平成30年5月10日

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米国特許出願番号	14/944,672
出願人	株式会社東芝殿、 国立研究開発法人　量子科学技術研究開発機構
名称	医用画像処理装置、方法、プログラム及び放射線治療装置
貴社整理番号	497US
当所整理番号	TO2524US

特許証送付の件

拝啓　貴社ますますご清栄のこととお慶び申し上げます。

さて、上記の件につきまして、現地代理人より特許証が送られてまいりました。誠にご同慶に存じます。

特許日及び特許番号は、次の通りです。

特 許 日：2018年3月20日
特許番号：9,919,164

以上、宜しくご査収下さい。

敬具

同封書類：2018年4月5日付現地代理人書信
特許証及び特許公報
弊所納品書及び現地代理人Debit Note

備　考：本件の存続期間は、2036年4月16日迄です。
なお、維持年金納付期限日は次の通りです。
第１回目(特許付与から　３年６ヶ月目)2021年9月20日
第２回目(特許付与から　７年６ヶ月目)2025年9月20日
第３回目(特許付与から１１年６ヶ月目)2029年9月20日

April 5, 2018

OBLON

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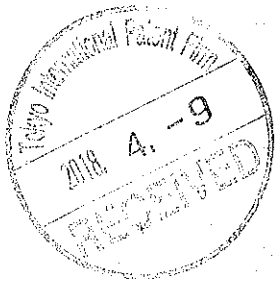

TOKYO INTERNATIONAL PATENT FIRM
2nd Floor, Miyata Building
17-16, Nishi-Shimbashi 1-chome
Minato-ku
Tokyo 105-0003
Japan

Re: U.S. Patent No: 9,919,164
Your Ref: TO2524US
Toshiba Ref: G90094069-US-A
Our Ref: 463283US

Dear Colleagues:

We are pleased to enclose herewith Letters Patent Number 9,919,164 and 1 Advanced Patent Copy.

The printed Patent has not been proofread for printing accuracy. Many printing errors which could affect the enforcement of the Patent may appear in the printed document. Such printing errors can be corrected by obtaining a Certificate of Correction from the United States Patent and Trademark Office.

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To maintain the patent in force, the USPTO charges maintenance fees. The first maintenance fee for this application will be due on September 20, 2021. To ensure that your maintenance fee service provider receives future correspondence from the USPTO, please instruct your service provider to file a "Fee Address Indication Form" with the USPTO. Alternatively, please provide us with the USPTO Customer Number of your service provider so that we can file the form. Our fee for this filing is $175. If you do not instruct your service provider or our firm to file the form, our firm will receive a maintenance fee reminder from the USPTO. Our fee for forwarding this reminder to you is $295. Therefore, please provide your instructions as soon as possible to your service provider or to our firm.

This Patent will expire on April 16, 2036.

With best regards,

Very truly yours,

OBLON, McCLELLAND,
MAIER & NEUSTADT, L.L.P.

Melissa Waller

for Surinder Sachar

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Minato-ku
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MAIER & NEUSTADT, L.L.P.

Melissa Waller

for Surinder Sachar

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Enclosures: Letters Patent
Debit Note
Advanced Patent Copy

US009919164B2

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

(10) **Patent No.: US 9,919,164 B2**
(45) **Date of Patent: Mar. 20, 2018**

(54) **APPARATUS, METHOD, AND PROGRAM FOR PROCESSING MEDICAL IMAGE, AND RADIOTHERAPY APPARATUS**

(71) Applicants: **Kabushiki Kaisha Toshiba**, Minato-Ku (JP); **National Institute of Radiological Sciences**, Chiba-Shi (JP)

(72) Inventors: **Yasunori Taguchi**, Kawasaki (JP); **Yukinobu Sakata**, Kawasaki (JP); **Ryusuke Hirai**, Shinagawa (JP); **Kyoka Sugiura**, Kawasaki (JP); **Tomoyuki Takeguchi**, Kawasaki (JP); **Shinichiro Mori**, Sakura (JP); **Fumi Maruyama**, Miura (JP)

(73) Assignees: **KABUSHIKI KAISHA TOSHIBA**, Minato-ku (JP); **National Institute of Radiological Sciences**, Chiba-Shi (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 150 days.

(21) Appl. No.: **14/944,672**

(22) Filed: **Nov. 18, 2015**

(65) **Prior Publication Data**

US 2016/0136458 A1 May 19, 2016

(30) **Foreign Application Priority Data**

Nov. 19, 2014 (JP) 2014-234672

(51) **Int. Cl.**
A61B 6/00 (2006.01)
G06T 7/00 (2017.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61N 5/1049*** (2013.01); ***A61B 6/032*** (2013.01); ***A61B 6/12*** (2013.01); ***A61B 6/5223*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06T 7/0012; G06T 7/11; G06T 7/174; G06T 7/194; G06T 2207/10116;
(Continued)

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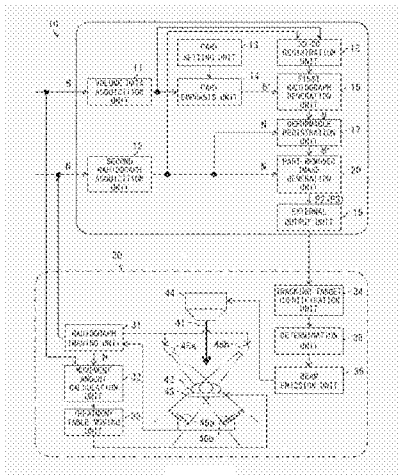
Primary Examiner — Andrew W Johns
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

According to one embodiment, a medical image processing apparatus, includes: a first acquisition unit; a second acquisition unit; and a part-removed image generation unit, wherein the first acquisition unit is adapted to acquire a first radiograph that is a virtual radiograph generated to have a specified part or a predetermined part, among parts included in volume data indicative of a three-dimensional structure of an inside of a body of a patient, being emphasized, the second acquisition unit is adapted to acquire a second radiograph of the inside of the body of the patient, and the part-removed image generation unit is adapted to generate a part-removed image by removing the specified or predeter-
(Continued)



mined part or parts other than the specified or predetermined part from the second radiograph with reference to the first radiograph.

6 Claims, 12 Drawing Sheets

(51) **Int. Cl.**

A61N 5/10	(2006.01)
G06T 11/00	(2006.01)
A61B 6/03	(2006.01)
A61B 6/12	(2006.01)
G06T 7/11	(2017.01)
G06T 7/174	(2017.01)
G06T 7/194	(2017.01)
A61B 6/02	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 6/5235*** (2013.01); ***A61B 6/5252*** (2013.01); ***A61N 5/107*** (2013.01); ***A61N 5/1067*** (2013.01); ***G06T 7/11*** (2017.01); ***G06T 7/174*** (2017.01); ***G06T 7/194*** (2017.01); ***G06T 11/008*** (2013.01); *A61B 6/022* (2013.01); *A61B 6/486* (2013.01); *A61N 2005/1061* (2013.01); *A61N 2005/1062* (2013.01); *G06T 2207/10016* (2013.01); *G06T 2207/10116* (2013.01); *G06T 2207/10124* (2013.01); *G06T 2207/30008* (2013.01)

(58) **Field of Classification Search**

CPC G06T 2207/20224; A61B 6/486; A61B 6/5217; A61B 6/5235; A61B 6/5252; A61N 5/1049; A61N 2005/1061; A61N 2005/1062

See application file for complete search history.

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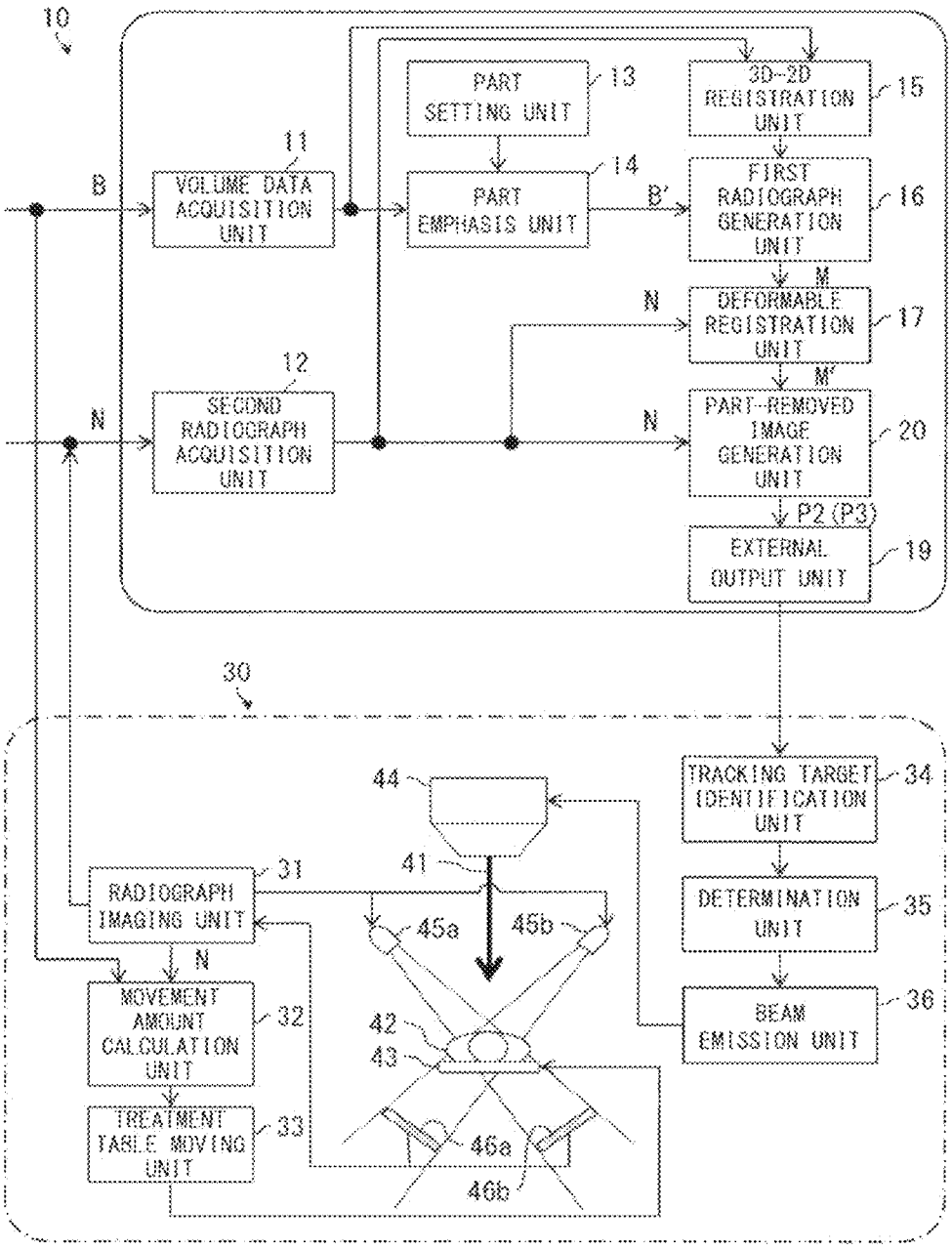
10
PART SETTING UNIT
13
3D-2D REGISTRATION UNIT
15
11
VOLUME DATA ACQUISITION UNIT
14
PART EMPHASIS UNIT
B'
FIRST RADIOGRAPH GENERATION UNIT
16
M
N
DEFORMABLE REGISTRATION UNIT
17
M'
12
SECOND RADIOGRAPH ACQUISITION UNIT
N
N
PART-REMOVED IMAGE GENERATION UNIT
20
P2(P3)
EXTERNAL OUTPUT UNIT
19
B
N
30
TRACKING TARGET IDENTIFICATION UNIT
34
44
41
RADIOGRAPH IMAGING UNIT
31
45a
45b
DETERMINATION UNIT
35
N
MOVEMENT AMOUNT CALCULATION UNIT
32
42
43
BEAM EMISSION UNIT
36
TREATMENT TABLE MOVING UNIT
33
46a
46b

FIG. 1

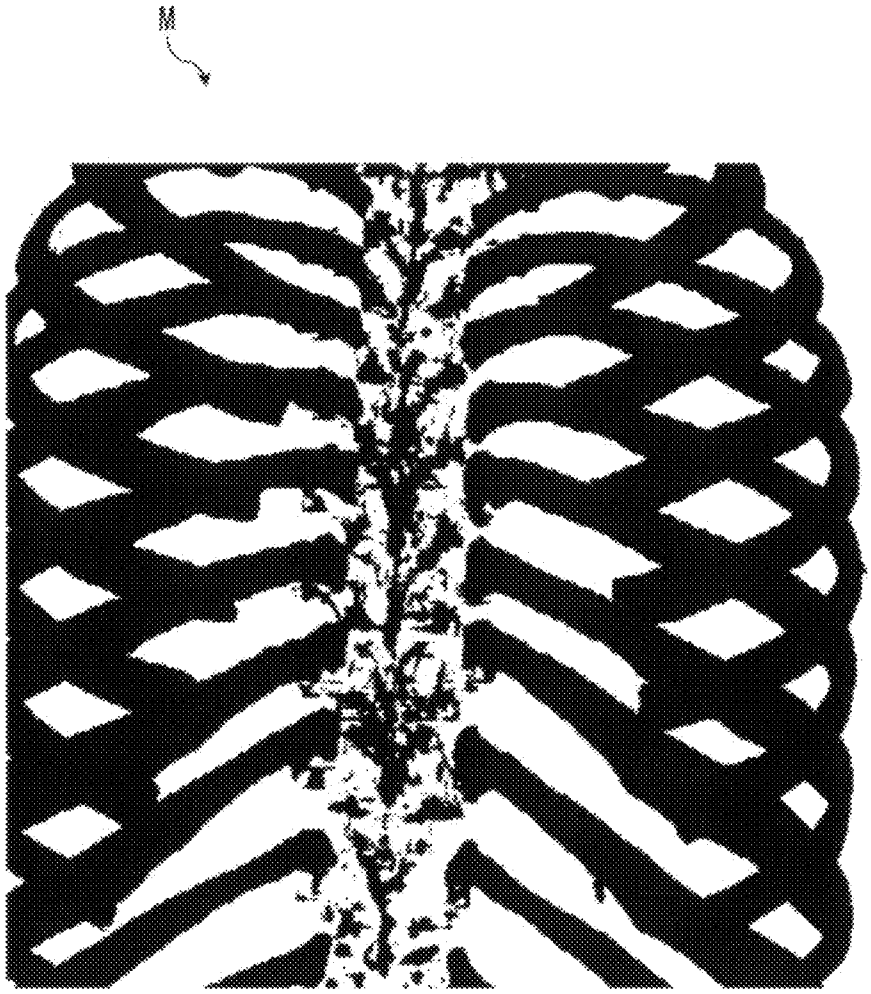

FIG. 2

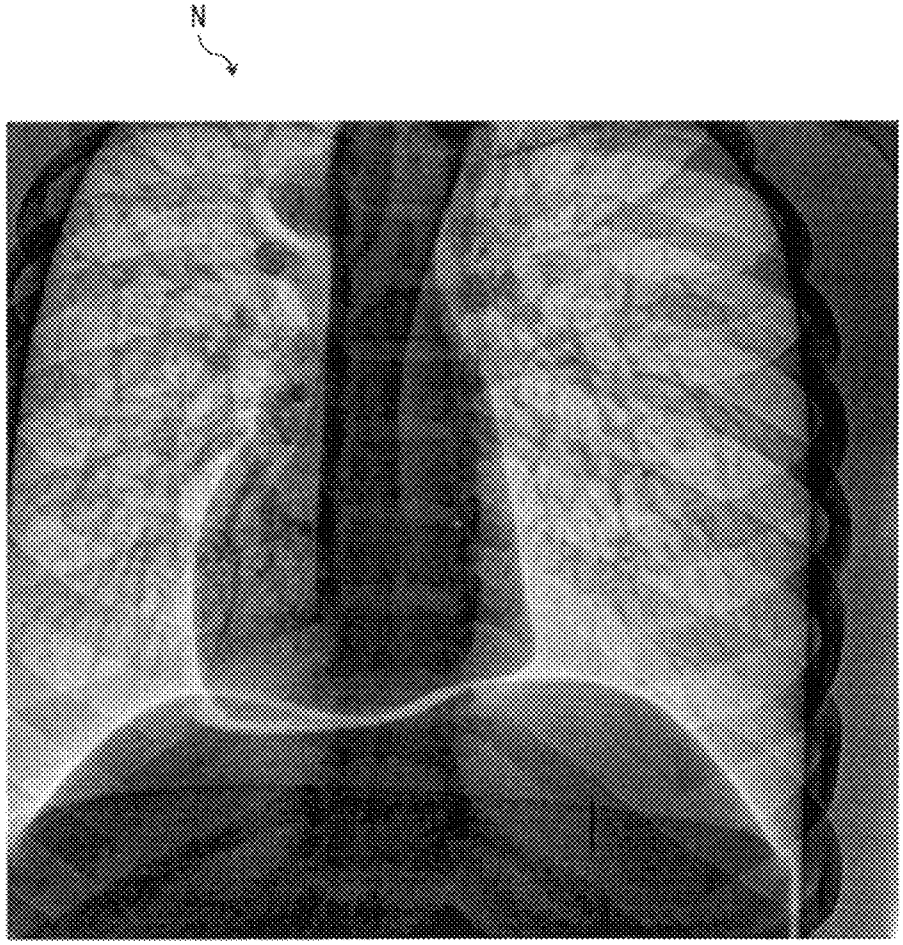

FIG. 3

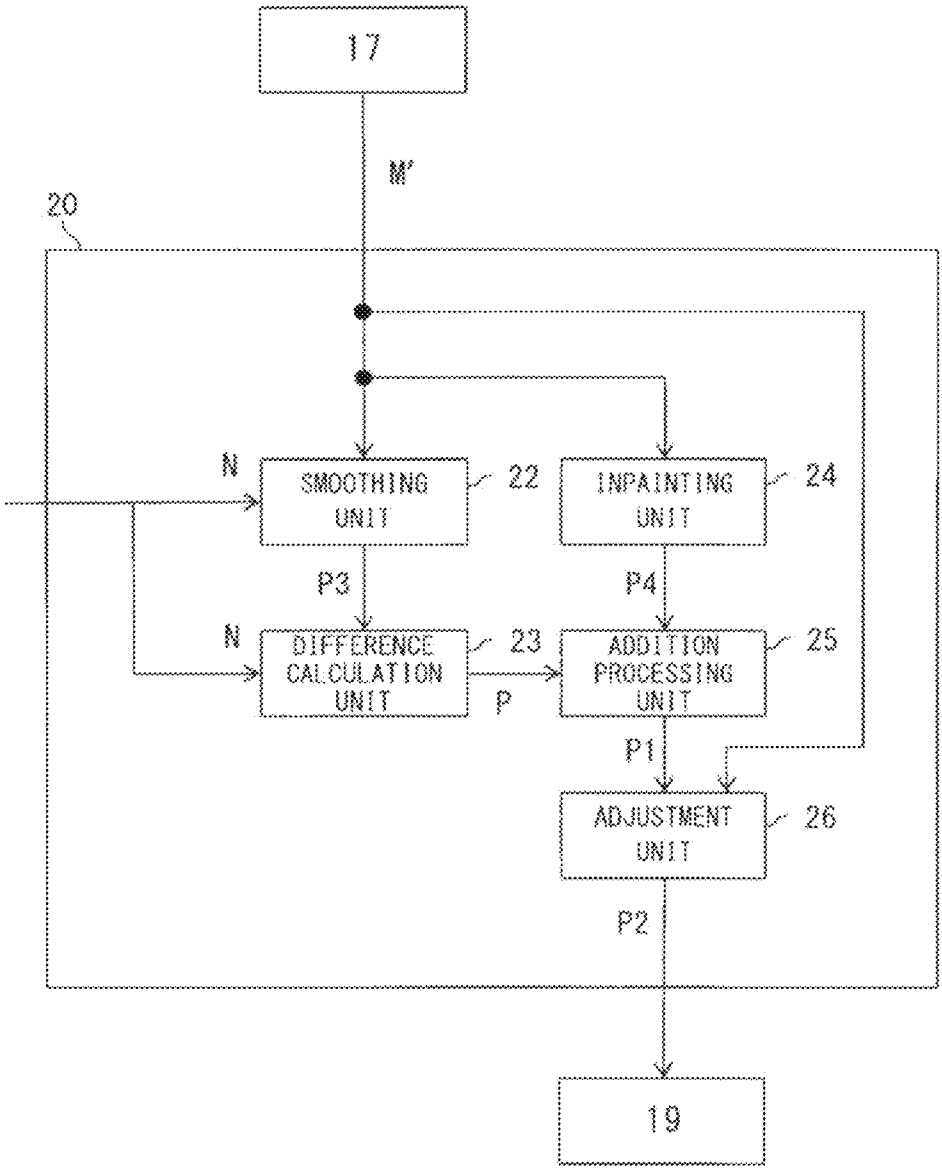
17
M'
20
N
SMOOTHING UNIT
22
INPAINTING UNIT
24
P3
P4
N
DIFFERENCE CALCULATION UNIT
23
P
ADDITION PROCESSING UNIT
25
P1
ADJUSTMENT UNIT
26
P2
19

FIG. 4

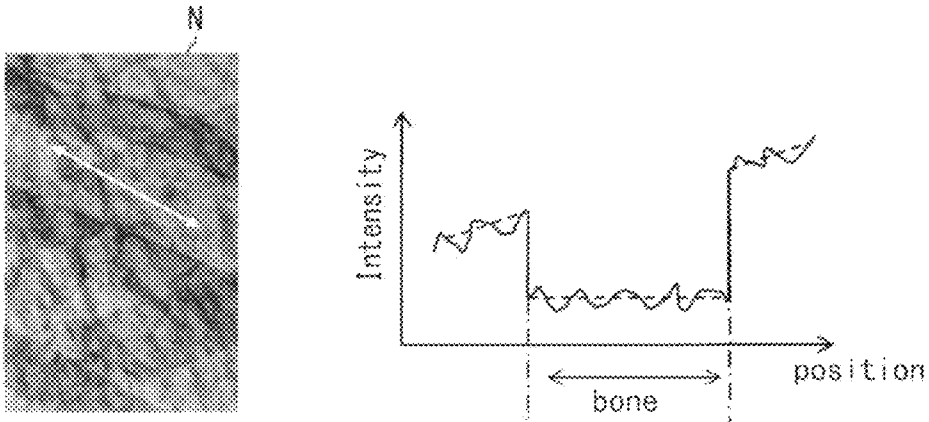

FIG. 5A

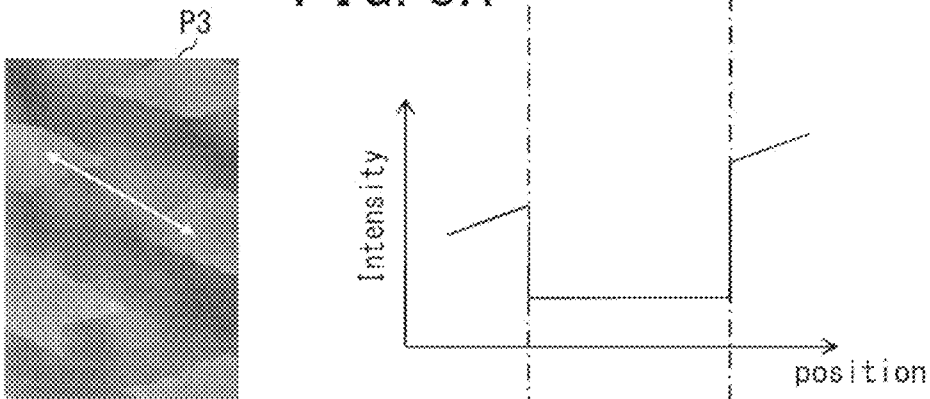

FIG. 5B

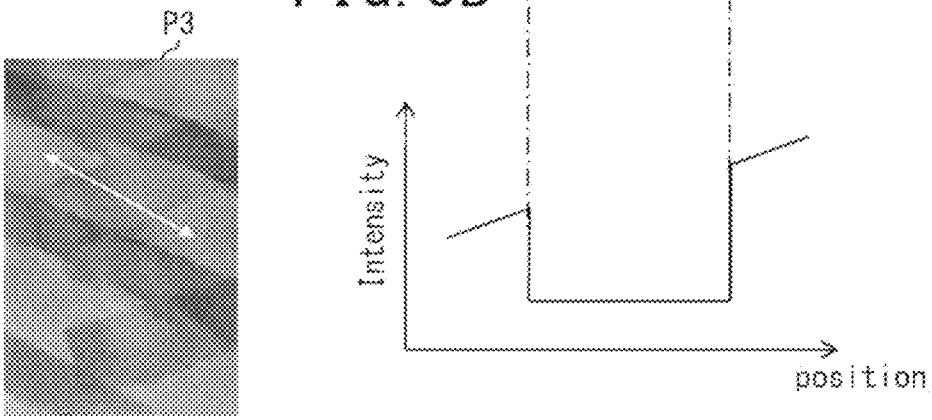

FIG. 5C

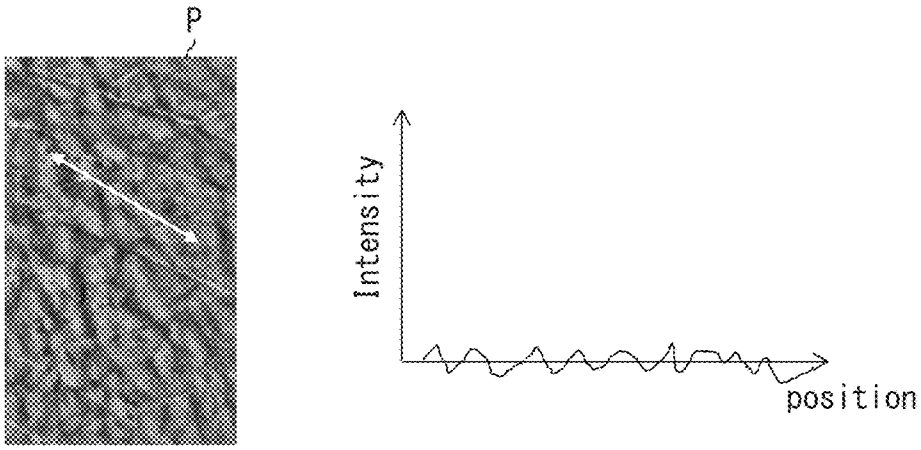

FIG. 6A

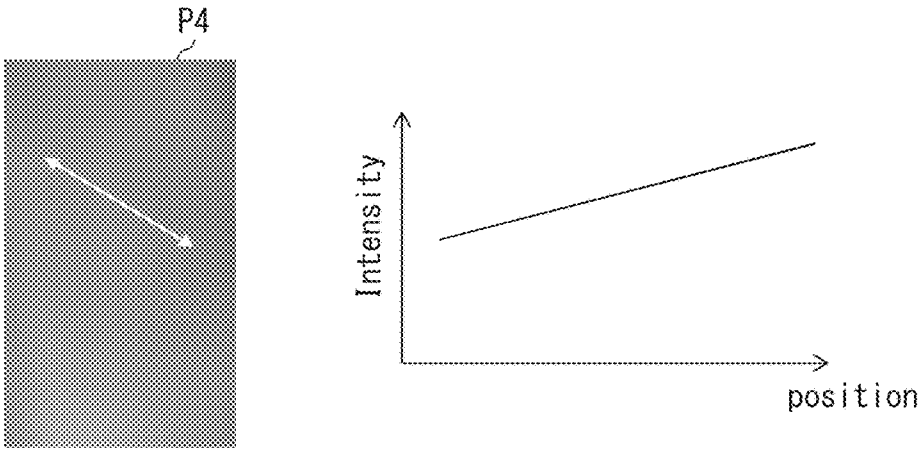

FIG. 6B

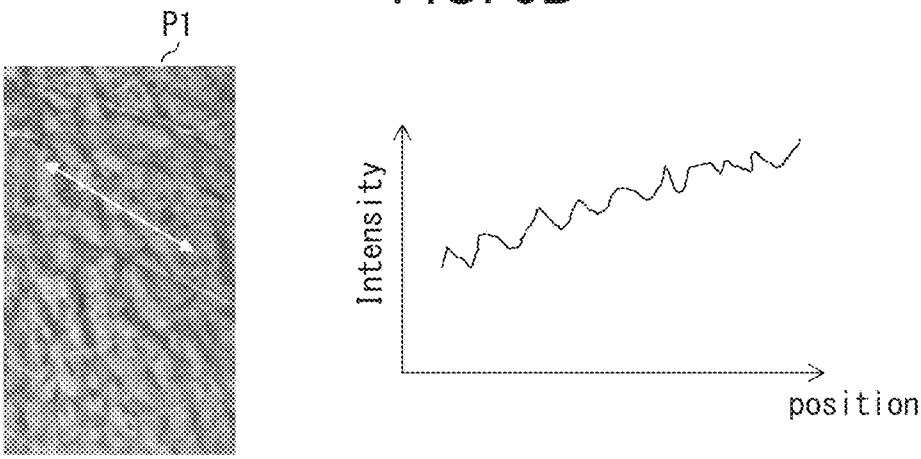

FIG. 6C

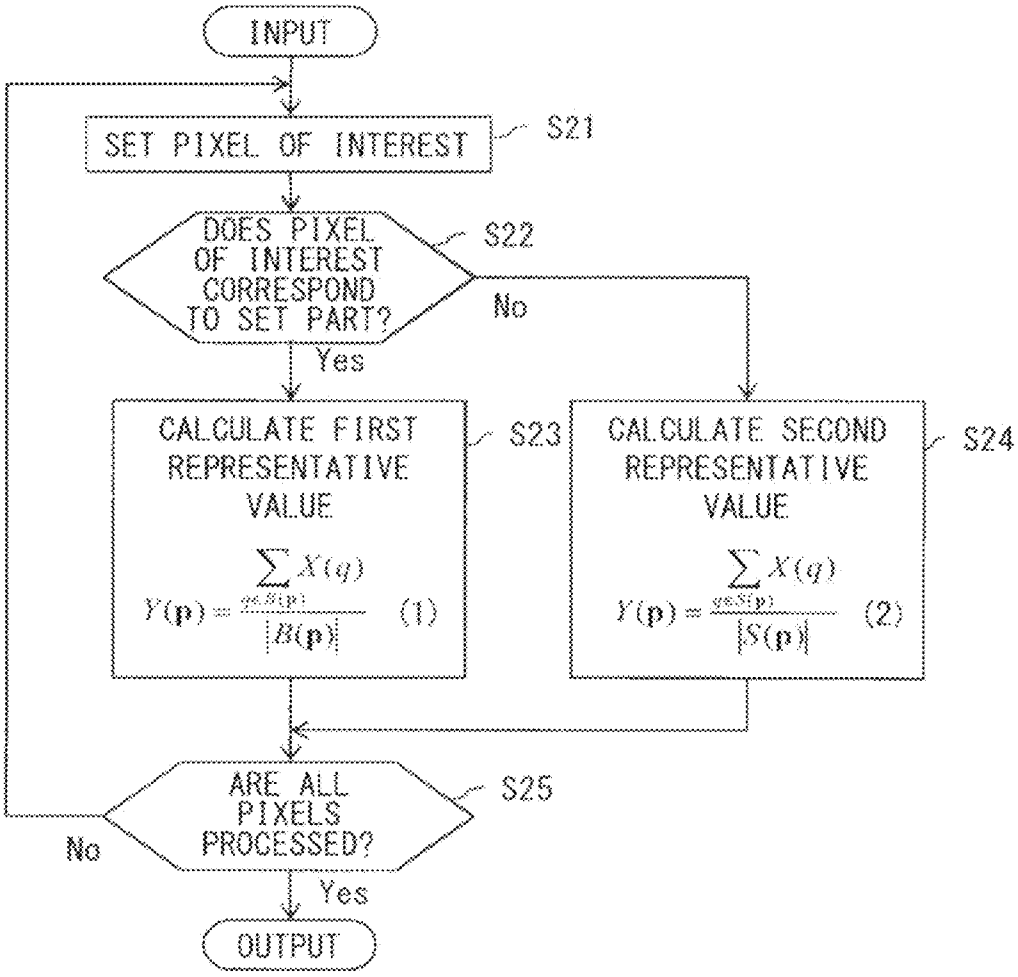
INPUT
SET PIXEL OF INTEREST
S21
DOES PIXEL OF INTEREST CORRESPOND TO SET PART?
S22
No
Yes
CALCULATE FIRST REPRESENTATIVE VALUE
$Y(\mathbf{p}) = \frac{\sum_{q \in B(\mathbf{p})} X(q)}{|B(\mathbf{p})|}$ (1)
S23
CALCULATE SECOND REPRESENTATIVE VALUE
$Y(\mathbf{p}) = \frac{\sum_{q \in S(\mathbf{p})} X(q)}{|S(\mathbf{p})|}$ (2)
S24
ARE ALL PIXELS PROCESSED?
S25
No
Yes
OUTPUT

FIG. 7

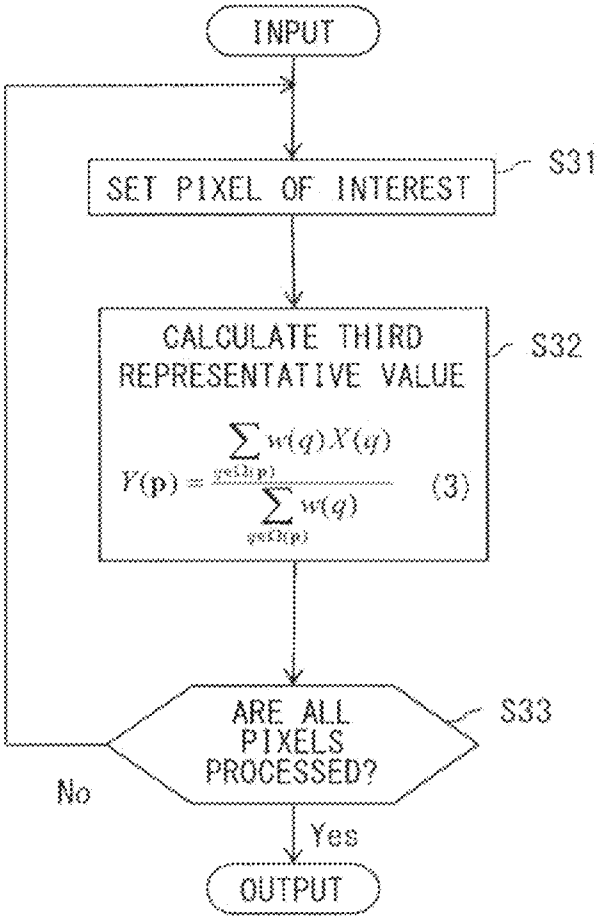
INPUT
SET PIXEL OF INTEREST
S31
CALCULATE THIRD REPRESENTATIVE VALUE
$Y(\mathbf{p}) = \frac{\sum_{q \in \Omega(\mathbf{p})} w(q) X(q)}{\sum_{q \in \Omega(\mathbf{p})} w(q)}$ (3)
S32
ARE ALL PIXELS PROCESSED?
S33
No
Yes
OUTPUT

FIG. 8

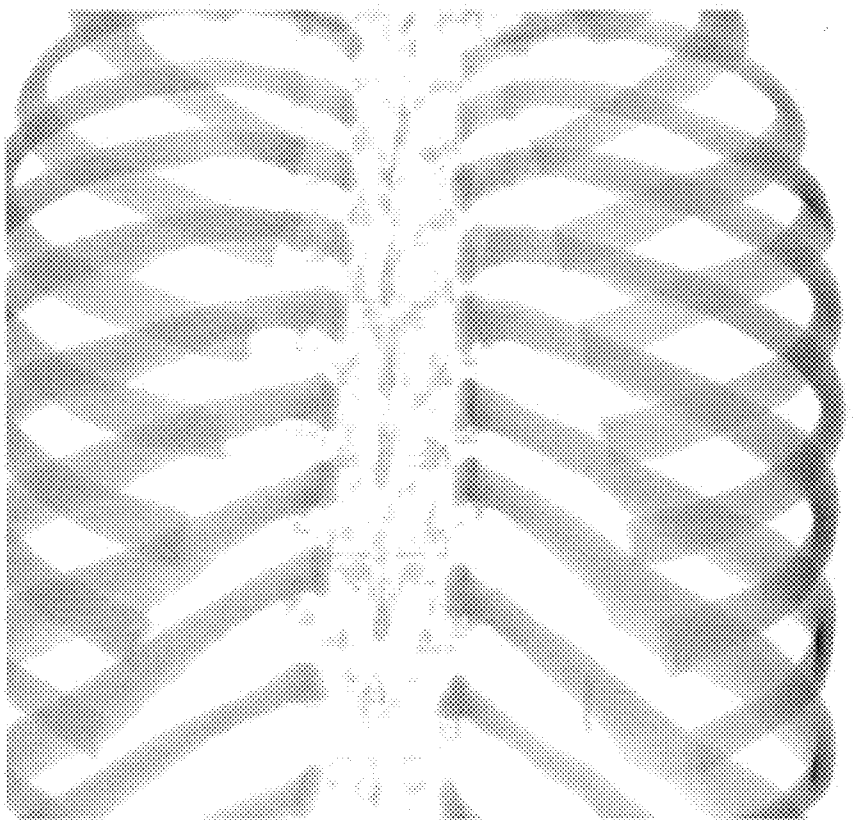

FIG. 9

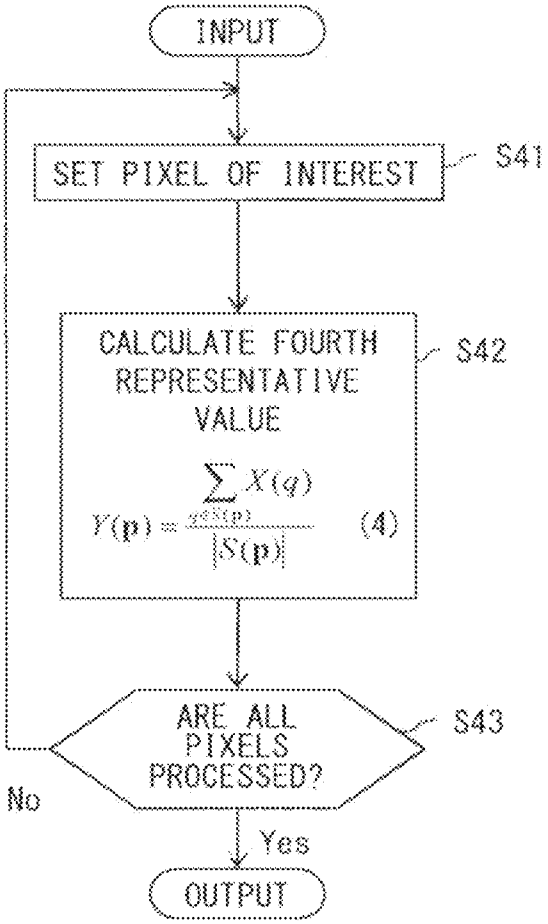
INPUT
SET PIXEL OF INTEREST
S41
CALCULATE FOURTH REPRESENTATIVE VALUE
$Y(\mathbf{p}) = \frac{\sum_{q \in S(\mathbf{p})} X(q)}{|S(\mathbf{p})|}$ (4)
S42
ARE ALL PIXELS PROCESSED?
S43
No
Yes
OUTPUT

FIG. 10

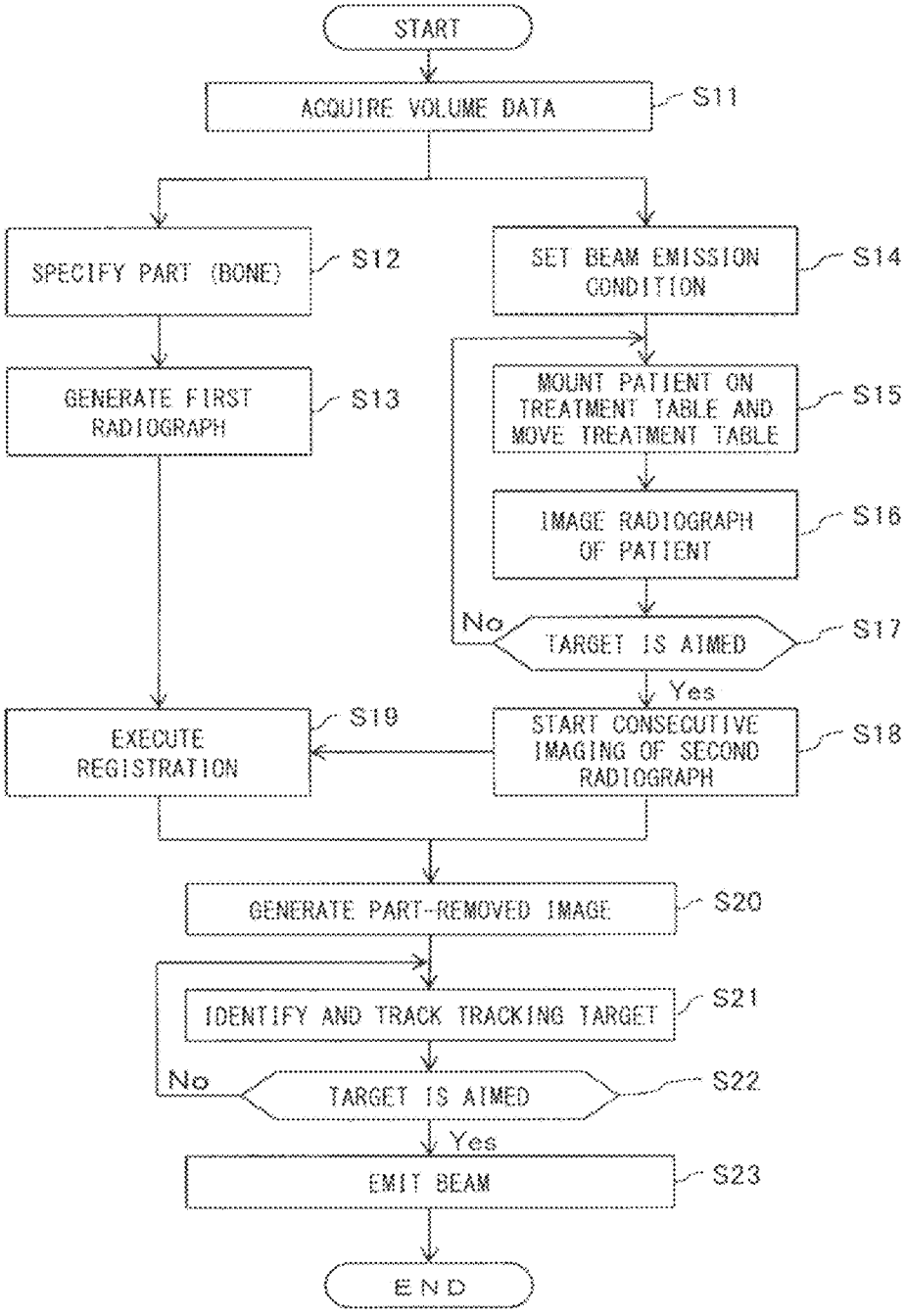
START
ACQUIRE VOLUME DATA
S11
SPECIFY PART (BONE)
S12
GENERATE FIRST RADIOGRAPH
S13
SET BEAM EMISSION CONDITION
S14
MOUNT PATIENT ON TREATMENT TABLE AND MOVE TREATMENT TABLE
S15
IMAGE RADIOGRAPH OF PATIENT
S16
No
TARGET IS AIMED
S17
Yes
START CONSECUTIVE IMAGING OF SECOND RADIOGRAPH
S18
EXECUTE REGISTRATION
S19
GENERATE PART-REMOVED IMAGE
S20
IDENTIFY AND TRACK TRACKING TARGET
S21
No
TARGET IS AIMED
S22
Yes
EMIT BEAM
S23
END

FIG. 11

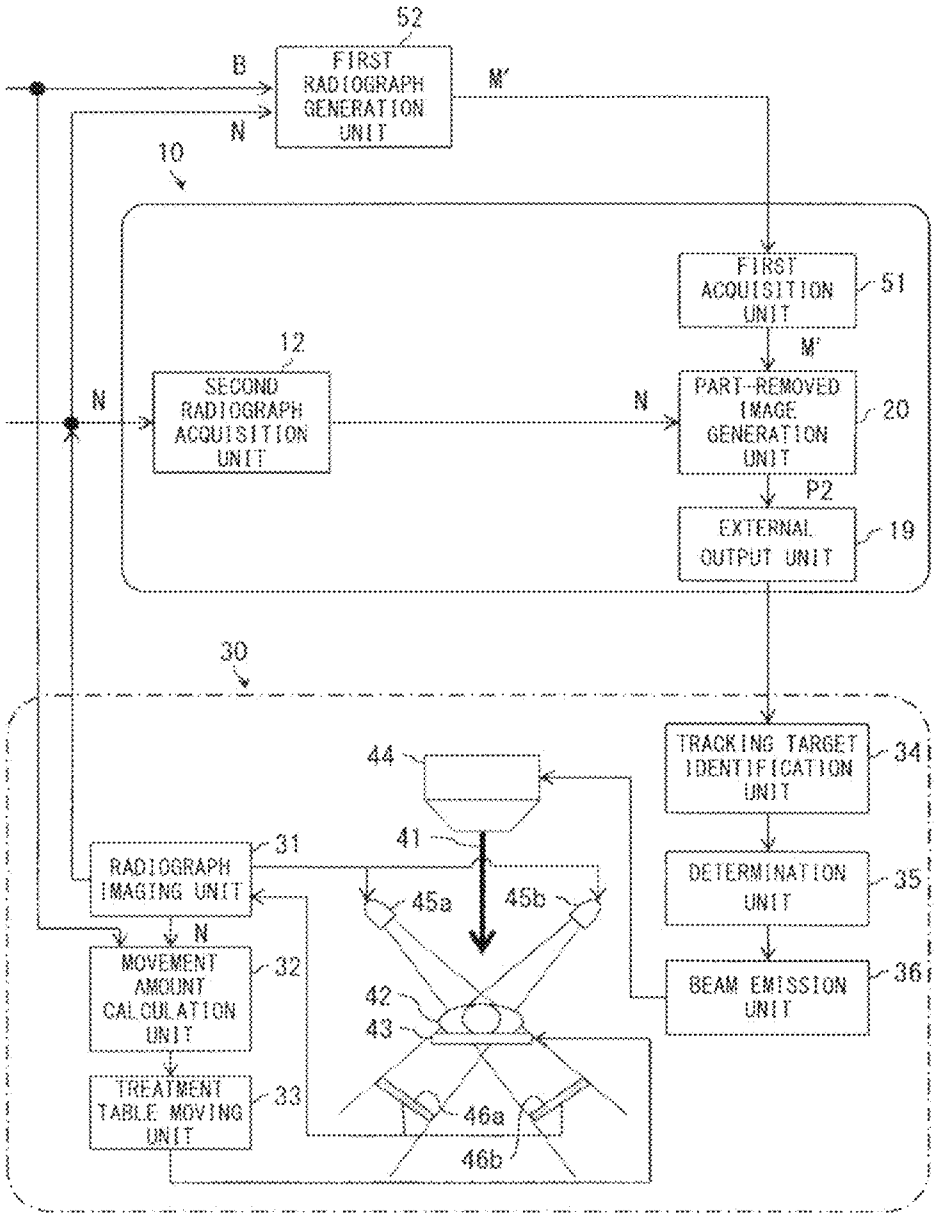
52
FIRST RADIOGRAPH GENERATION UNIT
B
N
M'
10
FIRST ACQUISITION UNIT
51
M'
12
SECOND RADIOGRAPH ACQUISITION UNIT
N
N
PART-REMOVED IMAGE GENERATION UNIT
20
P2
EXTERNAL OUTPUT UNIT
19
30
TRACKING TARGET IDENTIFICATION UNIT
34
44
41
RADIOGRAPH IMAGING UNIT
31
45a
45b
DETERMINATION UNIT
35
N
MOVEMENT AMOUNT CALCULATION UNIT
32
42
43
BEAM EMISSION UNIT
36
TREATMENT TABLE MOVING UNIT
33
46a
46b

FIG. 12

APPARATUS, METHOD, AND PROGRAM FOR PROCESSING MEDICAL IMAGE, AND RADIOTHERAPY APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patient application No. 2014-234672, filed on Nov. 19, 2014, the entire contents of each of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a medical image processing technique for processing a radiograph of an inside of a body of a patient and a radiotherapy apparatus using the same.

Description of the Related Art

In radiotherapy performed as a treatment by emitting radiation to an affected part of the patient, the affected part may change over time with respiration, heart beats, motions of intestines and internal gas, and the like in some cases. In such a case, the motion of the affected part is tracked to determine proper timing of emission of radiation, or radiation is emitted while the affected part is traced.

To track such a changeable affected part, a tracking scheme is known in which the affected part is tracked based on an X-ray radiograph showing the periphery of the affected part.

This scheme has a problem that a bone reflected in the radiograph lowers detection accuracy of a tracking target. To cope with this problem, a medical image processing technique is considered to be useful. The medical image processing technique generates, from an X-ray radiograph, a radiograph showing only bone and/or a radiograph with the bone removed. For example, in Patent Document 1 (U.S. Pat. No. 7,545,965), a radiograph is used to generate a radiograph showing only the bone. The radiograph showing only the bone is subtracted from the original radiograph to generate a radiograph without the bone.

However, the scheme of Patent Document 1 needs prior learning using a pair of radiographs as teacher images, the pair of radiographs being a radiograph and a radiograph showing only the bone, which are acquired in advance with a dual-energy X-ray imaging apparatus.

It is concerned that the scheme using the teacher images may cause deterioration in performance of medical image processing in the case where radiography conditions are different between the teacher images and a processing target image. Furthermore, there is a problem that a person who is an object of the teacher images is contaminated by radioactivity.

Note that the radiograph includes the meaning of radiographic image, fluoroscopic image and digitally reconstructed radiograph (DRR).

SUMMARY OF THE INVENTION

In consideration of such circumstances, an object of embodiments of the present invention is to provide a medical image processing technique that can provide a radiograph with a part such as bone being removed at high accuracy or a radiograph with parts other than the part such as bone being removed at high accuracy, regardless of radiography conditions and without teacher images.

Another object of the embodiments is to provide a radiotherapy apparatus using the medical image processing technique, the apparatus being capable of precisely recognizing a position of an affected part movable by respiration and other factors and emitting medical radiation only to the affected part so as to minimize an influence on healthy cells. Here, the medical radiation includes X-rays, γ rays, electron beams, proton beams, neutron beams, and heavy particle beams. Hereinafter, the medical radiation may also be referred to as a beam.

A medical image processing apparatus according to the embodiments of the present invention includes: a first acquisition unit; a second acquisition unit; and a part-removed image generation unit, wherein the first acquisition unit is adapted to acquire a first radiograph that is a virtual radiograph generated to have a specified part or a predetermined part, among parts included in volume data indicative of a three-dimensional structure of an inside of a body of a patient, being emphasized, the second acquisition unit is adapted to acquire a second radiograph of the inside of the body of the patient, and the part-removed image generation unit is adapted to generate a part-removed image by removing the specified or predetermined part or parts other than the specified or predetermined part from the second radiograph with reference to the first radiograph.

The radiotherapy apparatus according to the embodiments of the present invention includes: a radiograph imaging unit; a movement amount calculation unit; a treatment table moving unit; an identification unit; and a beam emission unit, wherein the radiograph imaging unit is adapted to image the second radiograph acquired by the second acquisition unit, the movement amount calculation unit is adapted to calculate a movement amount of a treatment table with the patient mounted thereon, based on the imaged second radiograph, the treatment table moving unit is adapted to move the treatment table in accordance with the movement amount, the identification unit is adapted to identify a tracking target based on the part-removed image consecutively output from an external output unit of the medical image processing apparatus, and the beam emission unit is adapted to emit a beam that is medical radiation such as an X-ray and a heavy particle beam to an affected part of the patient at timing when the tracking target changing in the consecutive part-removed images in plural matches with an irradiation point of the beam, or the beam emission unit is adapted to emit the beam to the tracking target while tracking the tracking target.

The embodiments of the present invention provide a medical image processing technique that can provide a radiograph with a part such as bone being removed at high accuracy or a radiograph with parts other than the part such as bone being removed at high accuracy, regardless of radiography conditions and without teacher images.

Furthermore, the embodiments of the present invention provide a radiotherapy apparatus using the medical image processing technique, the apparatus being capable of precisely recognizing a position of an affected part movable by respiration and other factors and emitting a beam only to the affected part so as to minimize an influence on healthy cells.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating a medical image processing apparatus and a radiotherapy apparatus using the same according to an embodiment of the present invention;

FIG. **2** illustrates a first radiograph that is a DRR with an area of bone included in volume data of a patient's chest being emphasized;

FIG. **3** illustrates a second radiograph of the patient's chest;

FIG. **4** is a block diagram illustrating an internal configuration of a part-removed image generation unit in the medical image processing apparatus according to the embodiment;

FIGS. **5**A, **5**B and **5**C are explanatory views illustrating processes of image processing in the part-removed image generation unit;

FIGS. **6**A, **6**B and **6**C are explanatory views illustrating processes of image processing in the part-removed image generation unit;

FIG. **7** is an explanatory view illustrating an example of a smoothing unit constituting the part-removed image generation unit;

FIG. **8** is an explanatory view illustrating another example of the smoothing unit constituting the part-removed image generation unit;

FIG. **9** is a schematic view illustrating one example of a part-removed image P**3**;

FIG. **10** is an explanatory view illustrating an example of an inpainting unit constituting the part-removed image generation unit;

FIG. **11** is a flowchart illustrating operation in a method and a program for processing a medical image and a radiotherapy apparatus using the same according to the embodiment; and

FIG. **12** is a block diagram illustrating a medical image processing apparatus and a radiotherapy apparatus using the same according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described hereinbelow with reference to the accompanying drawings.

As illustrated in FIG. **1**, a medical image processing apparatus **10** includes: a volume data acquisition unit **11** adapted to acquire volume data B indicative of a three-dimensional structure of an inside of a body of a patient; a part emphasis unit **14** adapted to generate volume data B' having an area of a specified part (for example, bone) being emphasized; a first radiograph generation unit **16** adapted to generate a first radiograph M as a virtual radiograph which is digitally reconstructed radiograph (DRR) based on the volume data B'; a second radiograph acquisition unit **12** adapted to acquire a second radiograph N showing the inside of the body of a patient **42** from a prescribed direction; and a part-removed image generation unit **20** adapted to remove a specified part (for example, bone) from the second radiograph N to generate a part-removed image P**2**, or to remove parts other than the specified part from the second radiograph N to generate a part-removed image P**3**.

In the medical image processing apparatus **10** of FIG. **1**, a first acquisition unit **51** (see FIG. **12**) positioned on an upstream side of the part-removed image generation unit **20** and adapted to acquire the first radiograph M (M') is omitted.

In the medical image processing apparatus **10**, the second radiograph acquisition unit **12** consecutively acquires the second radiograph N. The medical image processing apparatus **10** further includes: a deformable registration unit **17** adapted to execute deformable registration for deforming the first radiograph M into a first radiograph M' on the basis of the acquired second radiograph N; and an external output unit **19** adapted to consecutively output a part-removed image P**2** corresponding to the acquired second radiograph N to the outside.

A radiotherapy apparatus **30** includes: a radiograph imaging unit **31** adapted to image a second radiograph N acquired by the second radiograph acquisition unit **12** of the medical image processing apparatus **10**; a treatment table moving unit **33** adapted to move a treatment table **43** with the patient **42** mounted thereon so that a set target is aimed; a tracking target identification unit **34** adapted to identify a tracking target based on the part-removed image P**2** consecutively output from the external output unit **19** of the medical image processing apparatus **10**; a determination unit **35** adapted to determine whether or not the tracking target changeable in the consecutive part-removed images in plural P**2** matches with an irradiation point of a beam **41**; and a beam emission unit **36** adapted to emit the beam at timing when the tracking target is determined to match with the irradiation point.

The volume data B acquired by the volume data acquisition unit **11** is a three-dimensional image of the inside of the body of the patient imaged with, for example, an X-ray CT scanner. In addition, the volume data B may also be an image imaged with an MRI apparatus. The volume data B may be any image indicative of the three-dimensional structure of the inside of the body of the patient.

If this volume data B is used, parts inside the body such as bone and various organs can be analyzable based on values of respective voxels.

In a part setting unit **13**, names of various parts are listed in an information table. When a user hopes to remove or leave a certain part, the user can specify the name of the part, so that the part can be removed or left unremoved.

More specifically, in the part setting unit **13**, the user specifies a part to be removed from or left in the second radiograph N (FIG. **3**) in the end. Although the bone is specified in the embodiment, the part to be specified is not particular limited. When a part to be removed is predetermined, not the part specified by the user but the predetermined part may be set. In that case, the part setting unit **13** may be omitted. Hereinafter, the part set in the part setting unit **13** is stated as a set part.

The part emphasis unit **14** automatically determines, based on the values of the voxels, an area corresponding to the set part in the volume data B. The part emphasis unit **14** generates volume data B' by rewriting voxel values of the area corresponding to the set part in the first radiograph M generated in the first radiograph generation unit **16** so that the set part is emphasized.

For example, when the volume data B is CT data, the volume data B' is generated by setting the values of the voxels of the area corresponding to the set part to 1 and setting the values of the other voxels to 0. Or the volume data B' is generated by keeping the values of the voxels of the area corresponding to the set part unchanged while setting the values of the other voxels to 0.

The first radiograph generation unit **16** sets a virtual viewpoint and an image plane around the volume data B', and generates a first radiograph M that is a DRR of the volume data B' obtained by perspective projection.

The virtual viewpoint and the image plane of the first radiograph M are set by a 3D-2D registration unit **15**. The 3D-2D registration unit **15** receives input of the volume data B and the second radiograph N. In the 3D-2D registration unit **15**, the virtual viewpoint and the image plane similar in geometry to those used in photographing the second radiograph N (FIG. **3**) are calculated by 3D-2D registration. By

conducting the 3D-2D registration, positions of an object in the second radiograph N and the first radiograph M are aligned.

FIG. **2** illustrates an example of a first radiograph M of the volume data B' with bone as the set part being emphasized. FIG. **2** is a binary image expressing the bone in black and parts other than the bone in white. How the part area in the first radiograph M is emphasized is different depending on how the volume data B' in the part emphasis unit **14** is generated. For example, the first radiograph M may be a multi-valued image in which the area corresponding to the set part is shaded but other areas are not shaded and have only one value.

Since the first radiograph M that is a two-dimensional image is a perspective projection of the three-dimensional volume data B' onto an image plane, the emphasized area is an area of the set part (bone).

The first radiograph M generated in this way includes information indicating positions of the parts, which are to be removed from the second radiograph N, reflected on the second radiograph N.

A second radiograph N illustrated in FIG. **3** is, for example, an X-ray radioscopic image, which is imaged with an apparatus configured to radiograph the inside of the body of the patient by emitting an X-ray from a predetermined position. Radiation other than the X-ray may be used for radiographing.

The thus-imaged second radiograph N is electronically transmitted and is acquired by the second radiograph acquisition unit **12**.

The illustrated second radiograph N is an image of the patient **42** imaged in real time by an X-ray emission unit **45** and an X-ray detection unit **46** of the radiotherapy apparatus **30**.

In this case, in a plurality of second radiographs N acquired over time by the second radiograph acquisition unit **12**, a shape or a position of the set part (bone) sequentially change with respiration.

The first radiograph M and the second radiograph N do not necessarily coincide with each other in all the areas due to such factors as deviated photographing time, minor difference in posture on the bed, and deviation in phase of respiration, even though an identical patient is photographed.

Accordingly, the deformable registration unit **17** executes deformable registration that deforms the first radiograph M into a first radiograph M' on the basis of the acquired second radiograph N.

As a consequence, the position of the object in the first radiograph M' coincides with the position in the second radiograph N.

When the positions of the object in the first radiograph M and the second radiograph N coincide, it is not necessary to execute the deformable registration.

Even when the positions do not perfectly coincide, the deformable registration unit **17** is still omissible. To omit the unit **17**, the first radiograph M is adopted instead of the first radiograph M'. Omitting the deformable registration unit **17** when the positions do not perfectly coincide may cause deteriorated display quality of the part-removed image.

Here, tissue information about a plurality of parts inside the body (skin, bone, internal organs, blood vessels, bronchial tubes, and the like), which are penetrated by radiation that reaches each pixel of the X-ray detection unit **46**, is superimposed on pixels constituting the second radiograph N.

Accordingly, if some of the tissue information (bone information) included in the values of the respective pixels of the second radiograph N are removed, it becomes possible to obtain a radiograph with the corresponding part inside the body (bone) being removed.

The part-removed image generation unit **20** generates a part-removed image P**2** by removing the set part (bone) from the second radiograph N.

According to this part-removed image P**2**, it becomes possible to enhance visibility of other body tissues (an affected part) which are difficult to visually recognize due to the existence of some parts (bone) in the second radiograph N.

As illustrated in FIG. **4**, the part-removed image generation unit **20** has a smoothing unit **22** adapted to generate a part-removed image P**3** with parts other than the set part (bone) being removed, and a difference calculation unit **23** adapted to execute difference calculation of the second radiograph N and the part-removed image P**3** to generate a part-removed image P.

The part-removed image generation unit **20** further has: an inpainting unit **24** adapted to generate a part-removed image P**4** excluding both the set part (bone) and minute image patterns; an addition processing unit **25** adapted to add the part-removed image P to the part-removed image P**4** to generate a part-removed image P**1**; and an adjustment unit **26** adapted to remove artifact noise from the part-removed image P**1** or to perform image adjustment of the part-removed image P**1** to generate a part-removed image P**2**.

A left-side image of FIG. **5**A illustrates a partial cutaway view of the second radiograph N (FIG. **3**). A right-side graph view of FIG. **5**A is a schematic view illustrating intensity of the pixels on a line segment extending on the left-side image. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

As illustrated in the graph view, a portion in the vicinity of the center of the line segment where bone is plotted has an intensity relatively smaller than portions (lung field) on both sides of the line segment where bone is not plotted. Furthermore, according to the graph, the presence of image patterns originating from other body tissues (bronchial tubes and the like) is recognized irrespective of the presence of the bone.

A left-side image of FIG. **5**B illustrates partial region of a part-removed image P**3**. An example of the smoothing unit **22** will be described with reference to a flowchart of FIG. **7**.

Any one of the plurality of pixels constituting the second radiograph N (FIG. **5**B) is set as a pixel of interest (S**21**). Whenever the flow in FIG. **7** is repeated, the pixel of interest shifts to another adjacent pixel on the second radiograph N.

When the pixel of interest corresponds the set part (bone) (Yes in S**22**), a first representative value Y(p) is calculated in accordance with a calculation formula (1) that calculates an average of the values of the pixels representing the set part (bone), and the calculated first representative value Y(p) is set as a value of the pixel of interest of the part-removed image P**3** (S**23**). When the pixel of interest does not represent the set part (bone) (No in S**22**), a second representative value Y(p) is calculated in accordance with a calculation formula (2) that calculates an average of the values of the pixels not representing the set part (bone), and the calculated second representative value Y(p) is set as a value of the pixel of interest of the part-removed image P**3** (S**24**).

Here, whether or not the pixel of interest represents the set part (bone) is determined with reference to the first radiograph M'. In the formulas, p represents a position vector of

the pixel of interest, X(q) represents a value of a pixel of interest q that is defined as a pixel in the periphery of p, Ω(p) (see FIG. **8**) represents a set of pixels in the periphery of the pixel of interest, B(p) represents a set of pixels representing the set part (bone) among the pixels included in Ω(p), and S(p) represents a set of pixels not representing the set part (bone) among the pixels included in Ω(p). Terms |B(p)| and |S(p)| represent the number of elements of the set B(p) and the set S(p), respectively.

Furthermore, Ω(p) represents a union of the sets B(p) and S(p).

After the representative value Y(p) is calculated for all the pixels included in the second radiograph N (Yes in S**25**), a part-removed image P**3** is output. The part-removed image P**3** is a part-removed image formed by removing parts other than the set part (bone) from the second radiograph N.

A right-side graph view of FIG. **5**B is a schematic view illustrating intensity of the pixels on a line segment extending on a part-removed image P**3** on the left-side of FIG. **5**B. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

As indicated in the graph view, the part-removed image P**3** is free from minute image patterns originating from body tissues (bronchial tubes and the like) other than the set part (bone).

Another example of the smoothing unit **22** will be described with reference to a flowchart of FIG. **8**.

Any one of the plurality of pixels constituting the part-removed image P**3** (FIG. **5**B) is set as a pixel of interest (S**31**). Whenever the flow of FIG. **8** is repeated, the pixel of interest shifts to another adjacent pixel on the part-removed image P**3**.

Or any one of the plurality of pixels constituting the second radiograph N (FIG. **5**A) is set as a pixel of interest (S**31**). Whenever the flow of FIG. **8** is repeated, the pixel of interest shifts to another adjacent pixel on the second radiograph N.

A third representative value Y(p) is calculated in accordance with a calculation formula (3), irrespective of whether or not the pixel of interest represents the set part (bone) (S**32**).

In the formula, q represents a pixel in Ω(p), and w(q) represents a weight applied to each of the pixels q in Ω(p). The weight coefficient w(q) is set to be larger as the value of the pixel of interest p in the first radiograph M' is closer to the value of the pixel q in the first radiograph M'.

For example, when the pixel of interest p represents the set part (bone), and the pixel q does not represent the set part (bone), the values of the pixel of interest p and the pixel q are different from each other, so that the weight coefficient w(q) takes a small value.

On the contrary, when both the pixel of interest p and the pixel q represent the set part (bone), or when neither the pixel of interest p nor the pixel q represent the set part (bone), the values of the pixel of interest p and the pixel q are close to each other, so that the weight coefficient w(q) takes a large value.

After the third representative value Y(p) is calculated for all the pixels included in the second radiograph N (Yes in S**33**), a part-removed image P**3** is output. The part-removed image P**3** is a part-removed image formed by removing parts other than the set part (bone) from the second radiograph N.

A left-side image of FIG. **5**C illustrates part of a part-removed image P**3** smoothed by another example of the smoothing unit **22** (FIG. **4**) described before.

A right-side graph view of FIG. **5**C is a schematic view illustrating intensity of a pixel Y(p) on a line segment extending on the part-removed image P**3**. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

It is confirmed that the case of FIG. **5**C can also provide the result similar to FIG. **5**B.

The calculation formulas (1) and (2) for calculating an average value of each region and the calculation formula (3) for calculating a weighted average efficiency have been illustrated as a method for calculating the representative value Y(p) in the smoothing unit **22**. However, the method is not limited to the methods disclosed. The average value in each region calculated in the formulas (1) and (2) may be replaced with a median value in each region or a mode value in each region. A weighted median value may be adopted instead of the weighted average efficiency calculated in the calculation formula (3). Since the first radiograph M' is referred in either case, an edge preserving smoothing filter is provided. To calculate the representative value Y(p), other smoothing filters which refer to the first radiograph M' may be used. Examples of the smoothing filters include a bilateral filter, an epsilon filter, and a guided image filter. By performing smoothing with reference to the first radiograph M', the edge preserving smoothing filter is provided.

Thus, the part-removed image P**3** smoothed in the smoothing unit **22** (FIG. **4**) is a part-removed image formed by removing the parts other than the set part (bone) from the second radiograph N as illustrated in FIG. **9**.

The difference calculation unit **23** (FIG. **4**) executes difference calculation of the pixels constituting the part-removed image P**3** and the pixels constituting the second radiograph N. An image output as a result of executing the difference calculation is a part-removed image P that is the second radiograph N with the set part (bone) being removed.

A left-side image of FIG. **6**A illustrates part of a part-removed image P. A right-side graph view of FIG. **6**A is a schematic view illustrating intensity of the pixels on a line segment extending on the left-hand side image. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

As indicated in the graph view, the part-removed image P with the bone being removed clearly shows image patterns originating from other body tissues (bronchial tubes and the like), the presence of which is difficult to sense while the bone is depicted. In other words, it becomes possible to enhance the visibility of other tissues which are difficult to recognize in the state of overlapping with another body tissue. The part-removed image P may have negative values.

The inpainting unit **24** (FIG. **4**) generates a part-removed image P**4** by removing the set part (bone) and other minute image patterns from the second radiograph N with reference to the first radiograph M'.

Operation of the inpainting unit **24** will be described with reference to a flowchart of FIG. **10**.

Any one of the plurality of pixels constituting the second radiograph N (FIG. **5**B) is set as a pixel of interest (S**41**). Whenever the flow of FIG. **10** is repeated, the pixel of interest shifts to another adjacent pixel on the second radiograph N.

A fourth representative value Y(p) is calculated in accordance with a calculation formula (4), irrespective of whether or not the pixel of interest represents the set part (bone) (S**42**).

More specifically, the fourth representative value Y(p) is generated based on a set of pixels S(p) not representing the set part (bone) in the set of pixels Ω(p) in the periphery of the pixel of interest p (see the FIG. **8**). According to the calculation formula (4) of the fourth representative value

Y(p), an average value of one or more pixels included in the set of pixels S(p) is calculated. Instead of the average value used in the calculation formula (4), values such as a weighted average efficiency, a median value, a weight median value, and a mode value may be used.

Accordingly, when the pixel of interest p represents the set part (bone), the fourth representative value Y(p) is a value inpainted from surrounding pixels not representing the set part (bone).

When the pixel of interest p does not represent the set part (bone), the fourth representative value Y(p) takes a value obtained by smoothing the values of surrounding pixels not representing the set part (bone).

After the fourth representative value Y(p) is calculated for all the pixels included in the second radiograph N (Yes in S**43**), a part-removed image P**3** is output.

A left-side image of FIG. **6**B illustrates part of a part-removed image P**4** conversion-processed by the aforementioned inpainting unit **24** (FIG. **4**).

A right-side graph view of FIG. **6**B is a schematic view illustrating intensity of a pixel Y(p) on a line segment extending on the part-removed image P**4**. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

Thus, the inpainted part-removed image P**4** is a part-removed image with the bone and other tissues (bronchial tubes and the like) being removed.

The addition processing unit **25** (FIG. **4**) adds the pixels constituting the part-removed image P, and the pixels constituting the part-removed image P**4**.

A left-side image of FIG. **6**C illustrates part of a part-removed image P**1** addition-processed by the aforementioned addition processing unit **25** (FIG. **4**).

A right-side graph view of FIG. **6**C is a schematic view illustrating intensity of a pixel Y(p) on a line segment extending on the part-removed image P**1**. A horizontal axis of the graph view represents a position on the line segment, and a vertical axis represents intensity.

The part-removed image P**1** addition-processed in this way is an image without any negative value since the bone is removed so that the body tissues (bronchial tubes and the like) other than the bone are clear.

The adjustment unit **26** removes artifact noise from the part-removed image P**1** or performs image adjustment of the part-removed image P**1** to generate and output a part-removed image P**2**.

The artifact noise herein refers to unevenness in intensity generated in the vicinity of boundaries between the set part (bone) and other parts when the 3D-2D registration unit **15** or the deformable registration unit **17** has insufficient accuracy.

In this case, the artifact noise can be reduced by smoothing the intensity in the vicinity of the boundaries. Since the information on the boundaries is included in the first radiograph M', the artifact noise is reduced by smoothing the intensity with reference to the first radiograph M'.

Examples of the image adjustment include emphasizing and attenuating mage patterns by using an unsharp mask filter or a Gaussian filter, which can enhance the visibility of body tissues.

Although the adjustment unit **26** is placed subsequent to the addition processing unit **25** in FIG. **4**, the adjustment unit **26** may be placed in other positions or the plurality of the adjustment units **26** may be placed. For example, the adjustment unit **26** may be placed subsequent to the difference calculation unit **23** to process the part-removed image P.

In the aforementioned processing for removing the set part (bone) in the part-removed image generation unit **20**, the values of the pixels not representing the set part (bone) may be changed from the values of the second radiograph N. The processing may be modified so that the pixels not representing the set part (bone) take original values of the second radiograph N with reference to the first radiograph M.

In the aforementioned processing for removing the parts other than the set part (bone) in the part-removed image generation unit **20**, the values of the pixels representing the set part (bone) may be changed from the values of the second radiograph N. The processing may be changed so that the pixels representing the set part (bone) take original values of the second radiograph N with reference to the first radiograph M'.

The external output unit **19** (FIG. **1**) outputs the part-removed image P**2** output from the part-removed image generation unit **20** to the outside. When the plurality of second radiographs N are consecutively acquired in the second acquisition unit **12**, the external output unit **19** consecutively outputs corresponding part-removed images P**2** to the outside in synchronization with the acquisition.

The external output unit **19** may output not the part-removed image P**2** but any one of the part-removed image P, P**1**, P**3** and P**4**. When an output from the external output unit **19** is changed to other than the part-removed image P**2**, unnecessary components may be removed from the part-removed image generation unit **20**. For example, when an output from the external output unit **19** is changed to the part-removed image P, the inpainting unit **24**, the addition processing unit **25**, and the adjustment unit **26** which are not useful in generating the part-removed image P are not necessary for the part-removed image generation unit **20**.

The medical image processing apparatus **10** described in the foregoing includes a dedicated chip, a control device such as a field programmable gate array (FPGA), a graphics processing unit (GPU), or a central processing unit (CPU), a storage device such as a read only memory(ROM) and a random access memory (RAM), an external storage device such as a hard disk drive (HDD) and a solid state drive (SSD), a display device such as a display unit, an input device such as a mouse and a keyboard, and a communication I/F. The medical image processing apparatus **10** can be implemented by hardware configuration using a general computer.

A program executed in the medical image processing apparatus **10** is provided preinstalled in a ROM or other memory devices. Or the program may be stored in a computer readable storage medium such as a CD-ROM, a CD-R, a memory card, a DVD, and a flexible disk (FD) and be provided as a file in an installable or executable format.

The program executed in the medical image processing apparatus **10** according to the present embodiment may be stored on a computer connected to a network such as the Internet and be provided through downloading via the network.

The description will be continued with reference to FIG. **1** again.

The radiotherapy apparatus **30** takes a shot at an affected part inside the body of the patient **42** with the treatment beam **41** for treatment of the affected part.

When the beam **41**, which is a heavy particle beam, enters the body, the beam **41** loses its kinetic energy in the process of passing the body. Once the beam **41** slows down to a certain prescribed rate, it suddenly stops and generates a large dose of radiation called a Bragg peak. With the large

dose of radiation generated at a pinpoint in this way, only cancer cells can be shot and killed while influence on healthy cells can be minimized.

Accordingly, the treatment technique using the heavy particle beam **41** has excellent features of high therapeutic effects on malignant tumors such as cancer, low side effects, reduced load to the body, and the like.

Regardless of the types of the treatment beam **41**, the radiotherapy apparatus **30** is required to accurately aim the beam **41** to be emitted to the affected part so as to prevent normal tissues from being damaged.

Accordingly, a position of the affected part is specified by X-ray observation and the like before emission of the beam, and a position and an angle of the movable treatment table **43** with the patient mounted thereon are appropriately adjusted by the moving unit **33**, so that the affected part is accurately positioned within an emission range of the beam **41**.

The radiograph imaging unit **31** controls the X-ray emission unit **45** (**45***a*, **45***b*) and the X-ray detection unit **46** (**46***a*, **46***b*) to image a second radiograph N of the patient **42**.

The second imaged radiograph N is sent to the movement amount calculation unit **32** to be used for generating a movement amount of the treatment table moving unit **33** necessary for aiming the beam **41** at the affected part. The second imaged radiograph N is also acquired by the second acquisition unit **12**.

When the beam **41** is emitted to an affected part which is present in an internal organ with motion (lung and the like), it is necessary to determine emission timing in consideration of periodic displacement caused by respiration, heart beats and the like to ensure the accuracy of beam emission.

In such a case, in addition to the method for directly aiming the beam **41** at the affected part, a method for embedding a gold marker or the like in the vicinity of the affected part, tracking movement of the marker with the aid of X-ray photography, and identifying the position of the affected part is adopted.

The identification unit **34** identifies the tracking target (affected part or marker) based on the part-removed image P**2** consecutively output from the external output unit **19** of the medical image processing apparatus **10**.

The determination unit **35** determines whether or not the tracking target changing in the consecutive part-removed images in plural P**2** matches with the irradiation point of the beam **41**.

The beam emission unit **36** emits the beam at timing when the tracking target is determined to match with the irradiation point. The beam **41** emitted to the patient **42** includes X-rays, γ rays, electron beams, proton beams, neutron beams, and heavy particle beams.

A description is given of operation in the method and program for processing a medical image according to the embodiment and the radiotherapy apparatus using the same with reference to the flowchart of FIG. **11** (see FIG. **1** as necessary).

The inside of the body of a patient is imaged with an X-ray CT scanner or the like to acquire volume data (S**11**). A part (bone) included in the volume data is set (S**12**), and a DRR with the set part being emphasized is generated from the volume data as a first radiograph M (S**13**).

In the meanwhile, the acquired volume data is used to recognize a position and a range of an affected part, and emission conditions for emitting the beam **41** to the affected part is set (S**14**).

The patient **42** is mounted on the treatment table **43** of the radiotherapy apparatus **30**, and the treatment table **43** is moved directly below a muzzle **44** (S**15**).

In this state, the imaging unit **31** is operated to image a radiograph of the patient **42** (S**16**), so that the movement amount of the treatment table **43** necessary for aiming the beam **41** at the affected part is generated. Then, the treatment table **43** is moved until the affected part is aimed (No/Yes in S**17**).

The imaging unit **31** is operated again to start consecutive imaging of the second radiographs N of the patient **42** (S**18**).

The second radiograph N consecutively sent from the radiotherapy apparatus **30** is acquired in the medical image processing apparatus **10**, and deformable registration is executed for the first radiograph M on the basis of each of the second radiographs N (S**19**).

A first radiograph M' generated by deformable registration is referred to generate a part-removed image P**2** with bone being removed from the second radiograph N (S**20**), and the generated part-removed image P**2** is transmitted to the radiotherapy apparatus **30**.

The radiotherapy apparatus **30** identifies and tracks the tracking target (affected part or marker) out of the received part-removed images P**2** (S**21**). At timing when the tracking target matches with an irradiation point (No/Yes in S**22**), the beam **41** is emitted (S**23**).

The emitted beam **41** generates a Bragg peak at the position of the affected part displaced to the irradiation point, and thereby treats cells of this affected part (END).

An output from the external output unit **19** may be changed from the part-removed image P**2** to the part-removed image P or the part-removed image P**1**. Since the part-removed image P and the part-removed image P**1** are free from the set part (bone), the tracking target (affected part or marker) is easily recognized. In the case where, for example, a diaphragm is set as a set part and a tracking target, an output from the external output unit **19** may be changed from the part-removed image P**2** to the part-removed image P**3** or the part-removed image P**4**. Since the parts other than the set part (diaphragm) are removed from the part-removed image P**3** or the part-removed image P**4**, it is easy to track the diaphragm.

Although the radiotherapy apparatus **30** tracks the tracking target (affected part or marker) and emits the beam **41** at predetermined timing in the example disclosed, the radiotherapy apparatus **30** may track the affected part and emits the beam **41** while tracking the affected part.

A description is now given of a medical imaging apparatus **10** according to another embodiment with reference to FIG. **12**. In FIG. **12**, component members common in configuration or function with those in FIG. **1** are designated by identical reference numerals to omit redundant description.

A first radiograph generation unit **52** includes, for example, a volume data acquisition unit **11**, a part setting unit **13**, a part emphasis unit **14**, a 3D-2D registration unit **15**, a first radiograph generation unit **16**, and a deformable registration unit **17** of FIG. **1**.

The medical imaging apparatus **10** includes a first acquisition unit **51**, a second radiograph acquisition unit **12**, a part-removed image generation unit **20**, and an external output unit **19**.

The first acquisition unit **51** acquires a first radiograph M', and sends it to the part-removed image generation unit **20**. The first radiograph M' is generated outside of the medical imaging apparatus **10**.

Although the first radiograph M' may be generated by units other than the first radiograph generation unit **52**, the first radiograph M' is generated based on the volume data B and the second radiograph N.

Since what is input into the part-removed image generation unit **20** in both the medical image processing apparatus **10** of FIG. **1** and the medical imaging apparatus **10** of FIG. **12** is identical, what is output from the medical image processing apparatuses **10** is identical to what is output from the medical imaging apparatuses **10**. Therefore, the medical imaging apparatus **10** of FIG. **12** also has effects similar to those of the medical image processing apparatus **10** of FIG. **1**.

According to the medical image processing apparatus of the embodiments described in the foregoing, a part included in a second radiograph obtained by imaging a patient is specified by using a first radiograph generated based on volume data, so that a radiograph with the specified part such as bone being removed at high accuracy can be provided regardless of radiography conditions and without teacher images. Furthermore, the radiotherapy apparatus of the embodiments can precisely recognize a position of an affected part movable by respiration and other factors and emit a beam only to the affected part so as to minimize an influence on healthy cells.

Although some embodiments of the present invention have been described, these embodiments are in all respects illustrative and are not considered as the basis for restrictive interpretation. It should be understood that these embodiments can be performed in other various forms and that various removals, replacements, modifications, and combinations are possible without departing from the meaning of the present invention. These embodiments and their modifications are intended to be embraced in the range and meaning of the present invention, and are particularly intended to be embraced in the invention disclosed in the range of the claims and the equivalency thereof.

What is claimed is:

1. A medical image processing apparatus, comprising:

processing circuitry configured to

acquire a first radiograph that is a virtual radiograph representing a projection of volume data, the volume data representing a three-dimensional structure of an inside of a body of a patient, and the virtual radiograph being generated to emphasize a specified part or a predetermined part among parts indicative of the three-dimensional structure of the inside of body of the patient that are included in the volume data,

acquire a second radiograph of the inside of the body of the patient,

apply, to the second radiograph, a smoothing filter, the smoothing filter being based on the first radiograph, and

generate a part-removed image by removing one of the specified or predetermined part and other parts, which are parts other than the specified or predetermined part, wherein,

for a case in which the part-removed image is generated by removing the other parts, the part-removed image is generated from the second radiograph after the smoothing filter has been applied, and,

for a case in which the part-removed image is generated by removing the specified or predetermined part, the part-removed image is generated from a difference between the second radiograph before the smoothing filter has been applied and the second radiograph after the smoothing filter has been applied.

2. The medical image processing apparatus according to claim **1**, wherein the processing circuitry is further configured to

acquire the second radiograph consecutively, and

consecutively output the part-removed image.

3. The medical image processing apparatus according to claim **1**, wherein the processing circuitry is further configured to

acquire the volume data; and

generate the first radiograph, wherein

the acquiring of the volume data and the generating of the first radiograph are performed prior to the applying the smoothing filter and the generating of the part-removed image.

4. A radiotherapy apparatus, comprising:

the medical image processing apparatus according to claim **2**; and

a radiograph imager including

a radiation source configured to emit radiation, and

detectors configured to detect the radiation from the radiation source; and

another processing circuitry configured to

generate, based on the detected radiation, the second radiograph, which is subsequently signaled to and acquired by the processing circuitry of the medical image processing apparatus,

calculate a movement amount of a treatment table with the patient being mounted thereon, based on the imaged second radiograph,

control the treatment table to move in accordance with the movement amount,

identify a tracking target based on the part-removed image consecutively output from the processing circuitry of the medical image processing apparatus, wherein

the radiation emitted by the radiation source is medical radiation, and the another processing circuitry is further configured to control the radiation source to either

emit the medical radiation to an affected part of the patient upon the tracking target identified in multiple of the consecutively output part-removed images matching a pointing-direction of the radiation emitted from the radiation source, or

emit the medical radiation to the tracking target while tracking the tracking target.

5. A method for processing a medical image, comprising:

acquiring a first radiograph that is a virtual radiograph representing a projection of volume data, the volume data representing a three-dimensional structure of an inside of a body of a patient, and the virtual radiograph being generated to ha emphasize a specified part or a predetermined part among parts indicative of the three-dimensional structure of the inside of the body of the patient that are included in the volume data,

acquiring a second radiograph of the inside of the body of the patient,

applying, to the second radiograph, a smoothing filter, the smoothing filter being based on the first radiograph, and

generating a part-removed image by removing one of the specified or predetermined part and other parts, which are parts other than the specified or predetermined part from the second radiograph with reference to the first radiograph, wherein,

for a case in which the part-removed image is generated by removing the other parts, the part-removed image is

generated from the second radiograph after the smoothing filter has been applied, and,

for a case in which the part-removed image is generated by removing the specified or predetermined part, the part-removed image is generated from a difference between the second radiograph before the smoothing filter has been applied and the second radiograph after the smoothing filter has been applied.

6. A non-transitory computer readable storage medium including executable instructions of a medical image processing program that, when executed by a computer, cause the computer to perform the method according to claim **5**.

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