(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 August 2006 (17.08.2006)

PCT

(10) International Publication Number
WO 2006/085253 A2

(51) International Patent Classification:
A61B 6/03 (2006.01)

(21) International Application Number:
PCT/IB2006/050374

(22) International Filing Date: 6 February 2006 (06.02.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
05101025.4 11 February 2005 (11.02.2005) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT,

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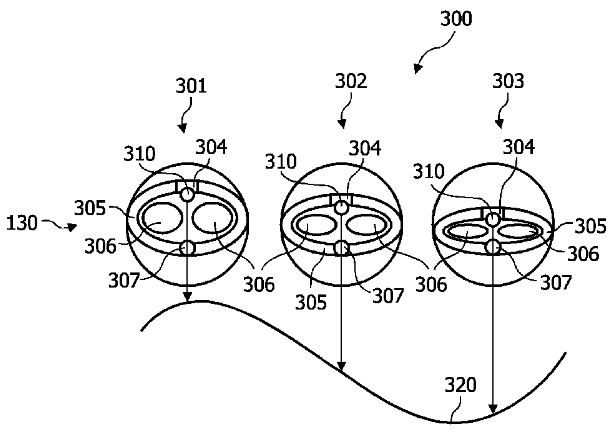
(54) Title: COMPUTER TOMOGRAPHY APPARATUS, METHOD OF EXAMINING AN OBJECT OF INTEREST WITH A COMPUTER TOMOGRAPHY APPARATUS, COMPUTER-READABLE MEDIUM AND PROGRAM ELEMENT



(57) Abstract: A computer tomography apparatus (100) for examination of a moving object of interest (130), comprising an electromagnetic radiation source (104) adapted to emit electromagnetic radiation to the object of interest (130) and adapted to rotate around the object of interest (130), detecting elements (123) adapted to detect electromagnetic radiation emitted by the electromagnetic radiation source (104) and passed through the object of interest (130), adapted to rotate around the object of interest (130) and adapted to detect first data related to a first motion interval of the object of interest (130) and to detect second data related to a second motion interval of the object of interest (130), and a determination unit (118) adapted to determine images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and to determine motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined images.

WO 2006/085253 A2

RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Computer tomography apparatus, method of examining an object of interest with a computer tomography apparatus, computer-readable medium and program element

The invention relates to the field of X-ray imaging. In particular, the invention relates to a computer tomography apparatus, to a method of examining an object of interest with a computer tomography apparatus, to a computer-readable medium and to a program element.

Computed tomography (CT) is a process of using digital processing to generate an image of the internals of an object (for instance a human body) from a series of two-dimensional projections taken around a single axis of rotation. The reconstruction of CT images can be done by applying appropriate algorithms.

Using computed tomography, it is possible to investigate the structure of, for instance, a lung. Having discovered the structure of the lung and having determined the presence of a tumour in the lung, a subsequent radiotherapy for destroying the tumour can be planned. During such a radiotherapy, it should be ensured that only those parts of the lung are irradiated with harmful electromagnetic radiation at which parts the tumour is located. For an improved radiotherapy planning, the motion of lung tumours due to the breathing cycle is of great interest.

So-called four-dimensional CT images denote a three-dimensional (steric) image which may be displayed over the time during which the object moves, wherein the time forms a fourth dimension. Such 4D CT images, which represent the structure and the dynamics of the thorax at different phases of the breathing cycle can be used to determine the motion field of tumours.

The three-dimensional images can be acquired using an electromagnetic radiation source and a detector which rotate, mounted on a gantry, around a patient under examination. Since, during the rotation and acquisition procedure, the thorax is not located at a fixed position due to breathing of the patient, different projections and three-dimensional images may relate to different breathing intervals and thus to different structural states of the thorax.

When a sequential acquisition protocol is used, image slabs are concatenated. Every slab is reconstructed at different breathing phases in order to form a 4D volume. If a helical acquisition is chosen (in which a gantry rotates around the patient and the patient is shifted simultaneously on a mounting table in a linear manner), the pitch (that is to say the table movement per rotation/slice collimation) and the rotation time of the gantry may be chosen in a way that every voxel of the object under investigation is covered throughout at least one full breathing cycle. The reconstruction is gated at different breathing phases to form a 4D volume.

Conventionally, the breathing cycle is determined with external sensors which are used for the synchronization of the reconstruction of the 4D volume, leading to breathing gating. However, using such sensors, it is difficult to accurately correlate sensor data with detector data, and the proper attachment of a sensor to the patient's skin requires additional effort.

US 2004/0218719A1 discloses a computer tomography scanner, wherein artefacts in reconstructed volume data of the CT system are removed by applying respiration correlation techniques. For this purpose, the phase of the patient's breathing is monitored while acquiring projection images continuously. On completion of the acquisition, projection images having comparable breathing phases can be selected from the complete set, and these are used to reconstruct the volume data. In order to generate a 3D volume data set, a feature in the projection images such as the patient's diaphragm may be used to determine the breathing phase.

There is a need to reconstruct a four-dimensional image of a moving object of interest with reasonable effort and in a simply and reliable manner.

This can be achieved by providing a computer tomography apparatus for examination of a moving object of interest, by a method of examination of a moving object of interest, by a computer-readable medium and by a program element having the features according to the independent claims.

According to an exemplary embodiment of the invention, a computer tomography apparatus for examination of a moving object of interest is provided comprising an electromagnetic radiation source adapted to emit electromagnetic radiation to the object of interest and adapted to rotate around the object of interest. Further, detecting elements are provided which are adapted to detect electromagnetic radiation emitted by the electromagnetic radiation source and passed through the object of interest, adapted to rotate around the object of interest and adapted to detect first data related to a first motion interval of the object of interest and to detect second data related to a second motion interval of the object of interest. Moreover, the computer tomography apparatus may comprise a determination unit adapted to determine images of the structure of the object of interest in the first motion interval and in the second motion interval and to determine motion information concerning the object of interest between the first motion interval and the second motion interval based on an analysis of the determined images.

According to another exemplary embodiment of the invention, a method for examination of a moving object of interest is provided, comprising the steps of emitting electromagnetic radiation to the object of interest, detecting emitted electromagnetic radiation passed through the object of interest as first data related to a first motion interval of the object of interest and as second data related to a second motion interval of the object of interest, and determining images of the structure of the object of interest in the first motion interval and in the second motion interval and determining motion information concerning the object of interest between the first motion interval and the second motion interval based on an analysis of the determined images.

According to still another exemplary embodiment of the invention, a computer-readable medium is provided, in which a computer program of examining a moving object of interest is stored, which, when being executed by a processor, is adapted to control the above-mentioned method steps.

Furthermore, according to yet another exemplary embodiment of the invention, a program element of examining a periodically moving object of interest is provided, which, when being executed by a processor, is adapted to control the above-mentioned method steps.

The system of the invention can be realized by a computer program, i.e. by software, or by using one or more special electronic optimization circuits, i.e. in hardware, or in hybrid form, i.e. by means of software components and hardware components. The computer-readable medium and the program element may be implemented in a control system for controlling a computer tomography apparatus.

The characterizing features according to the invention particularly have the advantage that a CT system for reconstructing a four-dimensional image of a (particularly periodically) moving object of interest is provided in which different three-dimensional images may be sorted according to the motion of the object of interest based on information about this motion which is derived directly from the determined images, without a necessity to provide separate external sensors. Since the use of sensors is dispensable according to the invention, problems related to how to correlate sensor data with detector data do not occur, which allows a simplified reconstruction. In other words, the synchronisation of the reconstruction of the different images which relate to different motion states or motion intervals of the moving object of interest (for instance a lung of a breathing person, or a beating heart) can be performed, according to the invention, based on image processing techniques. Thus, information necessary for ordering, sorting or selecting the different three-dimensional images in an order corresponding to the motion is directly taken from the determined images itself. Consequently, a chronological sequence of the images can be obtained so that a four-dimensional reconstruction is possible (steric information of the moving object over the time). The motion intervals can be defined in such a manner that, during each of the motion intervals, the motion states of the object do not differ too much so that averaging over such a sufficiently short motion interval still contains meaningful (averaged) information concerning the motion state in this particular motion interval.

The reconstruction scheme according to the invention can be used, for instance, for gating an electromagnetic radiation beam which is applied to destroy diseased tissue during a radiotherapy. There is no more the requirement to separately measure and interpret sensor signals and to coordinate sensor based result with the images derived from detected X-ray. In contrast to this, the entire information concerning structure and dynamics of the moving object is directly obtained from the detected X-rays. Thus, a reconstruction of a four-dimensional image of the moving object can be performed in a faster, more reliable, and more precise manner, and can be performed with reduced effort.

According to the invention, an approach is provided to obtain breathing cycle information from free breathing CT without using external sensors. Regions of the thorax can be reconstructed using, for instance, different 180° intervals of projection data according to the so-called “sliding window technique”. This technique can be applied in case of circular and helical acquisition modes by choosing different subsequent intervals of projection data of the redundant acquired data. Implementing image processing techniques, the breathing cycle can be determined automatically from the image data, for instance by tracking of an anatomic landmarks and/or by image similarity measurements between each sliding window reconstruction. After the automatic determination of the breathing cycle, a volume can be reconstructed at the required breathing phase. For the subsequent high-resolution 4D-reconstruction, projection data from more than one breathing cycle can be used to reconstruct each voxel increasing the temporal resolution. A coherent 4D volume, with regard to the breathing cycle, of the thorax can be obtained in such a way, constituting the base for the tumour motion field calculation.

Thus, image-based breathing cycle determination for free breathing CT is possible according to the invention. This has the advantage that it allows an improved radiotherapy planning, and a fully automatic breathing cycle determination and gating.

According to another aspect of the invention, the conventional determination of motion information using external sensors can be combined with the use of information derived from the reconstructed images. In other words, two complementary methods, namely the application of external sensors and the use of image information, can be combined as two independent sources of complementary information to determine motion information, like information concerning the breathing cycle, with improved accuracy. Such a sensor may be, for instance, a magnetic sensor or an infrared sensor to be attached to the thorax region of a person under examination. An infrared sensor may be tracked using an infrared camera. When using a magnetic sensor, a magnetic signal can be detected which varies with changing distance, do to the motion of the object of interest, between a magnetically encoded region and a magnetic field detector.

Referring to the dependent claims, further exemplary embodiments of the invention will be described in the following.

Next, preferred embodiment of the computer tomography apparatus for examination of a moving object of interest will be described. However, these embodiments may also be applied for the method, the computer-readable medium and the program element.

The determination unit of the computer tomography apparatus may be adapted to determine three-dimensional images of the structure of the object of interest in the first motion interval and in the second motion interval and to determine motion information concerning the object of interest between the first motion interval and the second motion interval based on an analysis of the determined three-dimensional images. In other words, a plurality of two-dimensional projections during the first motion interval can be combined to reconstruct a three-dimensional steric image of the object under investigation. Together with the time as the fourth dimension, a four-dimensional image of the moving, for instance periodically oscillating, object of interest can be obtained. Such information can be displayed on a display device like a cathode ray tube, a liquid crystal display or a plasma display device. A user may retrace the motion of the object in order to get an impression of the motion characteristics. Furthermore, this combined structural and dynamical information can be used to plan a subsequent irradiation or radiotherapy of the object of interest with a minimized radiation dose to which the object of interest is exposed.

The computer tomography apparatus according to the invention may be adapted to examine at least a portion of one of the group consisting of a thorax, a lung and a heart as the (for instance periodically) moving object of interest. Generally, the computer tomography apparatus according to the invention can be used to retrieve 4D information of any moving object which repeats its moving cycle after some time. For instance, a thorax or a lung is moved in accordance with the breathing cycle. Even a beating heart can be used as a periodically moving object of interest. In a human body, the thorax can be defined as the region of the body that extends from the neck to the diaphragm, not including the upper limbs. The heart and the lung reside in the thoracic cavity, as well as many blood vessels. This area is protected by the rib cage and the sternum.

The computer tomography apparatus may comprise an analyzing unit adapted to analyze the determined images of the structure of the object of interest and to analyze the determined motion information for planning a subsequent radiotherapy of at least a portion of the object of interest. In accordance with the estimated motion characteristics, the emission of radiation related to the radiotherapy can be gated to ensure that only a minimum amount of dose is exposed to the object, and that only selected portions of the object of interest which shall be treated with a radiotherapy are indeed irradiated. For such a radiotherapy, the coordinates of a tumour within an organ under consideration are calculated or estimated. These coordinates in combination with motion information can be used to determine in which manner, in which intensity and in which time intervals a radiation beam shall be directed to the tumour to destroy the same.

The determination unit may be adapted to determine a breathing cycle or a heart beat cycle as the motion information. Such cycles are periodical with relatively high accuracy, so that determining the cycles allows to predict a motion state also in the future, which may be of relevance for a radiotherapy.

Particularly, the determination unit may be adapted to determine the motion information concerning the object of interest by extracting a position of a component of the object of interest in the images and by sorting the images in an order corresponding to the periodical motion of the object of interest based on the extracted positions. In other words, an image may comprise regions or components which are very good resolved and which have a very good contrast with respect to the environment. For instance, a sternum of the thorax may be resolved with very high accuracy in a CT image. Thus, using image processing techniques, it is possible to exactly determine such a position in subsequently reconstructed images which relate to different motion states or intervals during the periodic motion cycle of the object of interest. When the position or location of such a well-resolvable component is extracted from the three-dimensional images, then it is possible to determine the periodic motion cycle from the change of the position of this component. For instance, a sternum may undergo a quasi-oscillating trajectory on different images which are reconstructed during the breathing cycle. The extraction of such a position may be carried out in an automatic manner, in a semi-automatic manner or in a manual manner. For instance, a user may use a cursor or a mouse pointer on a display to determine the position of a well-resolvable sub-component of the image, for instance a sternum. Or, the analysis of the images can be done automatically using image processing techniques, for instance by comparing database information with the images. When typical shapes and dimensions of a human sternum are stored in such a database, an automatic image processor may analyze an image to find a component within the image which fits to the pre-stored shapes and dimensions of a human sternum. Thus, it may be possible to determine the component or region of interest using model-based segmentation. In other words, a model for an expected region of interest may be introduced in the system so that the system detects the object of interest automatically to properly locate the component as a basis for determining the motion.

Additionally or alternatively to the described embodiment, the determination unit may also be adapted to determine the motion information concerning the object of interest by an image similarity analysis of the images. Such an image similarity analysis may determine a degree of similarity of different images. Images having a high degree of similarity probably may belong to relatively similar motion states. Images having a low degree of similarity probably may belong to relatively different motion states. Thus, a similarity analysis may help to properly select appropriate data from the redundantly acquired data for a reconstruction. Further, a similarity analysis may help to properly sort images in an order corresponding to the motion of the object. This information of similarity or missing similarity allows to reconstruct 4D data with high accuracy.

The computer tomography apparatus may be adapted such that the detecting elements may detect further data related to at least one further motion interval of the object of interest. The determination unit may be adapted to determine images of the structure of the object of interest in each of the at least one further motion interval and to determine motion information concerning the object of interest between the first motion interval and the second motion interval and the at least one further motion interval based on an analysis of the determined images. In other words, the invention is not restricted to the analysis of two motion intervals, but can analyse three or more motion intervals for reconstructing a four-dimensional image of the moving object. The higher the number of motion intervals, the better is the accuracy of the resulting four-dimensional image.

The computer tomography apparatus may comprise a rotatable gantry on which the electromagnetic radiation source and the detecting elements are mounted. This rotatable gantry may be adapted to rotate the electromagnetic radiation source and the detecting elements on a circular trajectory with respect to the object of interest. Particularly, when using multi-slice detector elements, it may be advantageous to carry out a circular scan because this allows in a very fast manner to determine the structure of the object of interest.

The computer tomography apparatus may further comprise a shiftable mounting device which is adapted to receive the object of interest. In other words, the object of interest may be arranged on the shiftable mounting device which can be moved along a linear direction in order to change the position of the object of interest with respect to the electromagnetic radiation source (an X-ray tube) and the detecting elements (an X-ray detector). The shiftable mounting device may be adapted to linearly shift the object of interest so that, in combination with a rotation of the gantry, the electromagnetic radiation source and the detecting elements perform a helical trajectory with respect to the object of interest. Acquiring a helical scan due to a combined rotation of the gantry and linear motion of the mounting table, a high quality data set for accurately reconstructing the four-dimensional image of the object of interest may be obtained. A helical scan provides data in a (partially) redundant manner, so that – retrospectively – data used for reconstructing a 3D or 4D image can be selected.

The computer tomography apparatus may comprise a collimator arranged between the electromagnetic radiation source and the detecting elements, wherein the collimator may be adapted to collimate an electromagnetic radiation beam emitted by the electromagnetic radiation source to form a fan-beam or a cone-beam. Thus, the invention can be realized in the frame of a fan-beam configuration or in the frame of a cone-beam configuration.

The detecting elements may form a single-slice detector array. This configuration allows to construct a computer tomography apparatus with low effort.

Alternatively, the detecting elements may form a multi-slice detector array. This configuration can be advantageously combined with a circular scan, particularly if the region of interest fits into the cone completely. However, even a helical scan can be combined with a multi-slice detector array to carry out the examination in a short fast time.

The computer tomography apparatus according to the invention may be configured as one of the group consisting of a medical application apparatus, a material testing apparatus and a material science analysis apparatus. The invention creates a high quality automatic system that can automatically recognize certain types of material in a four-dimensional manner. Such a system may have employed the computer tomography system of the invention with an X-ray radiation source for emitting X-rays which are transmitted through or passed through the examined person to a detector allowing to detect a region of interest within the object of interest in an accurate manner.

The computer tomography apparatus may be adapted for examination of a periodically moving object of interest. Thus, since the object moves periodically, it is possible to predict the structure of the object at a particular moment in the future, for instance to plan a radiotherapy. The invention can particularly be applied in the frame of cardiac CT or thorax CT.

The aspects defined above and further aspects of the invention are apparent from the examples of embodiment.

The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Fig. 1 shows a computer tomography apparatus according to an exemplary embodiment of the invention,

Fig.2 shows a schematic plan view for illustrating a sliding window reconstruction scheme according to the invention,

Fig. 3 shows a thorax at different breathing phases according to different sliding windows used for reconstructing a breathing cycle,

Fig. 4 shows an exemplary embodiment of a data processing device to be implemented in the computer tomography apparatus according to an exemplary embodiment of the invention.

The illustration in the drawings is schematically. In different drawings, similar or identical elements are provided with the same reference signs.

Fig. 1 shows an exemplary embodiment of a computed tomography scanner system according to the present invention.

With reference to this exemplary embodiment, the present invention will be described for the application in examination of an organ (particularly of a lung of a human thorax undergoing a breathing cycle, or of a beating heart) of a human patient. However, it should be noted that the present invention is not limited to this application, but may also be applied in other fields of medical imaging, or other industrial applications such as material testing.

The computer tomography apparatus 100 depicted in Fig. 1 is a cone-beam CT scanner. However, the invention may also be carried out with a fan-beam geometry. The CT scanner depicted in Fig. 1 comprises a gantry 101, which is rotatable around a rotational axis 102. The gantry 101 is driven by means of a motor 103. Reference numeral 104 designates a source of radiation such as an X-ray source, which, according to an aspect of the present invention, emits a monochromatic or a polychromatic radiation.

Reference numeral 105 designates an aperture system which forms the radiation beam emitted from the radiation source to a cone-shaped radiation beam 106. The cone-beam 106 is directed such that it penetrates an object of interest 107 arranged in the center of the gantry 101, i.e. in an examination region of the CT scanner, and impinges onto the detector 108. As may be taken from Fig. 1, the detector 108 is arranged on the gantry 101 opposite to the source of radiation 104, such that the surface of the detector 108 is covered by the cone beam 106. The detector 108 depicted in Fig. 1 comprises a plurality of detector elements 123 each capable of detecting X-rays which have passed through the object of interest 107.

During scanning the object of interest 107, the source of radiation 104, the aperture system 105 and the detector 108 are rotated along the gantry 101 in the direction indicated by an arrow 116. For rotation of the gantry 101 with the source of radiation 104, the aperture system 105 and the detector 108, the motor 103 is connected to a motor control unit 117, which is connected to a control unit 118 (which might also be denoted as a calculation or determination unit).

In Fig. 1, the object of interest 107 is a human patient which is disposed on a mounting table 119. During the scan of the object of interest 107, while the gantry 101 rotates around the item of human patient 107, the mounting table 119 displaces the object of interest 107 along a direction parallel to the rotational axis 102 of the gantry

101. By this, the object of interest 107 is scanned along a helical scan path. The mounting table 119 may also be stopped during the scans to thereby measure signal slices. However, it should be noted that in all of the described cases it is also possible to perform a circular scan, where there is no displacement in a direction parallel to the rotational axis 102, but only the rotation of the gantry 101 around the rotational axis 102.

Further, it shall be emphasized that, as an alternative to the cone-beam configuration shown in Fig. 1, the invention can be realized by a fan-beam configuration. In order to generate a primary fan-beam, the aperture system 105 can be configured as a slit collimator.

The detector 108 is connected to the control unit 118. The control unit 118 receives the detection result, i.e. the read-outs from the detector elements 123 of the detector 108 and determines a scanning result on the basis of these read-outs. Furthermore, the control unit 118 communicates with the motor control unit 117 in order to coordinate the movement of the gantry 101 with motors 103 and 120 with the mounting table 119 and communicates with the X-ray source 104 to control radiation dose and exposure time.

The control unit 118 may be adapted for reconstructing an image from read-outs of the detector 108. A reconstructed image generated by the control unit 118 may be output to a display 160.

The control unit 118 may be realized by a data processor to process read-outs from the detector elements 123 of the detector 108.

The computer tomography apparatus 100 comprises the X-ray source 104 adapted to emit X-rays to the object of interest 107. The collimator 105 provided between the electromagnetic radiation source 104 and the detecting elements 123 is adapted to collimate an electromagnetic radiation beam emitted from the electromagnetic radiation source 104 to form a cone-beam. Alternatively, not shown in Fig. 1, a slit collimator can be used instead of collimator 105 to produce a fan-beam. The detecting elements 123 form a multi-slice detector array 108. The computer tomography apparatus 100 is configured as a medical examination apparatus.

A thorax 130 of the human body 107 is investigated according to the described embodiment.

The computer tomography apparatus 100 is provided for examining the thorax 130 which is subject of a periodical motion due to the breathing cycle. The computer tomography apparatus 100 comprises the X-ray tube 104 which is adapted to emit electromagnetic radiation to the thorax 130 and which is adapted to rotate around the thorax 130. The detecting elements 123 are adapted to detect electromagnetic radiation emitted by the X-ray tube 104 and passed through the thorax 130 of the human body 107. The detecting elements 123 mounted on the gantry 101 are adapted to rotate around the object of interest 107. The detecting elements 123 are adapted to detect first data related to a first motion interval of the thorax 130 during the breathing cycle, to detect second data related to a second motion interval of the thorax 130 and are adapted to detect third data related to a third motion interval of the object of interest 107.

The determination unit 118 to which the acquired data are supplied determines three-dimensional images of the structure of the thorax 130 in the first motion interval, in the second motion interval and in the third motion interval and determines motion information concerning the thorax 130 between the first motion interval, the second motion interval and the third motion interval based on an analysis of the determined three-dimensional images.

In other words, the determination unit 108 determines a four-dimensional image of the thorax 130, wherein three spatial dimensions are related to the steric image of the thorax 130, and the fourth dimension is related to the time during which the thorax 130 is subject of a human breathing cycle. On the graphical user interface 160, a “movie” of the three-dimensional thorax 130 can be shown during different breathing cycle intervals of the thorax 130.

Further, an analyzing device 140 is provided which is coupled to the output of the determination unit 118. The analyzing unit 140 is adapted to analyze the determined four-dimensional image, that is the three-dimensional images of the structure of the thorax 130 and the motion information over time during the breathing cycle, for planning a subsequent radiotherapy of at least a portion of the thorax 130. In other words, the analyzing unit 140 provides a radiation device 150 with control commands to control a radiotherapy to selectively destroy tumours of the thorax 130 under consideration of the breathing cycle so that a gating signal can be generated by the radiation device 150 avoiding undesired irradiation of healthy tissue within the thorax 130 due to breathing.

According to the described embodiment, the determination unit 118 determines the motion information concerning the thorax 130 by extracting a position of a sternum as a component of the thorax 130 in the images and by sorting the images in an order corresponding to the periodical breathing cycle motion of the thorax 130 based on the extracted positions. The sternum which is a very characteristic and well-resolvable part of the image of the thorax 130 and is analyzed with image processing techniques, so that the breathing cycle is determined automatically from the image data by tracking the sternum as an anatomical landmark in different images. Additionally or alternatively, image similarity measurements can be used.

In the following, referring to Fig. 2 and Fig. 3, the process of retrieving the four-dimensional information concerning the thorax 130 will be described in more detail.

Fig. 2 shows a top view of the thorax 130 and shows three half circles of a helical scan which half circles relate to ranges of the rotating gantry 101 (on which the X-ray tube 104 and the detector 108 are mounted) during detection the first data, the second data and the third data. In more detail, regions of the thorax 130 are reconstructed using different 180° intervals of projection data with a so-called sliding window techniques. A first half cycle 201 relates to the first data which are acquired in a first motion interval of the thorax 130. A second half cycle 202 corresponds to the second data which are acquired during a second motion interval of the thorax 130. A third half cycle 203 relates to the third data which are acquired during the third motion interval of the thorax 130. From the data captured during each of the three half cycles 201 to 203, a respective three-dimensional image in a corresponding motion state of the thorax 130 is obtainable. During the acquisition of any of the three half cycles 201 to 203, the motion state of the thorax 130 is essentially constant or can at least be averaged in a meaningful manner. In other words, the acquisition time is sufficiently short that the motion states do not differ too much during the acquisition of any one of the three half cycles 201 to 203. In contrast to this, the motion state of the thorax 130 at different half cycles 201 to 203 may be significantly different. Thus, the reconstruction of the three-dimensional images of the thorax 130 from data measured in accordance with any of the three half cycles 201 to 203 may relate to very different motion states of the thorax 130.

In the following, referring to Fig. 3, a schematic view 300 will be described from which the technique of ordering the different images to obtain a four-dimensional image will be described.

Fig. 3 shows a first three-dimensional image 301 of the thorax 300 which has been reconstructed from the first data 201. A second image 302 has been reconstructed from the second data 202. A third image 303 has been reconstructed from the third data 203. The thorax 130 as reconstructed in the images 301 to 303 has a sternum 304, ribs 305, lungs 306 and a vertebra 307. The three images 301 to 303 show the thorax 130 at different breathing phases according to the sliding windows acquisition scheme illustrated in Fig. 2. According to the invention, the three images 301 to 303 are ordered according to the breathing cycle performed by the thorax 130.

For this purpose, the well-resolvable sternum 304 is taken as an anatomical landmark which is detected manually, semi-automatically or fully automatically, as indicated by a mapping circle 310. The mapping 310 relates to the different positions of the sternum 304 in the different images 301 to 303, due to the breathing cycle motion of the thorax 130. By tracking the sternum 304 in the different images 301 to 303, the breathing cycle 320 can be obtained.

After the automatic determination of the breathing cycle, a four-dimensional image is reconstructed at the different breathing phases. By taking this measure, a coherent 4D volume, with regard to the breathing cycle, of the thorax 130 can be obtained in such way, constituting the base for the tumour motion field calculation of the analyzing unit 140.

Fig. 4 depicts an exemplary embodiment of a data processing device 400 according to the present invention for executing an exemplary embodiment of a method in accordance with the present invention. The data processing device 400 depicted in Fig. 4 comprises a central processing unit (CPU) or image processor 401 connected to a memory 402 for storing image data depicting an object of interest, such as a patient. The data processor 401 may be connected to a plurality of input/output network or diagnosis devices, such as a CT device. The data processor 401 may furthermore be connected to a display device 403, for example a computer monitor, for displaying information or an image computed or adapted in the data processor 401. An operator or user may interact with the data processor 401 via a keyboard 404 and/or other output devices, which are not depicted in Fig. 4. Furthermore, via the bus system 405, it is also possible to connect the image processing and control processor 401 to, for example a motion monitor, which monitors a motion of the object of interest. In case, for example, a lung of a patient is imaged, a motion sensor may be provided, e.g. an exhalation sensor. In case the heart is imaged, the motion sensor may be an electrocardiogram (ECG).

Exemplary technical fields, in which the present invention may be applied advantageously, include medical applications, material testing, and material science. A reduced total dose to the patient may be achieved. Also, the invention can be applied in the field of heart scanning to detect heart diseases.

It should be noted that the term “comprising” does not exclude other elements or steps and the “a” or “an” does not exclude a plurality. Also elements described in association with different embodiments may be combined.

It should also be noted that reference signs in the claims shall not be construed as limiting the scope of the claims.

CLAIMS:

1. A computer tomography apparatus (100) for examination of a moving object of interest (130), wherein the computer tomography apparatus (100) comprises

an electromagnetic radiation source (104) adapted to emit electromagnetic radiation to the object of interest (130) and adapted to rotate around the object of interest (130);

detecting elements (123) adapted to detect electromagnetic radiation emitted by the electromagnetic radiation source (104) and passed through the object of interest (130), adapted to rotate around the object of interest (130) and adapted to detect first data related to a first motion interval of the object of interest (130) and to detect second data related to a second motion interval of the object of interest (130); and

a determination unit (118) adapted to determine images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and to determine motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined images.

2. The computer tomography apparatus (100) according to claim 1,

wherein the determination unit (118) is adapted to determine three-dimensional images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and to determine motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined three-dimensional images.

3. The computer tomography apparatus (100) according to claim 1, adapted to examine at least a portion of one of the group consisting of a thorax (130), a lung (306) and a heart as the object of interest.

4. The computer tomography apparatus (100) according to claim 1, comprising an analyzing unit (140) adapted to analyze the determined images of the structure of the object of interest (130) and to analyze the determined motion information for planning a subsequent radiotherapy of at least a portion of the object of interest (130).

5. The computer tomography apparatus (100) according to claim 1, wherein the determination unit (118) is adapted to determine a breathing cycle or a heart beat cycle as the motion information.

6. The computer tomography apparatus (100) according to claim 1, wherein the determination unit (118) is adapted to determine the motion information concerning the object of interest (130) by extracting a position of a component (304) of the object of interest (130) in the images and by sorting the images in an order corresponding to the periodical motion of the object of interest (130) based on the extracted positions.

7. The computer tomography apparatus (100) according to claim 1, wherein the determination unit (118) is adapted to determine the motion information concerning the object of interest (130) by an image similarity analysis of the images.

8. The computer tomography apparatus (100) according to claim 1, wherein the detecting elements (123) are adapted to detect further data related to at least one further motion interval of the object of interest (130); and

wherein the determination unit (118) is adapted to determine images of the structure of the object of interest (130) in each of the at least one further motion interval and to determine motion information concerning the object of interest (130) between the first motion interval and the second motion interval and the at least one further motion interval based on an analysis of the determined images.

9. The computer tomography apparatus (100) according to claim 1, comprising a rotatable gantry (101) on which the electromagnetic radiation source (104) and the detecting elements (123) are mounted.

10. The computer tomography apparatus (100) according to claim 9, wherein the rotatable gantry (101) is adapted to rotate the electromagnetic radiation source (104) and the detecting elements (123) on a circular trajectory with respect to the object of interest (130).

11. The computer tomography apparatus (100) according to claim 9, comprising a shiftable mounting device (119) adapted to receive the object of interest (130).

12. The computer tomography apparatus (100) according to claim 11, wherein the shiftable mounting device (119) is adapted to linearly shift the object of interest (130) so that, in combination with a rotation of the gantry (101), the electromagnetic radiation source (104) and the detecting elements (123) perform a helical trajectory with respect to the object of interest (130).

13. The computer tomography apparatus (100) according to claim 1, comprising a collimator (105) arranged between the electromagnetic radiation source (104) and the detecting elements (123), the collimator (105) being adapted to collimate an electromagnetic radiation beam emitted by the electromagnetic radiation source (104) to form a fan-beam or a cone-beam.

14. The computer tomography apparatus (100) according to claim 1, wherein the detecting elements (123) form a single-slice detector array.

15. The computer tomography apparatus (100) according to claim 1, wherein the detecting elements (123) form a multi-slice detector array (108).

16. The computer tomography apparatus (100) according to claim 1, configured as one of the group consisting of a medical application apparatus, a material testing apparatus and a material science analysis apparatus.

17. The computer tomography apparatus (100) according to claim 1, adapted for examination of a periodically moving object of interest (130).

18. A method for examination of a moving object of interest (130), the method comprising the steps of

emitting electromagnetic radiation to the object of interest (130);

detecting emitted electromagnetic radiation passed through the object of interest (130) as first data related to a first motion interval of the object of interest (130) and as second data related to a second motion interval of the object of interest (130); and

determining images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and determining motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined images.

19. A computer-readable medium, in which a computer program of examining a moving object of interest (130) is stored, which, when being executed by a processor (401), is adapted to control the steps of

emitting electromagnetic radiation to the object of interest (130);

detecting emitted electromagnetic radiation passed through the object of interest (130) as first data related to a first motion interval of the object of interest (130) and as second data related to a second motion interval of the object of interest (130); and

determining images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and determining motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined images.

20. A program element of examining a moving object of interest (130), which, when being executed by a processor (401), is adapted to control the steps of

emitting electromagnetic radiation to the object of interest (130);

detecting emitted electromagnetic radiation passed through the object of interest (130) as first data related to a first motion interval of the object of interest (130) and as second data related to a second motion interval of the object of interest (130); and

determining images of the structure of the object of interest (130) in the first motion interval and in the second motion interval and determining motion information concerning the object of interest (130) between the first motion interval and the second motion interval based on an analysis of the determined images.

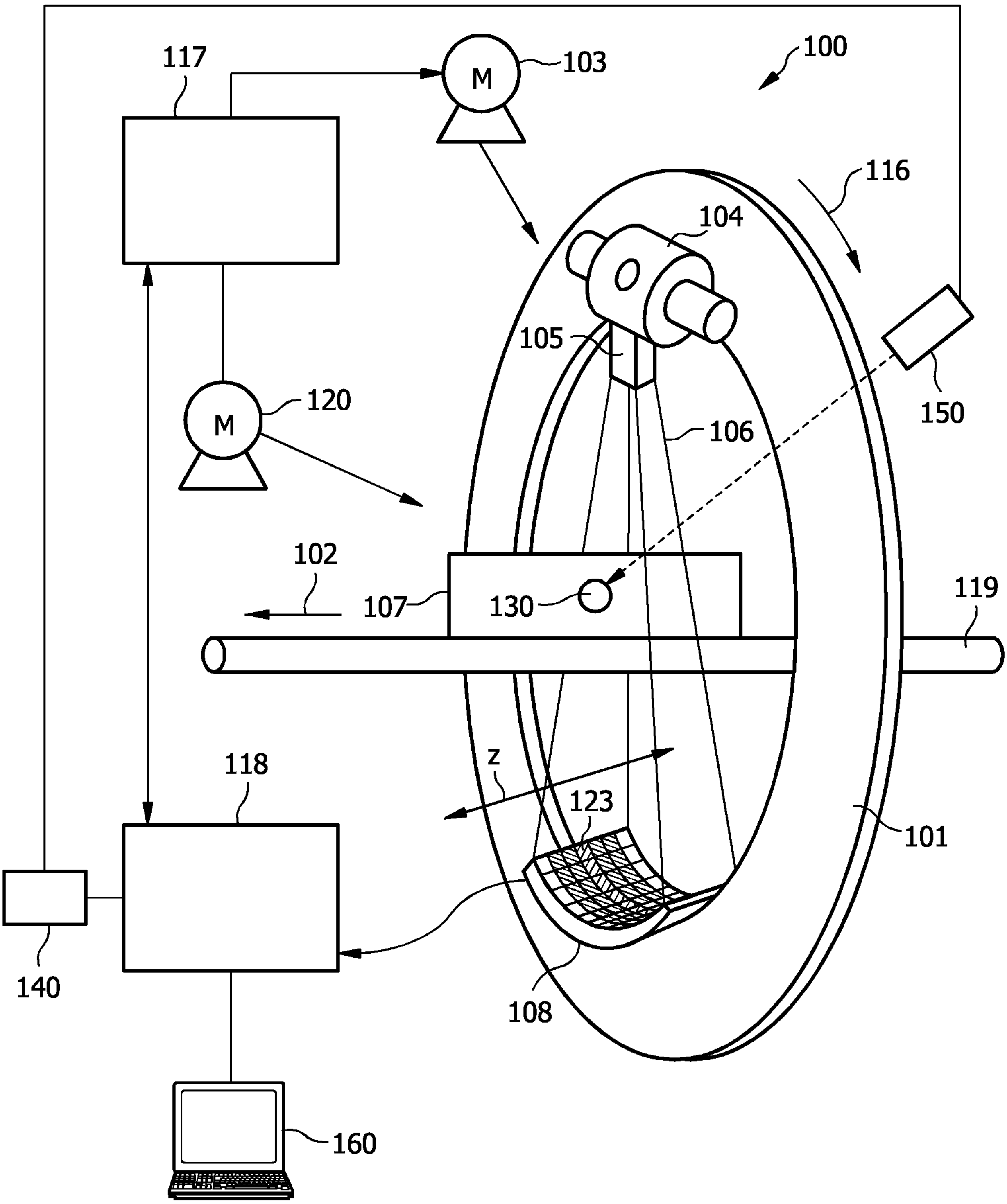

100
117
103
M
116
104
105
150
120
M
106
102
107
130
119
118
Z
123
101
140
108
160

FIG. 1

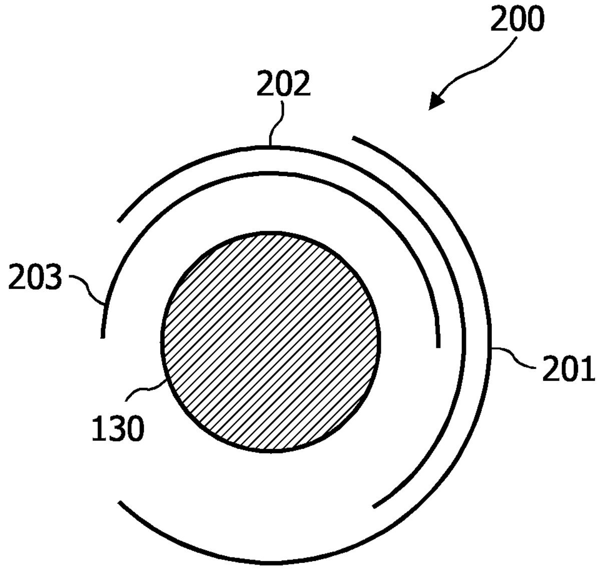


FIG. 2

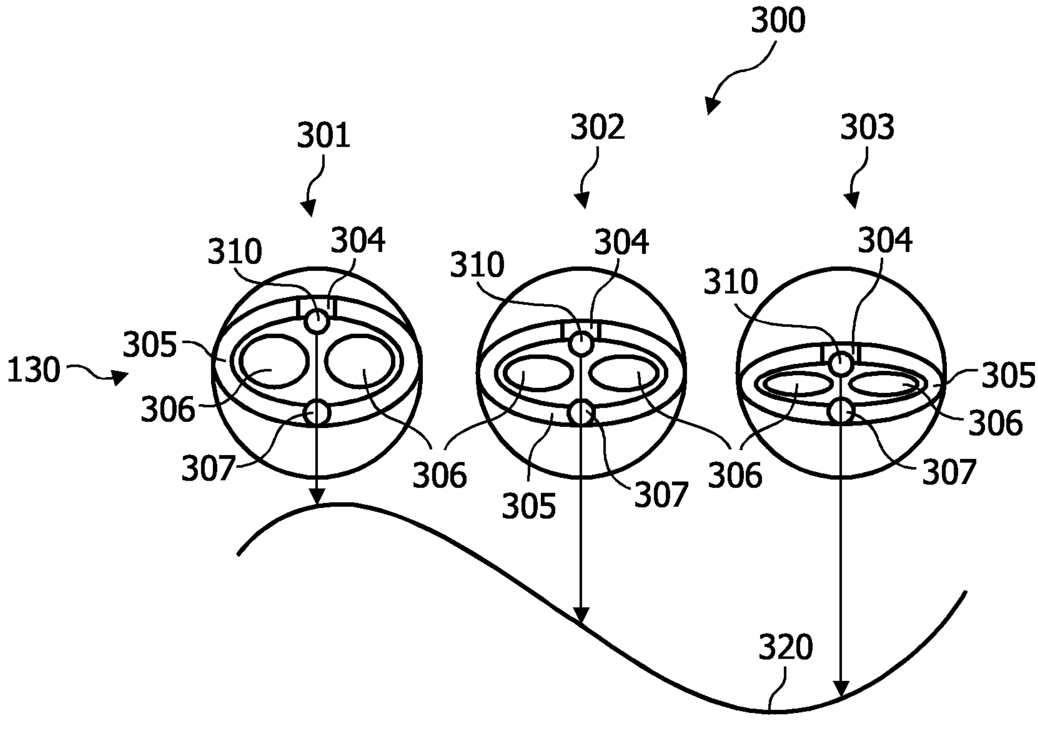


FIG. 3

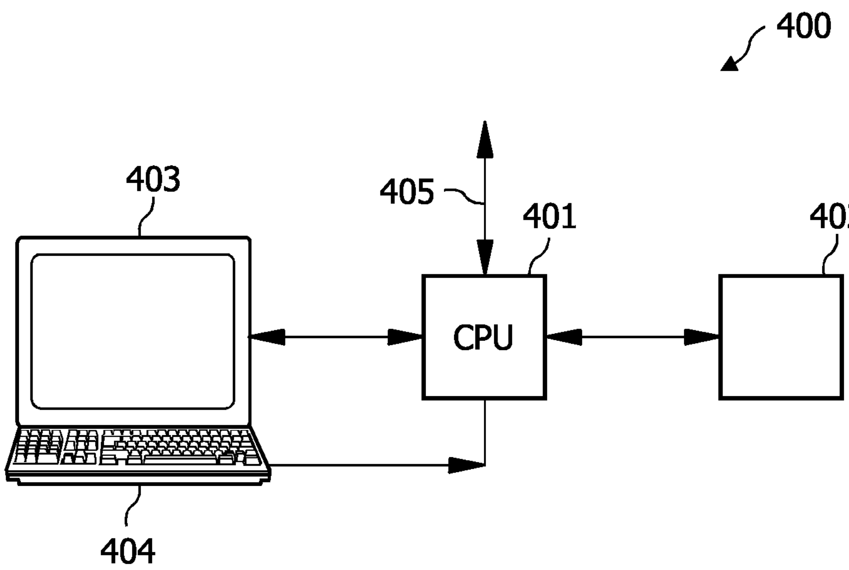


FIG. 4