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(71) Applicant and
(72) Inventor: **MASSIE, Ronald, E.** [US/US]; P.O. Box 873, Lake Ozark, MO 65049 (US).

(74) Agent: **BROWN, Mark, E.**; Shughart Thomson & Kilroy, P.C., 120 West 12th Street, Kansas City, MO 64105 (US).

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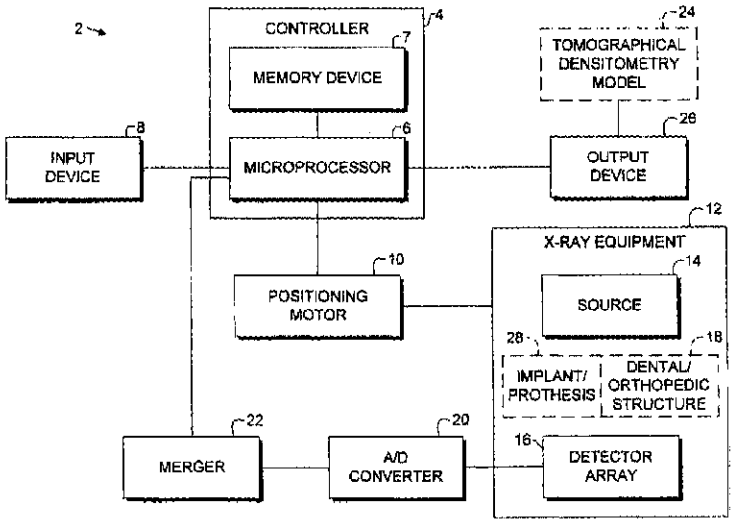
(54) Title: DENTAL AND ORTHOPEDIC DENSITOMETRY MODELING SYSTEM AND METHOD



(57) Abstract: A dental and orthopedic densitometry modeling system includes a controller (4) with a microprocessor (6) and a memory device (7) connected to the microprocessor (6). An input device (8) is also connected to the microprocessor (6) for inputting diagnostic procedure parameters and patient information. X-ray equipment including an X-ray source (14) and an X-ray detector array (16) are connected to a positioning motor (10) for movement relative to a patient's dental or orthopedic structure (18) in response to signals from the microprocessor (6). The output consists of a tomographical densitometry model. A dental/orthopedic densitometry modeling method involves moving the X-ray equipment across a predetermined scan path, emitting dual-energy X-ray beams, and outputting an image color-coded to correspond to a patient's dental or orthopedic density.

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DENTAL AND ORTHOPEDIC DENSITOMETRY MODELING SYSTEM AND METHOD

Background of the Invention

1. Field of the Invention

The present invention relates generally to dental and orthopedic diagnosis and treatment, and in particular to a densitometry modeling system and method.

2. Description of the Related Art

The field of dental diagnostics is generally concerned with locating pathologies in the dental structure, i.e. the teeth and surrounding tissue and bone. Three of the most common pathologies are: 1) caries associated with decay; 2) fractures; and 3) apical abscesses. The system and method of the present invention are primarily, but not exclusively, concerned with detecting these pathologies and with orthopedics.

Early detection of dental pathologies is very important in minimizing damage. Conventional diagnosis procedures are generally performed using dental X-rays (both fixed beam and scanning beam), explorers, and other conventional equipment.

Incipient caries, particularly those located beneath the enamel surface, often go undetected with conventional equipment. When such caries are finally found, considerable damage to tooth structure may have already occurred. Subsurface, incipient caries are located almost entirely within the enamel layer of the teeth. They are

sometimes referred to as "smooth surface" caries and are particularly difficult to locate using conventional diagnostic equipment and procedures. By the time such incipient caries are located, the extent of the damage is often 17% to 23% greater than it would appear to be on a conventional X-ray negative.

Dental fractures can result from bruxism (teeth grinding), trauma, etc. Dental structure which is weakened by various causes, such as decalcification, is particularly susceptible to fractures. Fractures can assume various configurations, including craize line patterns. Fracture patterns and configurations can be particularly difficult to locate using conventional X-ray equipment and procedures. For example, fractures which are generally parallel to the X-ray beam are often undetectable on an X-ray negative. Undetected, and hence untreated, fractures can provide direct paths through the enamel layer of the teeth whereby bacteria can invade the dentin and pulp layers. Pathologies in the dentin and pulp layers are often associated with considerable pain and tooth loss.

Apical abscesses comprise yet another dental condition which can be difficult to diagnose with conventional equipment, particularly in the early stages. Advanced apical abscesses can cause considerable pain because they involve the neurovascular bundles located in the root canals. Early detection of apical abscesses can lead to appropriate, early-stage treatment, thus avoiding advanced disease processes with resultant pain, swelling, and/or space involvement which left untreated could ultimately result in death.

Tomography or sectional radiography techniques using scanning X-ray beams have previously been employed for dental applications. For example, U.S. Patents No.

4,188,537; No. 4,259,583; No. 4,823,369; No. 4,856,038; and No. 5,214,686 all relate to dental X-ray diagnosis utilizing scanning techniques and are incorporated herein by reference.

In the medical field, densitometry procedures are used for measuring bone morphology density (BMD) by utilizing scanning X-ray beam techniques. Examples are shown in U.S. Patents No. 5,533,080; No. 5,838,765; and Re. 36,162, which are incorporated herein by reference. Medical applications of densitometry include the diagnosis and treatment of such bone diseases as osteoporosis.

The availability of relatively fast computers with large memories at reasonable costs has led to the digitalization of X-ray images for mapping BMD models in various formats. For example, BMD images use color to identify varying densities. Digital BMD patient models are also used for comparison purposes with standard models and with patients' own prior BMD histories. Age correction factors can be applied to patients' models for diagnosing and monitoring the onset and progress of such medical conditions as osteoporosis and the like. The present invention utilizes such densitometry modeling and mapping techniques for dental applications.

In addition to pathology detection and diagnosis, the present invention has applications in monitoring osseointegration. Osseointegration occurs at the interface between bone structures and prostheses, such as implants and replacement joints. For example, dental implants osseointegrate with patients' dental structure. The application of tomographical densitometry techniques to osseointegration monitoring can provide the

dental or medical practitioner with important information in evaluating the effectiveness of implant procedures.

Heretofore there has not been available a system or method for applying the technology of densitometry to dental and medical applications such as the detection of caries and decalcification and the monitoring of osseointegration in connection with dental and medical prostheses.

Summary of the Invention

In the practice of the present invention, a dental and orthopedic densitometry modeling system utilizes a controller with a microprocessor and memory. An input device inputs data to the microprocessor for controlling the operation of the modeling system and for providing a database including densitometry parameters for comparison with a patient's densitometry model. The controller controls the operation of X-ray equipment, which is adapted for scanning patients' dental and orthopedic structures along preprogrammed scan paths. The X-ray output is processed by the microprocessor for creating a densitometry model, which can be output in various formats. In the practice of the method of the present invention, a patient and the X-ray equipment are positioned relative to each other. A controller is preprogrammed with a scan path and with data corresponding to the patient. The X-ray equipment emits and detects X-ray beams at first and second energy levels to provide densitometry output. The densitometry output is digitized and merged to provide a tomographic model, which can be compared to

predetermined parameters unique to the patient. The model can be output in various formats, including a visual image color-coded to depict varying dental and orthopedic structure densities.

Principle Objects and Advantages of the Invention

The principle objects and advantages of the present invention include: providing a dental and orthopedic diagnostic application for densitometry; providing such an application which includes a method for modeling dental and orthopedic structure using densitometry; providing such a method which includes dual-energy, X-ray emission and detection; providing such a method which includes providing a color-coded output model showing dental density; providing such a method which detects incipient caries; providing such a method which is adapted for detecting decalcification beneath the surface of the dental enamel layer; providing such a method which employs scanning X-ray techniques; providing such a method which utilizes commercially available tomography equipment; providing such a method which detects dental fractures; providing such a method which detects dental apical abscesses; providing such a method which detects dental pathologies at the micron level; providing such a method which facilitates the monitoring of decalcification in dental structures for determining appropriate treatment; providing such a method which is adaptable for monitoring osseointegration; providing such a method which can be practiced with relatively minor

changes to existing densitometry equipment; and providing such a method which is economical in operation and particularly well adapted for the proposed usage thereof.

Other objects and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings wherein are set forth, by way of illustration and example, certain embodiments of this invention.

The drawings constitute a part of this specification and include exemplary embodiments of the present invention and illustrate various objects and features thereof.

Brief Description of the Drawings

Fig. 1 is a schematic, block diagram of a dental and orthopedic densitometry modeling system embodying the present invention.

Fig. 2 is a flowchart of a dental and orthopedic densitometry modeling method embodying the present invention.

Detailed Description of the Preferred Embodiments

I. Introduction and Environment

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as

a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed structure.

II. Dental Densitometry Modeling System 2

Referring to the drawings in more detail, the reference numeral 2 generally designates a dental and orthopedic densitometry modeling system embodying the present invention. The system 2 includes a controller 4 with a microprocessor 6 connected to a digital memory device 7. The hardware components of the controller 4, i.e. the microprocessor 6 and the memory device 7, can comprise any of a number of suitable hardware devices which are commercially available and are suitable for this application. In addition to various programable logic devices (PLDs) and special-purpose microprocessors, general purpose, commercially available personal computers can be utilized in the controller 4. The controller 4 can be programmed in any suitable manner utilizing any of a variety of commercially available programming languages and software development systems.

The microprocessor 6 is adapted to receive input from one or more input devices 8, such as a keyboard, a pointing device (e.g., a mouse), a communications link, or another computer. Without limitation on the generality of useful data which can be input via the input device(s) 8, such data can include: 1) a patient's dental and orthopedic records, including previous tomographical densitometry models; 2) baseline tomographical densitometry models, which can be adjusted to accommodate for such

factors as age, gender, size, weight, etc.; and 3) a preprogrammed scan path for the X-ray equipment.

The microprocessor 6 controls a positioning motor 10 which is operably connected to X-ray equipment 12 and is adapted for moving same through three axes of movement. Examples of X-ray equipment adaptable for use with the present invention are disclosed in U.S. Patents No. 5,533,080; No. 5,838,765; and No. Re. 36,162, which are incorporated herein by reference. The X-ray equipment 12 includes an X-ray beam source 14 and a detector array 16. The X-ray beam can suitably collimated to assume any suitable configuration, such as fan, pencil, cone, etc. With the scanning technique disclosed, a restricted (i.e. collimated) beam is preferred. The source and the detector array 14, 16 are adapted for positioning on either side of a patient's dental/orthopedic structure 18.

Analog signals from the detector array 16 are output to an analog-to-digital (A/D) convertor 20, from which digitized signals are transmitted to a merger device 22 for merging into formats suitable for processing and analyzing by the microprocessor 6. The microprocessor 6, using data from the merger device 22, creates a tomographical densitometry model 24 which is transmitted to an output device or devices 26. Without limitation on the generality of useful output devices 26, it can comprise a monitor, a display, a printer, a communications link, and/or another computer. For example, a color printer can be utilized to provide a color-coded graphical representation of the tomographical densitometry model 24. The color coding can correspond to densities,

thus identifying potential problem areas where decalcification has occurred and resulted in lower density. The tomographical densitometry model 24 can also be useful for monitoring osseointegration, since the density of the dental/orthopedic structure 18 (tissue and bone) in the vicinity of an implant 28 or other prostheses can provide an important diagnostic tool for the use of the dental or medical practitioner in assessing the effectiveness of an implant or prosthetic procedure. The tomographical densitometry model 24 is also entered into the computer's memory device 7.

III. Dental and Orthopedic Densitometry Modeling Method

Fig. 2 is a flow chart of a dental and orthopedic densitometry method embodying the present invention. The method steps include positioning a patient and positioning the X-ray equipment relative to the patient, i.e. with the patient's dental/orthopedic structure to be examined located between the X-ray source 14 and the detector array 16.

Diagnostic parameters are input to the system and can comprise, for example, the patient's prior tomographical densitometry models and standardized models. The tomographical densitometry models can be corrected and/or adjusted to account for patients' age, gender, physical characteristics, etc. The input diagnostic parameters can be stored in the computer's memory device. A scan path for the X-ray equipment is preprogrammed in the computer.

The scanning procedure is commenced by collimating a first energy band beam, detecting emissions from same with a detector array, and converting the analog output of the detector array to a digital signal. The digital signal is output for storage in the

computer. The steps of collimating the energy band beam and detecting, digitizing and storing same are repeated for a second energy band beam. The Bisek et al. U.S. Patent No. Re. 36,362 discloses the use of dual-energy X-ray beams in medical densitometry applications. As discussed therein, dual-energy densitometry can result in a more accurate patient model.

The X-ray equipment then traverses the preprogrammed scan path and the first/second energy band steps are repeated until the scanning procedure is complete. The digitized detector array output is merged and compared to the diagnostic parameters which are stored in the computer's memory. The dental/orthopedic densitometry is tomographically modeled and output, for example to a monitor or printer for converting the model to a visual image. The visual image is output in a visible form for use by dental and medical practitioners.

CLAIMS

What is claimed and desired to be secured by Letters Patent is as follows:

1. A system for tomographically modeling dental and orthopedic structure densitometry, which includes:

   a) a controller with a microprocessor and a memory device connected to the microprocessor;

   b) an input device connected to the microprocessor;

   c) a positioning motor connected to the microprocessor and movable in response to signals from said microprocessor;

   d) X-ray equipment including an X-ray source and a detector array;

   e) conversion means for converting a signal from said detector array, said conversion means being connected to said detector array and to said microprocessor; and

   f) an output device connected to said microprocessor and adapted for receiving a tomographical densitometry model from said microprocessor.

2. The system according to Claim 1 wherein said positioning motor is adapted for positioning said X-ray equipment with respect to three axes of movement.

3. The system according to Claim 1 wherein said conversion means comprises an analog-to-digital convertor connected to said detector array.

4. The system according to Claim 3 wherein said conversion means includes a merger device connected to said analog-to-digital converter and to said microprocessor.

5. The system according to Claim 1 wherein said X-ray equipment comprises a dual energy level, restricted beam device.

6. The system according to Claim 1 which includes:

a) a preprogrammed scan path for said X-ray equipment, said scan path being programmed into said microprocessor.

7. The system according to Claim 1 wherein said output device includes a color monitor adapted to receive said tomographical densitometry model output color-coded to represent densitometry.

8. The system according to Claim 1 wherein said output device includes a color printer adapted to print images color-coded to correspond to the densitometry of said model.

9. The system according to Claim 1 wherein said controller includes:

a) means for storing a pre-existing tomographical dental/orthopedic densitometry model; and

b) means for comparing pre-existing and current tomographical densitometry models.

10. A method of tomographically modeling dental and orthopedic densitometry, which includes the steps of:

a) providing a controller with a microprocessor and a memory device connected to said microprocessor;

b) providing an input device connected to said microprocessor;

c) inputting patient diagnostic parameters with said input device;

d) storing said diagnostic parameters in memory;

e) providing X-ray equipment with an X-ray source and an X-ray detector array;

f) positioning said X-ray equipment and a patient's dental/orthopedic structure relative to each other with said patient's dental/orthopedic structure between said source and said detector array;

g) emitting an X-ray beam from said source through said dental structure and to said detector array;

h) outputting a signal from said detector array to said microprocessor;

i) forming with said microprocessor a tomographical densitometry model of said dental/orthopedic structure;

j) providing an output device connected to said microprocessor; and

k) outputting said densitometry model to said output device.

11. The method according to Claim 10 which includes the additional steps of emitting, detecting, digitizing, and storing signals corresponding to first and second energy levels from said X-ray source.

12. The method according to Claim 10 which includes the additional steps of:

a) inputting to said controller a predetermined scan path for said X-ray equipment; and

b) traversing said X-ray equipment along said scan path.

13. The method according to Claim 12 which includes the additional steps of:

a) providing a positioning motor connected to said microprocessor and to said X-ray equipment for moving same through three axes of movement along said scan path.

14. The method according to Claim 10 which includes the additional step of detecting incipient caries with said tomographical densitometry model.

15. The method according to Claim 10 which includes the additional step of detecting dental fractures with said tomographical densitometry model.

16. The method according to Claim 10 which includes the additional step of detecting apical abscesses with said tomographical densitometry model.

17. The method according to Claim 10 which includes the additional step of analyzing the extent of osseointegration of a dental or orthopedic prostheses with respect to a patient's dental or orthopedic structure with said tomographical densitometry model.

18. The method according to Claim 10 which includes the additional steps of:

a) inputting to said microprocessor a pre-existing tomographical densitometry model; and

b) comparing said patient's current densitometry model to said pre-existing densitometry model.

19. The method according to Claim 10 which includes the additional steps of:

a) providing a color output device connected to said microprocessor; and

b) color coding said densitometry model in colors corresponding to the patient's dental or orthopedic structure density and outputting said densitometry model to said output device.

20. A method of tomographically modeling dental and orthopedic densitometry, which includes the steps of:

a) providing a controller with a microprocessor and a memory device connected to said microprocessor;

b) providing an input device connected to said microprocessor;

c) inputting with said input device dental or orthopedic patient diagnostic parameters, including a pre-existing densitometry model;

d) storing said diagnostic parameters in said memory device;

e) providing X-ray equipment connected to said microprocessor, said equipment including an X-ray source and an X-ray detector array;

f) positioning said X-ray equipment and a patient's dental or orthopedic structure relative to each other with said patient's dental or orthopedic structure located between said X-ray source and said detector array;

g) emitting an X-ray beam from said source at a first X-ray beam energy level, passing same through said dental or orthopedic structure, and detecting same with said detector array;

h) outputting a signal corresponding to said detected X-ray beam from said detector array;

i) digitizing said detector array output signal;

j) storing said digitized output signal in said memory device,

k) repeating steps f) - j) at a second X-ray beam energy level;

l) merging said stored output signals to form a present tomographical densitometry model of said dental or orthopedic structure;

m) comparing said present densitometry model with said pre-existing densitometry model;

n) adjusting said present densitometry model to account for patient parameters including age and gender;

o) providing an output device connected to said microprocessor;

p) color coding said present tomographical densitometry model with colors corresponding to dental or orthopedic structure density; and

q) outputting said color-coded model to said output device.

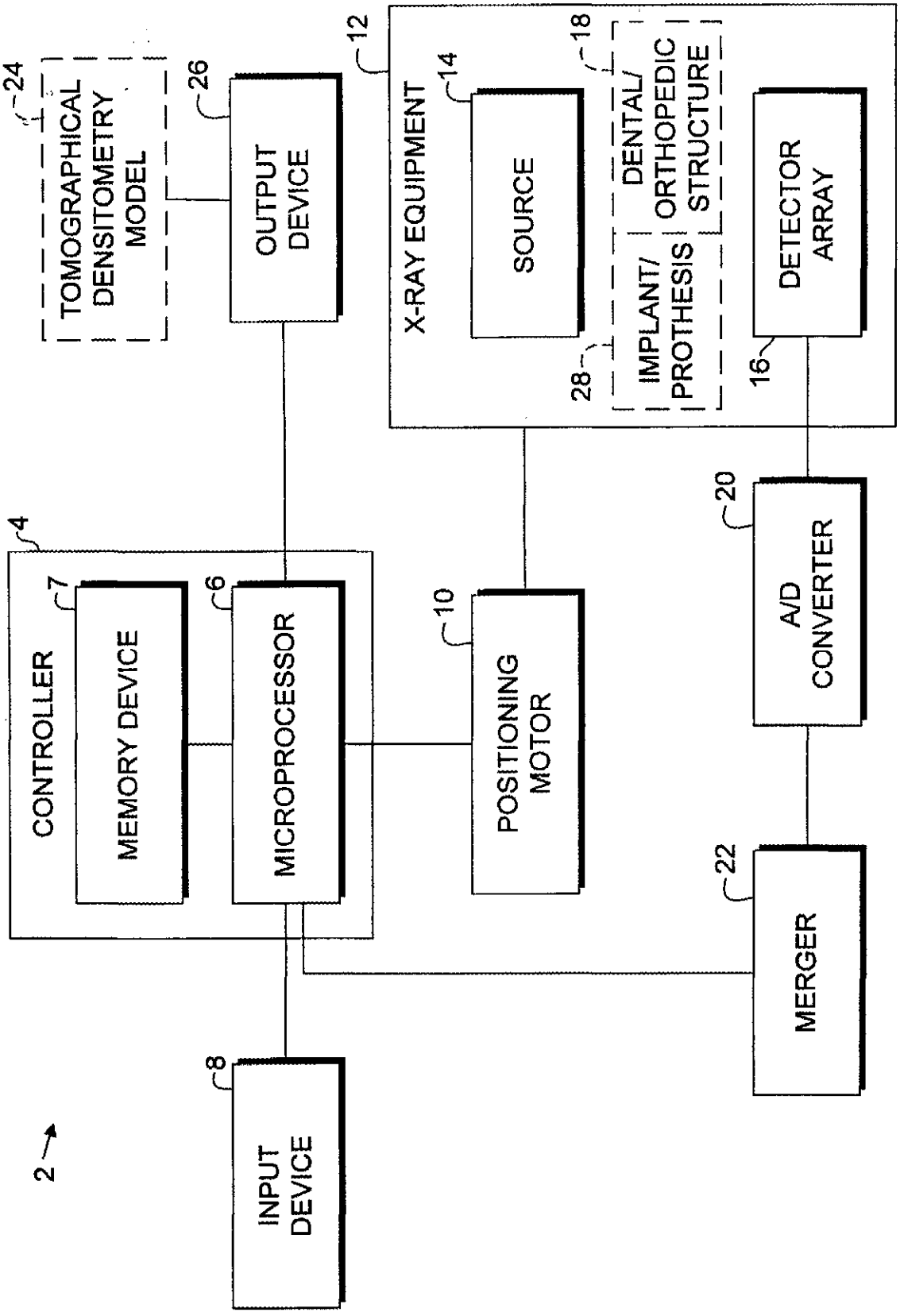
2
INPUT DEVICE
8
MERGER
22
A/D CONVERTER
20
DETECTOR ARRAY
16
IMPLANT/ PROTHESIS
28
DENTAL/ ORTHOPEDIC STRUCTURE
18
SOURCE
14
X-RAY EQUIPMENT
12
OUTPUT DEVICE
26
TOMOGRAPHICAL DENSITOMETRY MODEL
24
POSITIONING MOTOR
10
MICROPROCESSOR
6
MEMORY DEVICE
7
CONTROLLER
4

Fig. 1

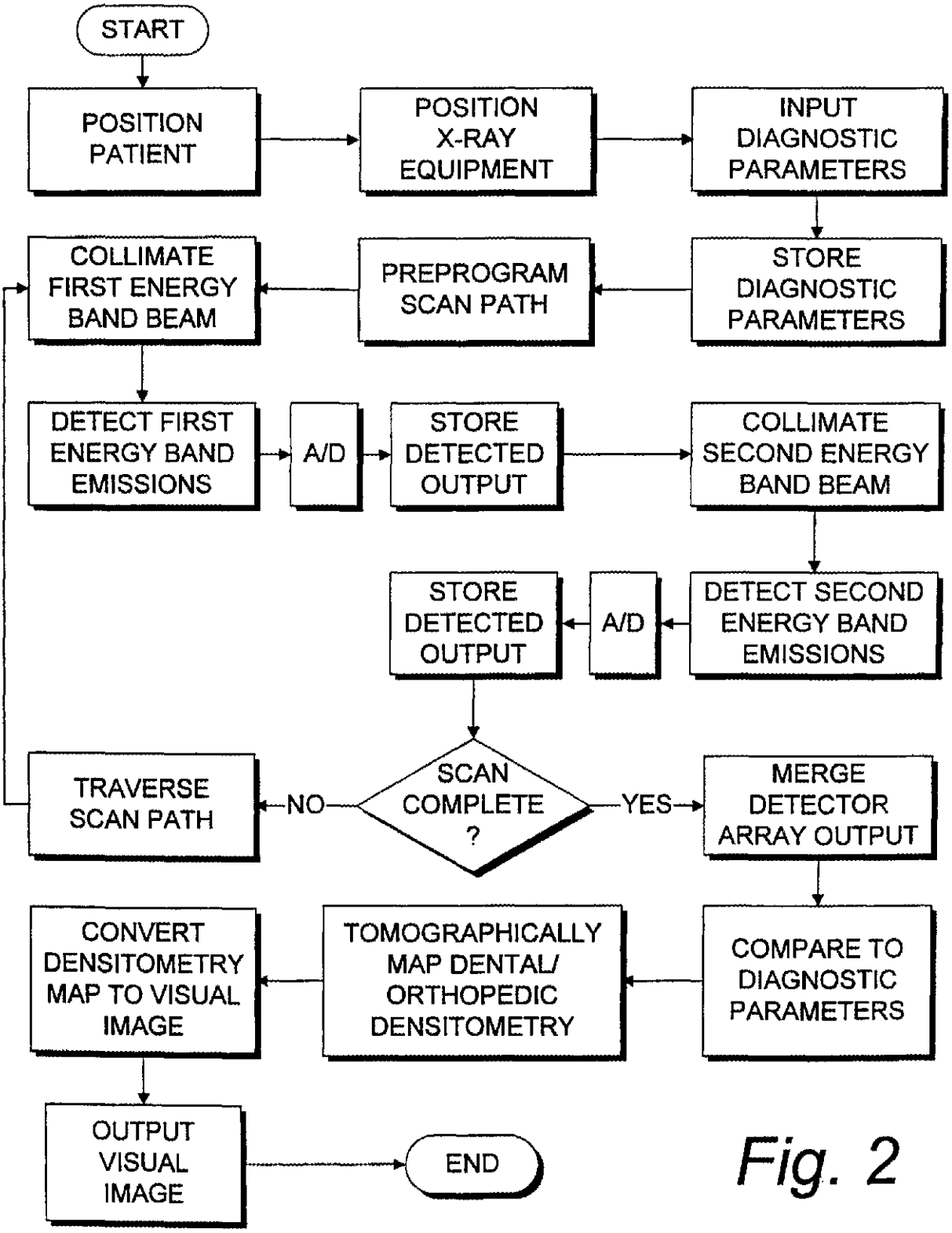
START
POSITION PATIENT
POSITION X-RAY EQUIPMENT
INPUT DIAGNOSTIC PARAMETERS
STORE DIAGNOSTIC PARAMETERS
PREPROGRAM SCAN PATH
COLLIMATE FIRST ENERGY BAND BEAM
DETECT FIRST ENERGY BAND EMISSIONS
A/D
STORE DETECTED OUTPUT
COLLIMATE SECOND ENERGY BAND BEAM
DETECT SECOND ENERGY BAND EMISSIONS
A/D
STORE DETECTED OUTPUT
SCAN COMPLETE ?
NO
TRAVERSE SCAN PATH
YES
MERGE DETECTOR ARRAY OUTPUT
COMPARE TO DIAGNOSTIC PARAMETERS
TOMOGRAPHICALLY MAP DENTAL/ ORTHOPEDIC DENSITOMETRY
CONVERT DENSITOMETRY MAP TO VISUAL IMAGE
OUTPUT VISUAL IMAGE
END

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32905

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61B 6/14; H05G 1/64
US CL : 378/205, 168, 170, 38, 39, 98.8

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)
U.S. : 378/205, 168, 170, 38, 39, 98.8

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST: Dental, Density, Densitomet$6, Position, Energy, Source, Detector

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,813,060 A (HEUBECK et al.) 14 March 1989 (14.03.1989), all.	1-20
Y	US 5,214,686 A (WEBBER) 25 May 1993 (25.05.1993), all.	1-20
Y	US 5,528,645 A (KOIVISTO) 18 June 1996 (18.06.1996), all.	1-20
Y	US 5,995,583 A (SCHICK et al.) 20 November 1999 (20.11.1999), all.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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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
16 January 2001 (16.01.2001)	26 JAN 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Drew A. Dunn Telephone No. 703-308-0956

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