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(54) Title: ONE-SHOT X-RAY IMAGING APPARATUS AND METHOD FOR THREE-DIMENSIONAL IMAGING OF DENTAL CASTS

(57) Abstract: The present invention relates to the field of digital imaging, especially to three-dimensional (3-D) imaging in dentistry. The invention particularly concerns apparatuses and methods for three-dimensional imaging of objects, such as dental casts.

ONE-SHOT X-RAY IMAGING APPARATUS AND METHOD FOR THREE-DIMENSIONAL IMAGING OF DENTAL CASTS

FIELD OF THE INVENTION

The present invention relates to the field of digital imaging, especially to three-dimensional (3-D) imaging in dentistry. The invention particularly concerns apparatuses and methods for three-dimensional imaging of objects, such as dental casts.

BACKGROUND OF THE INVENTION

Dentists employ different X-ray apparatuses to examine their patients:

Cephalometric one-shot X-ray apparatuses provide 2-D images of a patient's teeth. The patient may be standing or sitting in a chair during the recording of the 2-D image. Usually the patient's head is kept in a fixed position during the recording so as to avoid that the image gets blurred because of movements of the patient's head. The patient's head can be fixed by using a bite block, a chin rest, a forehead rest or by any combination of these. In the event that the patient sits in a chair during the recording, the patient's head may additionally or alternatively be fixed to the headrest during the recording.

In one-shot X-ray apparatuses, the image is recorded in one step using a single cone-shaped or pyramid- shaped X-ray beam. In contrast, older X-ray scan systems used a flat fan-shaped X-ray beam which is swept horizontally (or vertically) in such a manner that the beam covers the complete screen of the X-ray detector in the course of the recording. One-shot X-ray apparatuses are advantageous over X-ray scan systems in that the former need only a fraction of the time for recording one image as compared to the latter.

In one-shot X-ray apparatuses, the X-ray radiation source and the X-ray detector are stationary during the recording, i.e. during the shot. However, in some one-shot X-ray apparatuses the X-ray source and the X-ray detector are movably mounted so that the dentist (or the dental assistant or the radiographer) can move X-ray source and X-ray detector prior to the shot in order to focus on the part of the dental arch that is to be imaged.

A more recent development of X-ray imaging in the dental practice is the usage of computed tomography (CT) systems, which provide 3-D images of a patient's teeth. There are computed tomography (CT) systems using fan-beam CT techniques and systems using cone-beam CT (CBCT) techniques to provide 3-D images.

In CT systems, X-ray source and X-ray detector are typically mounted on opposite ends of a rotary arm so that X-ray source and X-ray detector maintain a fixed distance to each other. The rotary arm is rotatably mounted to the CT apparatus. During the recording, the object (i.e. the patient's upper jaw and lower jaw) is positioned between the X-ray source and X-ray detector. Usually the object is positioned half-way between the X-ray source and the X-ray detector so that the distance between X-ray source and the object stays about the same during the recording step. Likewise, the distance between X-ray detector and the object stays about the same during the recording step. During the recording step, the rotary arm makes a rotation of between 180° and 360° so that the X-ray source and X-ray detector revolve around the object. The digital X-ray detectors used in CT systems capture several digital images of the object. The digital image data is transmitted to a computer, which computes a 3-D image on the basis of the image data received from the X-ray detectors.

TECHNICAL PROBLEMS UNDERLYING THE PRESENT INVENTION AND THEIR SOLUTION

Dentists and dental surgeons have a need for digitizing three-dimensional (3-D) structures of dental casts (e.g. plaster models of a patient's upper and/or lower teeth) so as to facilitate storing, forwarding and/or printing of the data of the dental cast. Commonly, dentists use a laser scanning apparatus for digitizing dental casts.

Sohmura and co-workers used multi-slice medical computed tomography (CT) for three-dimensional (3-D) digitizing and computerization of dental casts (see: Taiji Sohmura et al., Dental Materials Journal 23(2): 121-128, 2004, the content of which is hereby incorporated by reference in its entirety). More precisely, Sohmura and co-workers have used a SOMATOM Sensationl6 (Siemens AG, Munich, Germany), which is a multi-slice helical CT apparatus developed for the use in hospitals. This kind of CT apparatus is capable of imaging various body parts of a patient (from head to toes), and as such it is oversized and too expensive for the needs of a dentist's office.

WO 2014/164405 describes the use computed tomography (CT) systems as used in dentist's offices to scan plaster models or impressions of a patient's teeth. However, CT systems are still relatively expansive and take up a lot of space. The content of WO 2014/164405 is hereby incorporated by reference in its entirety.

In contrast, one-shot cephalometric systems are much cheaper and require less space than CT systems. The present inventors found out that dental casts can be digitized by using cephalometric one-shot X-ray imaging apparatuses that are basically only capable of providing 2-D images. The inventors modified a one-shot cephalometric apparatus in such a

manner that the apparatus is capable of providing 3-D images of objects. Accordingly, the present invention provides an additional use for conventional one-shot 2-D X-ray imaging apparatuses used in dentist's offices.

The solution provided by the present invention abolishes the need for a separate laser-scanning system. Moreover, the apparatus presented herein is cheaper and requires less space than the apparatus used in WO 2014/164405 or used by Sohmura and co-workers (see Sohmura et al., 2004, supra).

The above-described objects are solved and the advantages are achieved by the subject-matter of the enclosed independent claims. Preferred embodiments of the invention are included in the dependent claims as well as in the following description.

The above overview does not necessarily describe all problems solved by the present invention.

SUMMARY OF THE INVENTION

In a first aspect the present invention relates to an X-ray imaging apparatus suitable for cephalometric one-shot 2-D X-ray imaging, wherein said apparatus comprises:

- an X-ray radiation source;
- an X-ray digital detector to receive the radiation from the X-ray radiation source and to transmit digital data to a computer system;
- a rotatable table positioned between the X-ray radiation source and the X-ray digital detector;
- a control system for rotating the rotatable table;
- a computer system; and
- a software program, wherein said software program is capable of calculating a digital 3-D model of an object positioned on the rotatable table on the basis of the digital data transmitted to the computer system; and wherein the software program is capable of saving the data of the calculated digital 3-D model in a storage medium being part of the computer system;

with the proviso that the apparatus is not capable of performing 3-D X-ray imaging, when the rotatable table is absent.

In a second aspect the present invention relates to a method for calculating a digital 3-D model of an object, comprising the steps:

(i) placing an object on a rotatable table of an X-ray imaging apparatus;

(ii) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;

(iii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;

(iv) transmitting digital data from the X-ray digital detector to a computer system;

(v) rotating the table by a defined angle;

(vi) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;

(vii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;

(viii) transmitting digital data from the X-ray digital detector to a computer system;

(ix) repeating steps (v) to (viii) until the table has been rotated by a pre-defined angle, wherein said pre-defined angle is between 180° and 360°; and

(x) calculating a digital 3-D model of the object on the basis of the digital data transmitted to the computer system in steps (iv) and (viii).

In a third aspect the present invention relates to a cephalometric one-shot 2-D X-ray imaging apparatus comprising means for implementing a method as defined in the second aspect.

DETAILED DESCRIPTION OF THE INVENTION

Before the present invention is described in detail below, it is to be understood that this invention is not limited to the particular methodology, protocols and reagents described herein as these may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the present invention which will be limited only by the appended claims. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integer or step.

Several documents (for example: patents, patent applications, scientific publications, manufacturer's specifications, instructions, etc.) are cited throughout the text of this

specification. Nothing herein is to be construed as an admission that the invention is not entitled to antedate such disclosure by virtue of prior invention. Some of the documents cited herein are characterized as being *"incorporated by reference"*. In the event of a conflict between the definitions or teachings of such incorporated references and definitions or teachings recited in the present specification, the text of the present specification takes precedence.

The present invention will now be further described. In the following passages different aspects of the invention are defined in more detail. Each aspect so defined may be combined with any other aspect or aspects unless clearly indicated to the contrary. In particular, any feature indicated as being preferred or advantageous may be combined with any other feature or features indicated as being preferred or advantageous, unless clearly indicated to the contrary.

In a first aspect the present invention is directed to an X-ray imaging apparatus suitable for cephalometric one-shot 2-D X-ray imaging, wherein said apparatus comprises:

- an X-ray radiation source;
- an X-ray digital detector to receive the radiation from the X-ray radiation source and to transmit digital data to a computer system;
- a rotatable table positioned between the X-ray radiation source and the X-ray digital detector;
- a control system for rotating the rotatable table;
- a computer system; and
- a software program, wherein said software program is capable of calculating a digital 3-D model of an object positioned on the rotatable table on the basis of the digital data transmitted to the computer system; and wherein the software program is capable of saving the data of the calculated digital 3-D model in a storage medium being part of the computer system;

with the proviso that the apparatus is not capable of performing 3-D X-ray imaging, when the rotatable table is absent.

As mentioned above, the present inventors modified cephalometric one-shot X-ray imaging apparatuses that are generally only capable of providing 2-D images (but no 3-D images) in such a manner that the apparatus is capable of providing 3-D images of objects.

The modifications by which this effect was achieved are the addition of a rotatable table, a control system for rotating the rotatable table, and a special software program that calculates a digital 3-D model of an object positioned on the rotatable table on the basis of the digital data transmitted from the X-ray digital detector. In other words, the apparatus of the first aspect does not include X-ray imaging apparatuses (such as CT apparatuses) that are already capable of calculating 3-D images in the absence of these modifications. This means that the proviso recited in the first aspect could alternatively (or additionally) be worded as *"with the proviso that the apparatus is not capable of performing 3-D X-ray imaging, when the control system for rotating the rotatable table is absent"*. The proviso could alternatively be worded as *"with the proviso that the apparatus is not capable of performing computed tomography (CT), when the rotatable table or the control system for rotating the rotatable table or both is/are absent"*.

In some embodiments of the first aspect, the software program is capable of displaying 2-D sections of the object on a monitor connected to the computer system. In particular embodiments of the first aspect, the position of these 2-D sections within the object can be selected by a user. In further embodiments of the first aspect, the software program is capable of printing the 2-D sections on a printer connected to the computer system.

In some embodiments of the first aspect, the apparatus further comprises an object positioned on the rotatable table. In further embodiments of the first aspect, the object is selected from the group consisting of a plaster model of a patient's upper teeth, a plaster model of a patient's lower teeth, an imprint of a patient's upper teeth, and an imprint of a patient's lower teeth. It is also considered within the ambit of the present invention that the apparatus may comprise more than one object (e.g. 2, 3, 4, 5, 6, 7, 8, 9, 10 or more objects) positioned on the rotatable table. For example, a plaster model of a patient's upper teeth and a plaster model of a patient's lower teeth may be positioned on the rotatable table at the same time. In a further example, an imprint of a patient's upper teeth and an imprint of a patient's lower teeth may be positioned on the rotatable table at the same time.

In a second aspect the present invention is directed to a method for calculating a digital 3-D model of an object, comprising the steps:

(i) placing an object on a rotatable table of an X-ray imaging apparatus;

(ii) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;

(iii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;

(iv) transmitting digital data from the X-ray digital detector to a computer system;

(v) rotating the table by a defined angle;

(vi) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;

(vii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;

(viii) transmitting digital data from the X-ray digital detector to a computer system;

(ix) repeating steps (v) to (viii) until the table has been rotated by a pre-defined angle, wherein said pre-defined angle is between 180° and 360°; and

(x) calculating a digital 3-D model of the object on the basis of the digital data transmitted to the computer system in steps (iv) and (viii).

In some embodiments of the second aspect, the predefined angle is between 200° and 360°, preferably between 220° and 360°; and more preferably between 240° and 360°. In the most preferred embodiments, the pre-defined angle is 360°.

In some embodiments of the second aspect, the method further comprises the step:

(xi) displaying the calculated digital 3-D model on a monitor.

In some embodiments of the second aspect, the method further comprises the step of saving the data of the calculated digital 3-D model to a storage medium. This step can be carried out directly after step (x) and the above-recited step (xi) is optional. Alternatively, the step of the step of saving the data of the calculated digital 3-D model to a storage medium can be carried out directly after step (xi).

In some embodiments of the second aspect, the object is selected from the group consisting of a plaster model of a patient's upper teeth, a plaster model of a patient's lower teeth, an imprint of a patient's upper teeth, and an imprint of a patient's lower teeth. It is also considered within the ambit of the present invention that more than one object (e.g. 2, 3, 4, 5, 6, 7, 8, 9, 10 or more objects) is placed on the rotatable table in the same measurement cycle so as to calculate a digital 3-D model for more than one object (e.g. 2, 3, 4, 5, 6, 7, 8, 9, 10 or more objects) in only one experimental set-up. For example, a plaster model of a patient's upper teeth and a plaster model of a patient's lower teeth may be placed on the rotatable table at the same time in order to digitize the dentals casts of the upper teeth and the lower teeth of

the same patient in one experimental set-up. In a further example, an imprint of a patient's upper teeth and an imprint of a patient' s lower teeth may be placed on the rotatable table at the same time in order to digitize the imprints of the upper teeth and the lower teeth of the same patient in one experimental set-up.

In some embodiments of the second aspect, the method is carried out using an apparatus according to the first aspect.

In a third aspect the present invention is directed to a cephalometric one-shot 2-D X-ray imaging apparatus comprising means for implementing a method as defined in the second aspect.

CLAIMS

1. An X-ray imaging apparatus suitable for cephalometric one-shot 2-D X-ray imaging, wherein said apparatus comprises:
   - an X-ray radiation source;
   - an X-ray digital detector to receive the radiation from the X-ray radiation source and to transmit digital data to a computer system;
   - a rotatable table positioned between the X-ray radiation source and the X-ray digital detector;
   - a control system for rotating the rotatable table;
   - a computer system; and
   - a software program, wherein said software program is capable of calculating a digital 3-D model of an object positioned on the rotatable table on the basis of the digital data transmitted to the computer system; and wherein the software program is capable of saving the data of the calculated digital 3-D model in a storage medium being part of the computer system;

   with the proviso that the apparatus is not capable of performing 3-D X-ray imaging, when the rotatable table is absent.

2. The apparatus according to claim 1, wherein the software program is capable of displaying 2-D sections of the object on a monitor connected to the computer system.

3. The apparatus according to claim 2, wherein the position of the 2-D sections within the object can be selected by a user.

4. The apparatus according to any one of claims 2 or 3, wherein the software program is capable of printing the 2-D sections on a printer connected to the computer system.

5. The apparatus according to any one of claims 1 to 4, wherein the apparatus further comprises an object positioned on the rotatable table.

6. The apparatus according to claim 5, wherein the object is selected from the group consisting of:
   - a plaster model of a patient' s upper teeth;

- a plaster model of a patient' s lower teeth;
- an imprint of a patient' s upper teeth; and
- an imprint of a patient' s lower teeth.

7. A method for calculating a digital 3-D model of an object, comprising the steps:
   (i) placing an object on a rotatable table of an X-ray imaging apparatus;
   (ii) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;
   (iii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;
   (iv) transmitting digital data from the X-ray digital detector to a computer system;
   (v) rotating the table by a defined angle;
   (vi) irradiating the object with X-rays from an X-ray source of the X-ray imaging apparatus;
   (vii) detecting X-rays transmitted through the object by means of an X-ray digital detector of the X-ray imaging apparatus;
   (viii) transmitting digital data from the X-ray digital detector to a computer system;
   (ix) repeating steps (v) to (viii) until the table has been rotated by a pre-defined angle, wherein said pre-defined angle is between 180° and 360°; and
   (x) calculating a digital 3-D model of the object on the basis of the digital data transmitted to the computer system in steps (iv) and (viii).

8. The method according to claim 7, further comprising the step:
   (xi) displaying the calculated digital 3-D model on a monitor.

9. The method according to claim 7 or 8, further comprising the step of saving the data of the calculated digital 3-D model to a storage medium.

10. The method according to any one of claims 7 to 9, wherein the object is selected from the group consisting of:
   - a plaster model of a patient' s upper teeth;
   - a plaster model of a patient' s lower teeth;
   - an imprint of a patient' s upper teeth; and
   - an imprint of a patient' s lower teeth.

11. The method according to any one of claims 7 to 10, wherein the method is carried out using an apparatus according to any one of claims 1-6.

12. A cephalometric one-shot 2-D X-ray imaging apparatus comprising means for implementing a method as claimed in any one of claims 7 to 10.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/076751

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/14 A61B6/04 A61C7/00 A61C9/00 A61B6/00 A61C13/00
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B A61C

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 023 895 A (MCCROSKEY WILLIAM K [US] ET AL) 11 June 1991 (1991-06-11) abstract column 8, line 45 - column 13, line 28 figures 1,2,6,7	1-5,8,9, 11,12
X	US 2003/129565 Al (KAZA SRINIVAS [US]) 10 July 2003 (2003-07-10) abstract paragraph [0025] - paragraph [0071] figures 3-9	1,2,4-12
A	WO 2014/164405 Al (CARESTREAM HEALTH INC [US]) 9 October 2014 (2014-10-09) cited in the application the whole document	1-12

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

[X] See patent family annex.

* Special categories of cited documents :

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

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

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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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 January 2016	28/01/2016

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

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 6 200 135 Bl (HULTGREN BRUCE WI LLARD [US]) 13 March 2001 (2001-03-13) abstract col umn 5, line 59 - col umn 6, line 44 f i gure 1	1-12
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/076751

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