dashboard. In case of illuminating the LCD matrix with a laser, a parallax barrier may be omitted, but if the LCD-matrix is illuminated by 'normal' light, it has to be provided with a parallax barrier.

[0033] As one can imagine, the 'virtual glasses', i.e. the projecting areas 8a and 8b, have to move with the driver's head 7. Otherwise it can happen that the left eye receives the image for the right eye whereas the right eye receives no image at all and vice versa. In a worst case the driver's head 7 completely moves out of the reception area, in other words the projecting areas 8a and 8b and his eyes do not coincide. Accordingly, means for detecting the position of the driver's head or his eyes are provided in a preferred embodiment. Several possibilities are imaginable. First of all, the position detection may be achieved by visual detection, i.e. by means of a camera, which can operate in the visible light spectrum or in the infrared spectrum. Here the algorithms for 'face detection', which have been incorporated in recent digital consumer cameras, can be used. Another possibility is to use a number of weight sensors in the driver's seat so as to detect the position of the center of gravity of his body. As the driver normally seats upright or slightly inclined, the position of the eyes can easily be determined. In this context it should also be mentioned, that the projecting areas 8a and 8b are not necessarily square-shaped but may also be in the form of narrow upright rectangles so that it does not matter if the driver moves his head in vertical direction. Finally, distance sensors may be used, e.g. ultrasonic distance sensors, passive

infrared sensors and so on. As these sensors are known per se, they are not explained in detail here.

[0034] Detecting the position of the driver's head 7 or his eyes is one part of the story. Advantageously, the inventive autostereoscopic display 1 comprises also means to shift the 'virtual glasses', i.e. the projecting areas 8a and 8b according to the detected position. If narrow, sufficiently high and upright rectangular projecting areas 8a and 8b are provided, a shift in the horizontal direction may be sufficient to follow the driver's eyes. If the vertical dimension is limited, i.e. does not cover the full vertical range of the eye's positions, then also a vertical shift of the projecting areas 8a and 8b may be employed. In case of a laser scanner, shifting of the projecting areas 8a and 8b is relatively simple as the image in principle can be projected at any desired position. In case of an active pixel matrix or a reflection modulator is used, things are more complicated.

[0035] If a reflection modulator in combination with a laser beam is employed, both the beam and the position on the modulator, where the image is generated, have to move. If an active pixel matrix is used, the position of the image generation has to move as well. Alternatively or in addition, a parallax barrier may move so that the position, from where the right and the left image can be viewed, varies. If the parallax barrier is formed by device, which allows for easy change of a 'picture', such as a LCD-matrix, the parallax barrier can easily be adapted to the detected position of the driver's head 7. In case of just a horizontal shift is needed, vertical stripes, whose transmission rate can individually be controlled, are proper means to adapt the projecting areas 8a and 8b to the actual eye-position. However, besides electronic shifting of the parallax barrier also mechanical shifting is imaginable. Here a predetermined structure, i.e. a sequence of transmissive parts and non-transmissive parts, is moved by a motor, usually a linear motor. The movement may be based on electromagnetic or piezoelectric effects for example.

[0036] So far, just movements of the driver's head 7 in a plane more or less perpendicular to the line of sight have been discussed. However, though it is less frequent, the head 7 may also move in direction of the line of sight and thus reduce or increase the distance between the eyes and the imaging device. Hand in hand with this movement the angle between the light beams generating the projecting areas 8a and 8b has to be adapted. If the distance is increased, the angle is decreased and vice versa. In case of a laser beam is used, the direction of the beam can be varied as discussed above. If systems are used, which need a dedicated parallax barrier, the parallax barrier has to be varied according to the distance between imaging system and driver.

[0037] It should be noted that all steps which are taken to detect the position of the driver's head 7 and to move the projecting areas 8a and 8b to said detected position may be performed once, on demand, or ongoing for example. Quite often, cars are used by just one user, who

rarely changes his position once he has found a comfortable position. In this case, it may be sufficient to run the adaptation sequence just initially, when the car is used first or on demand if, for example, a dedicated function is chosen. On the other hand, there are cars, whose users change very often, for example rental cars. In this case or if the driver is rather nervous and changes its position very often also during driving the car, a continuous adaptation of the projecting areas 8a and 8b might be useful.

[0038] It should also be noted that, cars and their drivers are subject to strongly varying light conditions, like night, bright sunlight and also front lights of opposing traffic. Without further measures the projected image can get badly visible or even invisible. Accordingly, measures are taken in a preferred embodiment to reduce or even avoid the influence of disturbing light sources and in particular stray light from these light sources. Proper means range from simple covers and black, matt coatings to block light from undesired directions over semi-reflective layers to electrochromic layers and light diffusers.

[0039] Said semi-reflective layers can increase the fraction of the light beams 6a and 6b, which is reflected, and at the same time increase the fraction of reflected light coming from outside the car. In this way the influence of disturbing light sources can substantially be decreased. Such layers can, for example, be arranged in the region, where the light beams 6a and 6b are reflected on the pane 2. A further possibility to reduce the influence of external light is to arrange electrochromic layers in said region. If disturbing light sources, e.g. blinding lights from opposing traffic, shine through said region, the layer is darkened by applying a voltage as it is known per se. In this way, the fraction of light which gets into the car can be dramatically decreased. It is understood that also the driver cannot look outside the pane in this region. However, it is better to keep, for example, a speedometer visible than blinding lights. In a preferred embodiment, the darkening effect gradually disappears in the border region so that no ugly, dark rectangular is produced on the pane 2. Yet another possibility is to arrange diffusers in the region where the light beams 6a and 6b are reflected on the pane 2. In this way, in particular the influence of dot-shaped light sources, e.g. again blinding lights, is decreased as they are 'blurred' over a particular region. It should be understood, that only a small number of possibilities for reducing the influence of disturbing light sources can be presented here. However, one skilled in the art will easily choose the best solution or combination of solutions out of the possibilities presented here and other possibilities, which are known per se, when he implements an inventive autostereoscopic display 1.

[0040] Furthermore, it should be noted that the invention does not apply to head-up displays for cars only. It also applies to head-up displays for vehicles in general and also to autostereoscopic displays in general, meaning also to stationary devices.

[0041] Finally, it should be noted that the above-mentioned embodiments illustrate rather than limit the inven-

tion, and that those skilled in the art will be capable of designing many alternative embodiments without departing from the scope of the invention as defined by the appended claims. In the claims, any reference signs placed in parentheses shall not be construed as limiting the claims. The verb 'comprise' and its conjugations do not exclude the presence of elements or steps other than those listed in any claim or the specification as a whole. The singular reference of an element does not exclude the plural reference of such elements and vice-versa. In a device claim enumerating several means, several of these means may be embodied by one and the same item of software or hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Claims

1. Autostereoscopic display (1), comprising

- a pane (2) which is partly reflective and partly transmissive and
- a light source (3) for generation of an image consisting of a plurality of pixels (5, 5a, 5b), wherein for each pixel (5, 5a, 5b) a left/right light beam (6a, 6b) is guided from the light source (3) to the left/right eye of the viewer via said pane (2),
- wherein said guiding of the light beams (6a, 6b) to the eyes is achieved only by pure reflection at said pane (2).

2. Display (1) according to claim 1, wherein the light beams (6a, 6b) are reflected at a surface (4) being inclined in relation to the pane (2).

3. Display (1) according to any one of the claims 1 or 2, wherein the light source (3) is designed as one out of the group: LED-display, LCD-display or OLED-display.

4. Display (1) according to any one of the claims 1 or 2, wherein the light source (3) is designed as a single laser light source for both light beams (6a, 6b).

5. Display (1) according to any one of the claims 1 or 2, wherein the light source (3) is designed as one laser light source for each light beam (6a, 6b).

6. Display (1) according to any one of the claims 4 or 5, wherein the pixels (5, 5a, 5b) are generated by modulation of a movable laser beam.

7. Display (1) according to any one of the claims 4 or 5, wherein the pixels (5, 5a, 5b) are generated by modulation of a reflection of a laser beam.

8. Display (1) according to claim 7, wherein the reflection modulation is done at the pane (2).
9. Display (1) according to the claims 2 and 7, wherein the reflection modulation is done at said inclined surface (4). 5
10. Display (1) according to any one of the claims 7 to 9, wherein a LCD-matrix is provided as reflection modulator. 10
11. Display (1) according to any one of the preceding claims, comprising means for detecting a position of the viewer, means for determining a desired position for the left/right light beam (6a, 6b) according to said position of the viewer and, means for adapting the left/right light beam (6a, 6b) to said desired position. 15

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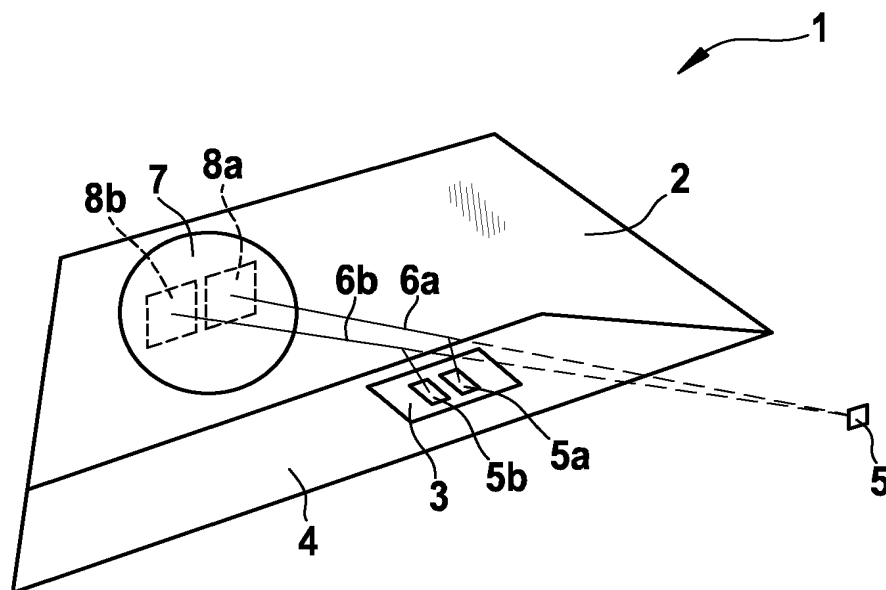


Fig. 1

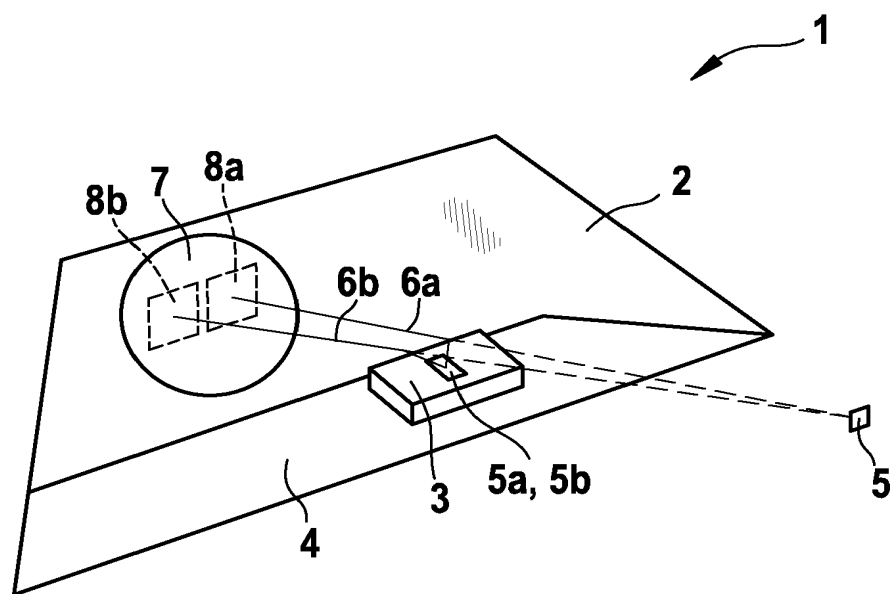


Fig. 2

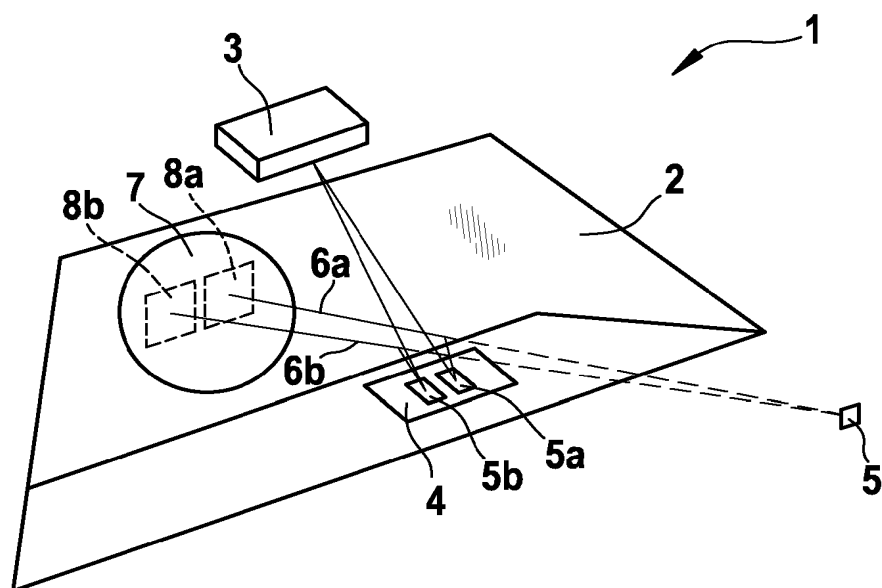


Fig. 3

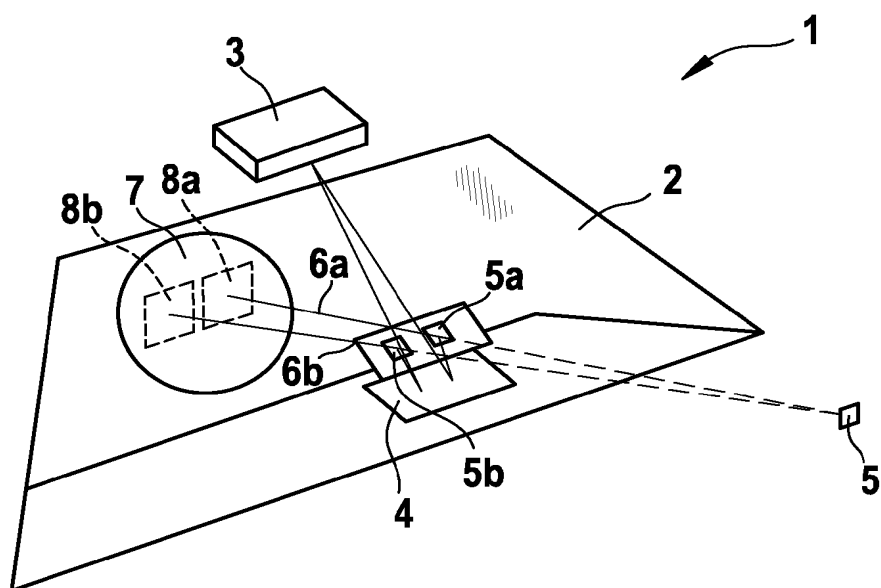


Fig. 4



EUROPEAN SEARCH REPORT

Application Number
EP 08 10 5999

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2005/052617 A1 (FUJIKAWA TAKAYUKI [JP] ET AL) 10 March 2005 (2005-03-10)	1-7,11	INV. H04N13/04
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X	US 2008/143895 A1 (PETERKA THOMAS [US] ET AL) 19 June 2008 (2008-06-19) * abstract * * paragraphs [0007], [0013] * * paragraph [0041]; figure 3 * * paragraphs [0120], [0121], [0124]; figure 12 *	1,3,11	
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 22 April 2009	Examiner Mao, Pauline
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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22-04-2009

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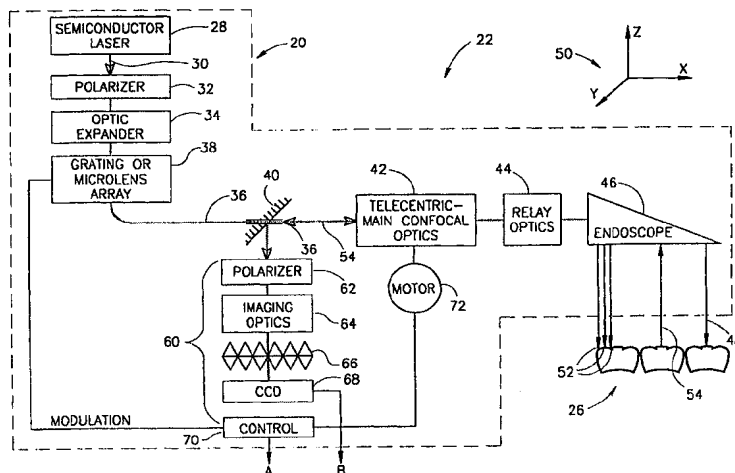
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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			(43) International Publication Date: 17 February 2000 (17.02.00)
(21) International Application Number: PCT/IL99/00431 (22) International Filing Date: 5 August 1999 (05.08.99) (30) Priority Data: 125659 5 August 1998 (05.08.98) IL (71) Applicant (for all designated States except US): CADENT LTD. [IL/IL]; Hamelacha Street 14, 60372 Or Yehuda (IL). (72) Inventors; and (75) Inventors/Applicants (for US only): BABAYOFF, Noam [IL/IL]; Laskov Street 25, 58672 Holon (IL). GLASER-INBARI, Isaia [IL/IL]; Hashnayim Street 24, 53230 Givataim (IL). (74) Agent: REINHOLD COHN AND PARTNERS; P.O. Box 4060, 61040 Tel-Aviv (IL).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: IMAGING A THREE-DIMENSIONAL STRUCTURE BY CONFOCAL FOCUSING AN ARRAY OF LIGHT BEAMS



(57) Abstract

Determining surface topology of a portion (26) of a three-dimensional structure is provided. An array of incident light beams (36) passing through a focusing optics (42) and a probing face is shone on said portion. The focusing optics defines one or more focal planes forward the probing face in a position which can be changed (72) by the focusing optics. The beams generate illuminated spots (52) on the structure and the intensity of returning light rays propagating in an optical path opposite to that of the incident light rays is measured (60) at various positions of the focal plane(s). By determining spot-specific positions yielding a maximum intensity of the returned light beams, data is generated which is representative of said topology. Measurement of teeth. Light beams by grating of matrix of pinholes, micro lens array. Simultaneous imaging from three angles. Quicker with three different light components.

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IMAGING A THREE-DIMENSIONAL STRUCTURE BY CONFOCAL FOCUSING AN ARRAY OF LIGHT BEAMS

FIELD OF THE INVENTION

This invention in the field of imaging techniques and relates to a method and an apparatus for non-contact imaging of three-dimensional structures, particularly useful for direct surveying of teeth.

5 BACKGROUND OF THE INVENTION

A great variety of methods and systems have been developed for direct optical measurement of teeth and the subsequent automatic manufacture of dentures. The term "*direct optical measurement*" signifies surveying of teeth in the oral cavity of a patient. This facilitates the obtainment of digital
10 constructional data necessary for the computer-assisted design (CAD) or computer-assisted manufacture (CAM) of tooth replacements without having to make any cast impressions of the teeth. Such systems typically includes an optical probe coupled to an optical pick-up or receiver such as charge coupled device (CCD) and a processor implementing a suitable image processing
15 technique to design and fabricate virtually the desired product.

One conventional technique of the kind specified is based on a laser-triangulation method for measurement of the distance between the surface of the tooth and the optical distance probe, which is inserted into the

oral cavity of the patient. The main drawback of this technique consists of the following. It is assumed that the surface of the tooth reflects optimally, e.g. Lambert's reflection. Unfortunately, this is not the case in practice and often the data that is obtained is not accurate.

5 Other techniques, which are embodied in CEREC-1 and CEREC-2 systems commercially available from Siemens GmbH or Sirona Dental Systems, utilize the light-section method and phase-shift method, respectively. Both systems employ a specially designed hand-held probe to measure the three-dimensional coordinates of a prepared tooth. However, the methods
10 require a specific coating (i.e. measurement powder and white-pigments suspension, respectively) to be deposited to the tooth. The thickness of the coating layer should meet specific, difficult to control requirements, which leads to inaccuracies in the measurement data.

 By yet another technique, mapping of teeth surface is based on
15 physical scanning of the surface by a probe and by determining the probe's position, e.g. by optical or other remote sensing means, the surface may be imaged.

 U.S. Patent No. 5,372,502 discloses an optical probe for three-dimensional surveying. The operation of the probe is based on the
20 following. Various patterns are projected onto the tooth or teeth to be measured and corresponding plurality of distorted patterns are captured by the probe. Each interaction provides refinement of the topography.

SUMMARY OF THE INVENTION

 The present invention is directed to a method and apparatus for
25 imaging three-dimensional structures. A preferred, non-limiting embodiment, is concerned with the imaging of a three-dimensional topology of a teeth segment, particularly such where one or more teeth are missing. This may allow the generation of data for subsequent use in design and manufacture of,

for example, prosthesis of one or more teeth for incorporation into said teeth segment. Particular examples are the manufacture of crowns or bridges.

The present invention provides, by a first of its aspects, a method for determining surface topology of a portion of a three-dimensional structure,
5 comprising:

- 10 (a) providing an array of incident light beams propagating in an optical path leading through a focusing optics and a probing face; the focusing optics defining one or more focal planes forward said probing face in a position changeable by said optics, each light beam having its focus on one of said one or more focal plane; the beams generating a plurality of illuminated spots on the structure;
- (b) detecting intensity of returned light beams propagating from each of these spots along an optical path opposite to that of the incident light;
- 15 (c) repeating steps (a) and (b) a plurality of times, each time changing position of the focal plane relative to the structure; and
- (d) for each of the illuminated spots, determining a spot-specific position, being the position of the respective focal plane, yielding a maximum measured intensity of a respective returned light beam;
- 20 and
- (e) based on the determined spot-specific positions, generating data representative of the topology of said portion.

By a further of its aspects, the present invention provides an apparatus for determining surface topology of a portion of a
25 three-dimensional structure, comprising:

- a probing member with a sensing face;
- an illumination unit for providing an array of incident light beams transmitted towards the structure along an optical path through said probing unit to generate illuminated spots on said portion;

- a light focusing optics defining one or more focal planes forward said probing face at a position changeable by said optics, each light beam having its focus on one of said one or more focal plane ;
- a translation mechanism coupled to said focusing optics for displacing said focal plane relative to the structure along an axis defined by the propagation of the incident light beams;
- a detector having an array of sensing elements for measuring intensity of each of a plurality of light beams returning from said spots propagating through an optical path opposite to that of the incident light beams;
- a processor coupled to said detector for determining for each light beam a spot-specific position, being the position of the respective focal plane of said one or more focal planes yielding maximum measured intensity of the returned light beam, and based on the determined spot-specific positions, generating data representative of the topology of said portion.

15 The probing member, the illumination unit and the focusing optics and the translation mechanism are preferably included together in one device, typically a hand-held device. The device preferably includes also the detector.

20 The determination of the spot-specific positions in fact amounts to determination of the in-focus distance. The determination of the spot-specific position may be by measuring the intensity *per se*, or typically is performed by measuring the displacement (S) derivative of the intensity (I) curve (dI/dS) and determining the relative position in which this derivative function indicates a maximum maximum intensity. The term "*spot-specific position (SSP)*" will be used to denote the relative in-focus position regardless of the manner in which it is determined. It should be understood that the SSP is always a relative position as the absolute position depends on the position of the sensing face. However the generation of the surface topology does not require knowledge of the absolute position, as all dimensions in the cubic field of view are absolute.

The SSP for each illuminated spot will be different for different spots. The position of each spot in an **X-Y** frame of reference is known and by knowing the relative positions of the focal plane needed in order to obtain maximum intensity (namely by determining the SSP) , the **Z** or depth coordinate can be associated with each spot and thus by knowing the **X-Y-Z** coordinates of each spot the surface topology can be generated.

In accordance with one embodiment, in order to determine the **Z** coordinate (namely the SSP) of each illuminated spot the position of the focal plane is scanned over the entire range of depth or **Z** component possible for the measured surface portion. In accordance with another embodiment the beams have components which each has a different focal plane. Thus, in accordance with this latter embodiment by independent determination of SSP for the different light components, e.g. 2 or 3 with respective corresponding 2 or 3 focal planes, the position of the focal planes may be changed by the focusing optics to scan only part of the possible depth range, with all focal planes together covering the expected depth range. In accordance with yet another embodiment, the determination of the SSP involves a focal plane scan of only part of the potential depth range and for illuminated spots where a maximum illuminated intensity was not reached, the SSP is determined by extrapolation from the measured values or other mathematical signal processing methods.

The method and apparatus of the invention are suitable for determining a surface topology of a wide variety of three-dimensional structures. A preferred implementation of method and apparatus of the invention are in determining surface topology of a teeth section.

In accordance with one embodiment of the invention, the method and apparatus are used to construct an object to be fitted within said structure. In accordance with the above preferred embodiment, such an object is at least one tooth or a portion of a tooth missing in the teeth section. Specific

examples include a crown to be fitted on a tooth stump or a bridge to be fitted within teeth.

By one embodiment of the invention, the plurality of incident light beams are produced by splitting a parent beam. Alternatively, each incident
5 light beam or a group of incident light beams may be emitted by a different light emitter. In accordance with a preferred embodiment, light emitted from a light emitter passes through a diffraction or refraction optics to obtain the array of light beams.

In accordance with one embodiment, the parent light beam is light
10 emitted from a single light emitter. In accordance with another embodiment, the parent light beam is composed of different light components, generated by different light emitters, the different light components differing from one another by at least one detectable parameter. Such a detectable parameter may, for example be wavelength, phase, different duration or pulse pattern, etc.
15 Typically, each of said light components has its focus in a plane differently distanced from the structure than other light components. In such a case, when the focal plane of the optics is changed, simultaneously the different ranges of depth (or **Z** component) will be scanned. Thus, in such a case, for each illuminated spot there will be at least one light component which will yield a
20 maximum intensity, and the focal distance associated with this light component will then define the **Z** component of the specific spot.

In accordance with an embodiment of the invention the incident light beams are polarized. In accordance with this embodiment, typically the apparatus comprises a polarization filter for filtering out, from the returned
25 light beams, light components having the polarization of the incident light, whereby light which is detected is that which has an opposite polarization to that of the incident light.

The data representative of said topology may be used for virtual reconstruction of said surface topology, namely for reconstruction within the

computer environment. The reconstructed topology may be represented on a screen, may be printed, etc., as generally known *per se*. Furthermore, the data representative of said topology may also be used for visual or physical construction of an object to be fitted within said structure. In the case of the
5 preferred embodiment noted above, where said structure is a teeth section with at least one missing tooth or tooth portion, said object is a prosthesis of one or more tooth, e.g. a crown or a bridge.

By determining surface topologies of adjacent portions, at times from two or more different angular locations relative to the structure, and then
10 combining such surface topologies, e.g in a manner known *per se*, a complete three-dimensional representation of the entire structure may be obtained. Data representative of such a representation may, for example, be used for virtual or physical reconstruction of the structure, may be transmitted to another apparatus or system for such reconstruction, e.g. to a CAD/CAM apparatus.
15 Typically, but not exclusively, the apparatus of the invention comprises a communication port for connection to a communication network which may be a computer network, a telephone network, a wireless communication network, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

20 In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figs. 1A and 1B are a schematic illustration by way of a block diagram
25 of an apparatus in accordance with an embodiment of the invention (Fig. 1B is a continuation of Fig. 1A);

Fig. 2A is a top view of a probing member in accordance with an embodiment of the invention;

Fig. 2B is a longitudinal cross-section through line II-II in Fig. 2A, depicting also some exemplary rays passing therethrough;

Fig. 3 is a schematic illustration of another embodiment of a probing member ; and

5 **Fig. 4** is a schematic illustration of an embodiment where the parent light beam, and thus each of the incident light beams, is composed of several light components, each originating from a different light emitter.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

10 Reference is first being made to Figs. 1A and 1B illustrating, by way of a block diagram an apparatus generally designated 20, consisting of an optical device 22 coupled to a processor 24. The embodiment illustrated in Fig. 1 is particularly useful for determining the three-dimensional structure of a teeth segment 26, particularly a teeth segment where at least one tooth or
15 portion of tooth is missing for the purpose of generating data of such a segment for subsequent use in design or manufacture of a prosthesis of the missing at least one tooth or portion, e.g. a crown or a bridge. It should however be noted, that the invention is not limited to this embodiment, and applies, *mutatis mutandis*, also to a variety of other applications of imaging of
20 three-dimensional structure of objects, e.g. for the recordal or archeological objects, for imaging of a three-dimensional structure of any of a variety of biological tissues, etc.

Optical device 22 comprises, in this specific embodiment, a semiconductor laser unit 28 emitting a laser light, as represented by arrow 30.
25 The light passes through a polarizer 32 which gives rise to a certain polarization of the light passing through polarizer 32. The light then enters into an optic expander 34 which improves the numerical aperture of the light beam 30. The light beam 30 then passes through a module 38, which may, for example, be a grating or a micro lens array which splits the parent beam 30

into a plurality of incident light beams **36**, represented here, for ease of illustration, by a single line. The operation principles of module **38** are known *per se* and the art and these principles will thus not be elaborated herein.

The light unit **22** further comprises a partially transparent mirror **40**
5 having a small central aperture. It allows transfer of light from the laser source through the downstream optics, but reflects light travelling in the opposite direction. It should be noted that in principle, rather than a partially transparent mirror other optical components with a similar function may also be used, e.g. a beam splitter. The aperture in the mirror **40** improves the
10 measurement accuracy of the apparatus. As a result of this mirror structure the light beams will yield a light annulus on the illuminated area of the imaged object as long as the area is not in focus; and the annulus will turn into a completely illuminated spot once in focus. This will ensure that a difference between the measured intensity when out-of- and in-focus will be larger.
15 Another advantage of a mirror of this kind, as opposed to a beam splitter, is that in the case of the mirror internal reflections which occur in a beam splitter are avoided, and hence the signal-to-noise ratio improves.

The unit further comprises a confocal optics **42**, typically operating in a telecentric mode, a relay optics **44**, and an endoscopic probing member
20 **46**. Elements **42**, **44** and **46** are generally as known *per se*. It should however be noted that telecentric confocal optics avoids distance-introduced magnification changes and maintains the same magnification of the image over a wide range of distances in the **Z** direction (the **Z** direction being the direction of beam propagation). The relay optics
25 enables to maintain a certain numerical aperture of the beam's propagation.

The endoscopic probing member typically comprises a rigid, light-transmitting medium, which may be a hollow object defining within it a light transmission path or an object made of a light transmitting material, e.g. a glass body or tube. At its end, the endoscopic probe typically

comprises a mirror of the kind ensuring a total internal reflection and which thus directs the incident light beams towards the teeth segment 26. The endoscope 46 thus emits a plurality of incident light beams 48 impinging on to the surface of the teeth section.

5 Incident light beams 48 form an array of light beams arranged in an X-Y plane, in the Cartesian frame 50, propagating along the Z axis. As the surface on which the incident light beams hits is an uneven surface, the illuminated spots 52 are displaced from one another along the Z axis, at different (X_i, Y_i) locations. Thus, while a spot at one location may be in
10 focus of the optical element 42, spots at other locations may be out-of-focus. Therefore, the light intensity of the returned light beams (see below) of the focused spots will be at its peak, while the light intensity at other spots will be off peak. Thus, for each illuminated spot, a plurality of measurements of light intensity are made at different positions along the
15 Z-axis and for each of such (X_i, Y_i) location, typically the derivative of the intensity over distance (Z) will be made, the Z_i yielding maximum derivative, Z_0 , will be the in-focus distance. As pointed out above, where, as a result of use of the punctured mirror 40, the incident light forms a light disk on the surface when out of focus and a complete light spot only when
20 in focus, the distance derivative will be larger when approaching in-focus position thus increasing accuracy of the measurement.

The light scattered from each of the light spots includes a beam travelling initially in the Z axis along the opposite direction of the optical path traveled by the incident light beams. Each returned light beam 54
25 corresponds to one of the incident light beams 36. Given the unsymmetrical properties of mirror 40, the returned light beams are reflected in the direction of the detection optics generally designated 60. The detection optics comprises a polarizer 62 that has a plane of preferred polarization oriented normal to the plane polarization of polarizer 32. The returned

polarized light beam **54** pass through an imaging optic **64**, typically a lens or a plurality of lenses, and then through a matrix **66** comprising an array of pinholes. CCD camera has a matrix or sensing elements each representing a pixel of the image and each one corresponding to one pinhole in the array
5 **66**.

The CCD camera is connected to the image-capturing module **80** of processor unit **24**. Thus, each light intensity measured in each of the sensing elements of the CCD camera, is then grabbed and analyzed, in a manner to be described below, by processor **24**.

10 Unit **22** further comprises a control module **70** connected to a controlling operation of both semi-conducting laser **28** and a motor **72**. Motor **72** is linked to telecentric confocal optics **42** for changing the relative location of the focal plane of the optics **42** along the Z-axis. In a single sequence of operation, control unit **70** induces motor **72** to displace the
15 optical element **42** to change the focal plane location and then, after receipt of a feedback that the location has changed, control module **70** will induce laser **28** to generate a light pulse. At the same time it will synchronize image-capturing module **80** to grab data representative of the light intensity from each of the sensing elements. Then in subsequent sequences the focal
20 plane will change in the same manner and the data capturing will continue over a wide focal range of optics **44**, **44**.

Image capturing module **80** is connected to a CPU **82** which then determines the relative intensity in each pixel over the entire range of focal planes of optics **42**, **44**. As explained above, once a certain light spot is in
25 focus, the measured intensity will be maximal. Thus, by determining the Z_i corresponding to the maximal light intensity or by determining the maximum displacement derivative of the light intensity, for each pixel, , the relative position of each light spot along the **Z** axis can be determined. Thus, data representative of the three-dimensional pattern of a surface in the

teeth segment, can be obtained. This three-dimensional representation may be displayed on a display **84** and manipulated for viewing, e.g. viewing from different angles, zooming-in or out, by the user control module **86** (typically a computer keyboard). In addition, the data representative of the surface topology may be transmitted through an appropriate data port, e.g. a modem **88**, through any communication network, e.g. telephone line **90**, to a recipient (not shown) e.g. to an off-site CAD/CAM apparatus (not shown).

By capturing, in this manner, an image from two or more angular locations around the structure, e.g. in the case of a teeth segment from the buccal direction, from the lingal direction and optionally from above the teeth, an accurate three-dimensional representation of the teeth segment may be reconstructed. This may allow a virtual reconstruction of the three-dimensional structure in a computerized environment or a physical reconstruction in a CAD/CAM apparatus.

As already pointed out above, a particular and preferred application is imaging of a segment of teeth having at least one missing tooth or a portion of a tooth, and the image can then be used for the design and subsequent manufacture of a crown or any other prosthesis to be fitted into this segment.

Reference is now being made to Figs. 2A AND 2B illustrating a probing member **90** in accordance with one, currently preferred, embodiment of the invention. The probing member **90** is made of a light transmissive material, typically glass and is composed of an anterior segment **91** and a posterior segment **92**, tightly glued together in an optically transmissive manner at **93**. Slanted face **94** is covered by a totally reflective mirror layer **95**. Glass disk **96** defining a sensing surface **97** is disposed at the bottom in a manner leaving an air gap **98**. The disk is fixed in position by a holding structure which is not shown. Three light rays are

99 are represented schematically. As can be seen, they bounce at the walls of the probing member at an angle in which the walls are totally reflective and finally bounce on mirror 94 and reflected from there out through the sensing face 97. The light rays focus on focusing plane 100, the position of
5 which can be changed by the focusing optics (not shown in this figure).

Reference is now being made to Fig. 3, which is a schematic illustration of an endoscopic probe in accordance with an embodiment of the invention. The endoscopic probe, generally designated 101, has a stem 102 defining a light transmission path (e.g., containing a void
10 elongated space, being made of or having an interior made of a light transmitting material. Probe 102 has a trough-like probe end 104 with two lateral probe members 106 and 108 and a top probe member 110. The optical fibers have light emitting ends in members 106, 108 and 110 whereby the light is emitted in a direction normal to the planes defined by
15 these members towards the interior of the trough-like structure 104. The probe is placed over a teeth segment 120, which in the illustrated case consists of two teeth 122 and 124, and a stamp 126 of a tooth for placement of a crown thereon. Such a probe will allow the simultaneous imaging of the surface topology of the teeth segment from three angles and
20 subsequently the generation of a three-dimensional structure of this segment.

Reference is now being made to Fig. 4. In this figure, a number of components of an apparatus generally designated 150 in accordance with another embodiment are shown. Other components, not shown, may be
25 similar to those of the embodiment shown in Fig. 1. In this apparatus a parent light beam 152 is a combination of light emitted by a number of laser light emitters 154A, 154B and 154C. Optic expander unit 156 then expands the single parent beam into an array of incident light beams 158. Incident

light beams pass through unidirectional mirror **160**, then through optic unit **162** towards object **164**.

The different light components composing parent beam **152** may for example be different wavelengths, a different one transmitted from each of
5 laser emitters **154A-C**. Thus, parent light beam **152** and each of incident light beams **158** will be composed of three different light components. The image of the optics, or an optical arrangement associated with each of light emitters may be arranged such that each light component focuses on a different plane, P_A , P_B and P_C , respectively. Thus in the position shown in
10 Fig. 3, incident light beam **158A** bounces on the surface at spot **170A** which in the specific optical arrangement of optics **162** is in the focal point for light component A (emitted by light emitter **154A**). Thus, the returned light beam **172A**, passing through detection optics **174** yield maximum measured intensity of light component A measured by two-dimensional array of
15 spectrophotometers **176**, e.g. a **3 CHIP CCD camera**. Similarly, different maximal intensity will be reached for spots **170B** and **170C** for light components B and C, respectively.

Thus, by using different light components each one focused simultaneously at a different plane, the time measurement can be reduced as
20 different focal plane ranges can simultaneously be measured.

CLAIMS:

1. A method for determining surface topology of a portion of a three-dimensional structure, comprising:
 - 5 (a) providing an array of incident light beams propagating in an optical path leading through a focusing optics and through a probing face; the focusing optics defining one or more focal planes forward said probing face in a position changeable by said optics, each light beam having its focus on one of said one or more focal plane; the beams generating a plurality of illuminated spots on the
10 structure;
 - (b) detecting intensity of returned light beams propagating from each of these spots along an optical path opposite to that of the incident light;
 - (c) repeating steps (a) and (b) a plurality of times, each time changing
15 position of the focal plane relative to the structure;
 - (d) for each of the illuminated spots, determining a spot-specific position, being the position of the respective focal plane yielding a maximum measured intensity of a respective returned light beam; and
 - 20 (e) generating data representative of the topology of said portion.
2. The method according to Claim 1, wherein the plurality of incident light beams are produced by splitting a single parent beam.
3. The method according to Claim 1, wherein step (a) comprises polarizing the incident light beams.
- 25 4. The method according to Claim 3, wherein step (b) comprises filtering light having polarization same as the incident light and measuring light of opposite polarization.

5. The method according to any one of Claims 1-4, wherein each of said beams is composed of at least two light components different in at least one parameter.
6. The method according to Claim 5, wherein said at least one
5 parameter is selected from the group consisting of wavelength, phase, light pulse duration and pattern.
7. The method according to Claim 5, comprising, in step (b), determining intensity independently for each of said at least two light components in the return light beams.
- 10 8. The method according to Claim 7, wherein each of said at least two light components focuses in a plane differently distanced from the sensing surface.
9. The method according to any one of Claims 1-8, wherein the data representative of said topology is used for constructing an object to be fitted
15 within said structure.
10. The method according to any one of Claims 1-9, wherein the data representative of said topology is converted into a form transmissible through a communication medium to recipient.
11. The method according to any one of the preceding claims, wherein
20 said structure is a teeth segment.
12. The method according to Claim 12, wherein said structure is a teeth segment with at least one missing tooth or a portion of a tooth and said object is said at least one missing tooth or the portion of the tooth.
13. A method for reconstruction of topology of a three-dimensional
25 structure comprising:
- (i) determining surface topologies from at least two different positions or angular locations relative to the structure, by the method defined in any one of Claims 1-12;

(ii) combining the surface topologies to obtain data representative of said structure.

14. The method according to Claim 13, for reconstruction of topology of a teeth portion, comprising:

- 5 - determining surface topologies of at least a buccal surface and a lingual surface of the teeth portion;
- combining the surface topologies to obtain data representative of a three-dimensional structure of said teeth portion.

15. The method according to Claim 14, for obtaining data representative
10 of a three-dimensional structure of a teeth portion with at least one missing tooth or a portion of a tooth.

16. The method according to Claim 15, wherein said data is used in a process of designing or manufacturing of a prostheses of said at least one missing tooth or a portion of a tooth.

15 17. The method according to Claim 16, wherein said prostheses is a crown or a bridge.

18. An apparatus for determining surface topology of a portion of a three-dimensional structure, comprising:

- a probing member with a sensing face;
- 20 - an illumination unit for providing an array of incident light beams transmitted towards the structure along an optical path through said probing unit to generate illuminated spots on said portion ;
- a light focusing optics defining one or more focal planes forward said probing face at a position changeable by said optics, each light beam
25 having its focus on one of said one or more focal plane;
- a translation mechanism for displacing said focal plane relative to the structure along an axis defined by the propagation of the incident light beams;

- a detector having an array of sensing elements for measuring intensity of each of a plurality of light beams returning from said spots propagating through an optical path opposite to that of the incident light beams;
- a processor coupled to said detector for determining for each light beam a spot-specific position, being the position of the respective focal plane of said one or more focal planes yielding maximum measured intensity of the returned light beam, and based on the determined spot-specific positions, generating data representative of the topology of portion.

19. The apparatus according to Claim 18, wherein said illumination unit comprises a source emitting a parent light beam and a beam splitter for splitting the parent beam into said array of incident light beams.

20. The apparatus according to Claim 19, wherein said illumination unit comprises a grating or microlens array.

21. The apparatus according to any one of Claims 18-20, comprising a polarizer for polarizing said incident light beams are polarized.

22. The apparatus according to Claim 21, comprising a polarization filter for filtering out from the returned light beams light components having the polarization of the incident light beams.

23. The apparatus according to any one of Claim 18-22, wherein the illumination unit comprises at least two light sources and each of said incident beams is composed of light components from the at least two light sources.

24. The apparatus according to Claim 23, wherein the at least two light sources emit each a light component of different wavelength.

25. The apparatus according to Claim 24, wherein said light directing optics defines a different focal plane for each light component and the detector independently detects intensity of each light components.

26. The apparatus according to Claim 23, wherein the at least two light sources are located so as to define optical paths of different lengths for the incident light beams emitted by each of the at least two light sources.

27. The apparatus according to any one of Claims 18-26, wherein said focusing optics operates in a telecentric confocal mode.
28. The apparatus according to any one of Claims 18-27, wherein said light directing optics comprises optical fibers.
- 5 29. The apparatus according to any one of Claims 18-28, wherein said sensing elements are an array of charge coupled devices (CCD).
30. The apparatus according to Claim 29, wherein, said detector unit comprises a pinhole array, each pinhole corresponding to one of the CCDs in the CCD array.
- 10 31. The apparatus according to any one of Claims 18-30, comprising a unit for generating data for transmission to CAD/CAM device.
32. The apparatus according to Claim 31, comprising a communication port of a communication medium.
33. The apparatus according to any one of Claims 18-32, for determining
- 15 surface topology of a teeth portion, comprising an optical probing member for placing proximal to the teeth.

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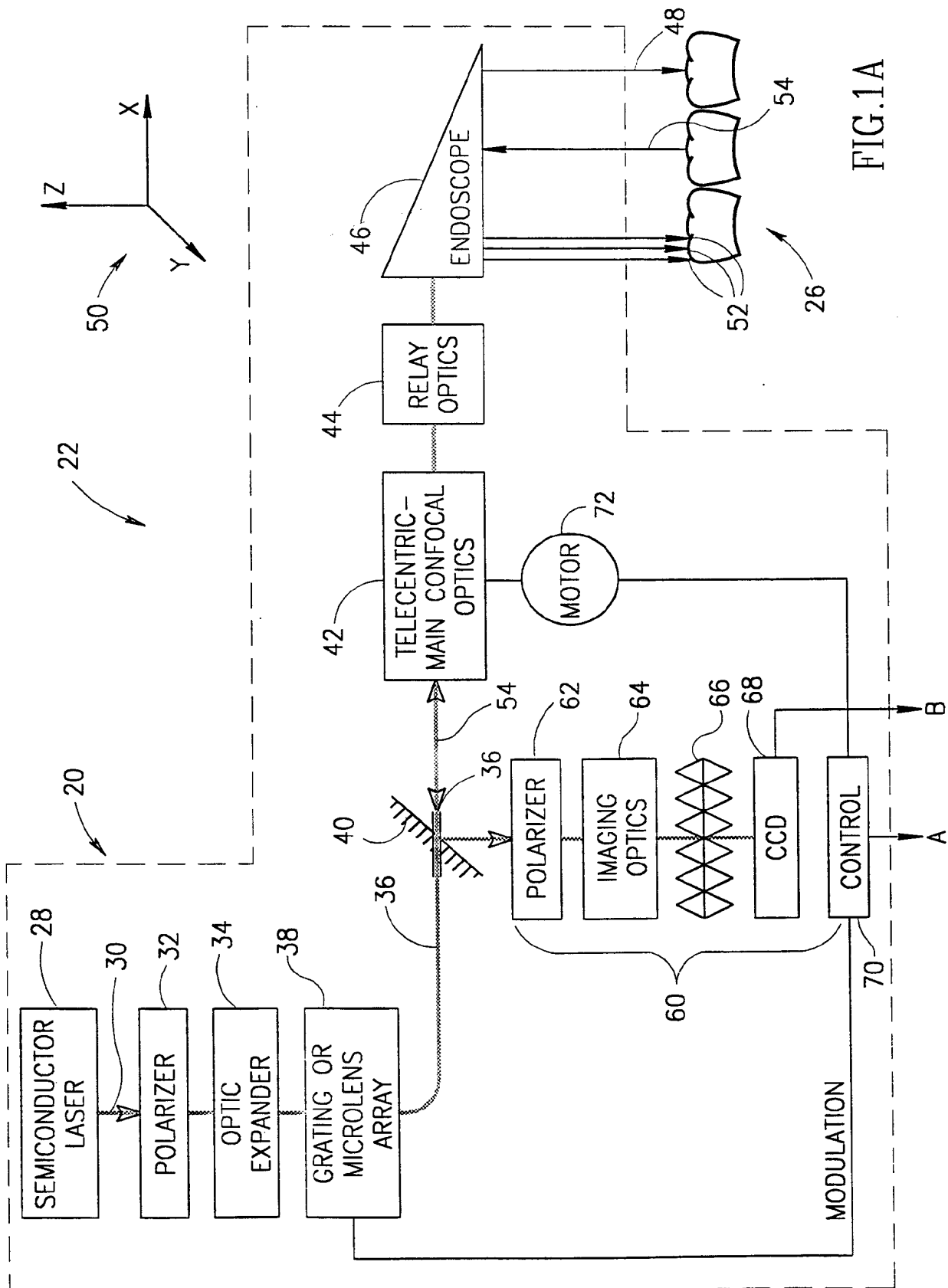


FIG.1A

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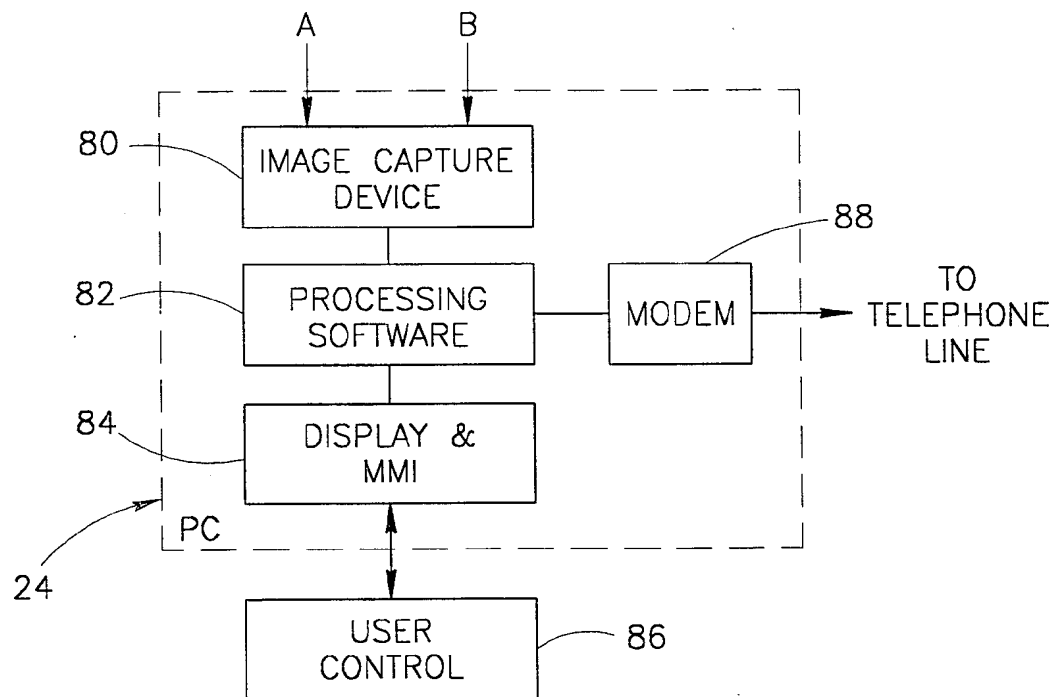
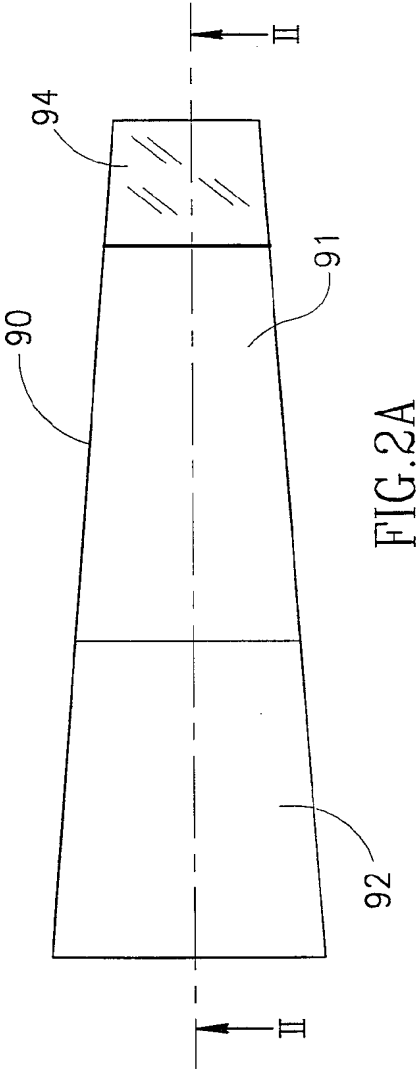
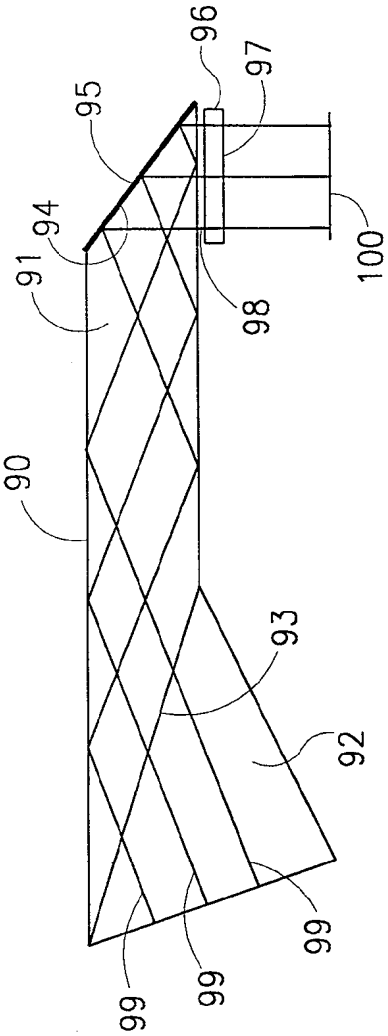


FIG.1B



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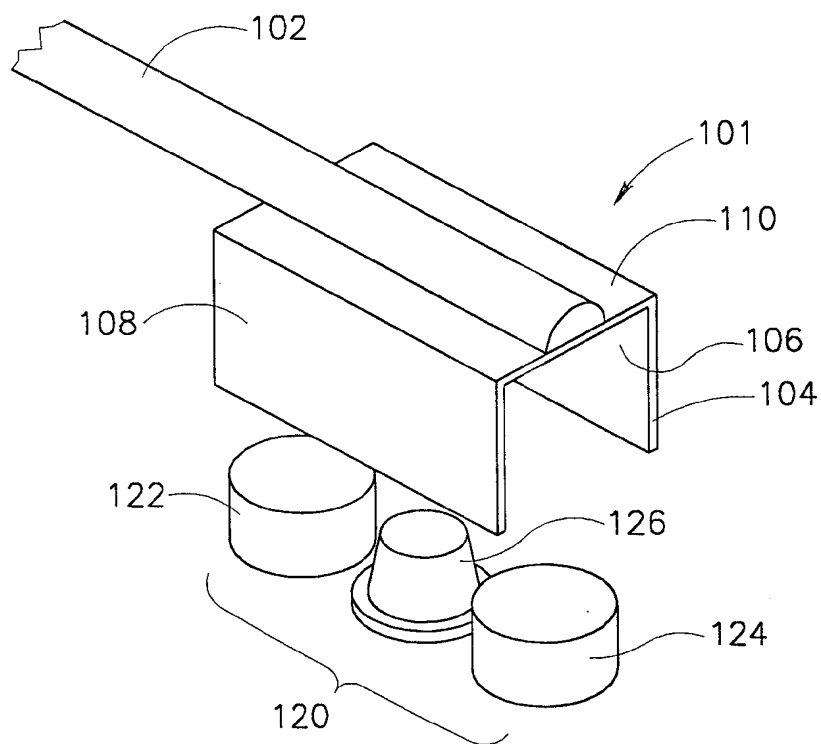


FIG.3

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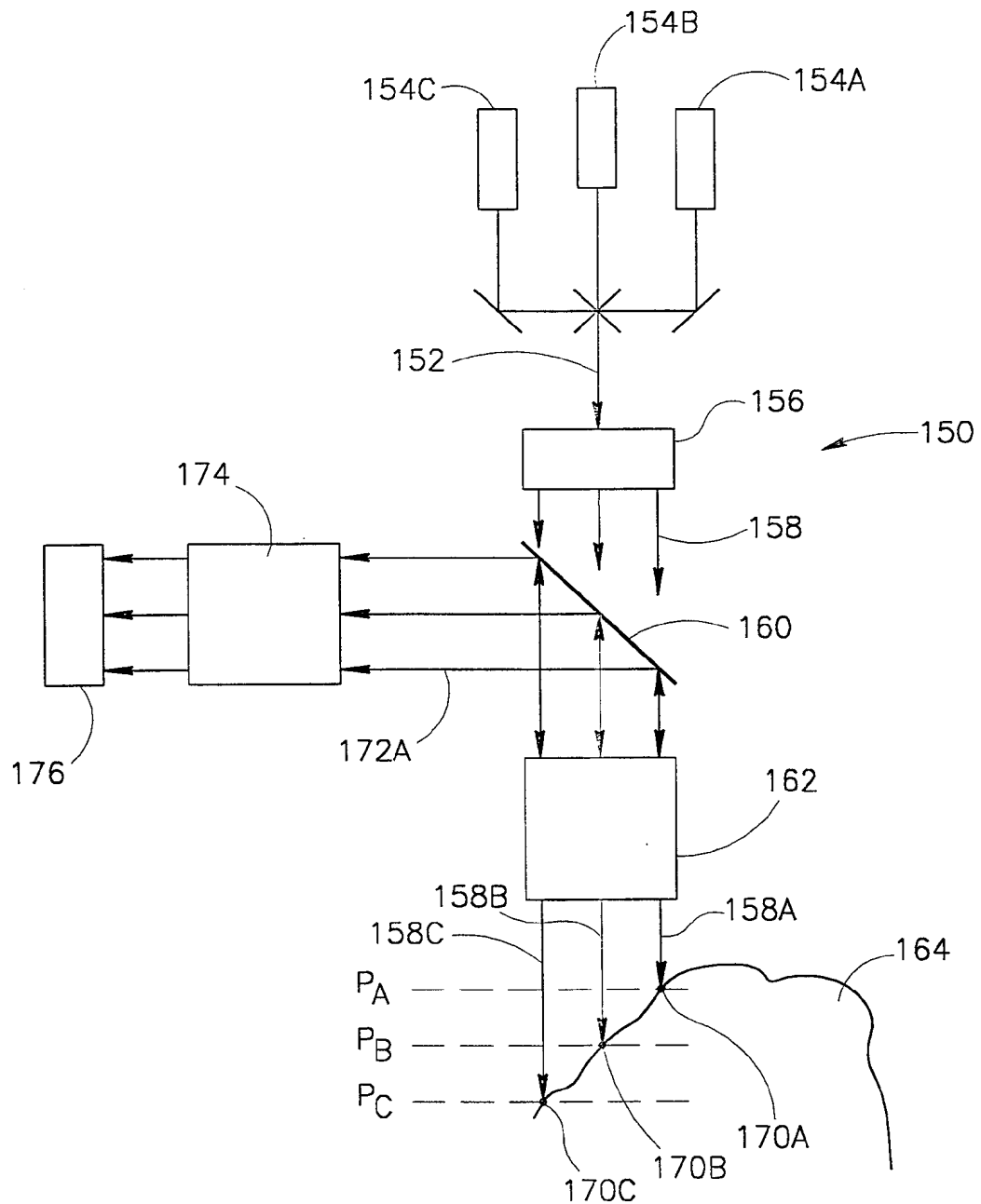


FIG.4

INTERNATIONAL SEARCH REPORT

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

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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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X	GB 2 321 517 A (YOKOGAWA) 29 July 1998 (1998-07-29) figures 3, 6, 7	1-3, 18-21
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A	US 4 575 805 A (MOERMANN ET AL.) 11 March 1986 (1986-03-11) column 9, line 61 - column 10, line 42	13
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☒ Further documents are listed in the continuation of box C.

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"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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C.(Continuation) 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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Information on patent family members

International Application No

PCT/IL 99/00431

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— of inventorship (Rule 4.1 7(iv))

Published:

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

(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 interior part of a human ear.



WO 2010/145669 A1

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.

5

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.

10

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.

15

US2007/01 09559 A 1 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.

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In WO 2008/1 25605, 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.

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Summary of the invention

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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:

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- 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,
- 10
- 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,
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- 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:
- 20
- 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
- 25
- 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.

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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.

15 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.

25 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.

35 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 present invention distinguishes itself from WO 2008/1 25605, because in the embodiments of the present invention that use a time-variant pattern, input images are not limited to two illumination profiles and can be obtained from any illumination profile of the pattern. This is because the orientation of the reference image does not rely entirely on a predetermined calibration, but rather on the specific time of the input image acquisition.

Thus WO 2008/125605 applies specifically exactly two patterns, which are realized physically by a chrome-on-glass mask as illuminated from either side, the reverse side being reflective. WO 2008/1 25605 thus has the advantage of using no moving parts, but the disadvantage of a comparatively poorer signal-to-noise ratio. In the present invention there is the possibility of using any number of pattern configurations, which makes computation of the light oscillation amplitude or the correlation measure more precise.

Definitions

Pattern: A light signal comprising an embedded spatial structure in the lateral plane. May also be termed "illumination pattern".

Time varying pattern: A pattern that varies in time, i.e. the embedded spatial structure varies in time. May also be termed "time varying illumination pattern". In the following also termed "fringes".

Static pattern: A pattern that does not vary in time, e.g. a static checkerboard pattern or a static line pattern.

Pattern configuration: The state of the pattern. Knowledge of the pattern configuration at a certain time amounts to knowing the spatial structure of the illumination at that time. For a periodic pattern the pattern configuration will include information of the pattern phase. If a surface element of the object being scanned is imaged onto the camera then knowledge of the pattern configuration amounts to knowledge of what part of the pattern is illuminating the surface element.

Focus plane: A surface where light rays emitted from the pattern converge to form an image on the object being scanned. The focus plane does not need to be flat. It may be a curved surface.

5 **Optical system:** An arrangement of optical components, e.g. lenses, that transmit, collimate and/or images light, e.g. transmitting probe light towards the object, imaging the pattern on and/or in the object, and imaging the object, or at least a part of the object, on the camera.

10 **Optical axis:** An axis defined by the propagation of a light beam. An optical axis is preferably a straight line. In the preferred embodiment of the invention the optical axis is defined by the configuration of a plurality of optical components, e.g. the configuration of lenses in the optical system. There may be more than one optical axis, if for example one optical system transmits probe light to the object and another optical
15 system images the object on the camera. But preferably the optical axis is defined by the propagation of the light in the optical system transmitting the pattern onto the object and imaging the object onto the camera. The optical axis will often coincide with the longitudinal axis of the scanner.

20 **Optical path:** The path defined by the propagation of the light from the light source to the camera. Thus, a part of the optical path preferably coincides with the optical axis. Whereas the optical axis is preferably a straight line, the optical path may be a non-straight line, for example when the light is reflected, scattered, bent, divided and/or the like provided e.g. by means of beam splitters, mirrors, optical fibers and the like.

25 **Telecentric system:** 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 is
30 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.

35 **Scan length:** A lateral dimension of the field of view. If the probe tip (i.e. scan head) comprises folding optics to direct the probe light in a direction different such as

perpendicular to the optical axis then the scan length is the lateral dimension parallel to the optical axis.

5 **Scan object:** The object to be scanned and on which surface the scanner provides information. "The scan object" may just be termed "the object".

10 **Camera:** Imaging sensor comprising a plurality of sensors that respond to light input onto the imaging sensor. The sensors are preferably ordered in a 2D array in rows and columns.

15 **Input signal:** Light input signal or sensor input signal from the sensors in the camera. This can be integrated intensity of light incident on the sensor during the exposure time or integration of the sensor. In general, it translates to a pixel value within an image. May also be termed "sensor signal".

20 **Reference signal:** A signal derived from the pattern. A reference signal may also be denoted a weight function or weight vector or reference vector.

25 **Correlation measure:** A measure of the degree of correlation between a reference and input signal. Preferably the correlation measure is defined such that if the reference and input signal are linearly related to each other then the correlation measure obtains a larger magnitude than if they are not. In some cases the correlation measure is a light oscillation amplitude.

30 **Image:** An image can be viewed as a 2D array of values (when obtained with a digital camera) or in optics, an image indicates that there exists a relation between an imaged surface and an image surface where light rays emerging from one point on said imaged surface substantially converge on one point on said image surface.

35 **Intensity:** In optics, intensity is a measure of light power per unit area. In image recording with a camera comprising a plurality of individual sensing elements, intensity may be used to term the recorded light signal on the individual sensing elements. In this case intensity reflects a time integration of light power per unit area on the sensing element over the exposure time involved in the image recording.

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Mathematical notation

	A	A correlation measure between the weight function and the recorded light signal. This can be a light oscillation amplitude.
5	I	Light input signal or sensor input signal. This can be integrated intensity of light incident on the sensor during the exposure time or integration of the sensor. In general, it translates to a pixel value within an image.
	f	Reference signal. May also be called weight value.
	n	The number of measurements with a camera sensor and/or several camera sensors that are used to compute a correlation measure.
10	H	Image height in number of pixels
	W	Image width in number of pixels

Symbols are also explained as needed in the text.

Detailed description of the invention

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.

Varying focus

A pivotal point of the invention is the variation, i.e. scanning, of the focal plane without moving the scanner in relation to the object being scanned. Preferably the focal plane may be varied, such as continuously varied in a periodic fashion, while the pattern generation means, the camera, the optical system and the object being scanned is fixed in relation to each other. Further, the 3D surface acquisition time should be small enough to reduce the impact of relative movement between probe and teeth, e.g. reduce effect of shaking. In the preferred embodiment of the invention the focus plane is varied by means of at least one focus element. Preferably the focus plane is periodically varied with a predefined frequency. Said frequency may be at least 1 Hz, such as at least 2 Hz, 3, 4, 5, 6, 7, 8, 9 or at least 10 Hz, such as at least 20, 40, 60, 80 or at least 100 Hz.

Preferably the focus element is part of the optical system. I.e. the focus element may be a lens in a lens system. A preferred embodiment comprises means, such as a translation stage, for adjusting and controlling the position of the focus element. In that way the focus plane may be varied, for example by translating the focus element back and forth along the optical axis.

If a focus element is translated back and forth with a frequency of several Hz this may lead to instability of the scanner. A preferred embodiment of the invention thus comprises means for reducing and/or eliminating the vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner. This may at least partly be provided by means for fixing and/or maintaining the centre of mass of the focus element adjustment system, such as a counter-weight to substantially counter-balance movement of the focus element; for example, by translating a counter-weight opposite to the movement of the focus element. Ease of operation may be achieved if the counter-weight and the focus element are connected and driven by the same translation means. This may however, only substantially reduce the vibration to the first order. If a counter-weight balanced device is rotated around the counter-weight balanced axis, there may be issues relating to the torque created by the counter-weights. A further embodiment of the invention thus comprises means for reducing and/or eliminating the first order, second order, third order and/or higher order vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner.

In another embodiment of the invention more than one optical element is moved to shift the focal plane. In that embodiment it is desirable that these elements are moved together and that the elements are physically adjacent.

In the preferred embodiment of the invention the optical system is telecentric, or near telecentric, for all focus plane positions. Thus, even though one or more lenses in the optical system may be shifted back and forth to change the focus plane position, the telecentricity of the optical system is maintained.

The preferred embodiment of the invention comprises focus gearing. Focus gearing is the correlation between movement of the lens and movement of the focus plane position. E.g. a focus gearing of 2 means that a translation of the focus element of 1 mm corresponds to a translation of the focus plane position of 2 mm. Focus gearing can be provided by a suitable design of the optical system. The advantage of focus gearing is that a small movement of the focus element may correspond to a large variation of the focus plane position. In specific embodiments of the invention the focus gearing is between 0.1 and 100, such as between 0.1 and 1, such as between 1 and

10, such as between 2 and 8, such as between 3 and 6, such as least 10, such as at least 20.

5 In another embodiment of the invention the focus element is a liquid lens. A liquid lens can control the focus plane without use of any moving parts.

Camera

The camera may be a standard digital camera accommodating a standard CCD or CMOS chip with one A/D converter per line of sensor elements (pixels). However, to
10 increase the frame rate the scanner according to the invention may comprise a high-speed camera accommodating multiple A/D converters per line of pixels, e.g. at least 2, 4, 8 or 16 A/D converters per line of pixels.

Pattern

15 Another central element of the invention is the probe light with an embedded pattern that is projected on to the object being scanned. The pattern may be static or time varying. The time varying pattern may provide a variation of light and darkness on and/or in 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
20 and darkness. The out-of-focus regions will display smaller or no contrast in the light oscillations. The static pattern may provide a spatial variation of light and darkness on and/or in the object. Specifically, the in-focus regions will display an oscillating pattern of light and darkness in space. The out-of-focus regions will display smaller or no contrast in the spatial light oscillations.

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Light may be provided from an external light source, however preferably the scanner comprises at least one light source and pattern generation means to produce the pattern. It is advantageous in terms of signal-to-noise ratio to design a light source such that the intensity in the non-masked parts of the pattern is as close to uniform in
30 space as possible. In another embodiment the light source and the pattern generation means is integrated in a single component, such as a segmented LED. A segmented LED may provide a static pattern and/or it may provide a time varying pattern in itself by turning on and off the different segments in sequence. In one embodiment of the invention the time varying pattern is periodically varying in time. In another embodiment

of the invention the static pattern is periodically varying in space.

Light from the light source (external or internal) may be transmitted through the pattern generation means thereby generating the pattern. For example the pattern generation means comprises at least one translucent and/or transparent pattern element. For generating a time varying pattern a wheel, with an opaque mask can be used. E.g. the mask comprises a plurality of radial spokes, preferably arranged in a symmetrical order. The scanner may also comprise means for rotating and/or translating the pattern element. For generating a static pattern a glass plate with an opaque mask can be used. E.g. the mask comprises a line pattern or checkerboard pattern. In general said mask preferably possesses rotational and/or translational periodicity. The pattern element is located in the optical path. Thus, light from the light source may be transmitted through the pattern element, e.g. transmitted transversely through the pattern element. The time varying pattern can then be generated by rotating and/or translating the pattern element. A pattern element generating a static pattern does not need to be moved during a scan.

Correlation

One object of the invention is to provide short scan time and real time processing, e.g. to provide live feedback to a scanner operator to make a fast scan of an entire tooth arch. However, real time high resolution 3D scanning creates an enormous amount of data. Therefore data processing should be provided in the scanner housing, i.e. close to the optical components, to reduce data transfer rate to e.g. a cart, workstation or display. In order to speed up data processing time and in order to extract in-focus information with an optimal signal-to-noise ratio various correlation techniques may be embedded / implemented. This may for example be implemented in the camera electronics to discriminate out-of-focus information. The pattern is applied to provide illumination with an embedded spatial structure on the object being scanned. Determining in-focus information relates to calculating a correlation measure of this spatially structured light signal (which we term input signal) with the variation of the pattern itself (which we term reference signal). In general the magnitude of the correlation measure is high if the input signal coincides with the reference signal. If the input signal displays little or no variation then the magnitude of the correlation measure is low. If the input signal displays a large spatial variation but this variation is different than the variation in the reference signal then the magnitude of the correlation measure

is also low. In a further embodiment of the invention the scanner and/or the scanner head may be wireless, thereby simplifying handling and operation of the scanner and increasing accessibility under difficult scanning situations, e.g. intra-oral or in the ear scanning. However, wireless operation may further increase the need for local data processing to avoid wireless transmission of raw 3D data.

The reference signal is provided by the pattern generating means and may be periodic. The variation in the input signal may be periodic and it may be confined to one or a few periods. The reference signal may be determined independently of the input signal. Specifically in the case of a periodic variation, the phase between the oscillating input and reference signal may be known independently of the input signal. In the case of a periodic variation the correlation is typically related to the amplitude of the variation. If the phase between the oscillating input and reference signals is not known it is necessary to determine both cosine and sinusoidal part of the input signal before the input signal's amplitude of variation can be determined. This is not necessary when the phase is known.

One way to define the correlation measure mathematically with a discrete set of measurements is as a dot product computed from a signal vector, $I = (I_1, \dots, I_n)$, with $n > 1$ elements representing sensor signals and a reference vector, $f = (f_1, \dots, f_n)$, of same length as said signal vector of reference weights. The correlation measure A is then given by

$$A = f \cdot I = \sum_{i=1}^n f_i I_i$$

The indices on the elements in the signal vector represent sensor signals that are recorded at different times and/or at different sensors. In the case of a continuous measurement the above expression is easily generalized to involve integration in place of the summation. In that case the integration parameter is time and/or one or more spatial coordinates.

A preferred embodiment is to remove the DC part of the correlation signal or correlation measure, i.e., when the reference vector elements sums to zero ($\sum_{i=1}^n f_i = 0$). The focus position can be found as an extremum of the correlation measure computed over all focus element positions. We note that in this case the correlation measure is proportional to the sample Pearson correlation coefficient between two variables. If the

DC part is not removed, there may exist a trend in DC signal over all focus element positions, and this trend can be dominating numerically. In this situation, the focus position may still be found by analysis of the correlation measure and/or one or more of its derivatives, preferably after trend removal.

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Preferably, the global extremum should be found. However, artifacts such as dirt on the optical system can result in false global maxima. Therefore, it can be advisable to look for local extrema in some cases. If the object being scanned is sufficiently translucent it may be possible to identify interior surfaces or surface parts that are otherwise occluded. In such cases there may be several local extrema that corresponds to surfaces and it may be advantageous to process several or all extrema.

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The correlation measure can typically be computed based on input signals that are available as digital images, i.e., images with a finite number of discrete pixels.

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Therefore conveniently, the calculations for obtaining correlation measures can be performed for image pixels or groups thereof. Correlation measures can then be visualized in as pseudo-images.

The correlation measure applied in this invention is inspired by the principle of a lock-in amplifier, in which the input signal is multiplied by the reference signal and integrated over a specified time. In this invention, a reference signal is provided by the pattern.

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Temporal correlation

Temporal correlation involves a time-varying pattern. The light signal in the individual light sensing elements in the camera is recorded several times while the pattern configuration is varied. The correlation measure is thus at least computed with sensor signals recorded at different times.

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A principle to estimate light oscillation amplitude in a periodically varying light signal is taught in WO 98/45745 where the amplitude is calculated by first estimating a cosine and a sinusoidal part of the light intensity oscillation. However, from a statistical point of view this is not optimal because two parameters are estimated to be able to calculate the amplitude.

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In this embodiment of the invention independent knowledge of the pattern configuration at each light signal recording allows for calculating the correlation measure at each light sensing element.

5 In some embodiments of the invention the scanner comprises means for obtaining knowledge of the pattern configuration. To provide such knowledge the scanner preferably further comprises means for registering and/or monitoring the time varying pattern.

10 Each individual light sensing element, i.e. sensor element, in the camera sees a variation in the light signal corresponding to the variation of the light illuminating the object.

One embodiment of the invention obtains the time variation of the pattern by translating
15 and/or rotating the pattern element. In this case the pattern configuration may be obtained by means of a position encoder on the pattern element combined with prior knowledge of the pattern geometry that gives rise to a pattern variation across individual sensing elements. Knowledge of the pattern configuration thus arises as a combination of knowledge of the pattern geometry that results in a variation across
20 different sensing elements and pattern registration and/or monitoring during the 3D scan. In case of a rotating wheel as the pattern element the angular position of the wheel may then be obtained by an encoder, e.g. mounted on the rim.

One embodiment of the invention involves a pattern that possesses translational and/or
25 rotational periodicity. In this embodiment there is a well-defined pattern oscillation period if the pattern is substantially translated and/or rotated at a constant speed.

One embodiment of the invention comprises means for sampling each of a plurality of the sensor elements a plurality of times during one pattern oscillation period, preferably
30 sampled an integer number of times, such as sampling 2, 3, 4, 5, 6, 7 or 8 times during each pattern oscillation period, thereby determining the light variation during a period.

The temporal correlation measure between the light variation and the pattern can be obtained by recording several images on the camera during one oscillation period (or at
35 least one oscillation period). The number of images recorded during one oscillation

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

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

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

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

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

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

To obtain a sharp image of an object by means of a camera the object must be in focus and the optics of the camera and the object must be in a fixed spatial relationship during the exposure time of the image sensor of the camera. Applied to the present invention this should imply that the pattern and the focus should be varied in discrete steps to be able to fix the pattern and the focus for each image sampled in the camera, i.e. fixed during the exposure time of the sensor array. However, to increase the sensitivity of the image data the exposure time of the sensor array should be as high as the sensor frame rate permits. Thus, in the preferred embodiment of the invention images are recorded (sampled) in the camera while the pattern is continuously varying (e.g. by continuously rotating a pattern wheel) and the focus plane is continuously

5 moved. This implies that the individual images will be slightly blurred since they are the result of a time-integration of the image while the pattern is varying and the focus plane is moved. This is something that one could expect to lead to deterioration of the data quality, but in practice the advantage of concurrent variation of the pattern and the focus plane is bigger than the drawback.

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

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

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

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

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

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

5 This may also be expressed as

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

where A is the calculated amplitude or correlation measure, i is the index for each sampling, f is the periodic function, p_i is the angular position / phase of the illumination pattern for sampling i and I_i is the signal of the light sensitive element for sampling i .

10 Preferably the periodic function averages to zero over a pattern oscillation period, i.e. $\sum_i f(p_i) = 0$.

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

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

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

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

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

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

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

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Optical correlation

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

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

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

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

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

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

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

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

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

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

10

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

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

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

Spatial correlation

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

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

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

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

In a further embodiment of the invention at least one spatial period of the pattern corresponds to a group of sensor elements. In a further embodiment of the invention all groups of sensor elements contain the same number of elements and have the same shape. E.g. when the period of a checkerboard pattern corresponds to a square group of e.g. 2x2, 3x3, 4x4, 5x5, 6x6, 7x7, 8x8, 9x9, 10x10 or more pixels on the camera.

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

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

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

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

Where n is the number of sensor elements in a group of sensors, $f_i = (f_{i1}, \dots, f_{iJ})$ is the reference signal vector obtained from knowledge of the pattern configuration, and $I_j = (I_{j1}, \dots, I_{jN})$ is input signal vector. For the case of sensors grouped in square regions with N sensors as square length then $n = N^2$.

5

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

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

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

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

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

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

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

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

- 5 where n is the number of sensor elements in group j , l_{ij} is the signal from the i th sensor element in group /and $f(i, j)$ is a predetermined function reflecting the pattern.

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

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

20 *Transforming correlation measure extrema to 3D world coordinates*

Relating identified focus position(s) for camera sensor or camera sensor groups to 3D world coordinates may be done by ray tracing through the optical system. Before such ray tracing can be performed the parameters of the optical system need to be known.

25 One embodiment of the invention comprises a calibration step to obtain such knowledge. A further embodiment of the invention comprises a calibration step in which images of an object of known geometry are recorded for a plurality of focus positions. Such an object may be a planar checkerboard pattern. Then, the scanner can be calibrated by generating simulated ray traced images of the calibration object and then

30 adjusting optical system parameters as to minimize the difference between the simulated and recorded images.

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

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

Specular reflections

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

A difficult kind of object, for instance, is an object displaying multiple scattering of the incident light with a light diffusion length large compared to the smallest feature size of the spatial pattern imaged onto the object. A human tooth is an example of such an
30 object. The human ear and ear canal are other examples. In case of intra oral scanning, the scanning should preferably be provided without spraying and/or drying the teeth to reduce the specular reflections and light penetration. Improved spatial contrast can be achieved by preferential imaging of the specular surface reflection from the object on the camera. Thus, one embodiment of the invention comprises means
35 for preferential / selectively imaging of specular reflected light and/or diffusively

reflected light. This may be provided if the scanner further comprises means for polarizing the probe light, for example by means of at least one polarizing beam splitter. A polarizing beam splitter may for instance be provided for forming an image of the object in the camera. This may be utilized to extinguish specular reflections,
5 because if the incident light is linearly polarized a specular reflection from the object has the property that it preserves its polarization state

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

The field of view (scanning length)

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

One embodiment of the invention comprises at least two light sources, such as light sources with different wavelengths and/or different polarization. Preferably also control means for controlling said at least two light sources. Preferably this embodiment comprises means for combining and/or merging light from said at least two light sources. 5 If waveguide light sources are used they may be merged by waveguides. However, one or more diffusers may also be provided to merge light sources.

10 Separation and/or merging may be provided by at least one optical device which is partially light transmitting and partially light reflecting, said optical device preferably located along the optical axis, an optical device such as a coated mirror or coated plate. One embodiment comprises at least two of said optical devices, said optical devices preferably displaced along the optical axis. Preferably at least one of said 15 optical devices transmits light at certain wavelengths and/or polarizations and reflects light at other wavelengths and/or polarizations.

One exemplary embodiment of the invention comprises at least a first and a second light source, said light sources having different wavelength and/or polarization, and 20 wherein
a first optical device reflects light from said first light source in a direction different from the optical axis and transmits light from said second light source, and
a second optical device reflects light from said second light source in a direction different from the optical axis. Preferably said first and second optical devices reflect 25 the probe light in parallel directions, preferably in a direction perpendicular to the optical axis, thereby imaging different parts of the object surface. Said different parts of the object surface may be at least partially overlapping.

Thus, for example light from a first and a second light source emitting light of different 30 wavelengths (and/or polarizations) is merged together using a suitably coated plate that transmits the light from the first light source and reflects the light from the second light source. At the scan tip along the optical axis a first optical device (e.g. a suitably coated plate, dichroic filter) reflects the light from the first light source onto the object and transmits the light from the second light source to a second optical device (e.g. a 35 mirror) at the end of the scan tip, i.e. further down the optical axis. During scanning the

focus position is moved such that the light from the first light source is used to project an image of the pattern to a position below the first optical device while second light source is switched off. The 3D surface of the object in the region below the first optical device is recorded. Then the first light source is switched off and the second light source is switched on and the focus position is moved such that the light from the second light source is used to project an image of the pattern to a position below the second optical device. The 3D surface of the object in the region below the second optical device is recorded. The region covered with the light from the two light sources respectively may partially overlap.

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

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

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

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

Color scanning

One embodiment of the invention is only registering the surface topology (geometry) of the object being scanned. However, another embodiment of the invention is being adapted to obtain the color of the surface being scanned, i.e. capable of registering the

color of the individual surface elements of the object being scanned together with the surface topology of the object being scanned. To obtain color information the light source needs to be white or to comprise at least three monochromatic light sources with colors distributed across the visible part of the electromagnetic spectrum.

5

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

10

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

15

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

20

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

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

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One embodiment of the invention comprises means for switching between at least two colors, preferably three colors, such as red, green and blue, of the probe light for a focal plane position. I.e. for a single focal plane position it is possible to switch between different colors of the probe light. For example by switching on and off different

5 monochromatic light sources (having one only light source turned on at a time) or by applying different color filters. Furthermore, the amplitude of the light signal of each of a plurality of the sensor elements may be determined for each color for each focal plane positions. I.e. for each focus position the color of the probe light may be switched. The embedded time varying pattern provides a single color oscillating light signal and the

10 amplitude of the signal in each sensor element may be determined for that color. Switching to the next color the amplitude may be determined again. When the amplitude has been determined for all colors the focus position is changed and the process is repeated. The color of the surface being scanned may then be obtained by combining and/or weighing the color information from a plurality of the sensor

15 elements. E.g. the color expressed as e.g. an RGB color coordinate of each surface element can be reconstructed by appropriate weighting of the amplitude signal for each color corresponding to the maximum amplitude. This technique may also be applied when a static pattern is provided where the color of at least a part of the pattern is varying in time.

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To decrease the amount of data to be processed the color resolution of the imaging may be chosen to be less than the spatial resolution. The color information is then provided by data interpolation. Thus, in one embodiment of the invention the amplitude of the light signal of each of a plurality of the sensor elements is determined for each

25 color for selected full color focal plane positions, and the amplitude of the light signal of each of a plurality of the sensor elements is determined for one color for each focal plane position. Then the color of the surface being scanned may be obtained by interpolating the color information from full color focal plane positions. Thus, for example the amplitude is registered for all colors at an interval of N focus positions;

30 while one color is selected for determination of the amplitude at all focus positions. N is a number which could be e.g. 3, 5, or 10. This results in a color resolution which is less than the resolution of the surface topology. This technique may also be applied when a static pattern is provided where the color of at least a part of the pattern is varying in time.

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

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Impression scanning

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

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Small cavity scanner

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

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

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Thus, one embodiment of the invention comprises

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

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Preferably, the point of emission of probe light and the point of accumulation of light returned from the scanned object is located on said probe. The optical system in the

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

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

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

30 In one embodiment of the invention the probe light is directed toward the object in a direction substantially parallel with the optical axis and/or the longitudinal axis of the probe. In a further embodiment the probe comprises a posterior reflective element, such as a mirror, for directing the probe light in a direction different from the optical
35 axis, preferably in a direction perpendicular to the optical axis. Applying to the

abovementioned example with a stand-alone scanner housing with the probe detached, the probe light may exit the housing in a direction parallel with the optical axis of the optical system in the housing (i.e. the second optical system), whereas with the probe attached the probe light may be directed in a direction different than the optical axis of the optical system of the probe (i.e. the first optical system). Thereby the probe is better adapted to scanning a cavity.

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

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

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

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

interior and exterior part of the ear provided, thereby providing a full 3D model of a human ear.

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

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Use of motion, gravity, and magnetic sensors

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

- 25 A) Motion sensors can detect vibrations and/or shaking. Scans such affected can be either discarded or corrected by use of image stabilization techniques.
- B) Motion sensors can help with stitching and/or registering partial scans to each other. This advantage is relevant when the field of view of the scanner is smaller than the object to be scanned. In this situation, the scanner is applied for small regions of the object (one at a time) that then are combined to obtain
30 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.

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

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

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

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

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

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

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

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

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

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

- each of a plurality of groups of the sensor elements for a range of focus plane positions, and
 - b) transforming in-focus data into 3D real world coordinates;
- wherein the scanner further comprises counter-weight means for counter-
- 5 balancing the means for varying the position of the focus plane.

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

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

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

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Brief description of the drawings

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

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

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

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

[Fig. 5: - deleted -]

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Detailed description of the drawings

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

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

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

object being probed and from the object being probed to the camera. One application of the device could be for determining the 3D structure of teeth in the oral cavity. Another application could be for determining the 3D shape of the ear canal and the external part of the ear.

5

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

10

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

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25 *Pattern generation*

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

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Fig. 3b illustrates another embodiment of the pattern generation means: A segmented light source 135, preferably a segmented LED. In this embodiment the LED surface is

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imaged onto the object under investigation. The individual LED segments 136 are turned on and off in a fashion to provide a known time-varying pattern on the object. The control electronics 137 of the time varying pattern is connected to the segmented light source via electrical wires 138. The pattern is thus integrated into the light source and a separate light source is not necessary.

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

Temporal correlation

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

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

$$A_j = \sum_{I=1}^n f_{i,j}^I U_{pi}$$

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

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

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Spatial correlation

In an example of the spatial correlation scheme, one image of the object with projected checkerboard pattern is recorded with as high resolution as allowed by the image sensor. The scheme in the spatial correlation is then to analyze groups of pixels in the recorded image and extract the correlation measure in the pattern. An extremum in the obtained correlation measures indicates the in-focus position. For simplicity, one can use a checkerboard pattern with a period corresponding to $n = N \times N$ pixels on the sensor and then analyze the correlation measure within one period of the pattern (in the general case the pattern need not be quadratic $N \times N$). In the best case, it will be possible to align the pattern so that the checkerboard edges coincide with the pixel edges but the scanning principle does not rely upon this. Fig. 16 shows this for the case $n = A \times A = 16$. For a sensor with $W \times H = 1024 \times 512$ pixels, this would correspond to obtaining 256×128 correlation measure points from one image. Extraction of the correlation measure A_j within an $N \times N$ group of pixels with label j is given by

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

where $f_i = (f_{i,1}, \dots, f_{i,n})$ is the reference signal vector obtained from knowledge of the pattern configuration, and $I_j = (I_{1,j}, \dots, I_{n,j})$ is input signal vector.

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

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

25

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

30

Optical correlation

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

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

Finding the predetermined reference function

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

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

As the focus plane generally is not a geometrical plane, different regions of the flat surface will be in focus in different images. Examples of three such images are shown

in Figs 17a - 17c, where 1700 is an in-focus region. Note that in this stylized figure, transitions between regions in and out of focus, respectively, are exaggerated in order to demonstrate the principle more clearly. Also, in general there will be many more images than just the three used in this simple example.

5

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

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

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

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

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

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The "correlation image"

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

$$A_j = \frac{1}{L} \sum_{i=1}^N f_{iJ} I_{H,j},$$

where $f_s = (f_1, \dots, f_n)$ are values from the fused image, and $I_j = (I_1, \dots, I_n)$ are values from a recorded image on the camera. The pixel groupings used in any DC removal and possibly normalization that yielded the fused image are the same as in the above calculation. For each image recorded by the scanner during a sweep of the focusing element, there will thus be an array of $(H/N) \times (W/N)$ values of A . This array can be visualized as an image.

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

The array of values of A can be computed for every image recorded in a sweep of the focus element. Combining the global extrema (over all images) of A in all pixel groups in the same manner the fused image was combined, one can obtain a pseudo-image of dimension $(H/N) \times (W/N)$. This we call the "fused correlation image". An example of a

fused correlation image of some teeth and gingiva is shown in Figure 19. As can be seen, it is useful for visualization purposes.

Increasing field of view

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

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

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

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

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

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Achieving high spatial contrast of pattern projected onto difficult objects

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

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

depolarized and one half of this light will be directed towards the image sensor 181 by the beam splitter 140.

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

Reducing shaking caused by focus element

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

Color measurement

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

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

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

Ear scanner embodiment

Figs. 12-15 schematically illustrate an embodiment of a time-varying structured light illumination-based scanner for direct scanning of human ears by scanning both the exterior (outer) and interior (inner) part of a human ear by use of a common scanner

exterior handle and a detachable probe. This embodiment is advantageous in that it allows for non-intrusive scanning using a probe designed to be inserted into small cavities, such as a human ear. This is done in part by positioning the bulky and essential parts of the scanner, such as the scanner camera, light source, electronics and focusing optics outside the closely confined part of the ear canal.

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

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

this way and using the same system, the combined scanner exterior and probe are able to both scan larger external areas along with smaller internal areas.

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

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

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

The optical part of the scanner probe consists of an endoscopic optical relay system 1009 followed by a probe objective 1010, both of which are of sufficiently small
35 diameter to fit into the canal of a human ear. These optical systems may consist of both

a plurality of optical fibers and lenses and serve to transport and focus the light from the scanner exterior onto the scan object 1014 (e.g. the interior surface of an ear), as well as to collimate and transport the reflected light from the scan object back to the scanner exterior. In one embodiment, the probe objective provides telecentric
5 projection of the fringe pattern onto the scan object. Telecentric projection can significantly ease the data mapping of acquired 2D images to 3D images. In another embodiment, the chief rays (center ray of each ray bundle) from the probe objective are diverging (non-telecentric) to provide the camera with an angle-of-view larger than zero, as shown in fig. 13a.

10

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

25

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

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To reduce the probe movement required by a scanner operator, the mirror arrangement may be rotated using a motor 1013. In one embodiment, the mirror

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

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

"Pistol-like" grip

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

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

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are

recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

5 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.

10 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
15 may be implemented by hardwired circuitry instead of software or in combination with software.

Claims

1. A scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:
- 5 - 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,
 - 10 - 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,
 - 15 - 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
 - 20 of the spatial pattern;
 - data processing means for:
 - a) determining by analysis of the correlation measure the in-focus position(s) of:
 - 25 - 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.
 - 30
2. A scanner according to claim 1, wherein the light returned from the object to the camera is light that is reflected and/or scattered and/or fluorescence light and/or phosphorescence light.

3. A scanner according to claims 1 or 2, wherein the means for evaluating a correlation measure is a data processing means.
- 5 4. A scanner according to claims 1 or 2, wherein the means for evaluating a correlation measure is an optical means.
- 10 5. A scanner according to any of the preceding claims, wherein the correlation measure is found mathematically substantially as an at least local extremum position of an optionally smoothed series of dot products computed for a plurality of said focus plane positions.
- 15 6. A scanner according to the previous claim, wherein each dot product is computed from a signal vector with more than one element representing sensor signals and a weight vector of same length as said signal vector of weights.
- 20 7. A scanner according to any of the preceding claims, wherein the pattern is varying in time.
8. A scanner according to the previous claim, wherein the time varying pattern is periodically varying in time.
- 25 9. A scanner according to any of the preceding claims, wherein the pattern is static.
10. A scanner according to any of the preceding claims, wherein the means for transmitting light returned from the object to the camera comprises means for imaging onto the camera said illuminated part of the object with said pattern.
- 30 11. A scanner according to any of the preceding claims, wherein the means for transmitting light returned from the object to the camera comprises means for imaging onto the camera the pattern itself and a superposition of light returned from the object to the camera such that the image on the camera substantially is a multiplication of said illuminated part of the object with said pattern and the pattern itself.

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12. A scanner according to any of the preceding claims, wherein the embedded spatial structure of said pattern is varying in time.
- 5 13. A scanner according to any of the preceding claims, comprising at least one light source and pattern generation means.
- 10 14. A scanner according to the previous claim, wherein light from said probe light generating means is transmitted through said pattern generation means thereby generating the pattern.
- 15 15. A scanner according to any of claims 13 or 14, wherein said pattern generation means comprises a mask of transparent and opaque parts.
- 16 16. A scanner according to the previous claim, wherein said opaque parts absorb incident light.
- 20 17. A scanner according to any of the preceding claims, wherein said pattern possess translational and/or rotational periodicity.
- 25 18. A scanner according to any of the preceding claims, wherein said pattern illuminating the object is varying in time by translating and/or rotating said pattern.
- 30 19. A scanner according to any of claims 13-18, wherein light returned from the object is retransmitted through said pattern generating means before being imaged on said camera, preferably retransmitted in the opposite direction as the probe light.
20. A scanner according to any of the preceding claims, wherein the image of the pattern illuminating the object is coinciding with an image of the pattern itself.
21. A scanner according to any of the preceding claims, further comprising means for synchronizing exposure time of said sensor elements with pattern oscillation time.

22. A scanner according to any of the preceding claims, wherein exposure time of said sensor elements is an integer number of light oscillation cycles.
- 5 23. A scanner according to any of the preceding claims, wherein exposure time of said sensor elements is a large number of light oscillation cycles, such as at least 10 times the light oscillation cycle, such as at least 100 times the light oscillation cycle.
- 10 24. A scanner according to any of claims 13-23, wherein light from the light source is transmitted through the pattern generation means thereby generating the pattern.
- 15 25. A scanner according to any of the preceding claims, wherein the focus plane of the camera is adapted to be moved synchronously with the focus plane of the pattern.
- 20 26. A scanner according to any of the preceding claims, wherein the object is an anatomical object, such as an ear canal, or a dental object, such as teeth.
27. A scanner according to any of the preceding claims, comprising an optical system for transmitting the probe light towards the object and/or for imaging light returned from the object to the camera.
- 25 28. A scanner according to any of the preceding claims, further comprising at least one beam splitter located in the optical path.
29. A scanner according to any of the preceding claims, wherein an image of the object is formed in the camera by means of at least one beam splitter.
- 30 30. A scanner according to any of the preceding claims, wherein the pattern is transmitted towards the object along the same optical axis as reflected light transmitted from the object to the camera.
- 35 31. A scanner according to any of the preceding claims, wherein the optical system comprises a lens system.

32. A scanner according to any of the preceding claims, wherein one lens system transmits the pattern towards the object and images light returned from the object to the camera.
- 5 33. A scanner according to any of the preceding claims, wherein one lens system transmits the pattern towards the object and images the light returned from the object to the pattern generating means.
- 10 34. A scanner according to claims 31-33, wherein the lens system is telecentric or near telecentric.
35. A scanner according to any of the preceding claims, wherein the pattern is transmitted in the opposite direction of light imaged from the object to the camera.
- 15 36. A scanner according to any of the preceding claims, wherein the pattern is transmitted in the opposite direction of light imaged from the object to the pattern generating means.
- 20 37. A scanner according to any of the preceding claims, wherein the sensor signal is an integrated light intensity substantially reflected from the surface of the object.
38. A scanner according to any of the preceding claims, wherein the focus plane position is periodically varied with a predefined frequency.
- 25 39. A scanner according to the previous claim, wherein said frequency is at least 1 Hz, such as at least 2 Hz, 3, 4, 5, 6, 7, 8, 9 or at least 10 Hz, such as at least 20, 40, 60, 80 or at least 100 Hz.
- 30 40. A scanner according to any of the preceding claims, further comprising at least one focus element.
41. A scanner according to the previous claim, wherein the focus element is part of the lens system.
- 35

42. A scanner according to any of claims 40-41 further comprising means for adjusting and controlling the focus element.
- 5 43. A scanner according to any of claims 40-42, wherein the focus element is a single lens.
44. A scanner according to any of claims 40-43, further comprising a translation stage for adjusting the position of the focus element.
- 10 45. A scanner according to any of claims 40-44, wherein the focus element is translated back and forth along the optical axis.
46. A scanner according to any of claims 31-45, wherein the lens system is telecentric or near telecentric for all focus plane positions.
- 15 47. A scanner according to any of claims 40-46, further comprising focus gearing.
48. A scanner according to the previous claim, wherein the focus gearing is between 0.1 and 100, such as between 0.1 and 1, such as between 1 and 10, such as
20 between 2 and 8, such as between 3 and 6, such as at least 10, such as at least 20.
49. A scanner according to any of claims 40-48, further comprising means for reducing and/or eliminating the vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner.
- 25 50. A scanner according to any of claims 40-49, further comprising means for fixing and/or maintaining the centre of mass of the focus element adjustment system.
- 30 51. A scanner according to any of claims 40-50, further comprising means for reducing and/or eliminating the first order, second order, third order and/or higher order vibration and/or shaking from the focus element adjustment system, thereby increasing the stability of the scanner.

52. . A scanner according to any of the preceding claims, further comprising a counter-weight to substantially counter-balance movement of the focus element.
53. A scanner according to the previous claim, further comprising means for translating the counter-weight opposite to movement of the focus element.
54. A scanner according to claims 52 or 53, wherein the counter-weight and the focus element are connected and driven by the same translation means.
55. A scanner according to any of claims 40-54, wherein the focus element is a liquid lens.
56. A scanner according to any of claims 13-55, wherein the pattern generation means comprises at least one translucent and/or transparent pattern element with an opaque mask.
57. A scanner according to any of the preceding claims, wherein the pattern is a static line pattern or a static checkerboard pattern.
58. A scanner according to claims 56 or 57, further comprising means for rotating and/or translating the pattern element.
59. A scanner according to any of claims 56-58, wherein said pattern element is a wheel.
60. A scanner according to any of claims 56-59, wherein said mask possesses rotational and/or translational periodicity.
61. A scanner according to any of claims 56-60, wherein said mask comprises a plurality of radial spokes, preferably arranged in a symmetrical order.
62. A scanner according to any of claims 56-61, wherein the pattern element is located in the optical path.

63. A scanner according to any of claims 56-62, wherein light is transmitted through the pattern element, preferably transmitted transversely through the pattern element.
- 5 64. A scanner according to any of claims 56-63, wherein the time varying pattern is generated by rotating and/or translating the pattern element.
65. A scanner according to any of the preceding claims, comprising at least one segmented light source, such as a segmented LED.
- 10 66. A scanner according to the previous claim, wherein the pattern is generated by means of said segmented light source(s).
67. A scanner according to any of claims 65 or 66, wherein the time varying pattern is generated by switching on and off individual segments of the segmented light source(s).
- 15 68. A scanner according to any of the claims 7 to 67, further comprising means for synchronizing the time varying pattern oscillation with the integration time of a sensor element.
- 20 69. A scanner according to any of the claims 13 to 68, further comprising means for registering and/or monitoring the phase and/or the position and/or the angular position of the time varying pattern and/or the pattern generation means.
- 25 70. A scanner according to any of the claims 56 to 69, wherein the phase and/or the position and/or the angular position of the time varying pattern and/or the pattern element is registered by means of a position encoder on the pattern element.
- 30 71. A scanner according to any of the claims 7 to 70, further comprising means for sampling each of a plurality of the sensor elements a plurality of times during one pattern oscillation period, preferably sampled an integer number of times, such as sampling 2, 3, 4, 5, 6, 7 or 8 times during each pattern oscillation period, thereby determining the correlation measure using the formula,

$$A_J = \sum_{i=1}^n f_{ij} h_i$$

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

72. A scanner according to any of the preceding claims, wherein at least a part of the object surface is imaged in the camera.
- 10 73. A scanner according to any of the preceding claims, wherein a superposition of the pattern with at least a part of the object surface is imaged in the camera.
74. A scanner according to any of the claims 13 to 73, wherein light reflected from the object is retransmitted through the pattern generating means before entering the
 15 camera, preferably retransmitted in the opposite direction.
75. A scanner according to any of the claims 7 to 74, further comprising means for recording each of a plurality of the sensor elements over a plurality of pattern oscillation periods, such as up to 2, 5, 10, 20, 50, 100, 250, 500, 1000, 5000 or up
 20 to 10000 pattern oscillation periods.
76. A scanner according to the previous claim, further comprising means for determining the maximum signal value of each of a plurality of the sensor elements over a range of focus plane positions.
 25
77. A scanner according to any of the preceding claims, wherein the resolution of the measured 3D geometry is equal to the resolution of the camera.
78. A scanner according to any of the preceding claims, wherein the resolution of the
 30 measured 3D geometry is lower than the resolution of the camera, such as at least 2 times lower, such as at least 3 times lower, such as at least 4 times lower, such as at least 5 times lower.

79. A scanner according to any of the preceding claims, wherein the sensor element array is divided into groups of sensor elements, preferably rectangular groups, such as square groups of sensor elements, preferably adjacent sensor elements.
- 5 80. A scanner according to any of the preceding claims, wherein the image of the pattern, such as a line pattern or a checkerboard pattern, is aligned with the rows and/or the columns of the array of sensor elements.
81. A scanner according to any of the preceding claims, wherein at least one spatial
10 period of the pattern corresponds to a group of sensor elements.
82. A scanner according to any of the preceding claims, wherein one or more edges of the pattern is aligned with and/or coincide with one or more edges of the array of sensor elements.
- 15 83. A scanner according to any of the preceding claims, wherein the correlation measure within a group of sensor elements is determined by means of the following formula: $A_j = \sum_{i=1}^n f_{ij} I_{ij}$, where A_j is the correlation measure of the group of sensor elements with label j , n is the number of sensor elements in the
20 group, $f_{1j}, \dots, f_{nj}$ are the values of the weight function based on information of the configuration of the spatial pattern, and $I_{1j}, \dots, I_{nj}$ are the recorded sensor signals at each of the sensor elements in the group.
- 25 84. A scanner according to the previous claim, wherein integration of the weight function over a group of sensor elements is zero, i.e. $0 = \sum_{i=1}^n f_{ij}$, for the group with label j , thereby suppressing the DC part of the correlation measure.
85. A scanner according to any of the preceding claims, further comprising means for
30 selective imaging of specularly and/or diffusively reflected light.
86. A scanner according to any of the preceding claims, further comprising means for polarizing the probe light, such as a polarizing element.

87. A scanner according to any of the preceding claims, further comprising at least one polarizing beam splitter.
- 5 88. A scanner according to any of the preceding claims, wherein an image of the object is formed in the camera by means of at least one polarizing beam splitter.
89. A scanner according to any of the preceding claims, further comprising means for changing the polarization state of the probe light and/or the light reflected from the object.
- 10 90. A scanner according to any of the preceding claims, further comprising a retardation plate and a linearly polarizing element, located in the optical path, a retardation plate such as a quarter wave retardation plate.
- 15 91. A scanner according to any of the preceding claims, further comprising at least one light reflecting element, preferably located along the optical axis, for directing the probe light and/or imaging an object in a direction different from the optical axis, a light reflecting element such as a mirror.
- 20 92. A scanner according to the previous claim, further comprising means for increasing the extension of the scanned surface in the direction of the optical axis.
- 25 93. A scanner according to any of the preceding claims, comprising at least two light sources, such as light sources with different wavelengths and/or different polarization.
- 30 94. A scanner according to the previous claim, further comprising control means for controlling said at least two light sources.
- 35 95. A scanner according to any of claims 93 or 94, further comprising means for combining and/or merging light from the at least two light sources, such as light sources with different wavelengths and/or different polarization states.

96. A scanner according to any of claims 93 to 95, further comprising means for separating light from at least two light sources, such as light sources with different wavelengths and/or different polarization states.
- 5 97. A scanner according to any of the preceding claims, further comprising at least one optical device which is partially light transmitting and partially light reflecting, said optical device preferably located along the optical axis, an optical device such as a coated mirror or coated plate.
- 10 98. A scanner according to the previous claim, comprising at least two of said optical devices, said optical devices preferably displaced along the optical axis.
99. A scanner according to claim 97 or 98, wherein at least one of said optical devices transmits light at certain wavelengths and/or polarizations and reflects light at
15 other wavelengths and/or polarizations.
100. A scanner according to any of claims 97 to 99, comprising at least a first and a second light source, said light sources having different wavelength and/or polarization, and wherein
20 a first optical device located along the optical path reflects light from said first light source in a direction different from the optical axis and transmits light from said second light source, and
a second optical device located further down the optical path reflects light from said second light source in a direction different from the optical axis.
25
101. A scanner according to the previous claim, wherein said first and second optical devices reflect the probe light in parallel directions, preferably in a direction perpendicular to the optical axis, thereby imaging different parts of the object surface.
30
102. A scanner according to the previous claim, wherein said different parts of the object surface are at least partially overlapping.

103. A scanner according to any of claims 93 to 102, comprising control means for providing a coordination of the light sources and the focus element.
- 5 104. A scanner according to any of the preceding claims, further comprising at least one curved fold mirror for directing the probe light and/or imaging an object in a direction different from the optical axis, such as in a direction perpendicular to the optical axis.
- 10 105. A scanner according to the previous claim, further comprising one or more optical elements, such as lenses, with surfaces that may be aspherical to provide corrected optical imaging.
- 15 106. A scanner according to any of the preceding claims, further comprising at least one grating for directing the probe light and/or imaging an object in a direction different from the optical axis, such as in a direction perpendicular to the optical axis.
- 20 107. A scanner according to the previous claim, wherein the grating provides anamorphic magnification, whereby the image of the pattern on the object being scanned is stretched.
- 25 108. A scanner according to claims 106 or 107, wherein the grating is blazed.
109. A scanner according to any of the preceding claims, wherein the point of emission of probe light and the point of accumulation of reflected light being located on a probe, said probe being adapted to be entered into a cavity, such as a body cavity.
- 30 110. A scanner according to the previous claim, wherein the probe is adapted to scan one or more objects in a cavity, such as teeth in a mouth.
111. A scanner according to claim 109, wherein the probe is adapted to scan at least a part of the surface of a cavity, such as an ear canal.
- 35 112. A scanner according to any of the preceding claims, comprising:

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

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

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

10

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

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

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

20

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

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

30

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

121. A scanner according to any of claims 112 to 120, wherein the probe comprises a posterior reflective element, such as a mirror, or prism, for directing the probe light in a direction different from the optical axis, preferably in a direction perpendicular to the probe axis.
- 5
122. A scanner according to the previous claim, further comprising means for rotating the reflective element, preferably around an axis substantially parallel with the optical axis.
- 10
123. A scanner according to any of claims 112 to 122, wherein the probe is adapted to provide scan 360° around the optical axis and/or the longitudinal axis of the probe, preferably without rotation of probe and/or scanner.
- 15
124. A scanner according to any of claims 112 to 123, wherein a plurality of different probes matches the housing.
- 20
125. A scanner according to any of claims 112 to 124, comprising a first probe being adapted to scan the interior part of a human ear and a second probe being adapted to scan the exterior part of said human ear.
- 25
126. A scanner according to any of claims 112 to 125, wherein the housing is adapted to perform a 3D surface scan.
- 30
127. A scanner according to any of claims 112 to 126, wherein the housing with the probe attached is adapted to scan the interior part of a human ear and the housing with the probe detached is adapted to scan the exterior part of said human ear.
128. A scanner according to any of claims 112 to 127, further comprising means for merging and/or combining 3D data for the interior and exterior part of the ear, thereby providing a full 3D model of a human ear.
129. A scanner according to any of the preceding claims, being adapted to impression scanning, such as scanning of dental impressions and/or ear channel

impressions.

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

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

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

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

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

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

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

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

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

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

30

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

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

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

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

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

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

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

- each of a plurality of the sensor elements for a range of focus plane positions, or
 - each of a plurality of groups of the sensor elements for a range of focus plane positions, and
- 5 - transforming in-focus data into 3D real world coordinates;
wherein the method further comprises counter-balancing the means for varying
the position of the focus plane.

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

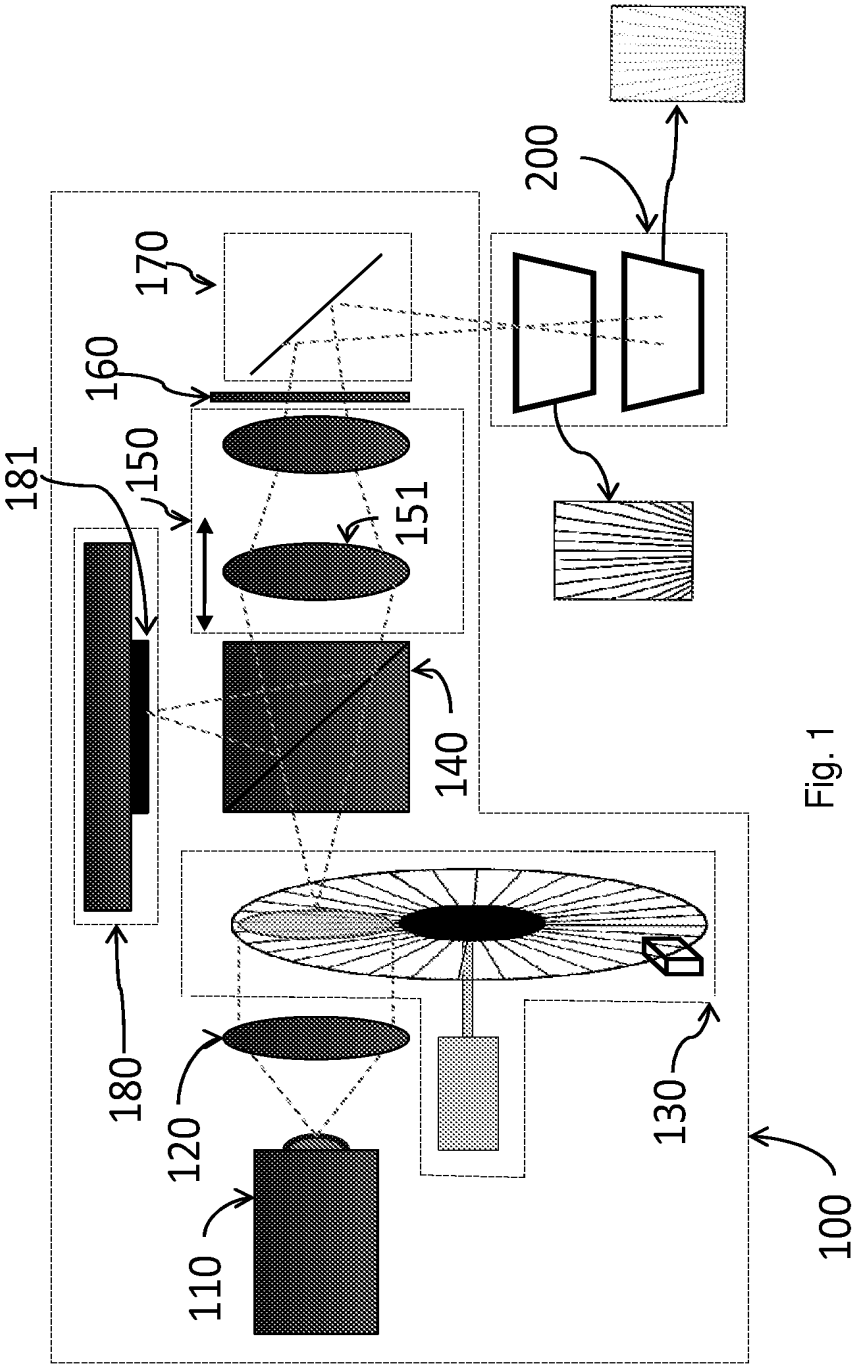


Fig. 1

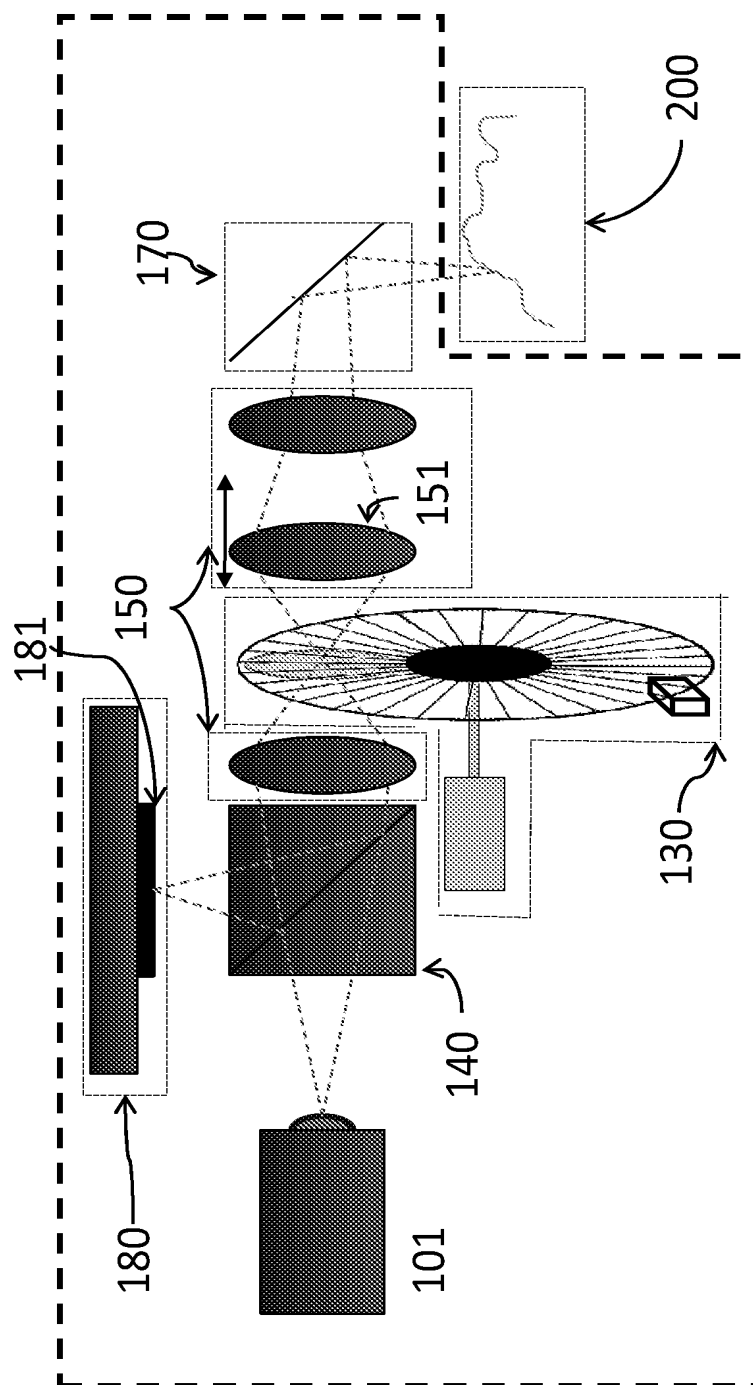


Fig. 2

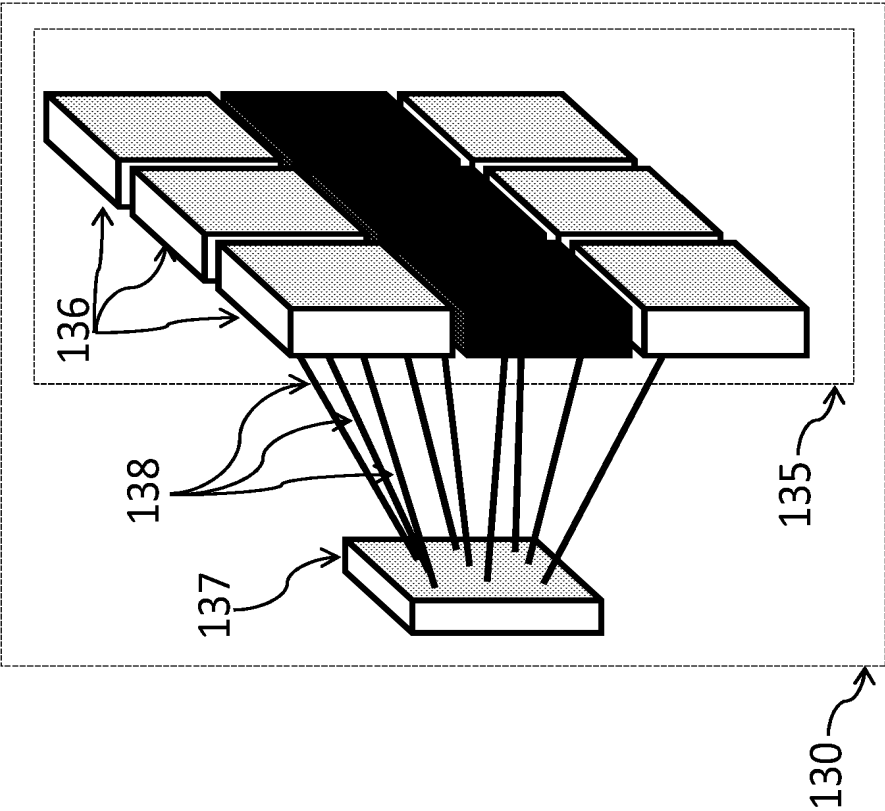


Fig. 3a

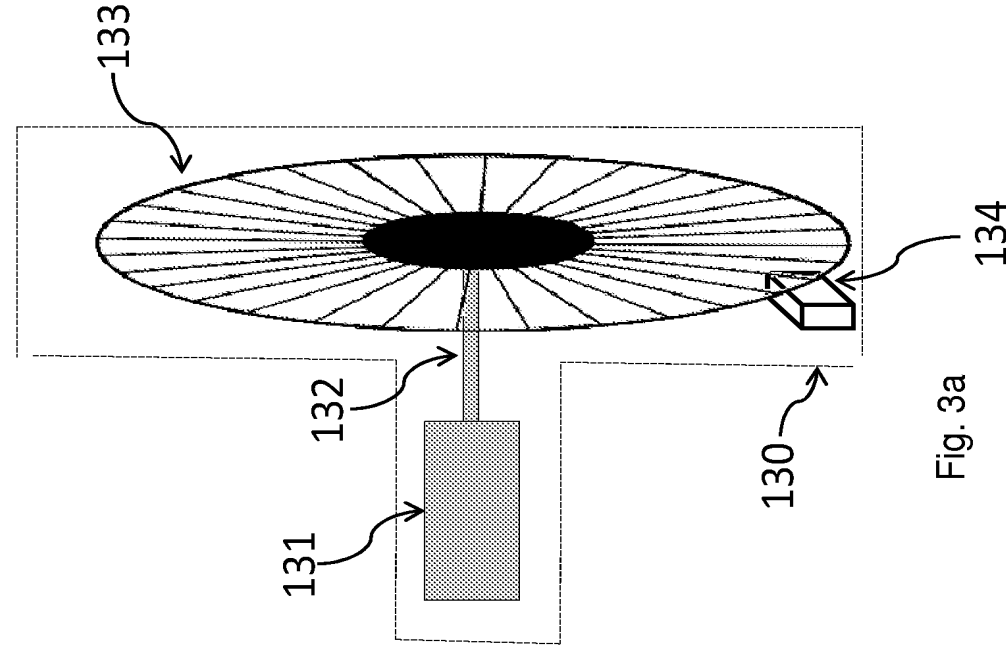


Fig. 3b

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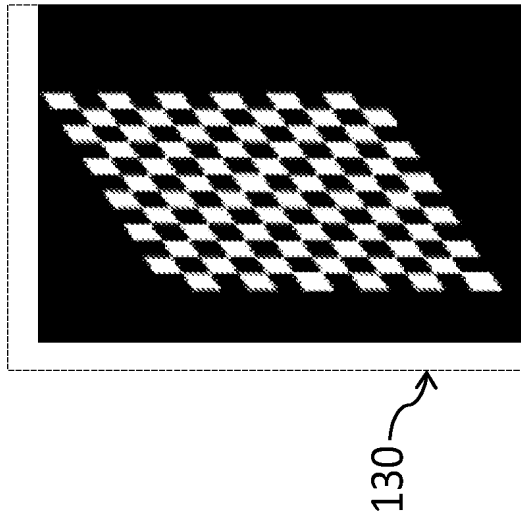


Fig. 3c

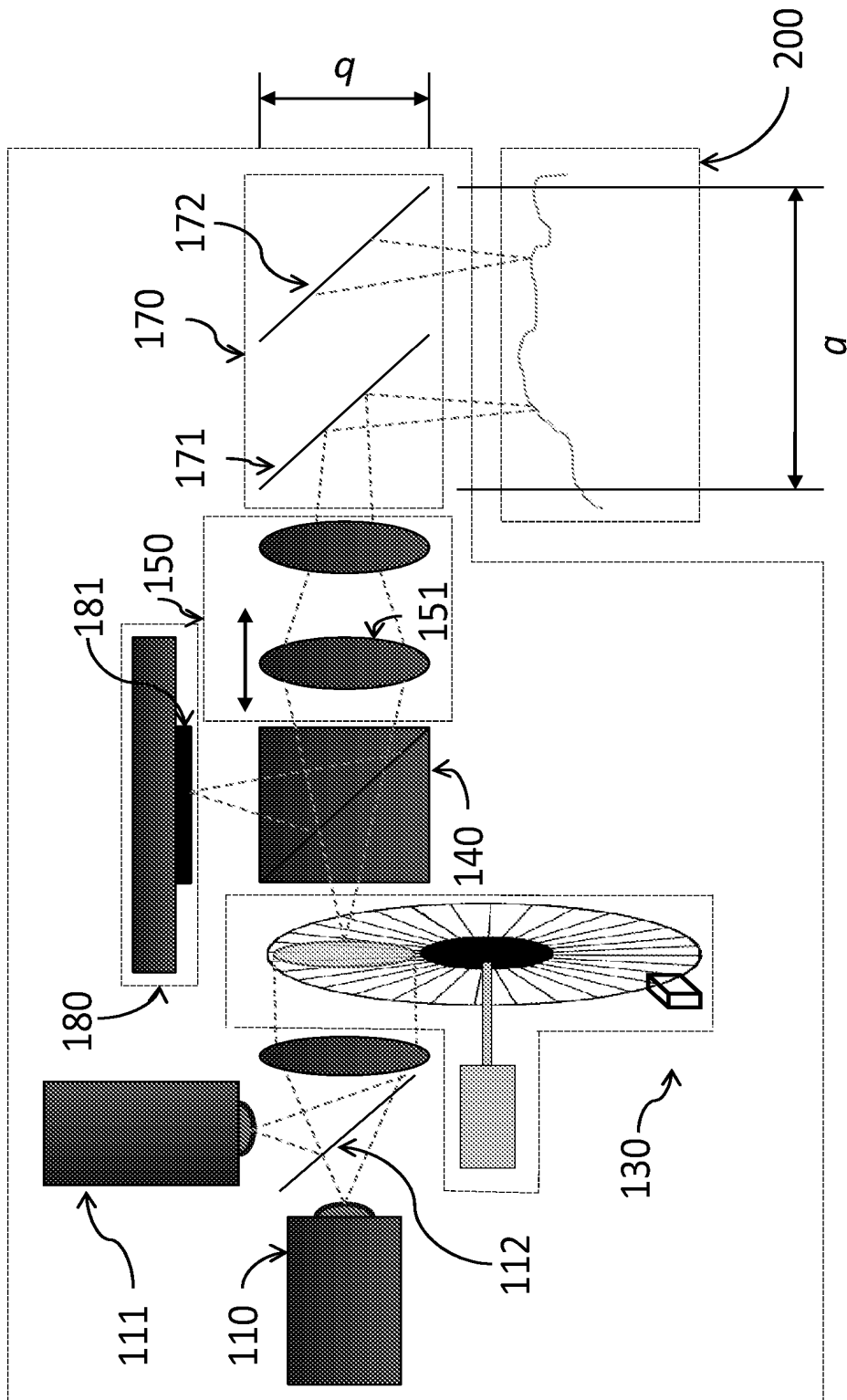


Fig. 4

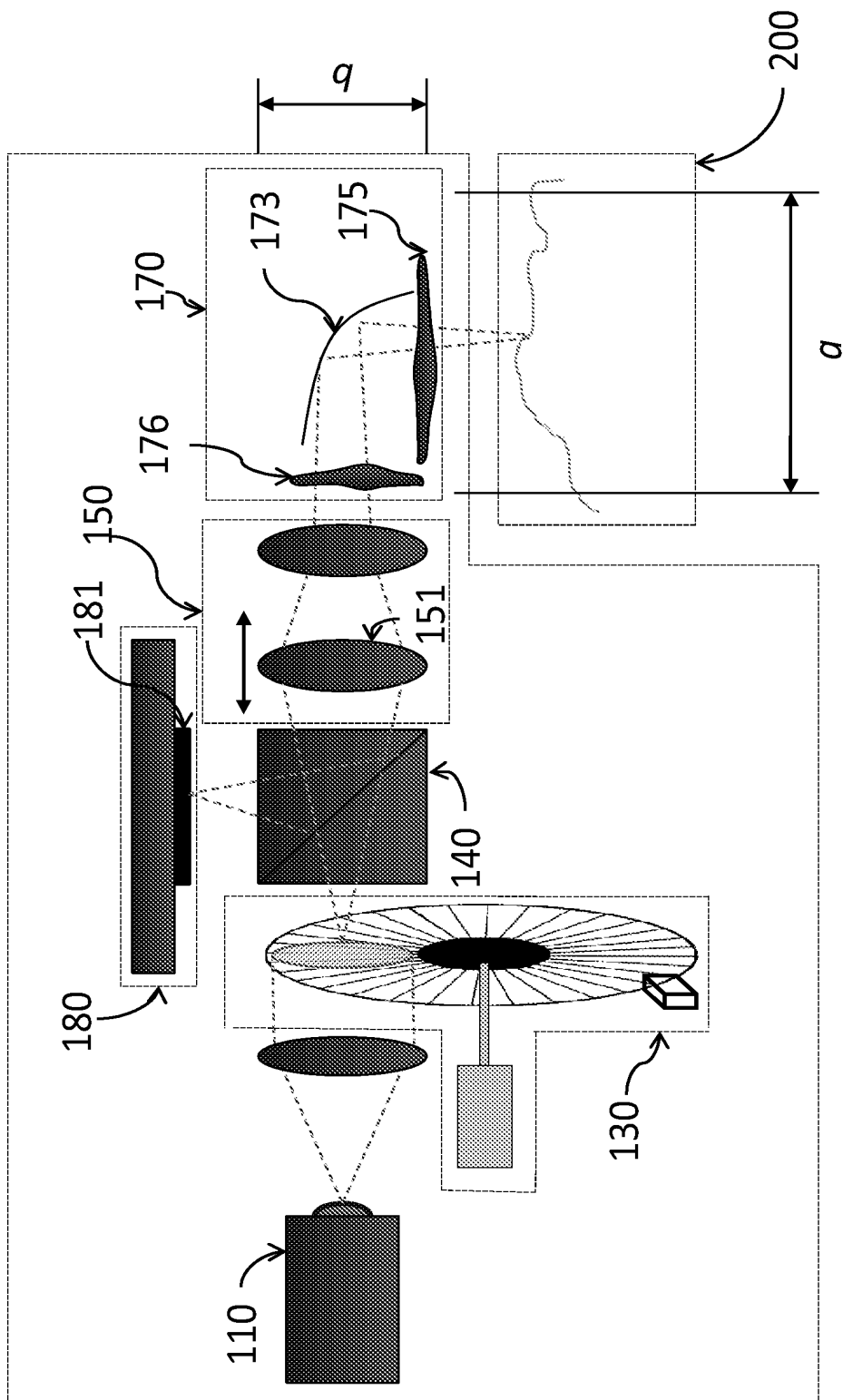


Fig. 6

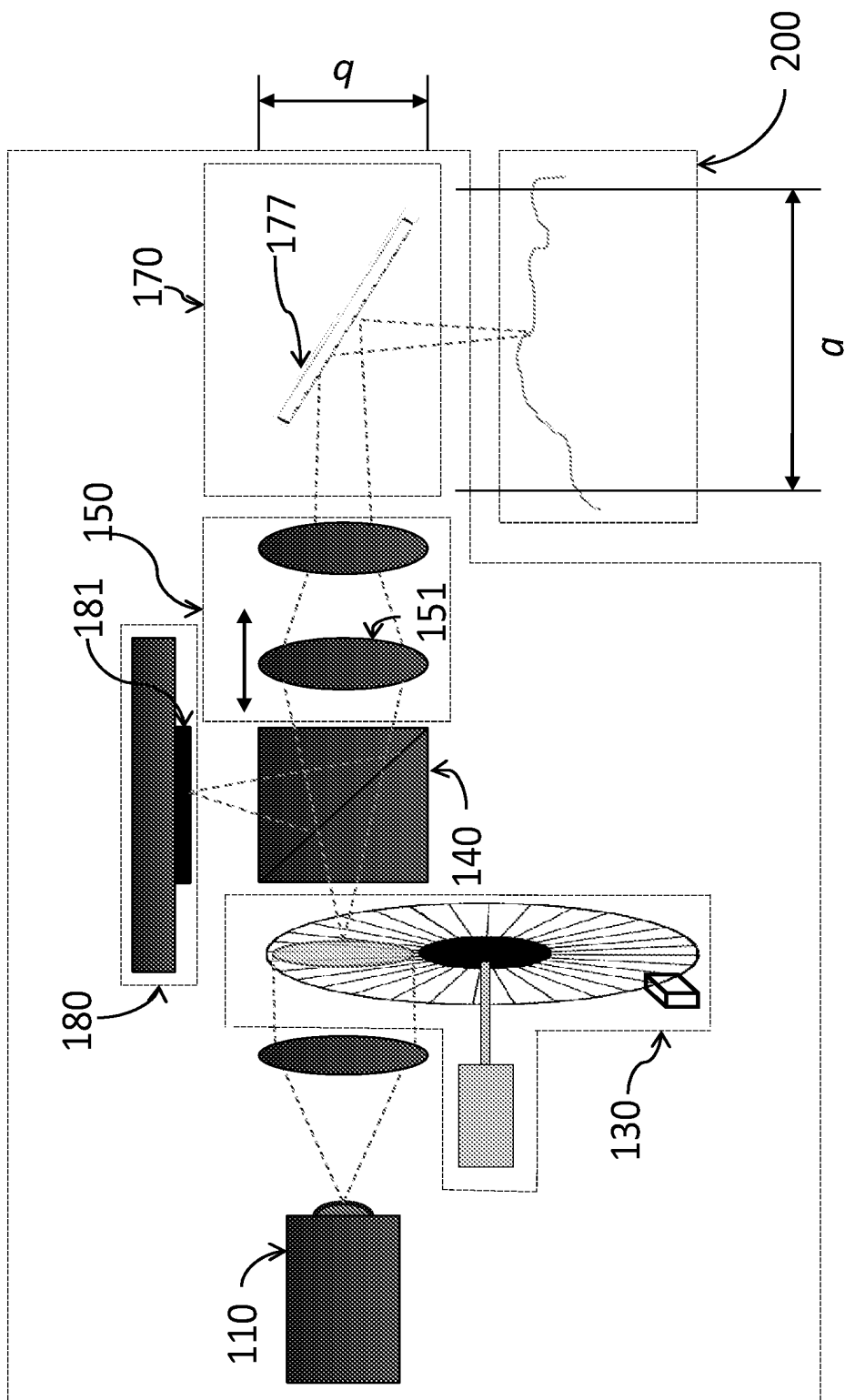


Fig. 7

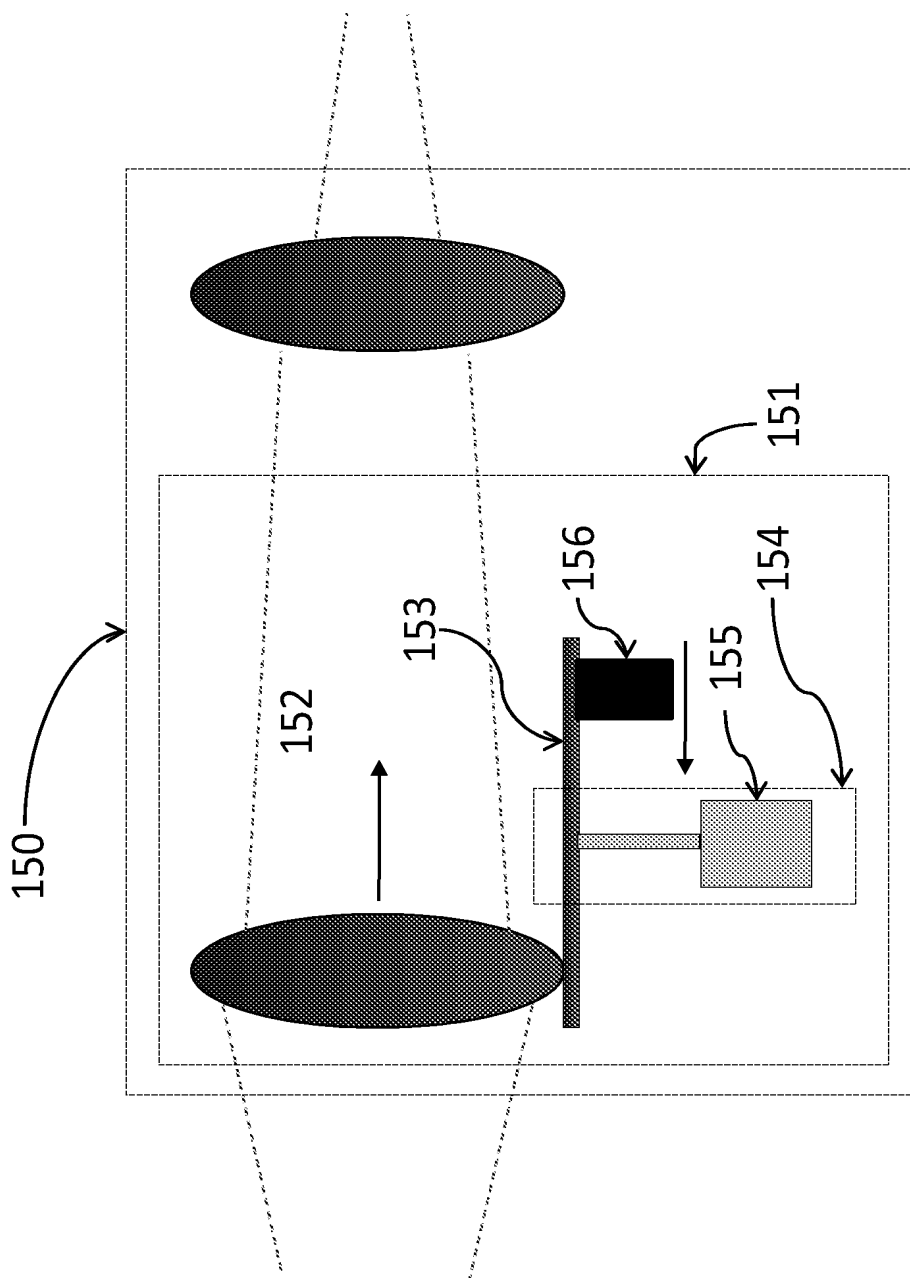


Fig. 8

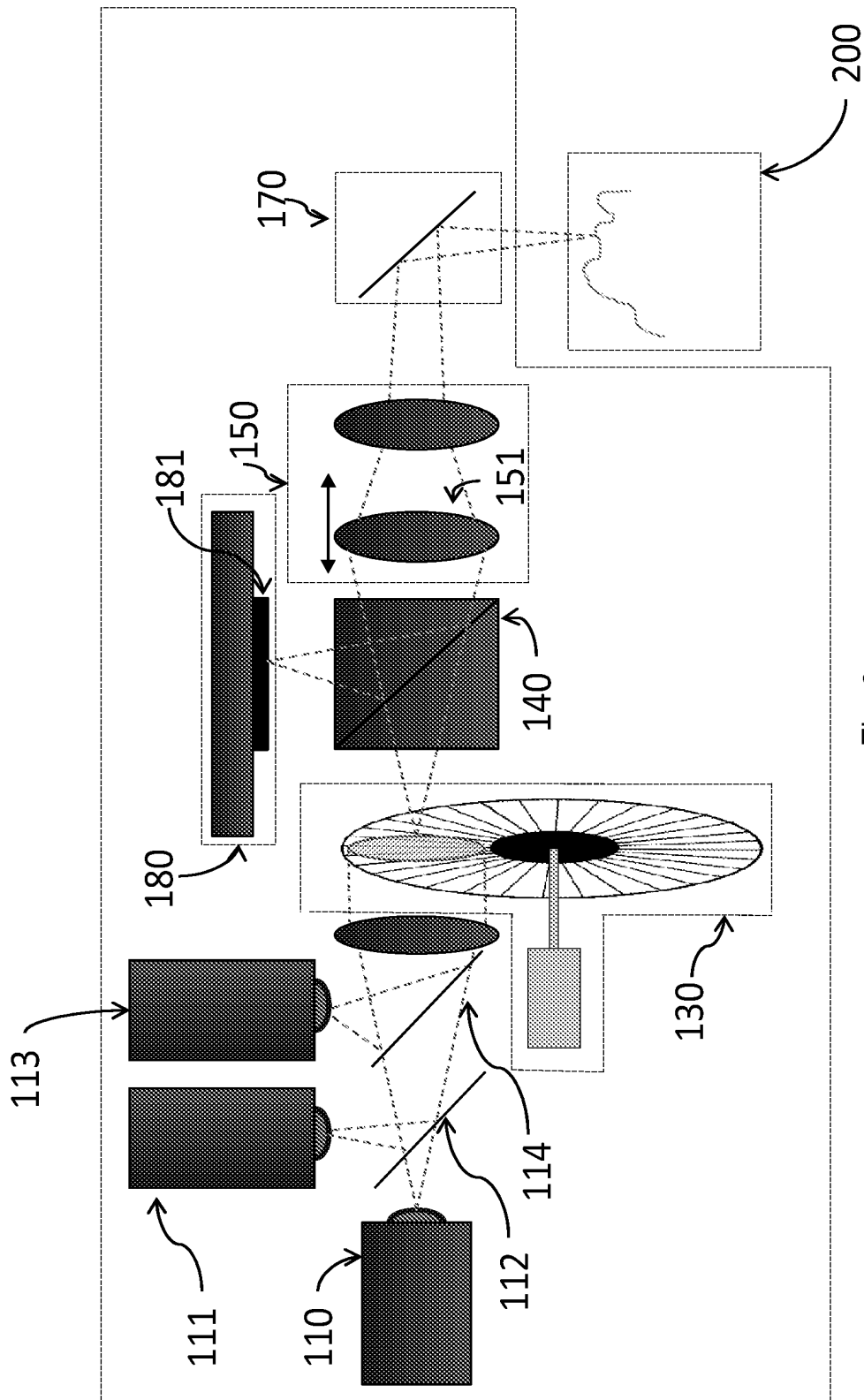


Fig. 9

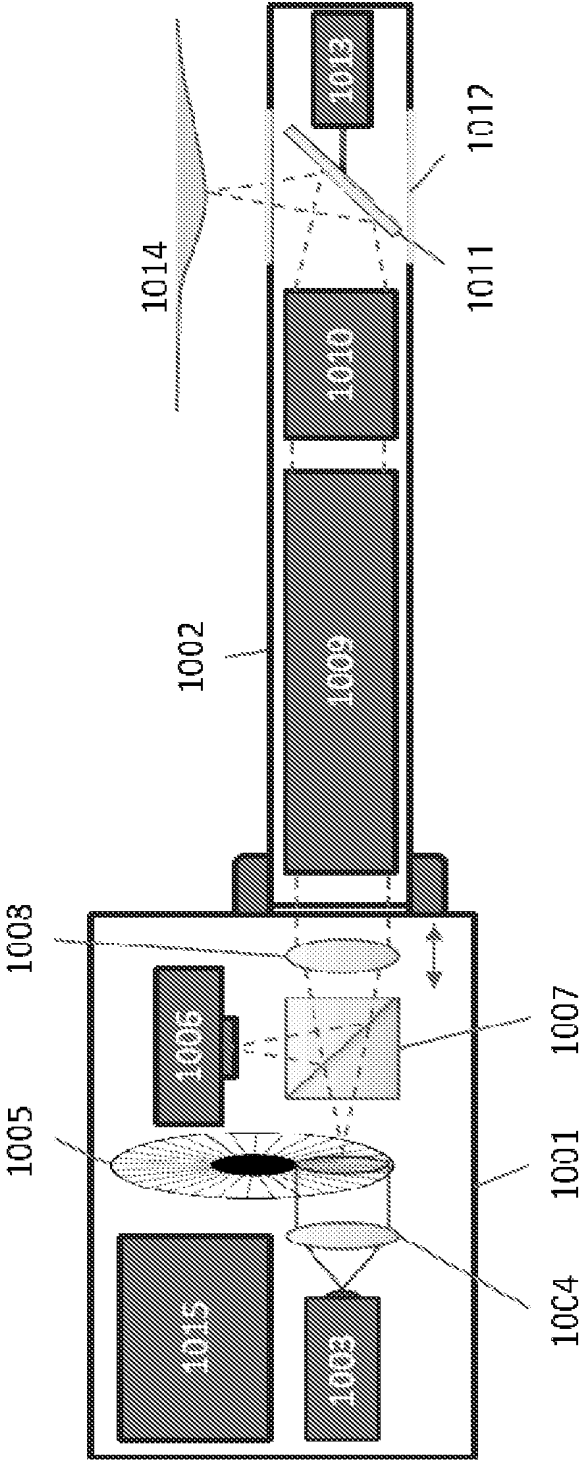


Fig. 12

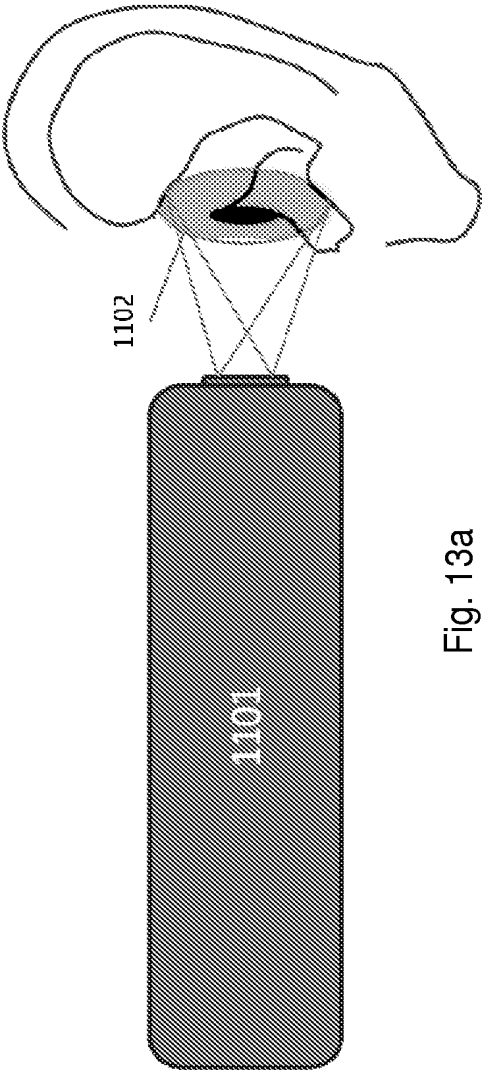


Fig. 13a

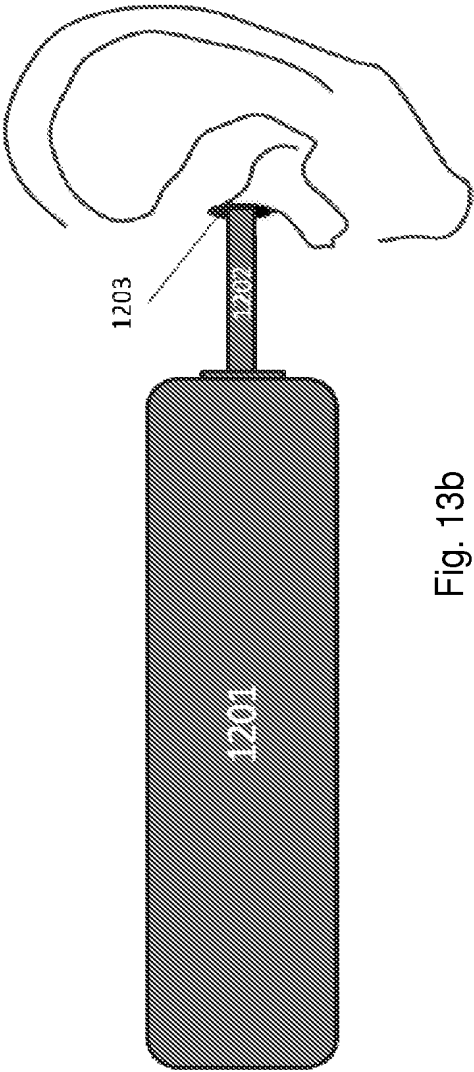


Fig. 13b

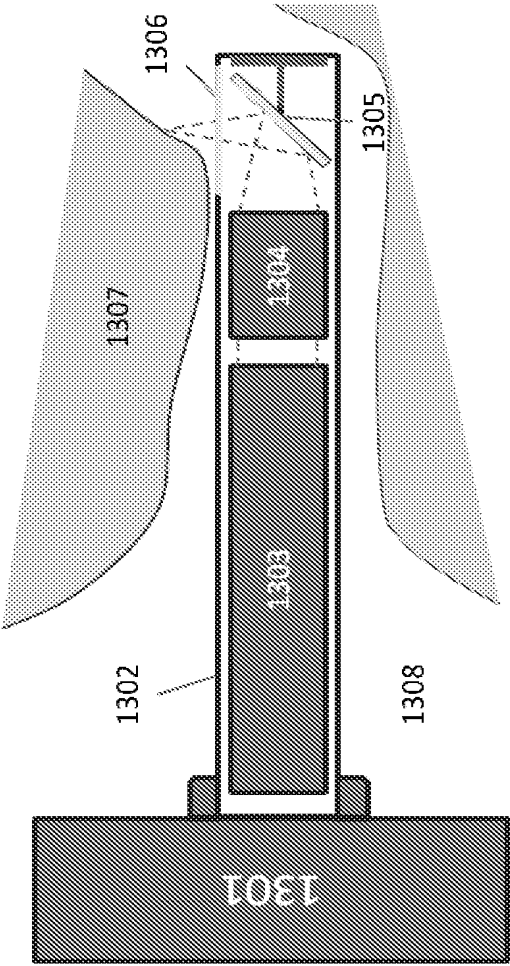


Fig. 14

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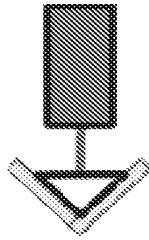
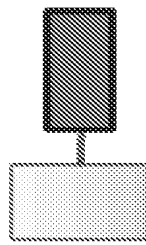


Fig. 15d

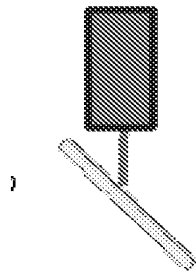
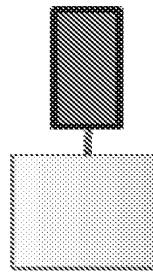


Fig. 15c

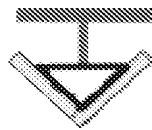
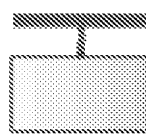


Fig. 15b

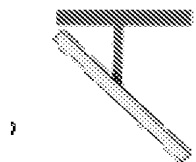
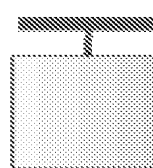


Fig. 15a

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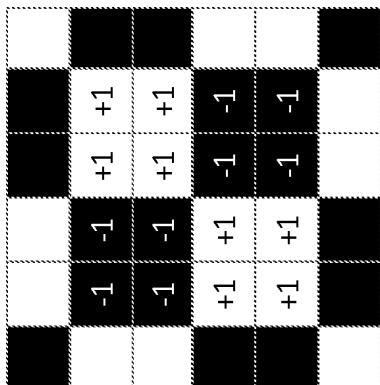


Fig. 16

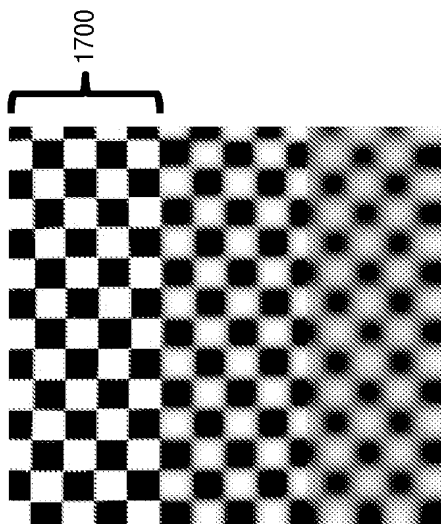


Fig. 17c

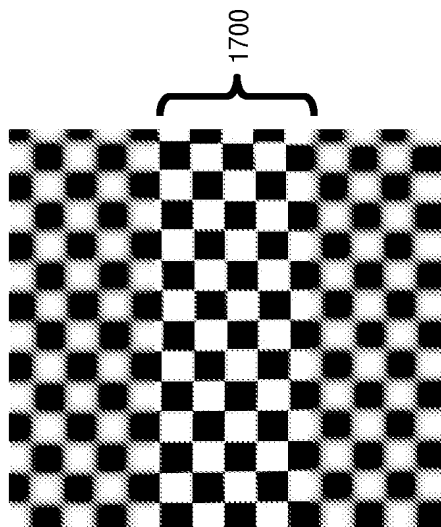


Fig. 17b

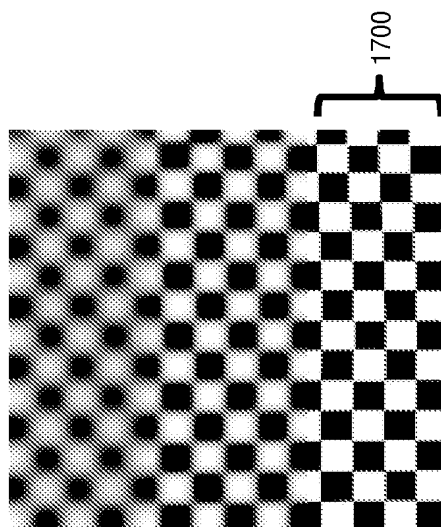


Fig. 17a

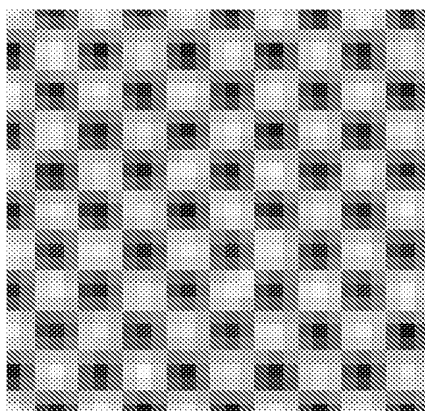


Fig. 17e

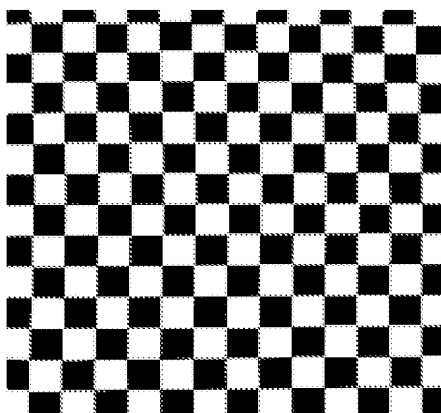


Fig. 17d

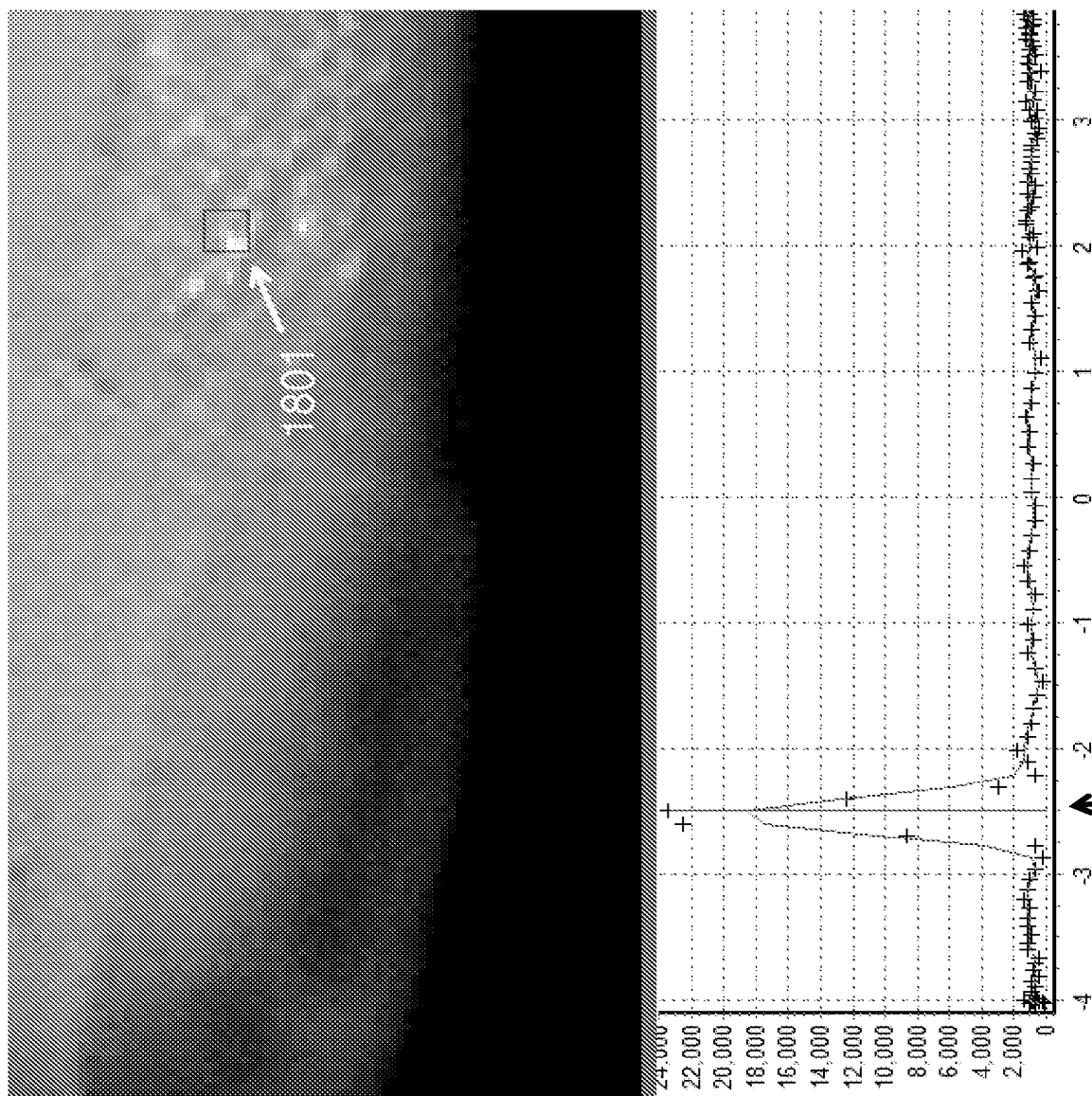


Fig. 18

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Fig. 19

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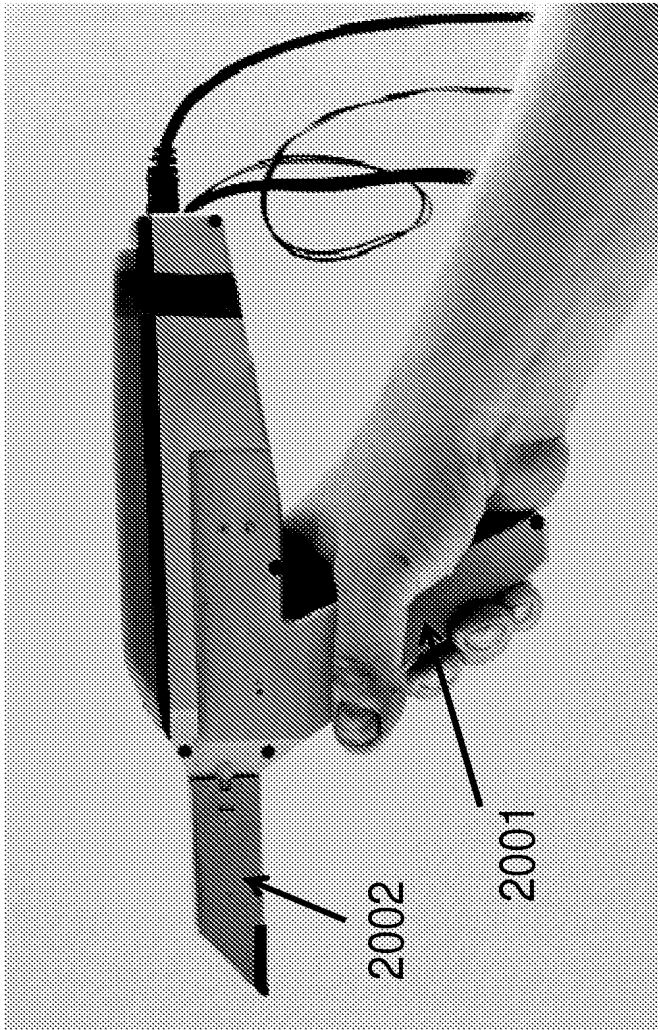


Fig. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2010/050148

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/107
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)
A61B

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

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

EPO-InterPat 1

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

☒ Further documents are listed in the continuation of Box C

☒ See patent family annex

* Special categories of cited documents

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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

29 September 2010

Date of mailing of the international search report

06/10/2010

Name and mailing address of the ISA/
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Authorized officer

Hunt, Brynley

INTERNATIONAL SEARCH REPORT

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/DK2010/050148

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

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DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
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ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI,
NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD,
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EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
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Published:

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(54) Title: SCANNING OF CAVITIES WITH RESTRICTED ACCESSIBILITY

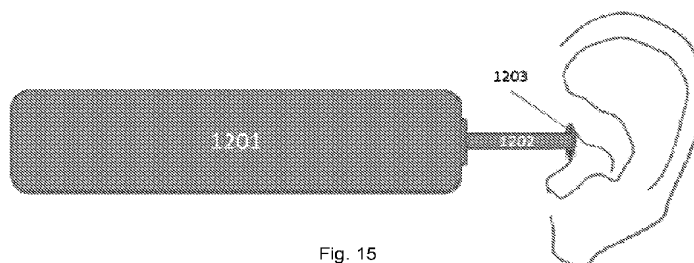


Fig. 15

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

Scanning of cavities with restricted accessibility

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

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

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

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

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

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

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

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

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

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

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

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

25

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

In some embodiments, the method comprises:

- providing that the camera comprises a plurality of sensor elements or a plurality of groups of sensor elements;
- varying the focus plane of the pattern over a range of focus plane positions while maintaining a substantially fixed spatial relation of the camera and said interior surface,

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

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

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

15

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

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

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

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

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

Disclosed is a method for scanning interior surfaces comprising the

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

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

15 surface information, by e.g. using kinds of data other than image data.

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

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

In the context of the present invention, the phrase "hole in the surface information" may relate to a part of the surface where data is lacking. Such a

25 lack of data may e.g. occur when visual access to the interior surface is blocked. The holes may also be referred to as occluded holes when caused by an object that blocks the visual access to the interior surface of the object

Furthermore it is an advantage that surface information can be obtained even

30 if the surface in e.g. the ear is not clean, such that 2D images do not correctly show the recorded surface, e.g., if there are foreign objects, such as ear wax

in the ear covering parts of the surface, or if there are other foreign objects such as hair, scars or animals in the ear diminishing the quality of the scanning. Thus foreign object may be hair, ear wax, small animals such as insects, eggs from insects, pearls, sand, dirt, pimples, scars etc.

5

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

10

Both the ear canal and the external part of the ear, called the pinna, may be scanned.

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

15

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

20

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

25

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

30

Furthermore it is an advantage that the direct scanning of the ear significantly reduces the production cost of hearing aids, since the impressions used

today are rendered superfluous. Obviating the impression removes the handling and mailing cost and cuts down the production time and improves flexibility.

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

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

According to one aspect the invention relates to a method for 3D modeling and production comprising obtaining 3D real world coordinates of an interior surface of a cavity provided using the method according to the invention, and
15 creating a piece adapted to fit into the cavity.

Thereby, the steps for manufacturing the piece are reduced to the absolute minimum and an essentially perfect fit of the piece can be obtained. The interior surface may be scanned a number of times, such as under different conditions affecting the geometry of the interior surface. Thereby the
20 variations in the dimensions of the interior surface can be recorded. This is very cumbersome using the prior art techniques.

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

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

5

In some embodiments holes in the surface information are registered.

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

In some embodiments holes in the surface information are closed by fitting to higher-order mathematical surfaces, such as second-order, third--order, fourth-order etc.

15 The information from neighbour areas etc can be used to infer the contour at holes. Thus the artificial hole closing may be performed by fitting parametric surface such as spline surface or higher-order mathematical surfaces.

In some embodiments holes in the surface information are closed by using
20 information about where there exists no surface.

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

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

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

5

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

It is an advantage to use data from other sources or sensors than the camera providing the image data, if there exist no image data covering an area of the surface.

10

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

15

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

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

In some embodiments a part of the data of surface information of the left ear is used as a part of the data of surface information for the right ear, if there are parts of the right ear where surface information has not been acquired, and vice versa.

25

It is an advantage to use corresponding scan data from one ear to the other ear, because of symmetry between a person's two ears.

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

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

10

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

In some embodiments identifying foreign objects comprises detecting reflections from the foreign object.

- 15 It is an advantage because foreign objects such as hair may reflect light very well, and thus the reflections from hair and other foreign objects may be distinct from reflections from skin in the ear.

- 20 In some embodiments a foreign object is identified by analyzing the difference in the reflected light from the skin and the foreign object, respectively.

The difference in the reflected light may be the difference in contrast of the reflected light.

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

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

30

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

5

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

10

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

20 In some embodiments the method comprises identifying foreign objects by correlating surface data with the 3D position of the specific data.

It is an advantage because the places in the ear where hair and ear wax are typically present may be known in advance. Likewise the places in the ear where hair or ear wax seldom or never are present may also be known in advance. Thus by correlating the predefined knowledge about typical places for hair and ear wax, respectively, with the actual scan, it is possible to either rule out that a foreign object can be hair or ear wax, or possible to determine with a high probability that a detected foreign object is hair or ear wax.

25

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

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

- 5 In some embodiments foreign objects in the ear are filtered out from the images of the ear.

It is an advantage that the ear shall not be cleansed and rinsed before scanning the ear, because foreign object such as ear wax is filtered out from the images.

10

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

15

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

20

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

In some embodiments detecting hair comprises detecting and deleting single points on the images.

25

It is an advantage because hair may appear as single points on the images, because a hair is normally not thick enough to provide a real image of it.

In some embodiments detecting hair comprises detecting the root of the hair in the skin.

30

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

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

- 5 In some embodiments detecting hair comprises detecting the thickness of the hair.

It is an advantage because hereby it can be determined whether a hair is so thick that it may influence the measurements or whether the hair is thin enough to be disregarded.

10

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

- 15 In some embodiments the method comprises determining whether scar tissue is fresh or old, when detecting a foreign object in the form of scar tissue,

It is an advantage because if the scar is fresh, the scar should heal before the ear scanned and a hearing device is applied in the ear.

- 20 On the other hand if the scar is old, then a hearing device can be fitted by avoiding that the hearing device applies pressure on the scar, which will be uncomfortable for the user.

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

In some embodiments color filters are applied to the light source.

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

30

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

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

- 5 In some embodiments the light source emits multi-colored light.

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

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

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

20

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

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

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

30

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

5 In some embodiments the polarization state of the emitted and/or the detected light is controlled.

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

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

In some embodiments the light source is a laser and light from said laser is guided to impinge on the surface in a small spot.
20

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

25 In some embodiments the light source emits infrared light.

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

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

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

- 5 In some embodiments the method comprises detecting the hardness under the skin in different parts of the ear canal.

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

- 15 In some embodiments light with different wavelengths is used to detect the hardness under the skin in the ear canal.

It is an advantage because the different layers of skin, bone, tissue etc has different properties regarding absorption and/or scattering for different light wavelengths.

20

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

scattering. Soft or hard tissue in the ear may differ in the amount of light absorption and/or scattering. Thus this may be used to identify soft or hard regions in the ear.

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

10 In some embodiments the scanner comprises guide means adapted to assist the operator in holding the scanner in the correct distance and/or position relative to the ear.

The distance may be relative to an external part of the ear, the pinna, or relative to a part of the ear canal.

15

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

The point on the ear may a point on the external part of the ear.

20

In some embodiments the guide means comprises a first and a second set of two laser beams, and when the first set of laser beams are crossing each other at a first point on the ear, the distance between scanner and ear is correct for scanning of a first region of the ear, and when the second set of

25 laser beams are crossing each other at a second point on the ear the distance between the scanner and ear is correct for scanning of a second region of the ear.

The points on the ear may be one point or two different points on the external part of the ear. The first and the second point may indicate the distance the

30 scanner probe should be moved in/out of the ear.

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

In some embodiments the ear is scanned in a first configuration where the mouth is closed, and in a second configuration, where the mouth is open.

- 5 It is an advantage because then the two extreme configurations of the jaw and mouth and thereby the ear are recorded.

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

In some embodiments the image data of the first and the second configurations are merged into one image by means of CAD.

- 15 Thus it is possible to superimpose the scans on one another to create a combined image or model, which will fit the patient's ear under all conditions. Such a model is naturally made as a combination of or a compromise between the different sizes of the ear canal.

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

- In some embodiments the touch sensor comprises a tactile component at the
25 probe tip.

It is an advantage to also perform a touch or contact measurement to thereby obtain a double check of the real time image detection, and to acquire further data which can be used to obtain a complete scan of the ear canal.

- 30 In some embodiments the touch sensor is a capacitive sensor.

In some embodiments the direction of the ear canal towards the ear drum is determined by means of image data and/or one or more other data.

It is an advantage because when the direction of the ear canal towards the ear drum is known, the speaker or transceiver in a hearing aid can be arranged such that it points directly towards the ear drum, whereby the user of the hearing aid will receive the sounds directly at the ear drum, whereby the sound quality is improved for the user.

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

It is an advantage also to perform motion measurement, since this can be used in registration.

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

In some embodiments the scanner comprises a number of marks in its cover, such that an operator can visually determine how far the scanner must be moved into the ear canal.

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

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

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

In some embodiments a user interface of the scanner is adapted to direct the operator to move the probe a certain distance in any three-dimensional direction.

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

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

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

It is an advantage to record the scanner position relative to the ear by means of a regular camera capturing photographs or by means of a video camera.

In some embodiments the method comprises the steps of:

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

- determining the in-focus position(s) of:

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

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

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

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

5

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

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

25

The method and apparatus relating to focus scanning is for providing a 3D surface registration of objects using light as a non-contact probing agent. The light is provided in the form of an illumination pattern to provide a light oscillation on the object. The variation / oscillation in the pattern may be

30 spatial, e.g. a static checkerboard pattern, and/or it may be time varying, for example by moving a pattern across the object being scanned.

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

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

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

When a time varying pattern is applied a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane and
30 at different instances of the pattern. As the focus plane coincides with the scan surface at a single pixel position, the pattern will be projected onto the

surface point in-focus and with high contrast, thereby giving rise to a large variation, or amplitude, of the pixel value over time. For each pixel it is thus possible to identify individual settings of the focusing plane for which each pixel will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel basis.

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

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

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

The 2D to 3D conversion of the image data can be performed in a number of ways known in the art. I.e. the 3D surface structure of the probed object can be determined by finding the plane corresponding to the maximum light oscillation amplitude for each sensor element, or for each group of sensor

elements, in the camera's sensor array when recording the light amplitude for a range of different focus planes. Preferably, the focus plane is adjusted in equal steps from one end of the scanning region to the other. Preferably the focus plane can be moved in a range large enough to at least coincide with
5 the surface of the object being scanned.

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

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

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

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

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

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

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

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

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

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

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

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

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

- 5 In some embodiments, the data conversion device and said probe shaped scanner are integrated in one device.

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

- 10 In some embodiments, the said data processing device and said probe shaped scanner are integrated in one device.

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

15

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

20

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

25

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

30

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

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

10

Brief description of the drawings

15 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:

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

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

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

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

30

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

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

10

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

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

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

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

25

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

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

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

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

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

Fig. 16 shows an example of scanner with an extra camera mounted.
10

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

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

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

parts of the surface at each position and usually it has to be moved around handheld or automatically to scan the full interior surface.

- The light is generated by one or more light sources such as lasers, variable output-powered laser, light emitting diodes (LED), halogen spots or other spotlights and travels through the light guides such as optical fibers. In some applications it might be relevant to use monochromatic, coherent or polarized light. At the end of the light guides optics and mirrors and/or prisms may create the desired pattern. Examples of optics are filters, lenses or prisms.
- 5
- 10 An alternative to the use of light guides is to place the light source near the tip of the scanner. Note that the projection of light, even lasers, onto the surface does not damage the surface.

- The light sources for some applications preferably are as small as possible to minimize the dimensions of the scanner. It is thus contemplated that the light source may have a cross section perpendicular to the direction of emitted light of less than 5 mm², preferably less than 4 mm², for example less than 3 mm², such as less than 2 mm², for example less than 1 mm², such as less than 0.5 mm², for example less than 0.25 mm².
- 15

- The scanner may work with only one light source, but for many purposes it is advantageous to have several such as at least two light sources, such as at least three light sources, for example at least four light sources, such as at least five light sources, such as at least six light sources, for example at least seven light sources, such as at least eight light sources, for example at least ten light sources, such as at least twelve light sources, for example at least sixteen light sources, such as at least twenty light sources.
- 20
- 25

Depending on the desired pattern one, two, three or more optics and one, two, three, four or more mirror and/or prisms are required. The structured light pattern may be a number of rays forming a grid of spots on the surface

consisting of one, two, three, four or more rows of points, one, two, three or more cones of light forming contours on the surface, one, two, three or more planes of light forming contours on the surface, one, two, three or more thick planes of light forming thick contours on the surface, a number of rectangular shaped rays forming a distorted checker board pattern on the surface or more complex shapes.

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

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

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

Occlusion effects represent a problem for some types of scanning of interior surfaces. Some of these can be overcome by selecting a direction of emission and recording of light with respect to the axis of the scanner, which

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

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

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

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

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

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

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

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

The light pattern may be reflected from the surface directly into the camera or into one or more light reflecting means such as mirrors or prisms before ending up in the camera. In the embodiment of the scanner in Figure 1 no mirrors are applied, since the scanner only needs to "look" forward with respect to the camera, i.e. the direction of the view is always parallel with the optical axis of the camera. Figure 5 illustrates the simple emission of the light pattern 501 and its reflections 504 from the object surface 502 into the

camera 505 without the use of mirrors. Figure 5 is a simplified illustration of the principle used in the scanner in Figure 1.

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

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

In the case of very small dimensions of the cavity and/or high requirements for accuracy it is infeasible to place the camera on the head of the scanner. The problem is solved by moving the cameras out of the probe. The image/light is then directed into the cameras by the use of light guides such as a lens system or optical fibres. An embodiment of the invention where a

lens system 701 and optical fibres 801 are used as light guides are illustrated in Figure 7 and Figure 8, respectively. The lens system might be similar to the lens systems used in periscopes and endoscopes. At the moment the lens system is superior to optical fibres with respect to smallest dimensions and image quality. The disadvantage of the lens system is that it requires the probe be rigid, whereas the optical fibres are fully flexible, i.e. the probe can be flexible.

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

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

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

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

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

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

In the case of scanning the human ear canal the width of the part is requested to be below 4 mm. Figure 3 shows a scanner designed for scanning ear canals, where the width of the probe is 3.5 mm. The length of

the probe can also be varied freely down to approximately 5 mm, e.g. the length can be 20, 35, 50, 100, 200, 300 or 500 mm. The length of the probe shown in Figure 1 and Figure 3 is 55 mm.

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

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

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

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

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

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

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

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

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

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

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

A possibility according to the invention is to scan the ear canal directly. This can be done by building the components of the scanner into an apparatus, which can be inserted into the ear of the patient. Embodiments of this
25 scanner are shown in Figure 11. Preferably, the light source, e.g. the laser, and the camera are located outside the ear. The laser light can be carried into the scanner by light guides 201, and similarly, the reflected signals can be carried to a camera by another light guide 801. The scanner also consists

of a position sensor 203, which measures the relative position of the scanner with respect to the object. During the scan, the scanner preferably rests on the edge of the ear canal, most preferably in those places where bones are closest to the skin surface. This is in order to obtain the highest stability and is very important, since the scanner itself works with an accuracy of less than 0.05 mm. The length of the ear canal can be scanned by moving the scanner in or out and record a series of overlapping images of the ear canal. The scanner may comprise only one laser source and one camera as the one shown in the left of Figure 11. In that case the scanner has to rotate while the camera records images. The scanner may comprise multiple laser sources such as four as shown in the scanner in the right part of Figure 11. The presence of multiple laser sources and cameras removes the need for rotation of the scanner in the ear canal. In the laser scanner disclosed in Figure 11, the laser source or sources project a ray of laser light on the surface of the ear canal.

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

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

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

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

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

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

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

25 Devices based on detection of vibration instead of sound can be used in the noisiest environments, since they only pick up the speech of the wearer and they allow for quiet communication, since the speaker can speak with a low

voice when needed. The devices allow for completely hand-free communication.

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

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

- To obtain the highest precision both the light pattern and the camera need to be calibrated. Preferably the calibration should be performed using a calibration object with symmetrical 3D object feature curves and the corresponding methods as described below and in 3Shape's prior art
15 document "Method for modeling customized earpieces" with publication number WO02071794 published in 2002. The main advantage of this type of calibration objects is that the light pattern can be calibrated independently of the calibration of the camera. An embodiment of the hollow calibration object used for calibration of the scanner is shown in Figure 10. Note the symmetric
20 3D object feature curves 1001 on the calibration object, which are utilized in the calibration.

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

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

The image feature coordinates are found as the intersection between image feature curves. These intersections could be seen in the images as corners or sharp edges of the image feature curves. The image feature coordinates may be found as the intersection between the image feature curves such as

5 the intersection between two n^{th} order curves, as the intersection between two first order curves, as the intersection between two second order curves, as the intersection between two third order curves, as the intersection between a first order curve and a second order curve, as the intersection between a first order curve and a third order curve, or as the intersection

10 between a second order curve and a third order curve or as the intersection between any other possible combination of curves.

Preferably, the calibration method comprises plotting of a mathematical combination of image feature points or features derived from these points against the angle of rotation or the translation of the calibration object. By

15 plotting this function and optionally estimating a mathematical function describing the relationship between the function of an image coordinate and the angle of rotation or the translation, estimation of the light parameters and angle or rotation and/or translation becomes especially precise. The method may comprise determination of the mean plane of symmetry in the plot.

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

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

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

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

- 2D coordinates of the 3D object feature curves corresponding to a discrete number of values of angle or rotation and/or translation may be calculated from mathematical functions determining the 3D object feature curves. In order to determine the calibration parameters such as camera position, camera orientation, and camera optic parameters, pairs of 2D light pattern coordinates are compared to calculated 2D coordinates for a discrete number of values of angle or rotation and/or translation. This comparison preferably comprises using the Tsai or the Heikkilae algorithm. The advantage of the Tsai and the Heikkilae algorithms in this context is that they provide rapid and precise estimation of the calibration parameters such as radial lens distortion.
- Alternative methods for calibration comprise direct linear transformation and direct non-linear matrix transformation optionally in combination with an optimization procedure such as least squares to minimize the error. In these cases initial calibration parameters may be estimated to facilitate the convergence of the parameters during optimization.
- To improve calibration, precision outliers may be excluded from the calibration. Outliers can e.g. be identified in the plot of the mathematical combination of image feature coordinates against the angle of rotation / the translation or by back projection of coordinates after an initial calibration.

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

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

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

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

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

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

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

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

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

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

In fig. 17b) two sets of two laser beams 1613, 1616 from two sets of light sources 1612, 1615, respectively, guide the scanner operator (not shown) to
30 hold the scanner 1601 in the correct distance from the ear 1604 for scanning. The two sets of light sources 1612, 1615 are arranged on the external part of

the scanner 1601. The two laser beams 1613 cross each other at a first point 1614, and the two other laser beams 1616 cross each other at a second point 1617. When for example the first point 1614 is at the external surface of the ear, then the scanner 1601 is in a correct first distance from the ear 1604, and when for example the second point 1617 is at the external surface of the ear, then the scanner 1601 is in a correct second distance from the ear 1604. The first distance may be the distance in which a first set of scanning images are made, and afterwards the scanner 1601 may be moved into the ear to the second distance to capture a second set of scanning images or vice versa such that the scanner 1601 is first arranged at the second distance to capture images and then the scanner is moved out of the ear to the first distance to capture images there.

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

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

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

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

References

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Claims:

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

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

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

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

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

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

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

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

20

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

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

25

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

where the combining of 2D images comprises determining by analysis of said

5 2D images the in-focus position(s) of the focus plane for:

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

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

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

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

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

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

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

25

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

30

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

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

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

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

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

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

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

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

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

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

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

10

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

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

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

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

25

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

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

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

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

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

10

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

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

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

20

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

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

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

30

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

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

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

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

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

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

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

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

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

5

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

10

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

15

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

20

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

25

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

30

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

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

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

10

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

15

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

20

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

25

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

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

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

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

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

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

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

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

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

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object, where said light source emits light from a point of emission; and
 - at least one camera, adapted to record 2D images of the pattern, where the camera accumulates light at a point of accumulation;
- 5
- a data conversion device adapted to convert 2D images into 3D real world coordinates,
 - a data processing device configured to create surface information for areas of the surface, where image scanning is not complete.

10

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

15

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

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

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

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

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

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

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

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

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

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

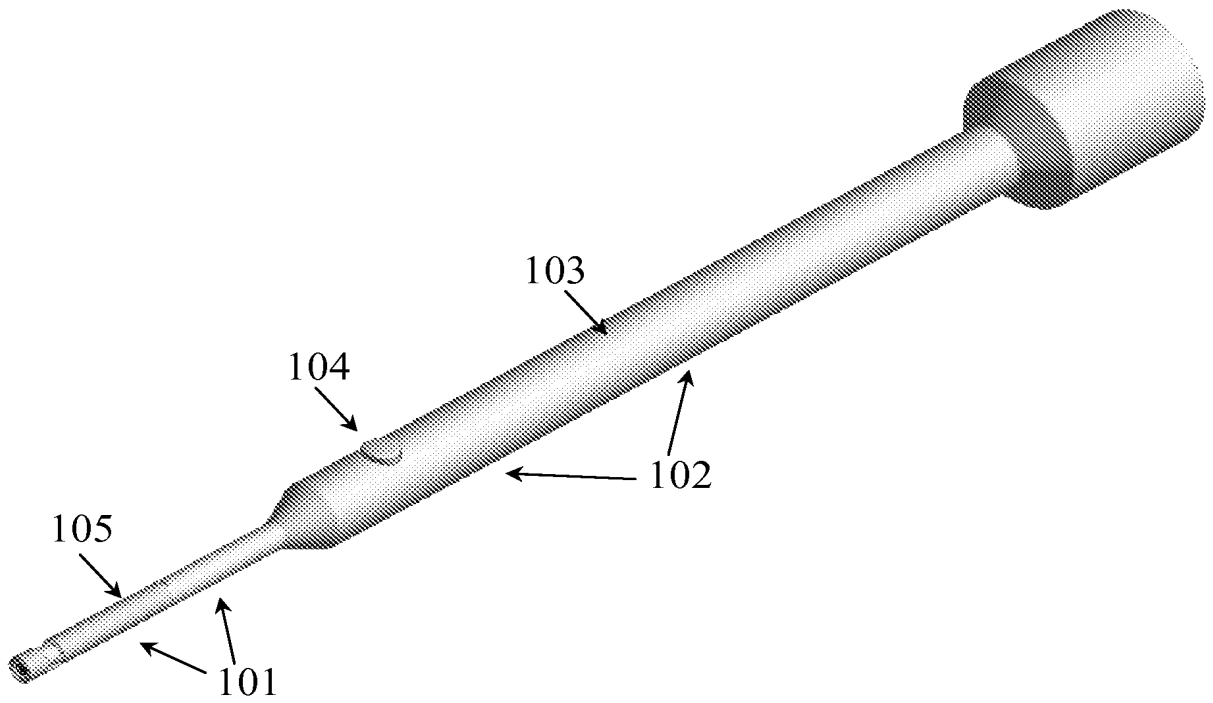


Figure 1

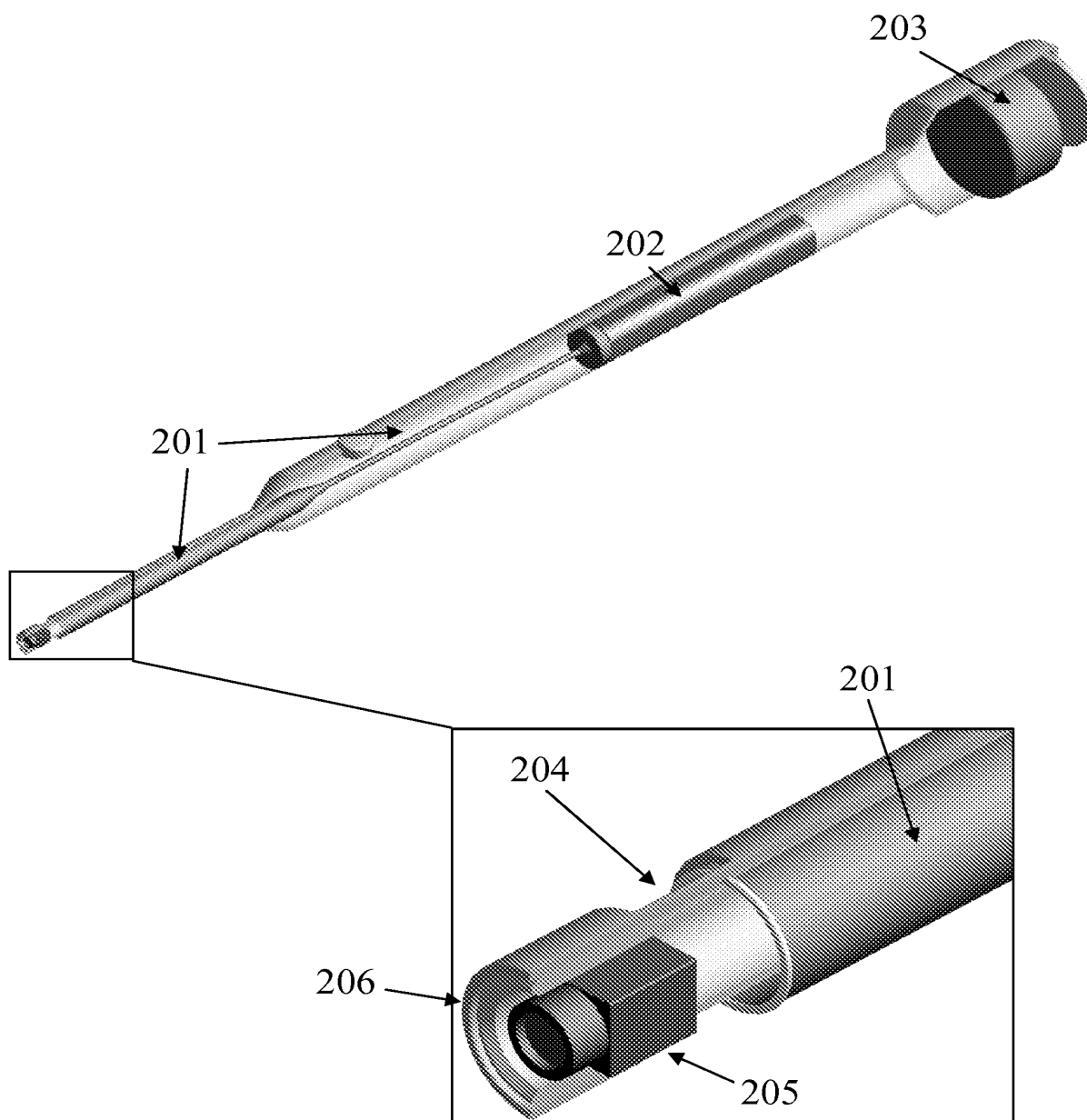


Figure 2

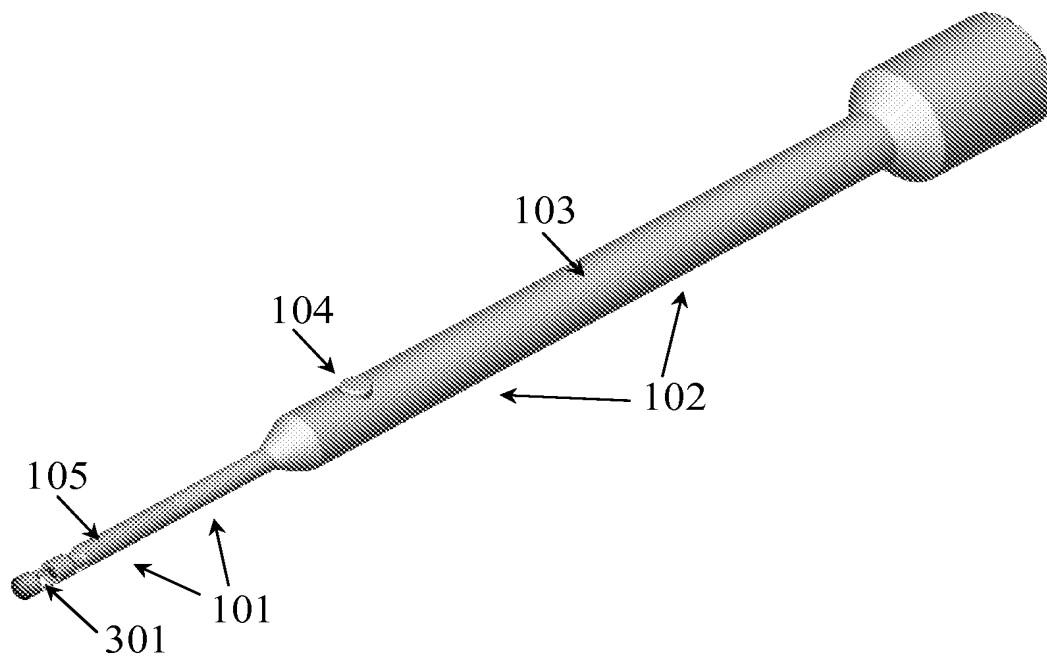


Figure 3

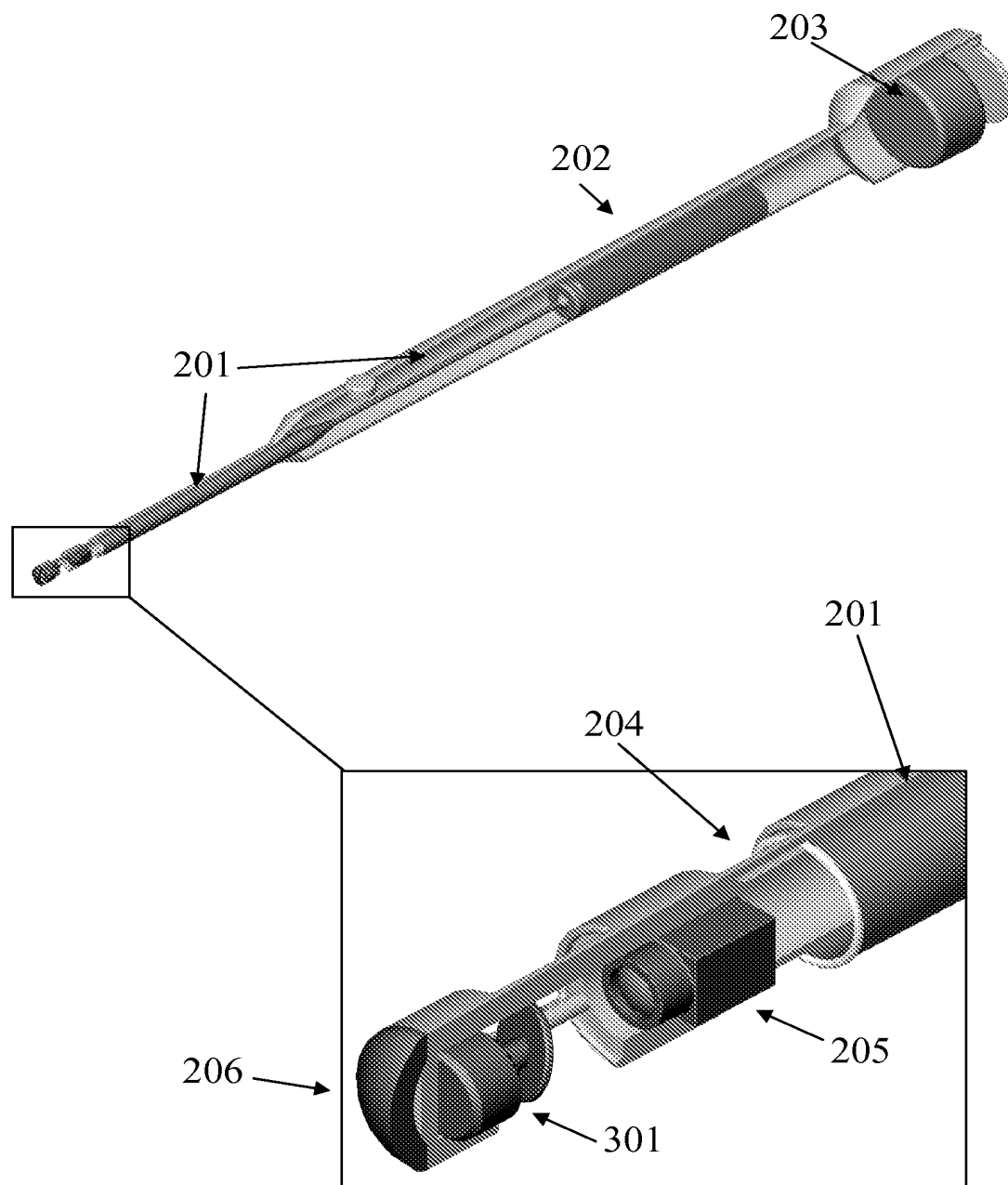


Figure 4

5 / 15

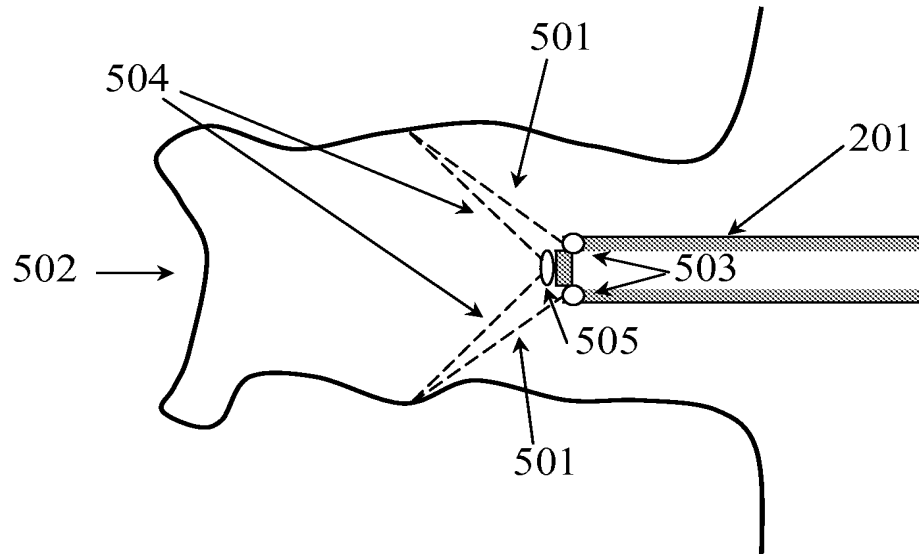


Figure 5

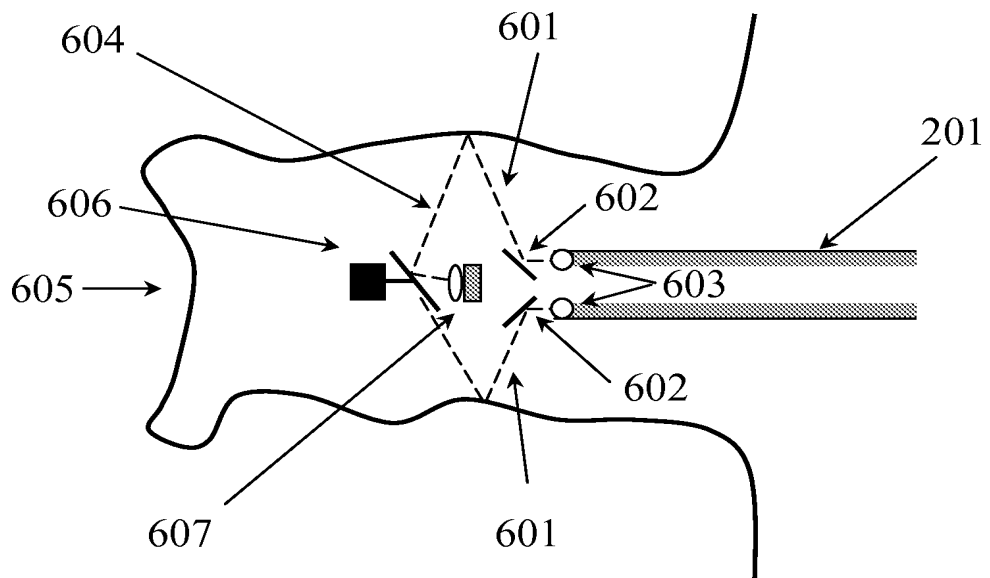


Figure 6

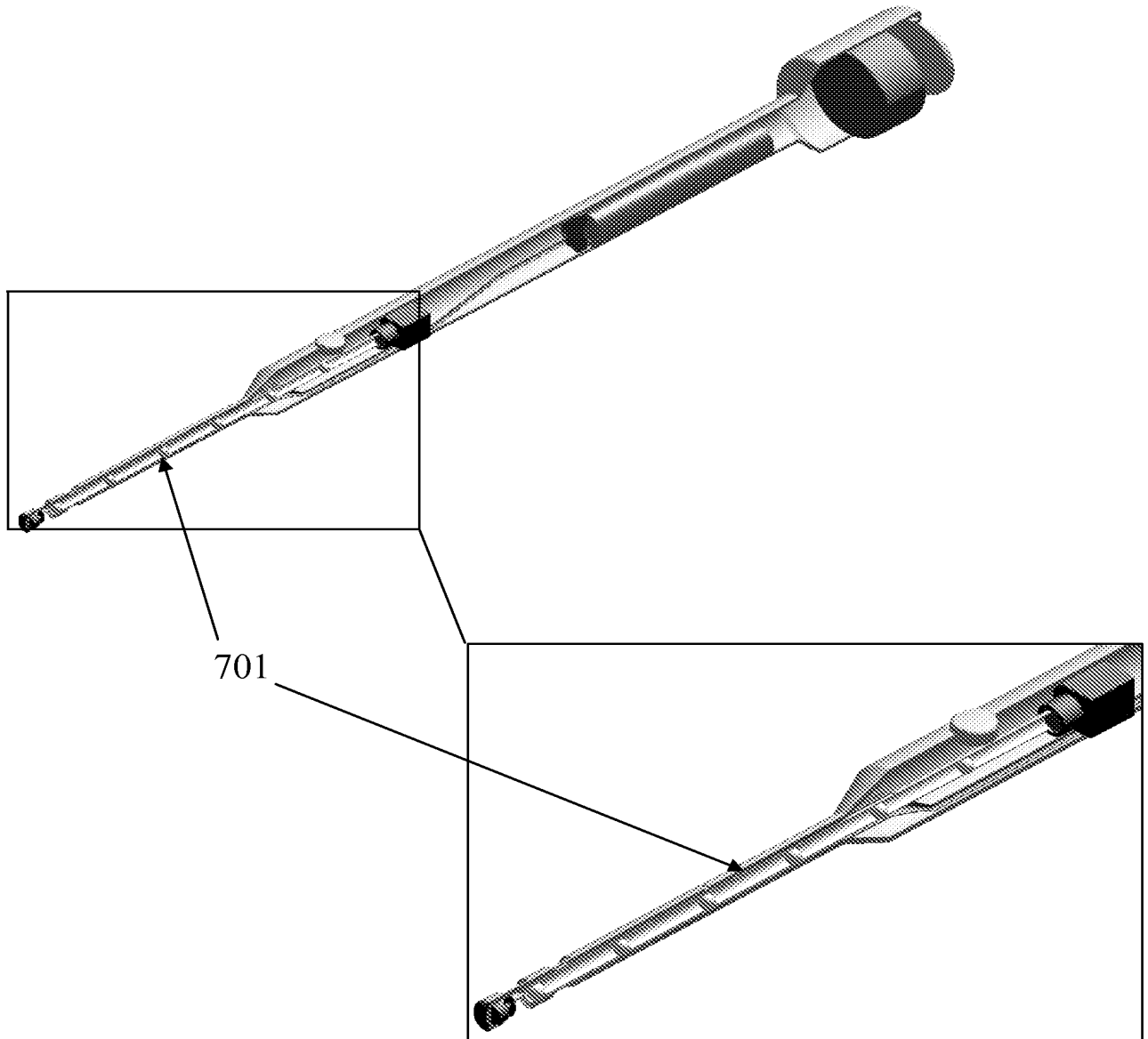


Figure 7

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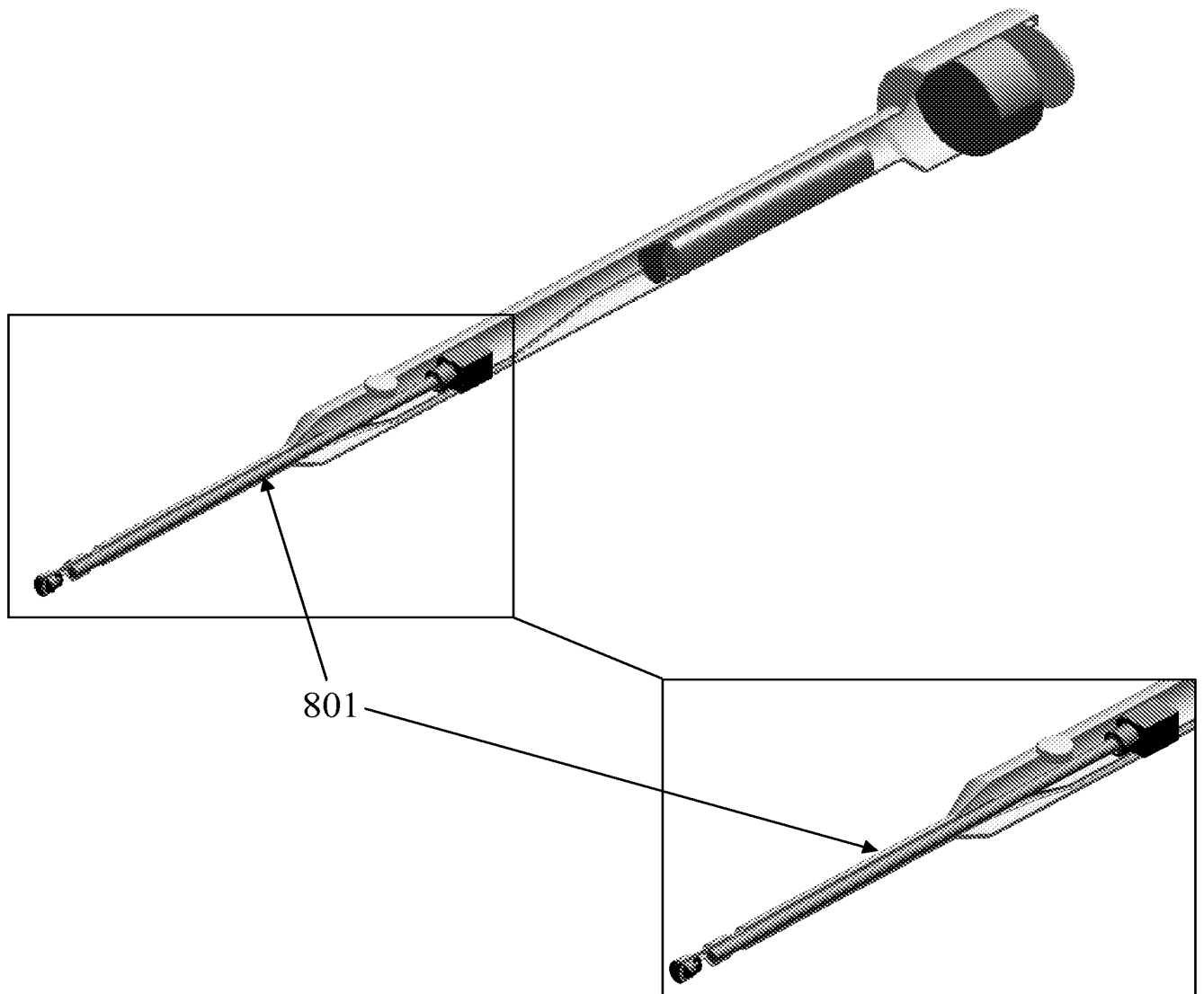


Figure 8

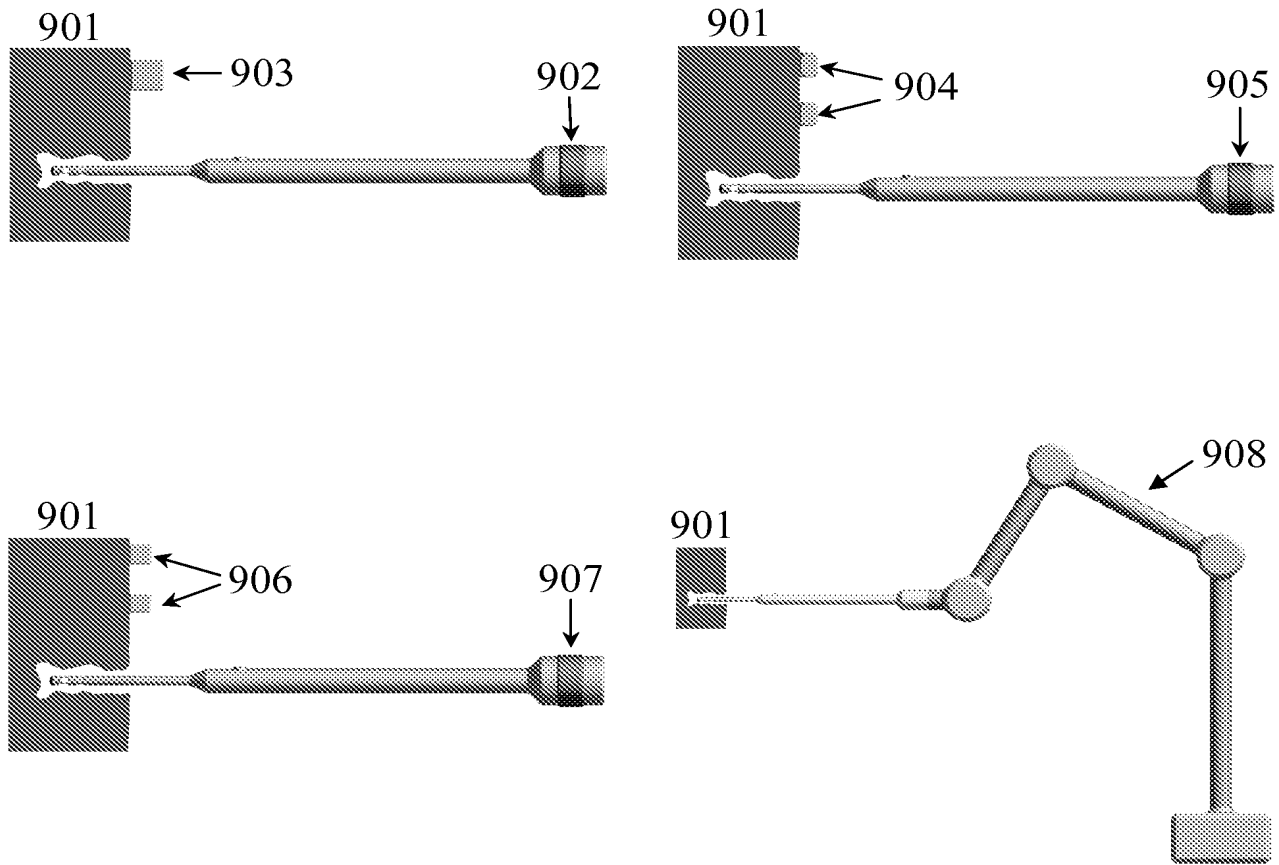


Figure 9

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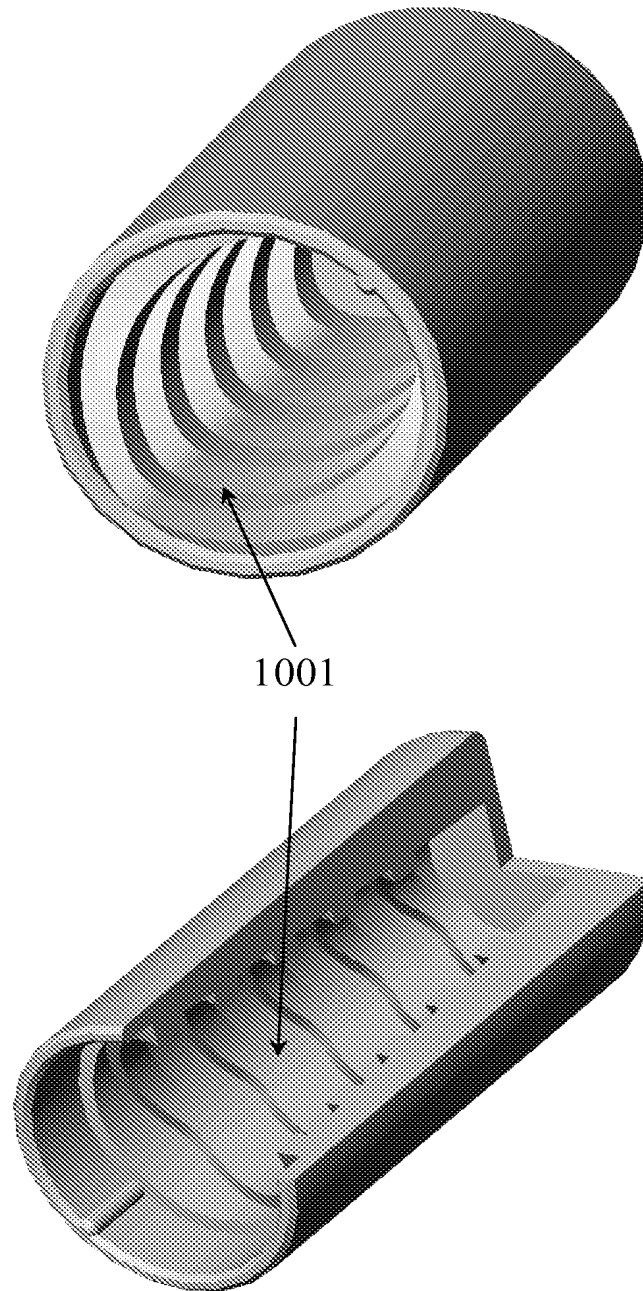


Figure 10

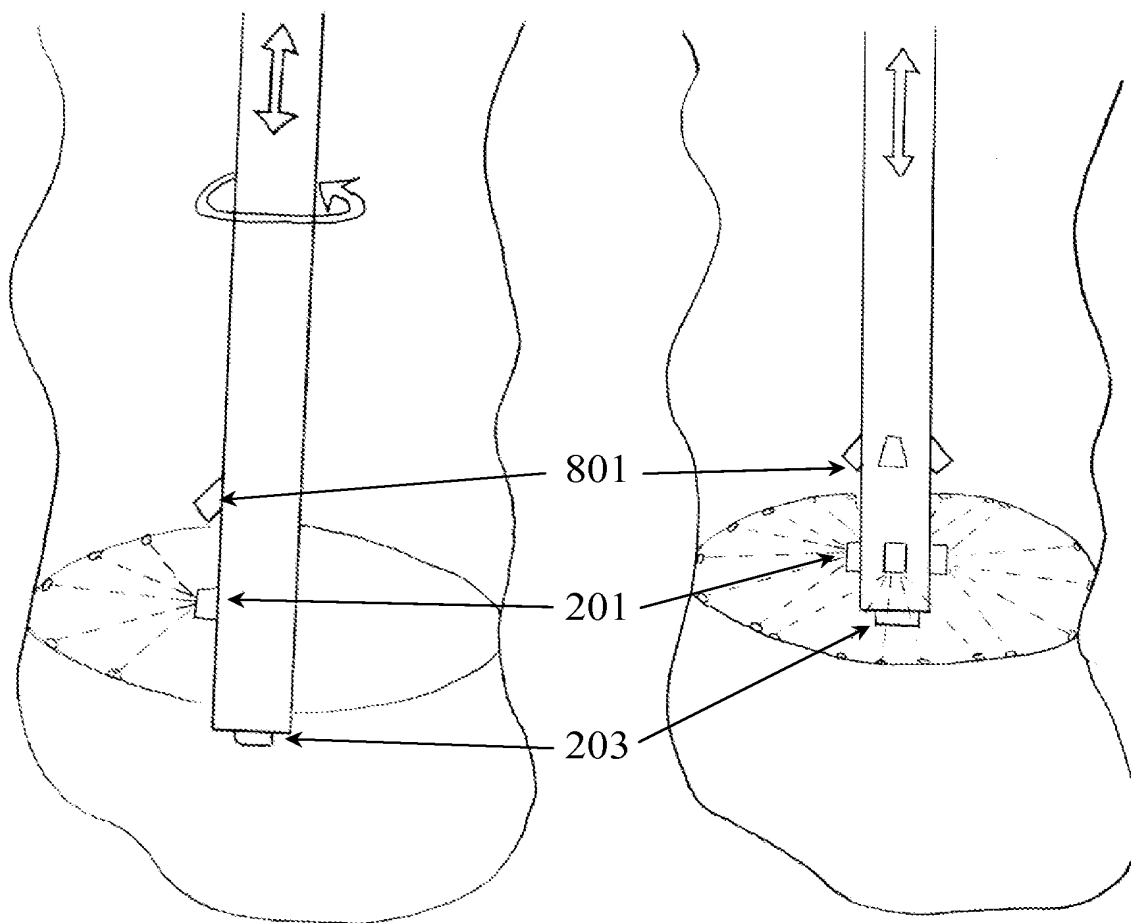


Figure 11

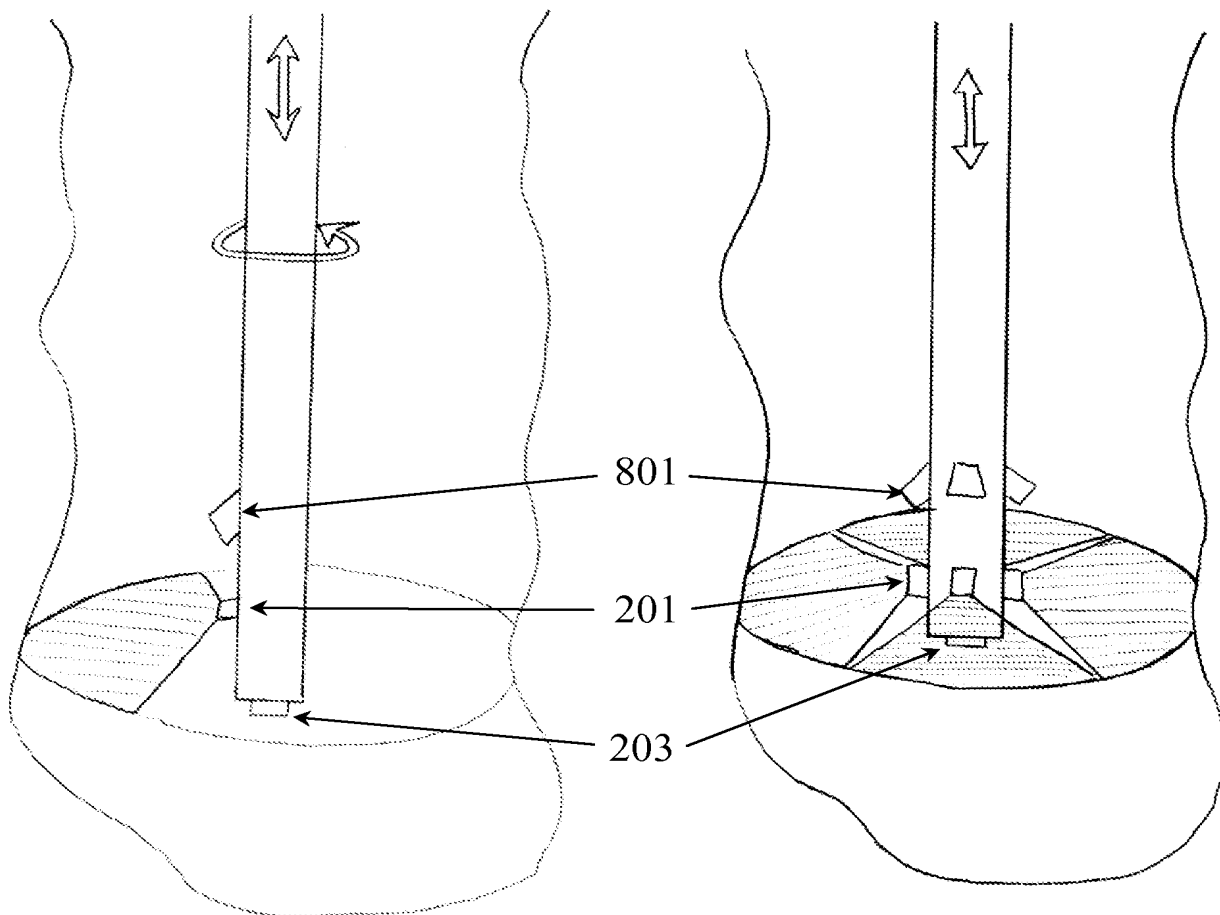


Figure 12

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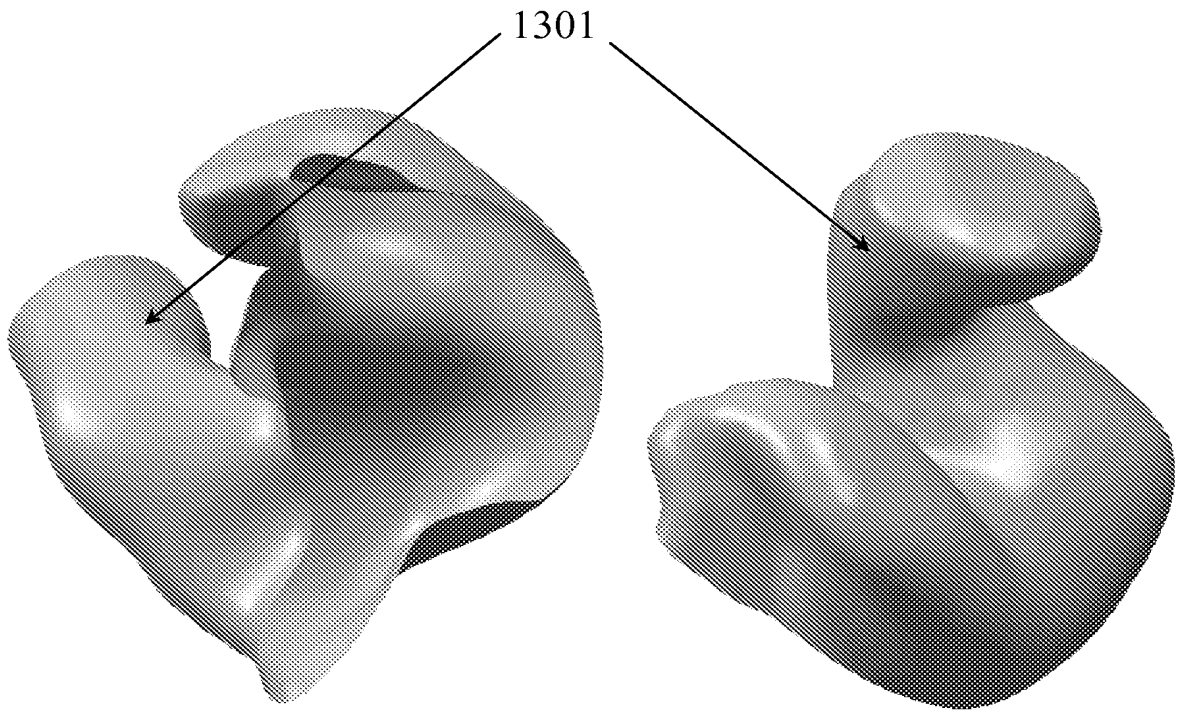


Figure 13

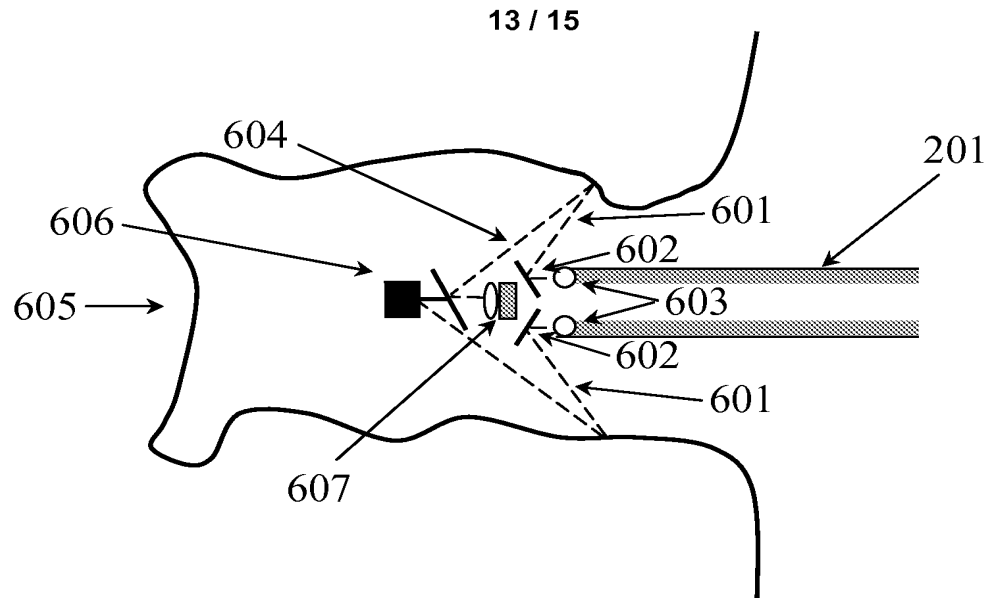


Figure 14

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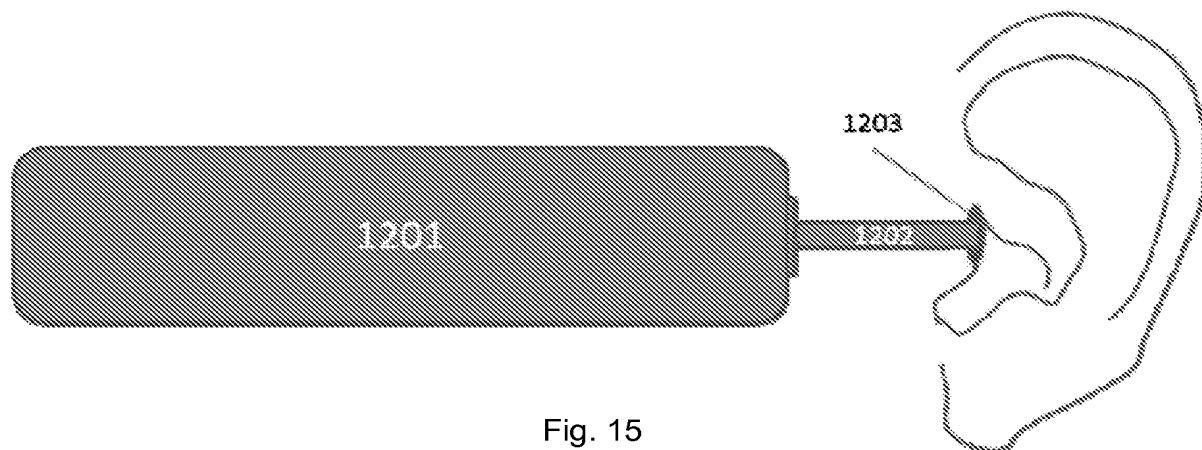


Fig. 15

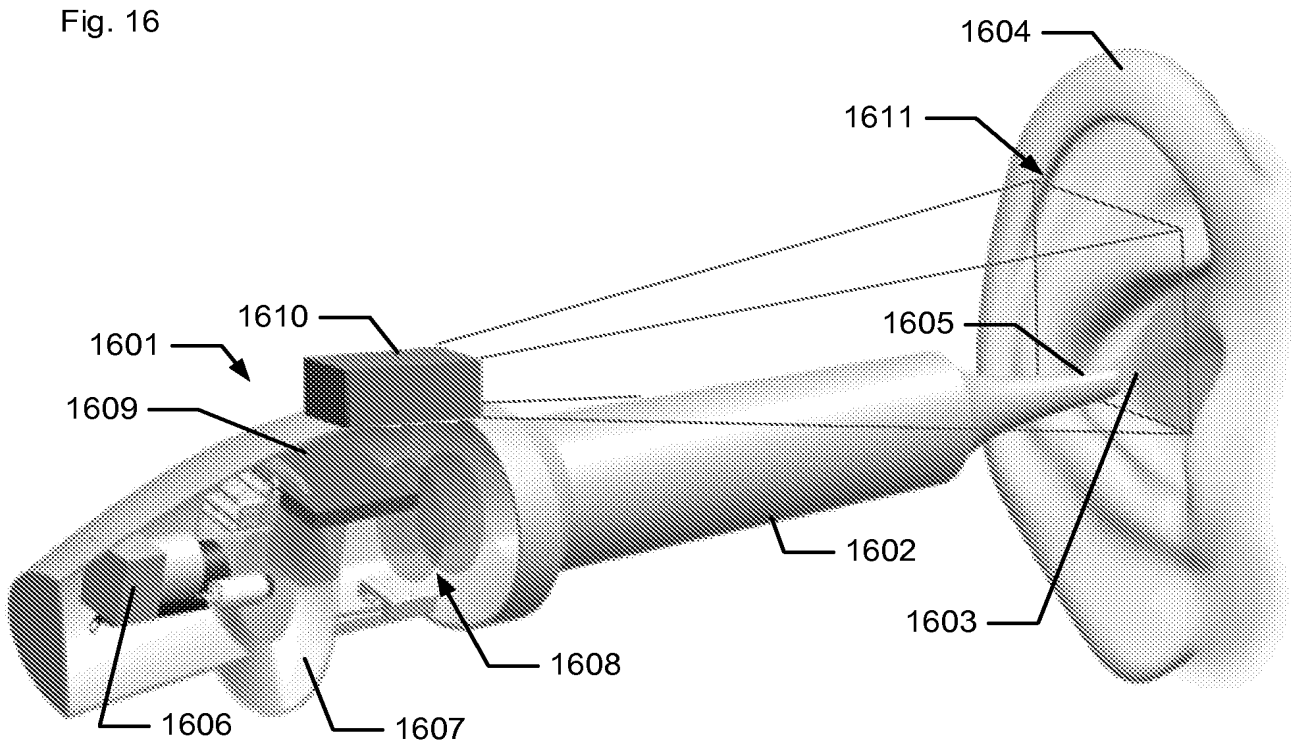


Fig. 16

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Fig. 17a)

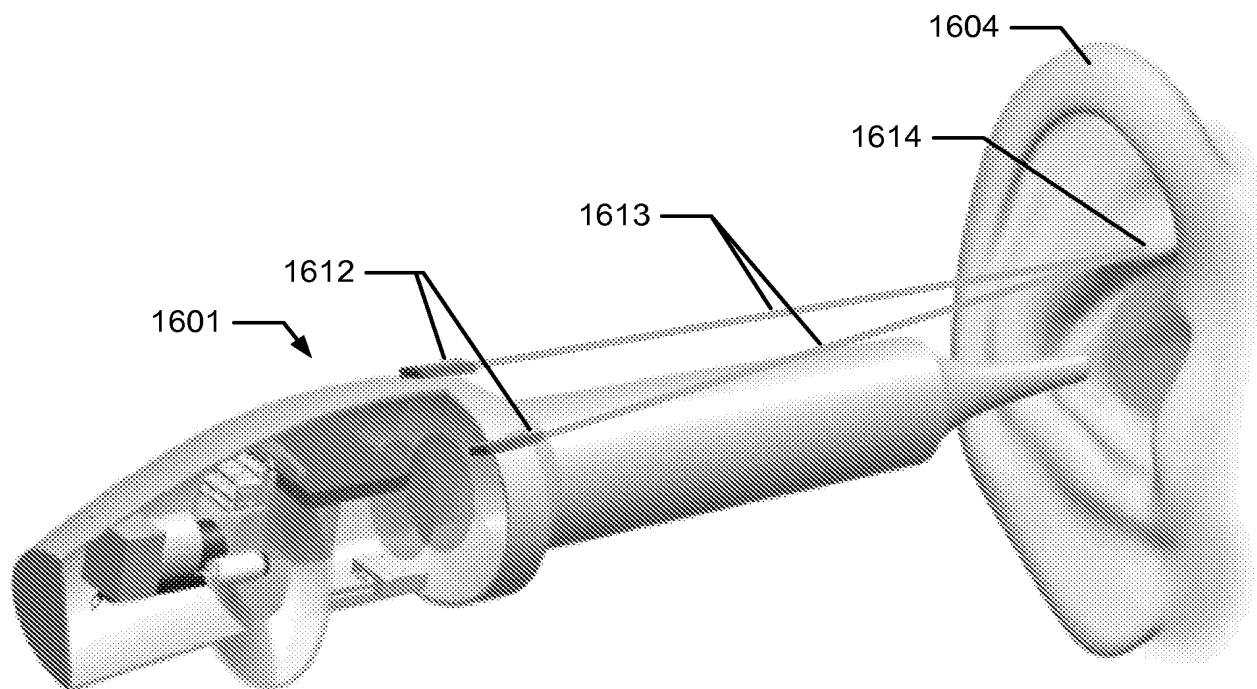
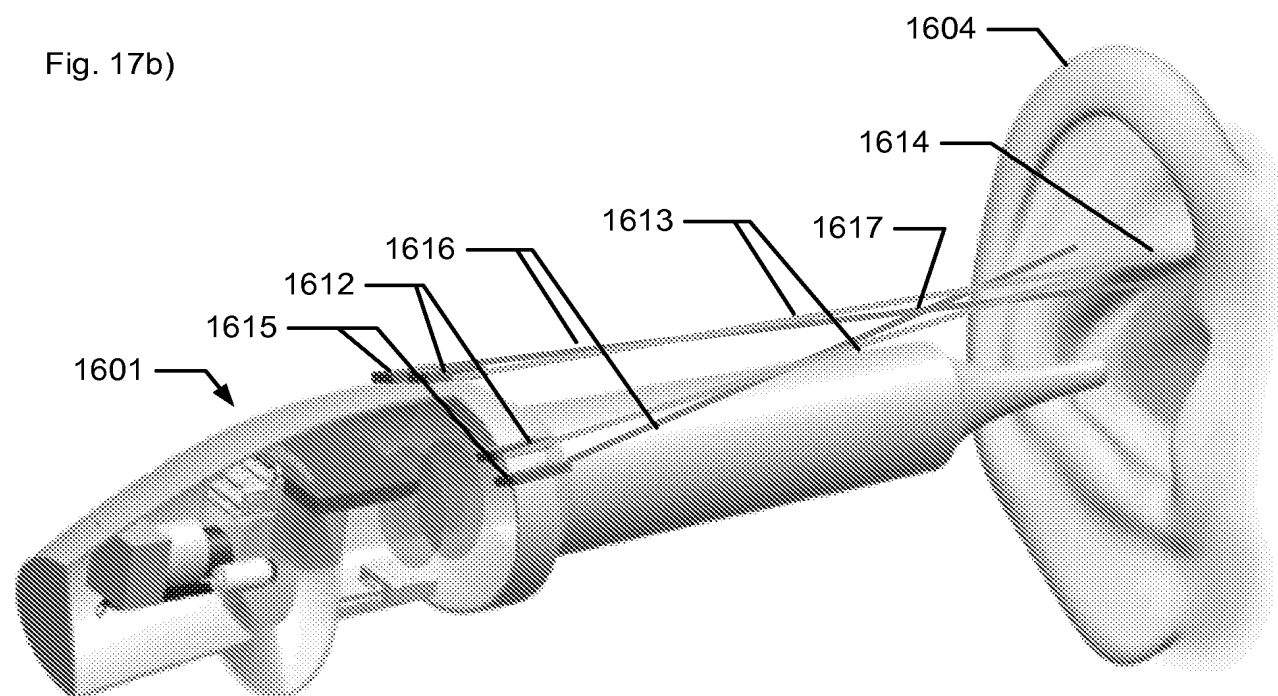


Fig. 17b)



INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

A. CLASSIFICATION OF SUBJECT MATTER

A61B1/227 (2006.01), A61B1/06 (2006.01), A61B5/107 (2006.01), G01B11/25 (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC, ECLA: A61B, G01B.

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

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

EPODOC, WPI, TXTE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

10/05/2011

Date of mailing of the international search report

20/06/2011

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

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

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

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

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

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

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

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

There are at least 3 unrelated inventions (See explanation on extra sheet):

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

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

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

1-61, 69-71

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/DK2011/050103

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

(Continuation of box III)

There are at least 3 unrelated inventions:

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

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

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

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

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

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

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

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