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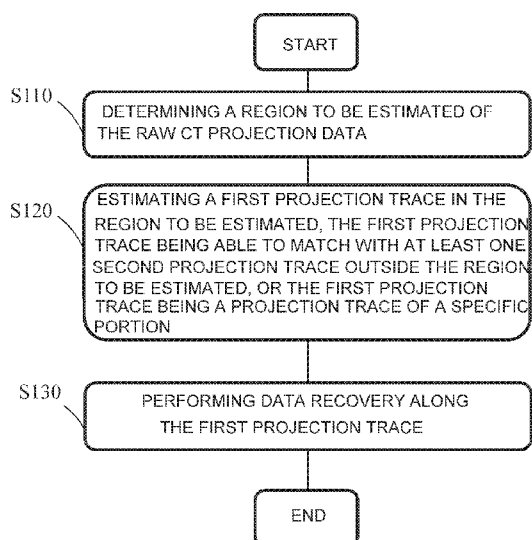


Fig. 1

(57) Abstract: The present invention provides a method for recovering raw CT projection data, comprising: determining a region to be estimated of the raw CT projection data; estimating a first projection trace in the region to be estimated, wherein the first projection trace can match with at least one second projection trace outside the region to be estimated, or the first projection trace is a projection trace of a specific portion; and performing data recovery along the first projection trace.

METHOD AND APPARATUS FOR RECOVERING RAW CT PROJECTION

DATA AND CT IMAGING SYSTEM

FIELD

[0001] The present invention relates to the field of X-Ray imaging and, in particular, relates to a method and an apparatus for data recovery of raw CT projection data and a CT imaging system.

BACKGROUND

[0002] In medical imaging technique of Computed Tomography (CT), raw data collected from a detector is arranged into a two-dimensional matrix with a horizontal axis of detector channel and a vertical axis of scan field of view as raw CT projection data of the reconstructed image, which is also referred to as a sinogram and is essentially a winding superimposition of curves formed by the points on the image. For example, if the collected CT projection data is reconstructed as an image with a size of 512×512 , then any point on the image is a curve trace in the matrix of the raw CT projection data. The amplitude of the curve trace depends on a distance of the point from a center of rotation for virtual collection, in which the greater the distance, the greater the amplitude. The phase of the curve trace depends on a position of the point on a certain circle with the center of rotation as the center of the circle.

[0003] Data of low credibility is often present in the raw CT projection data, which may be caused by several reasons, for example, temporary failure or failure during the entire collection process of some detector channel, data abnormality of some field of view, data fall due to bulb tube ignition, incredible data on the corresponding curve trace due to the metal in the body of the detected object and the like. Thus, when performing CT image reconstruction, data compensation or recovery usually needs to be performed for the raw data, for example, sometimes encryption also needs to be performed for data between neighboring fields of view or neighboring

detector channels, or repairing also needs to be performed for data with large spacing between channels and the like.

[0004] Traditional data compensation operations are all based on interpolation within the detector row or interpolation between channels with the same opening angle between the detector rows. The quality of the reconstructed images thereby cannot be efficiently enhanced and sometimes good and sometimes bad characteristic are exhibited for different objects to be scanned.

SUMMARY

[0005] One object of the present invention is to provide a method and an apparatus for more accurate data recovery of CT raw projection data as well as a CT imaging system employing the apparatus.

[0006] An exemplary embodiment of the present invention provides a method for recovering raw CT projection data, comprising: determining a region to be estimated of the raw CT projection data; estimating a first projection trace in the region to be estimated, wherein the first projection trace can match with at least one second projection trace outside the region to be estimated, or the first projection trace is a projection trace of a specific portion; and performing data recovery along the first projection trace.

[0007] An exemplary embodiment of the present invention further provides an apparatus for recovering raw CT projection data, comprising a region-to-be-estimated determination module, a first-projection-trace estimation module and a data recovery module. The region-to-be-estimated determination module is used to determine a region to be estimated of the raw CT projection data. The first-projection-trace estimation module estimates a first projection trace in the region to be estimated, wherein the first projection trace can match with at least one second projection trace outside the region to be estimated, or the first projection trace is a projection trace of a specific portion. The data recovery module is used to perform data recovery along the first projection trace.

[0008] An exemplary embodiment of the present invention further provides a CT imaging system, comprising a bulb tube to emit X-rays to an object to be scanned, a detector to receive the X-rays that pass through the object to be scanned to generate the above mentioned raw CT projection data and the above mentioned apparatus for recovering CT raw projection data.

[0009] Other features and aspects will be apparent through the following detailed description, figures and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention can be understood better in light of the description of exemplary embodiments of the present invention with reference to the accompanying drawings, in which:

[0011] Fig. 1 is a flow chart of a method for recovering raw CT projection data provided by a first embodiment of the present invention;

[0012] Fig. 2 is a schematic view of the raw CT projection data acquired in the first embodiment of the present invention;

[0013] Fig.3 is a schematic diagram of determining a first vector in a region to be estimated according to texture orientation of CT projection data of a trusted region, in one exemplary embodiment of the present invention;

[0014] Fig. 4 is a schematic view of the raw CT projection data acquired in a second embodiment of the present invention;

[0015] Fig. 5 is a schematic view showing that the CT projection trace of one pixel point acquired in a third embodiment of the present invention passes through the region to be estimated;

[0016] Fig. 6 is a schematic view of a second projection trace outside the region to be estimated of Fig. 5;

[0017] Fig. 7 is a schematic view of a first projection trace estimated in the region to be estimated in Fig. 5;

[0018] Fig. 8 is a reconstructed image obtained by reconstruction with CT projection data having data of low credibility;

[0019] Fig. 9A is a reconstructed image obtained by reconstruction after recovering the raw CT projection data with the prior art;

[0020] Fig. 9B is a reconstructed image obtained by reconstruction after recovering the raw CT projection data with the technical solution of the third embodiment of the present invention;

[0021] Fig. 10 is a schematic view of the raw CT projection data acquired in a fourth embodiment of the present invention;

[0022] Fig. 11 is the raw CT image obtained by image reconstruction according to the raw CT projection data shown in Fig. 10;

[0023] Fig.12 is an image of a metal portion acquired in Fig. 11;

[0024] Fig. 13 is the CT projection data of the metal portion acquired according to the image shown in Fig. 12;

[0025] Fig. 14 is a block diagram of an apparatus for recovering raw CT projection data provided by an embodiment of the present invention;

[0026] Fig.15 is a block diagram of a CT imaging system provided by one embodiment of the present invention.

DETAILED DESCRIPTION

[0027] Hereafter, a detailed description will be given for preferred embodiments of the present disclosure. It should be pointed out that in the detailed description of the embodiments, for simplicity and conciseness, it is impossible for the Description to describe all the features of the practical embodiments in details. It should be understood that in the process of a practical implementation of any embodiment, just as in the process of an engineering project or a designing project, in order to achieve a specific goal of the developer and in order to satisfy some system-related or business-related constraints, a variety of decisions will usually be made, which will

also be varied from one embodiment to another. In addition, it can also be understood that although the effort made in such developing process may be complex and time-consuming, some variations such as design, manufacture and production on the basis of the technical contents disclosed in the disclosure are just customary technical means in the art for those of ordinary skilled in the art associated with the contents disclosed in the present disclosure, which should not be regarded as insufficient disclosure of the present disclosure.

[0028] Unless defined otherwise, all the technical or scientific terms used in the Claims and the Description should have the same meanings as commonly understood by one of ordinary skilled in the art to which the present disclosure belongs. The terms "first", "second" and the like in the Description and the Claims of the present utility model do not mean any sequential order, number or importance, but are only used for distinguishing different components. The terms "a", "an" and the like do not denote a limitation of quantity, but denote the existence of at least one. The terms "comprises", "comprising", "includes", "including" and the like mean that the element or object in front of the "comprises", "comprising", "includes" and "including" covers the elements or objects and their equivalents illustrated following the "comprises", "comprising", "includes" and "including", but do not exclude other elements or objects. The term "coupled" or "connected" or the like is not limited to being connected physically or mechanically, nor limited to being connected directly or indirectly.

[0029] First Embodiment

[0030] Fig. 1 is a flow chart of a method for recovering raw CT projection data provided by a first embodiment of the present invention. A skilled person in the art would understand that the above mentioned raw CT projection data may be, for example, projection data collected from a detector channel of the CT imaging system, or projection data subjected to some pre-processing after being collected, in which the pre-processing may comprise, by way of example, removing dark current by offset correction, removing fluctuation of radial energy in respective fields of view by reference channel correction, removing non-uniformity of initial incoming energy of

respective channels by aircal correction, removing inconsistency in absorption between high and low energy rays by beam hardening correction, converting data into summations in theory by -ln mathematical transformation, and so on.

[0031] Fig. 2 is a schematic view of the raw CT projection data acquired in the first embodiment of the present invention. The horizontal axis in Fig.2 denotes the detection channel and the vertical axis in Fig.2 denotes the scan field of view. Each data point in the raw CT projection data is a superimposition of data collected in corresponding scan fields of view by corresponding detection channels. Since there may be a region with low data credibility in the raw CT projection data, CT projection data of each point in the region needs to be re-estimated, to perform image reconstruction more accurately.

[0032] As shown in Fig.1, the method of recovering raw CT projection data comprises a region-to-be-estimated determination step S110, a first-projection-trace estimation step S120 and a data recovery step S130.

[0033] The region-to-be-estimated determination step S110: determining a region to be estimated of the raw CT projection data. For example, the region A with low credibility in the raw CT projection data as shown in Fig.2 may be analyzed through observation by naked-eye or data analysis by computer or the like, and may be determined as a region to be estimated.

[0034] The first-projection-trace estimation step S120: estimating a first projection trace in the region to be estimated, wherein the first projection trace can match with at least one second projection trace outside the region to be estimated. The data recovery step S130: performing data recovery along the first projection trace.

[0035] Optionally, the first projection trace being able to match with a second projection trace outside the region to be estimated may specifically comprise: the first projection trace can be connected with at least one second projection trace outside the region to be estimated, to form a complete projection trace. The above mentioned second projection trace may be a part of any complete CT projection trace that is located outside the region to be estimated, i.e., a trusted part of the CT projection

trace. The above mentioned first projection trace may be estimated in the region to be estimated by multiple technical means, which may comprise, for example, image processing, data analyses in various forms, or the like.

[0036] Optionally, the above mentioned first projection trace comprises a first vector estimated in the region to be estimated, and the method for recovering raw CT projection data of the present embodiment may further comprise a trusted-region determination step and a texture-orientation detection step:

[0037] The trusted-region determination step: determining a trusted region adjacent to the region to be estimated in the raw CT projection data, the trusted region just comprising the above mentioned second projection trace; and

[0038] The texture-orientation detection step: detecting texture orientation of the second projection trace in the trusted region to acquire multiple second vectors.

[0039] Specifically, when an orientation difference between the first vector and at least one second vector is not greater than a preset value, the first projection trace matches with the second projection trace corresponding to the second vector.

[0040] For example, in the present embodiment, region (s) B1 and/or B2 with relatively high data credibility adjacent to the region A may be determined as a trusted region. It should be noted that the above determined trusted region and the region to be estimated are not limited in their shape or size.

[0041] The above mentioned second vector may represent, for example, texture trend of the projection trace in the trusted regions B1, B2.

[0042] As shown in Fig.2, in the first embodiment, one or more first vectors that match with a second vector in the trusted regions B1 and/or B2 may be determined in the region A to be estimated according to the second vector in the trusted regions B1 and/or B2, as the first projection trace.

[0043] Fig.3 is a schematic diagram of determining a first vector in a region to be estimated according to texture orientation of CT projection data of a trusted region, in

one exemplary embodiment of the present invention. As shown in Fig.3, for the projection trace on the CT projection data, since its coordinates (or data points) vary continuously, its texture orientation may comprise multiple specific vectors along the CT projection trace. Each of the specific vectors may be represented in a number of forms, for example, only in the form of stored data (such as a length of each segment of trace, angle or slope of each segment of trace at the corresponding coordinate position), or may also be represented by respective directional line segments shown in Fig.3, wherein each directional line segment has a specific direction, i.e. has a specific angle or slope, representing that there is a second projection trace in the direction pointed by the directional line segment, or may be understood as: the directional line segment is a segment of a certain complete CT projection trace. For any projection trace, if all corresponding directional line segments thereof are known and these directional line segments are connected in turn, the overall trend of the projection trace may be obtained. A skilled person in the art may understand that the texture trend of a trace on the CT projection data represented in other forms may also be acquired.

[0044] Optionally, estimating a first projection trace in the region to be estimated may comprise a vector determination step and a matching step:

[0045] The first vector determination step: for each data point to be estimated, determining one first straight line that passes through the data point;

[0046] The matching step: if the first straight line can rotate about the data point as a center of rotation to a matching angle, a part of the first straight line at the matching angle in the region to be estimated is determined as the first vector, i.e., one first projection trace. Specifically, at the matching angle, the orientation difference between the first vector and at least one second vector is not greater than the above preset value. The orientation difference may comprise, for example, angle difference, slope difference and so on.

[0047] The matching precision may be adjusted by adjusting the above preset angle; for example, if the preset angle is set to be 0, only with one first straight line that is exactly in line with directional line segments at one side or opposite sides of

the data point P1, can a part of it within the region to be estimated be considered as the first vector.

[0048] By way of example, as a specific example, one straight line L1 may be at first determined with a horizontal angle or another angle as a starting point for the data point P1 in Fig.3, and the first straight line may be rotated about the data point P1 as a center of rotation within 360 degrees. If the first straight line L1 is approximately in line with the directional line segments D1 and D2 at opposite sides of the data point P1 after being rotated 30 degree, one first vector can be determined at the orientation of 30 degree; if the straight line L1 is approximately in line with the directional line segments D3 and D4 at opposite sides of the data point P1 after being rotated 150 degree, one first vector can be determined at the orientation of 150 degree. Of course, in some situations, if the first straight line L1 is only approximately in line with the directional line segment D1 at one side of the data point P1 while is at a too large angle with respect to the directional line segment D2 at the other side of the data point P1 after being rotated 30 degree, a part of the first straight line L1 within the region A to be estimated may also be determined as the first vector. That is, each first vector is regarded as one first projection trace as long as it is matched with at least one second vector.

[0049] Apparently, in determining the first projection trace, in order to be matched with the texture trend of the projection trace outside the region to be estimated, the first projection traces determined in the region to be estimated are not along the detecting channel direction or not all of them are along the detecting channel direction, i.e., are not horizontal lines or vertical lines or not all of them are horizontal lines or vertical lines, and they may be oblique lines. The first projection trace may be understood as representing the trend of the CT projection trace in the region to be estimated, which, for example, can smoothly be connected to one second projection trace matched therewith in the trusted region.

[0050] Optionally, performing data recovery along the first projection trace may specifically comprise: calculating CT projection data on the first projection trace by interpolation according to the CT projection data on the second projection trace

matched with the first projection trace. The CT projection data calculated by interpolation may comprise CT projection values, for example.

[0051] The CT projection data of the region A to be estimated may be re-estimated by interpolation. After calculating the CT projection value of each first projection trace by interpolation, if there are multiple interpolation results for each data point to be estimated (for example, there are multiple first projection traces passing through the same data point to be estimated), the multiple interpolation results are summed as the final interpolation result of the data point.

[0052] The CT projection data of the region to be estimated obtained by the above interpolation may be a high-frequency part in the CT projection data.

[0053] Optionally, after determining the region A to be estimated and the trusted regions B1 and/or B2, the following steps may also be included to estimate a low-frequency part of the CT projection data in the region A to be estimate:

[0054] A data fitting step: performing data fitting for the CT projection data of the trusted region to acquire a space curved surface equation. For example, data fitting may be performed for the CT projection data in the trusted regions B1 and B2 in Fig.2, and the above mentioned data fitting may comprise, for example, least square data fitting.

[0055] An estimation step: re-estimate CT projection data of the region to be estimated according to the above mentioned space curved surface equation.

[0056] Optionally, re-estimating CT projection data of the region to be estimated according to the space curved surface equation comprises: taking coordinates and CT projection values of a data point to be estimated in the region to be estimated as input values for the above mentioned space curved surface equation, and calculating output values of the space curved surface equation as a low-frequency part of the new CT projection data of the data point.

[0057] In particular, the low-frequency data in the CT projection data of the trusted region may be acquired prior to data fitting, for example, the low-frequency data in

the raw CT projection data may be acquired by performing low-pass filtering for the raw CT projection data. Then in the data fitting step, data fitting may be performed for the low-frequency part of the CT projection data of the trusted region to obtain the space curved surface equation.

[0058] Optionally, estimating the first projection trace in the region to be estimated may comprise: acquiring the above mentioned second vector according to the high-frequency data in the CT projection data of the trusted region. In particular, the high-frequency data in the CT projection data of the trusted region may be acquired at first prior to acquiring the second vector, to acquire the corresponding second vector according to the high-frequency data.

[0059] The high-frequency data in the CT projection data of the trusted region may be acquired through the following two ways: one may be calculating the low-frequency data of the CT projection data of the trusted region according to the space curved space equation obtained in the data fitting step (for example, taking the coordinates and the CT projection data of the data points to be estimated of the trusted region as input values to be introduced into the space curved surface equation and using the output values as the corresponding low-frequency data), and subtracting the low-frequency data of the CT projection data of the trusted region calculated according to the space curved surface equation from the raw CT projection data of the trusted region, to obtain the corresponding high-frequency data; the other one may be performing filtering and strengthening for the raw CT projection data to obtain the raw high-frequency data, wherein the above high-frequency data in the CT projection data of the trusted region may be determined from the raw high-frequency data directly.

[0060] Optionally, estimating the first projection trace in the region to be estimated may comprise: filtering the CT projection data outside the region to be estimated to acquire a second vector distributed outside the region to be estimated. When filtering the CT projection data outside the region to be estimated with a filter, filtering may be performed for only the raw CT projection data in the trusted region or for only the high-frequency part therein; filtering may also be performed for the raw CT

projection data in the whole data region or the high-frequency part therein to obtain the second vector on the whole data region.

[0061] The above mentioned filter may comprise a Gabor filter, for example, Gabor filters of multiple directions may be generated. Said Gabor filters of multiple directions are used to filter the data to be filtered in the corresponding directions, and the directional result of each Gabor filter is just the highest amplitude of the Gabor filtering response at each data point, i.e., information for representing texture orientation, e.g., the second vector. The texture orientation information obtained with the Gabor filters may comprise multiple directional line segments as shown in Fig.3.

[0062] Of course, filters in other forms may also be used as long as the texture orientation information of the CT projection data can be obtained.

[0063] Thus, embodiments of the present invention realize interpolation operation along the actual trend of the projection trace instead of interpolation within the channel row or interpolation between channels with the same opening angle between rows. In this way, the recovered data is more accurate and quality of the acquired CT image is better.

[0064] Optionally, estimating a first projection trace in the region to be estimated may further comprise the following steps:

[0065] A comparison step: comparing a data intensity at a data point corresponding to the first vector (e.g., directional line segments D1 and/or D2) with a preset data intensity;

[0066] A classification step: if the data intensity at the data point corresponding to anyone of the first vectors is greater than or equal to the preset data intensity, the corresponding first vector is determined as a desired first projection trace; otherwise if the data intensity at the data point corresponding to anyone of the first vectors (e.g., directional line segments D1 and/or D2) is less than the preset data intensity, the corresponding first vector is determined as a first projection trace that can be ignored.

[0067] At this moment, calculating the CT projection data on the first projection trace by interpolation may comprise: selectively calculating the CT projection data on the desired first projection trace by interpolation. It may be understood as: searching for a first projection trace having a relatively high data intensity in the region to be estimated and performing interpolation operation along the projection trace. The above mentioned data intensity means an absolute value of the CT projection value at the corresponding data point. In the above manner, not only computation of the interpolation operation is reduced, but also the accuracy of data recovery is increased.

[0068] In order to reduce workload of data recovery, data fitting may be performed only for the low-frequency data to re-estimate the low-frequency part of the CT projection data of the region to be estimated, or the high-frequency data on the first projection trace is calculated by interpolation after the first projection trace is determined in the region to be estimated.

[0069] To guarantee accuracy of data recovery, the method for recovering raw CT projection data of the present invention may further comprise a summation processing step: performing summation for the low-frequency CT projection data acquired by data fitting and the high-frequency CT projection data acquired in the interpolation operation, to facilitate subsequent image reconstruction according to the CT projection data after summation.

[0070] Second Embodiment

[0071] During the process of CT scan imaging, when the object being scanned is too large or is disposed at a position off center, a part of the object being scanned will be outside coverage of the detector. Accordingly, a part of the raw CT projection data will not be displayed in the raw CT projection image, which, in the present embodiment, is referred to as truncated data. In a projection space, the region within which the truncated data is located is referred to as a truncated region.

[0072] In the second embodiment, when the raw CT projection data is truncated, the CT projection trace and data thereon of the truncated region needs to be

re-estimated, in which case it is required that the CT projection trace of the truncated region, as a first projection trace, can be connected with at least one truncated CT projection trace in the raw CT projection data to form one complete projection trace.

[0073] The method of recovering raw CT projection data of the second embodiment of the present invention comprises the above mentioned region-to-be-estimated determination step S110, first-projection-trace estimation step S120 and data recovery step S130. The second embodiment is similar to the first embodiment except that:

[0074] In the second embodiment, the region-to-be-estimated determination step S110 may comprise: determining a truncated region of the raw CT projection data, which may be achieved by any method.

[0075] Optionally, the first-projection-trace estimation step S120 may specifically comprise the following steps:

[0076] detecting a truncated CT projection trace in the raw CT projection data, as a second projection trace; and

[0077] performing data fitting for the coordinate information of the second projection trace to acquire the first projection trace. For example, texture trend of the second projection trace in the truncated region may be estimated by performing data fitting for the coordinate information of the second projection trace, thus acquiring the first projection trace.

[0078] The data recovery step S130 may comprise: performing extrapolation according to the CT projection data on the second projection trace to obtain the CT projection data on the first projection trace. The first projection trace and the CT projection data thereon are added into the raw CT projection data, such that recovery of the raw CT projection data is realized.

[0079] When detecting a truncated CT projection trace in the raw CT projection data (credible data), some truncated traces that perform relatively significantly in the projection space may be detected according to a preset determination threshold,

such as CT projection traces of high-density substances (metals, bones and the like) and low-density substances (air). Filtering or methods for detecting high-frequency information in the CT projection data may be employed for the specific detection process.

[0080] Fig. 4 is a schematic view of the raw CT projection data acquired in the second embodiment of the present invention. As shown in Fig.4, since a part of the CT projection trace 401 is outside the raw CT projection data, the CT projection trace 601 is one truncated trace that may be detected, i.e., a second projection trace outside the region to be estimated.

[0081] In the present embodiment, the truncated CT projection trace is extrapolated to obtain the CT projection data on the first projection trace, such that the truncated CT projection trace and the first projection trace form a complete, non-truncated projection trace.

[0082] Optionally, in the present embodiment, extrapolation may be performed for the linear trace in the truncated CT projection trace.

[0083] The linear trace herein may be a projection trace with a width less than a preset threshold. For example, the truncated trace 401 shown in Fig.4 may be considered as one linear trace.

[0084] In one embodiment of the present invention, data of the truncated part of the CT projection trace, i.e., data retained in the raw projection data, may be used to determine shape and position of the linear trace. In one embodiment of the present invention, the shape of the linear trace may be a sinusoidal curve or a sinusoidal-like curve, and may also be other curves of high powers. No matter which type of curve it is, its information such as position, trend and so on may be determined by coordinates of points on the curve.

[0085] Extrapolation may be performed for the linear trace according to a predetermined shape and position.

[0086] A trend of the linear trace in the truncated region may be estimated by any extrapolation method according to the shape, position of the linear trace to acquire the first projection trace, and extrapolation may be performed for the CT projection data on the first projection trace according to the CT projection data (for example, it may comprise the CT projection value) on the truncated linear trace to recover the truncated linear trace to a complete CT projection trace.

[0087] Optionally, extrapolation may also be performed for a strip trace in the truncated projection trace. The strip trace herein may be a projection trace with a width greater than a preset threshold.

[0088] The so-called centerline of the strip trace refers to a curve located at a middle position along the width direction of the strip trace. In one embodiment of the present invention, the centerline position of the strip trace in the truncated region may be estimated by acquiring coordinates of the centerline of the strip trace, no matter whether the centerline is a sinusoidal curve or a sinusoidal-like curve, or other curves of high-powers.

[0089] In one example, the width of the strip trace may be calculated along the channel direction of the CT detector.

[0090] Thus, extrapolation may be performed for a part of the strip trace in the truncated region (i.e., the first projection trace) according to the width as well as shape and position of the centerline.

[0091] In one example, a sum of the CT projection values may be calculated along the width direction, and then extrapolation may be performed for the strip trace according to the sum of the CT projection values, the centerline position and the width of the strip trace, so as to recover the strip trace to a complete trace.

[0092] Usually, there may be multiple CT projection traces that pass through one truncated region. Thus, in one embodiment of the present invention, the multiple CT projection traces may be recovered to be complete by the above mentioned method, and afterwards weighted summation may be performed for the multiple complete CT projection traces.

[0093] In an embodiment of the present invention, recovery may also be performed for the truncated background data in the raw CT projection data to obtain a better image quality. In particular, it may include the following steps:

[0094] determining an extrapolation range for the background data according to an envelope of the multiple complete CT projection traces; in the embodiments of the present invention, there may be multiple truncated CT projection traces. Thus, for each truncated CT projection trace, it may be recovered to a complete CT projection trace. The outermost perimeter of the envelope of these multiple complete CT projection traces may just constitute an extrapolation range for performing extrapolation recovery for the background data;

[0095] The complete background data may be obtained by performing background data extrapolation in the extrapolation range.

[0096] The extrapolation for the background data may be performed with any method for extrapolation of background data, and may be performed according to the following three principles: 1) sums of signals in respective views are equal; 2) there should be no apparent signal hopping in the channel direction of the detector; 3) extrapolated sum may be obtained by subtracting the raw CT projection data from a forward projection of the extrapolated image.

[0097] By the above method, recovery of CT projection data of a truncated region is realized, which can enlarge the CT display field of view and remove artifacts introduced due to truncation in comparison with traditional methods of increasing a bore diameter of a CT.

[0098] Third Embodiment

[0099] As shown above, because of the reasons that the performance of some channels on the detector is degraded, the object to be scanned contains metal and the like, the raw CT projection data would include data of low credibility. Artifacts would appear on the CT raw image obtained by reconstruction with those data.

[00100] In the third embodiment, in the CT projection trace obtained by performing forward projection for the CT raw image, when a trusted projection trace overlaps with a non-trusted strip or linear projection trace, texture trend of the trusted projection trace in the overlapped region needs to be estimated and data recovery needs to be performed along the texture trend.

[00101] Similar to the first embodiment and the second embodiment, the method of recovering raw CT projection data of the third embodiment of the present invention comprises the above mentioned region-to-be-estimated determination step S110, the first-projection-trace estimation step S120 and the data recovery step S130.

[00102] Optionally, in the region-to-be-estimated determination step S110, determining the region to be estimated of the raw CT projection data may comprise: acquiring a low credibility region in the raw CT projection data as the region to be estimated.

[00103] The low credibility region may be a region on the raw CT projection data corresponding to some known detector channel of low performance, and may also be a region reflected onto the raw CT projection data due to tube spit or the like. For example, for the situation of known detector channel of low performance, the corresponding detector channel may be directly selected on the projection space, and a region composed of all data corresponding to the channel may be regarded as the low credibility region. For the situation of tube spit, a region composed of all data for the view may be regarded as the low credibility region.

[00104] Optionally, the low credibility region may be a region on the raw CT projection data corresponding to a metal region on the raw CT image, the above mentioned raw CT image being an image obtained by reconstruction according to the raw CT projection data.

[00105] Thus, in the present embodiment, acquiring a low credibility region in the raw CT projection data may comprise the following steps:

[00106] choosing a target region on the raw CT image; the target region may be a region within which artifacts are located, and may also be a region deemed as having low credibility by a user; and

[00107] performing forward projection for the target region to obtain a low credibility region.

[00108] For some artifacts of specific styles, for example, steak artifact, ring artifact, band artifact and the like, information such as their shapes, positions, sizes and the like may be recognized from the reconstructed image.

[00109] For example, information such as the view, the number of channels of the detector along the X-direction, the number of rows of the detector along the Z-direction and the like are computed from the direction of the steak artifact and the distance from the steak artifact to the rotation center, thereby determining the region of the steak artifact in the raw CT projection data. For another example, the view, the number of channels and the number of rows of the ring artifact or the band artifact may be computed from the radius and the circumference coverage range of the ring artifact or the band artifact, thereby determining the region of the ring artifact or the band artifact in the raw CT projection data.

[00110] Thus, in the present embodiment, acquiring a low credibility region in the raw CT projection data may further comprise the following steps:

[00111] acquiring artifact information on a raw CT image; and

[00112] calculating a low credibility region according to the artifact information.

[00113] Optionally, the first-projection-trace estimation step S120 may comprise the following steps:

[00114] performing forward projection for all or part of the pixel points on the raw CT image to obtain a CT projection trace for each pixel point, and using a part of the CT projection trace of each pixel point outside the region to be estimated as the

above mentioned second projection trace; the above mentioned raw CT image is an image obtained by reconstruction according to the raw CT projection data; and

[00115] estimating a part of the CT projection trace of each pixel point that passes through the region to be estimated as the above mentioned first projection trace.

[00116] For example, forward projection may be performed on pixel points in the regions within which the objects with a relatively high density (for example, metals, bones and so on) are located on the raw CT image, to obtain CT projection traces of these pixel points. Forward projection may also be performed on the raw CT image for pixel points in the regions with objects having relatively large density differences (for example, regions with high-density substance and low-density substance close to each other), to obtain CT projection traces of these pixel points. In such case, if the CT projection trace of some pixel point passes through the region to be estimated, the CT projection trace of the pixel point comprises a second projection trace outside the region to be estimated.

[00117] By estimating a trend of the part of the CT projection trace of the pixel point that passes through the region to be estimated, a first projection trace may just be determined in the region to be estimated, where the first projection trace and the second projection trace of the pixel point are connected to form one complete CT projection trace. For example, according to coordinate information of a CT projection trace outside the region to be estimated, a first projection trace that matches with the CT projection trace may be estimated in the region to be estimated.

[00118] A part of the CT projection data corresponding to the pixel point within the region to be estimated may be recovered by perform interpolation for the first projection trace according to the CT projection data on the second projection trace.

[00119] In the raw CT projection data of some CT machines, the CT projection trace is a sinusoidal curve, thus, in one embodiment of the present invention, the overlapped region on the CT projection trace may be recovered by performing interpolation according to a trend of the sinusoidal curve.

[00120] Fig. 5 is a schematic view showing that the CT projection trace of one pixel point acquired in a third embodiment of the present invention passes through the region to be estimated. Fig. 6 is a schematic view of a second projection trace outside the region to be estimated in Fig. 5. Fig. 7 is a schematic view of the first projection trace estimated in the region to be estimated in Fig. 5. Fig. 8 is a reconstructed image obtained by reconstruction with CT projection data having data of low credibility; Fig. 9A is a reconstructed image obtained by reconstruction after recovering the raw CT projection data with the prior art; Fig. 9B is a reconstructed image obtained by reconstruction after recovering the raw CT projection data with the technical solution of the third embodiment of the present invention.

[00121] As shown in Fig. 5, a part of the projection trace that does not pass through the region to be estimated may be regarded as a trusted region. Thus, CT projection traces in the overlapped region (region to be estimated) may be obtained using a sinusoidal change pattern, and data recovery may be realized by performing interpolation along the first projection trace according to the CT projection data in the trusted region (i.e., CT projection data on the second projection trace).

[00122] In the raw CT projection data of some other CT machines, the projection trace may be a sinusoidal-like curve or other arbitrary curve of high powers; thus, in another embodiment of the present invention, the overlapped region on the CT projection trace may be recovered by interpolation according to the trend and the change pattern of the sinusoidal-like curve or the high-power curve.

[00123] Optionally, when there are multiple CT projection traces that pass through the same region to be estimated, weighted summation may be performed for the complete projection traces obtained by interpolation. The weights of the projection traces may be equal. The projection traces of greater strength may be assigned greater weights as well.

[00124] In one embodiment of the present invention, the data after being recovered may further be merged with the data before being recovered. Such merging process may be a weighted superimposing process, for instance, the data after being recovered may be trusted entirely while the data before being recovered may not be

trusted at all. The data after being recovered may also be trusted partly, in this way, the data before being recovered and the data after being recovered may be assigned with some weights respectively and the two may be weighted superimposed with each other. The data as stated herein may be projection data, and may also be data of the reconstructed image, i.e., this merging may be performed at a projection space, and may also be performed at an image space.

[00125] Fourth Embodiment

[00126] One reason why the data of low credibility is present in the raw CT projection data may be caused by a composition of a specific portion within the detected object. The composition of the specific portion may be a metal tissue or other tissue components that would make projection data incredible. For instance, on a certain data point of the CT projection data, not only credible data is included, e.g., data related to muscle tissue, bone tissue and the like, but incredible data is also included, e.g., data related to a metal tissue. The credible data and the incredible data are superimposed together, so data recovery needs to be performed on the data point. In the fourth embodiment, when there are strip or linear projection traces caused by specific portions such as metal in the raw CT projection data, the projection trace of the metal may be used as the first projection trace and data recovery may be performed along the projection trace of the metal.

[00127] Similar to the first embodiment, the second embodiment and the third embodiment, the method of recovering raw CT projection data of the fourth embodiment of the present invention comprises the above mentioned region-to-be-estimated determination step S110, the first-projection-trace estimation step S120 and the data recovery step S130.

[00128] Optionally, in the fourth embodiment, the region-to-be-estimated determination step S110 comprises the following steps:

[00129] reconstructing the raw CT image according to the raw CT projection data;

[00130] detecting a specific portion in the raw CT image; and

[00131] performing forward projection for an image of the specific portion to acquire a CT projection trace of the specific portion, wherein a region in the raw CT projection data corresponding to the CT projection trace of the specific portion is just the region to be estimated.

[00132] Optionally, a data pre-processing step may further be included prior to the region-to-be-estimated determination step S110: pre-processing the above raw CT projection data. Therefore, in the region-to-be-estimated determination step S110, the raw CT image may be reconstructed directly based on the raw CT projection data collected by the detector channel, or reconstructed based on the pre-processed raw CT projection data. The pre-processing may include, for example, offset correction to remove dark current, reference channel correction to remove fluctuation of ray energy of all fields of view, aircal correction to remove inhomogeneity of initially entering energies of all channels, beam hardening correction to remove inconsistency in absorptivity between high energy rays and low energy rays, -ln mathematical transformation to make data become a meaning of added sum in theory, and the like.

[00133] Fig. 10 is a schematic view of the raw CT projection data acquired in a fourth embodiment of the present invention. Fig. 11 is the raw CT image obtained by image reconstruction according to the raw CT projection data as shown in Fig. 10. In the raw CT image obtained by image reconstruction according to raw CT projection data, different portions have different CT values; for example, generally the CT value of the metal tissue portion is not less than 3500 HU, surely the obtained CT values of metal tissues may also vary in different models.

[00134] Thus, a specific portion may be determined by detecting the CT values of the raw CT image, which may specifically comprise the following steps:

[00135] comparing the CT value of each pixel in the raw CT image with a preset CT value; and

[00136] determining a region within which a pixel having a CT value greater than the above mentioned preset CT value is located as a specific portion.

[00137] For example, the above preset CT value may be 3500HU, and then a region within which a pixel having a CT value greater than 3500HU is located in the raw CT image as shown in Fig. 11 may be determined as a specific portion.

[00138] Fig.12 is an image of the metal portion acquired in Fig. 11. As shown in Fig.12, the CT value of each of the pixels in the raw CT image outside the specific portion may be set to be 0; for example, in Fig. 11, the CT values at the pixels outside the metal portion may all be set to 0, by which the image other than the specific portion may be removed from the raw CT image to obtain an image of the metal portion as shown in Fig. 12.

[00139] Fig. 13 is the CT projection data of the metal portion acquired according to the image shown in Fig. 12. Optionally, in the first-projection-trace estimation step S120, a CT projection trace and the projection data thereon may be acquired by performing forward projection for the image of the specific portion; the CT projection trace of the specific portion is just the first projection trace of the present embodiment, and the region corresponding to the first projection trace in the raw CT projection data is just the region to be estimated.

[00140] Accordingly, the data recovery step S130 may comprise: subtracting the CT projection data on the first projection trace from the raw CT projection data to obtain credible data in the raw CT projection data. For example, the metal projection in the metal trace region in Fig. 10 is removed, leaving the projection trace of non-metal substance in this region. In particular, the following operation may be performed:

[00141] If a data point belongs to a region across which the metal trace sweeps in Fig. 13, for each data point of the region, its data values in Fig. 13 are subtracted from its data values (CT projection values) in Fig. 10 to obtain new data values. The new data values are just the credible data detected in Fig. 10. If a data point does not belong to a region across which the metal trace sweeps in Fig. 13, its data values in Fig. 10 are retained.

[00142] Optionally, in the fourth embodiment, prior to the data recovery step S150, the method may further comprise: adjusting a data magnitude of the CT projection data of the above mentioned specific portion. For example, before performing an operation on the data as shown in Fig. 13 and the raw CT projection data, appropriate scale transformation or weighting processing may be performed to adapt to some changes of data magnitude that may appear and are brought by intermediate calculations. In this way, the CT projection data of the specific portion may be made adapt with the raw CT projection data in data magnitude.

[00143] Fig. 14 is a block diagram of an apparatus for recovering raw CT projection data provided by an embodiment of the present invention. As shown in Fig.14, the apparatus of recovering raw CT projection data may comprise a region-to-be-estimated determination module 141, a first-projection-trace estimation module 143 and a data recovery module 145.

[00144] The region-to-be-estimated determination module 141 may be used to determine a region to be estimated of the raw CT projection data.

[00145] The first-projection-trace estimation module 143 may be used to estimate a first projection trace in the above mentioned region to be estimated, wherein the first projection trace can match with at least one second projection trace outside the region to be estimated, or the first projection trace is a projection trace of a specific portion.

[00146] Optionally, the first projection trace can be connected with at least one second projection trace outside the region to be estimated to form one complete projection trace.

[00147] The data recovery module 145 may be used to perform data recovery along the first projection trace. Optionally, the data recovery module 145 may calculate the CT projection data on the first projection trace by interpolation according to the CT projection data on the second projection trace matched with the first projection trace.

[00148] Optionally, the first projection trace may comprise a first vector estimated in the region to be estimated, and the apparatus for recovering raw CT projection data of the present invention further comprises a trusted-region determination module and a detection module.

[00149] The trusted-region determination module may determine a trusted region adjacent to the region to be estimated in the raw CT projection data, the trusted region comprising the second projection trace.

[00150] The detection module may detect texture orientation of the second projection trace in the trusted region to acquire multiple second vectors. When an orientation difference between the first vector and at least one second vector is not greater than a preset value, the first projection trace matches with the second projection trace corresponding to the second vector.

[00151] Optionally, the region-to-be-estimated determination module 141 may further be used to determine a truncated region of the raw CT projection data.

[00152] The first-projection-trace estimation module 143 may comprise a first detection unit and a data fitting unit.

[00153] The first detection unit may detect a truncated CT projection trace from the raw CT projection data, as the second projection trace.

[00154] The data fitting unit may perform data fitting for coordinate information of the second projection trace to acquire the first projection trace.

[00155] The data recovery module 147 may perform extrapolation according to the CT projection data on the second projection trace to obtain the CT projection data on the first projection trace.

[00156] Optionally, the first-projection-trace estimation module 143 may further comprise a first forward projection unit and an estimation unit.

[00157] The first forward projection unit may perform forward projection for all or part of the pixel points on the raw CT image to obtain CT projection traces of the pixel

points, and use a part of the CT projection trace of each pixel point outside the region to be estimated as the second projection trace. The raw CT image is an image obtained by reconstruction according to the raw CT projection data.

[00158] The estimation unit may estimate a part of the CT projection trace of each pixel point that passes through the region to be estimated as the first projection trace.

[00159] Optionally, the region-to-be-estimated determination module 141 may further comprise a reconstruction unit, a second detection unit and a second forward projection unit.

[00160] The reconstruction unit may reconstruct the raw CT image based on the raw CT projection data.

[00161] The second detection unit may detect a specific portion in the raw CT image.

[00162] The second forward projection unit may perform forward projection for an image of the specific portion to acquire a CT projection trace of the specific portion, wherein a region in the raw CT projection data corresponding to the CT projection trace of the specific portion is the region to be estimated.

[00163] The first-projection-trace estimation module may use the CT projection trace of the specific portion as the above mentioned first projection trace.

[00164] The data recovery module 147 may subtract the CT projection data on the first projection trace from the raw CT projection data to obtain credible data in the raw CT projection data.

[00165] Fig.15 is a block diagram of a CT imaging system provided by one embodiment of the present invention. As shown in Fig. 15, the system comprises a bulb tube 151, a detector 153 and the apparatus for recovering raw CT projection data of the above embodiments. The bulb tube 151 is used to emit X-rays to the object to be scanned, and the detector 153 is used to receive the X-rays that pass

through the object to be scanned to generate the above mentioned raw CT projection data.

[00166] The apparatus for recovering the raw CT projection data may perform data recovery for the raw CT projection data, so as to perform image reconstruction.

[00167] In the embodiments of the present invention, by determining a region to be estimated of the raw CT projection data and estimating the actual trend of the CT projection trace in the region to be estimated to obtain a first projection trace which is the trace that needs data recovery, data recovery may be realized based on the projection trace in the CT projection data, which can provide more reliable data for image reconstruction in comparison with the conventional manner of interpolation within a row or between rows of a detector, and thus may obtain images of higher quality.

[00168] Some exemplary embodiments have been described in the above. However, it should be understood that various modifications may be made thereto. For example, if the described techniques are carried out in different orders, and/or if the components in the described system, architecture, apparatus or circuit are combined in different ways and/or replaced or supplemented by additional components or equivalents thereof, proper results may still be achieved. Accordingly, other implementation also falls within a protection range of the Claims.

What is claimed is:

1. A method of recovering raw CT projection data, comprising:

determining a region to be estimated of the raw CT projection data;

estimating a first projection trace in said region to be estimated, wherein said first projection trace can match with at least one second projection trace outside said region to be estimated, or said first projection trace is a projection trace of a specific portion; and

performing data recovery along said first projection trace.

2. The method of recovering raw CT projection data according to claim 1, wherein said first projection trace can be connected with at least one second projection trace outside said region to be estimated to form one complete projection trace.

3. The method of recovering raw CT projection data according to claim 1, wherein said first projection trace comprises a first vector estimated in said region to be estimated, said method of recovering raw CT projection data further comprising:

determining a trusted region adjacent to said region to be estimated in said raw CT projection data, said trusted region comprising said second projection trace therein; and

detecting texture orientation of the second projection trace in said trusted region to acquire multiple second vectors;

when an orientation difference between said first vector and at least one second vector is not greater than a preset value, said first projection trace matches with the second projection trace corresponding to the second vector.

4. The method of recovering raw CT projection data according to claim 1, wherein performing data recovery along said first projection trace comprising:

calculating CT projection data on said first projection trace by interpolation according to CT projection data on the second projection trace matched with said first projection trace.

5. The method of recovering raw CT projection data according to claim 1, wherein determining a region to be estimated in the raw CT projection data comprising: determining a truncated region of said raw CT projection data;

estimating the first projection trace in said region to be estimated comprising:

detecting a truncated CT projection trace in said raw CT projection data, as said second projection trace; and

performing data fitting for coordinate information of said second projection trace to acquire said first projection trace;

performing data recovery along said first projection trace comprising: performing extrapolation according to the CT projection data on said second projection trace to obtain the CT projection data on said first projection trace.

6. The method of recovering raw CT projection data according to claim 1, wherein estimating the first projection trace in said region to be estimated comprising:

performing forward projection for all or part of pixels on a raw CT image to obtain a CT projection trace for each of the pixels, and using a part of the CT projection trace of each of the pixels outside said region to be estimated as said second projection trace, said raw CT image being an image obtained by reconstruction according to said raw CT projection data; and

estimating a part of the CT projection trace of each of the pixels that passes through said region to be estimated as said first projection trace.

7. The method of recovering raw CT projection data according to claim 1, wherein determining a region to be estimated of the raw CT projection data comprising:

reconstructing a raw CT image based on said raw CT projection data;

detecting a specific portion in said raw CT image; and

performing forward projection for an image of said specific portion to acquire a CT projection trace of the specific portion, wherein a region in said raw CT projection data corresponding to the CT projection trace of said specific portion is said region to be estimated;

estimating the first projection trace in said region to be estimated comprising: using the CT projection trace of said specific portion as said first projection trace;

performing data recovery along said first projection trace comprising: subtracting the CT projection data on said first projection trace from said raw CT projection data to obtain credible data in said raw CT projection data.

8. An apparatus for recovering raw CT projection data, comprising:

a region-to-be-estimated determination module to determine a region to be estimated of the raw CT projection data;

a first-projection-trace estimation module to estimate a first projection trace in said region to be estimated, wherein said first projection trace can match with at least one second projection trace outside said region to be estimated, or said first projection trace is a projection trace of a specific portion; and

a data recovery module to perform data recovery along said first projection trace.

9. The apparatus for recovering raw CT projection data according to claim 8, wherein said first projection trace can be connected with at least one second projection trace outside said region to be estimated to form one complete projection trace.

10. The apparatus for recovering raw CT projection data according to claim 8, wherein said first projection trace comprises a first vector estimated in said region to

be estimated, said apparatus for recovering raw CT projection data further comprising:

a trusted-region determination module to determine a trusted region adjacent to said region to be estimated in said raw CT projection data, said trusted region comprising said second projection trace therein; and

a detection module to detect texture orientation of the second projection trace in said trusted region to acquire multiple second vectors;

when an orientation difference between said first vector and at least one second vector is not greater than a preset value, said first projection trace matches with the second projection trace corresponding to the second vector.

11. The apparatus for recovering raw CT projection data according to claim 8, wherein said data recovery module is to calculate CT projection data on said first projection trace by interpolation according to CT projection data on the second projection trace matched with said first projection trace.

12. The apparatus for recovering raw CT projection data according to claim 8, wherein said region-to-be-estimated determination module is to determine a truncated region of said raw CT projection data;

said first-projection-trace estimation module comprising:

a first detection unit to detect a truncated CT projection trace in said raw CT projection data, as said second projection trace; and

a data fitting unit to perform data fitting for coordinate information of said second projection trace to acquire said first projection trace;

said data recovery module is to perform extrapolation according to the CT projection data on said second projection trace to obtain the CT projection data on said first projection trace.

13. The apparatus for recovering raw CT projection data according to claim 8, wherein said first-projection-trace estimation module comprising:

a first forward projection unit to perform forward projection for all or part of pixels on a raw CT image to obtain a CT projection trace for each of the pixels, and use a part of the CT projection trace of each of the pixels outside said region to be estimated as said second projection trace, said raw CT image being an image obtained by reconstruction according to said raw CT projection data; and

an estimation unit to estimate a part of the CT projection trace of each of the pixels that passes through said region to be estimated as said first projection trace.

14. The apparatus for recovering raw CT projection data according to claim 8, wherein said region-to-be-estimated determination module comprising:

a reconstruction unit to reconstruct a raw CT image based on said raw CT projection data;

a second detection unit to detect a specific portion in said raw CT image; and

a second forward projection unit to perform forward projection for an image of said specific portion to acquire a CT projection trace of the specific portion, wherein a region in said raw CT projection data corresponding to the CT projection trace of said specific portion is said region to be estimated;

said first-projection-trace estimation module being used to use the CT projection trace of said specific portion as said first projection trace;

said data recovery module being used to subtract the CT projection data on said first projection trace from said raw CT projection data to obtain credible data in said raw CT projection data.

15. A CT imaging system comprising a bulb tube to emit X-rays to an object to be scanned, a detector to receive the X-rays that pass through said object to be

scanned to generate said raw CT projection data and an apparatus for recovering CT raw projection data according to anyone of claims 8-14.

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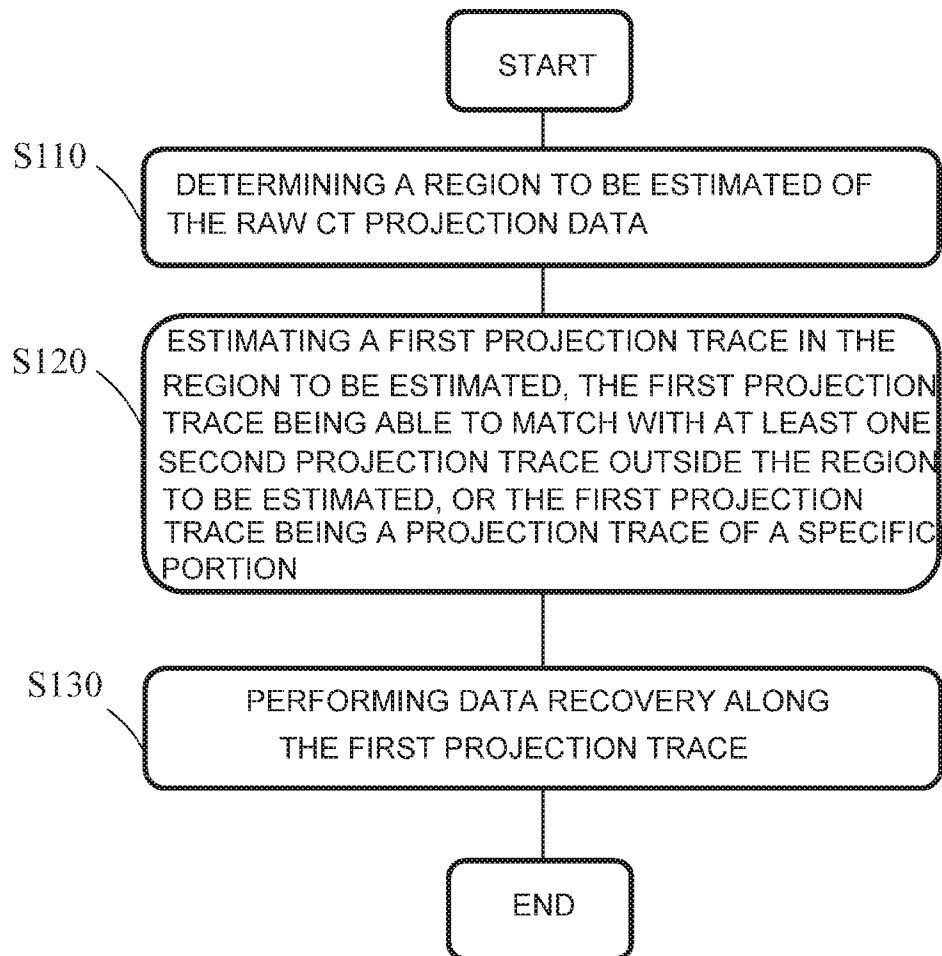


Fig. 1

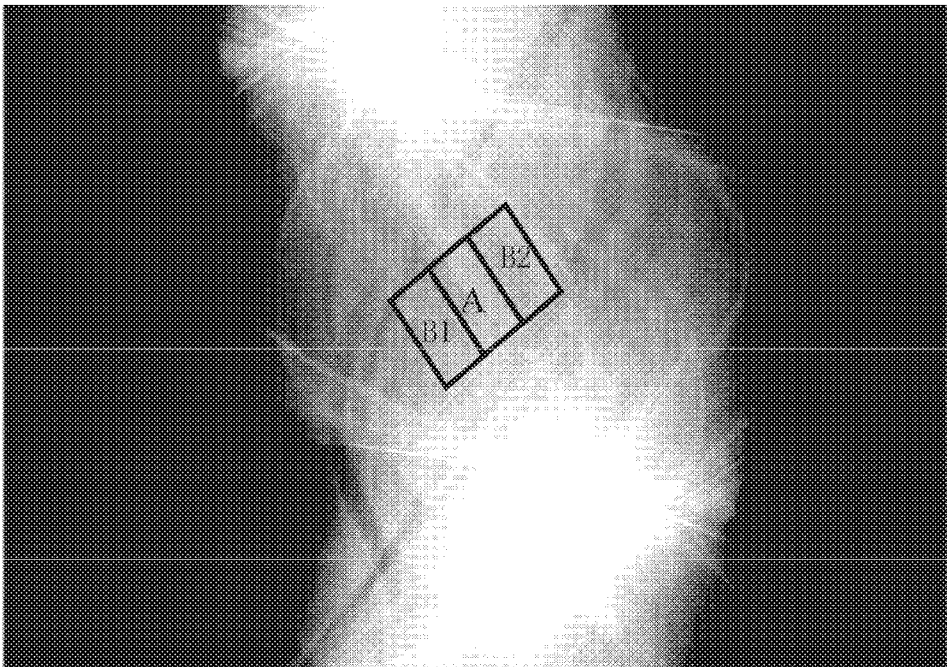


Fig. 2

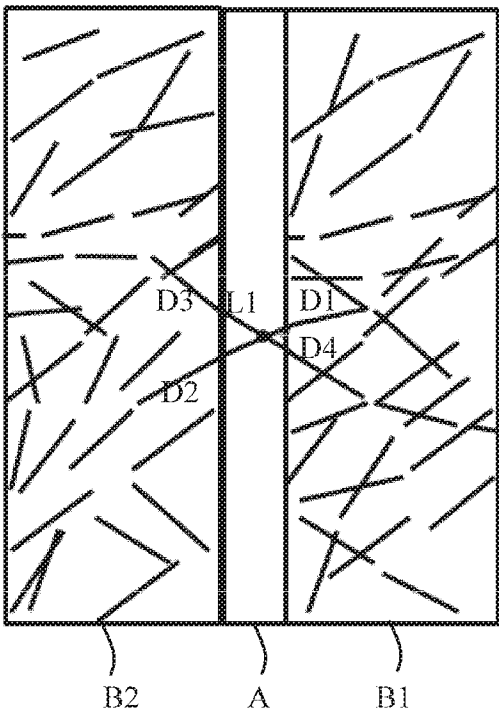


Fig. 3

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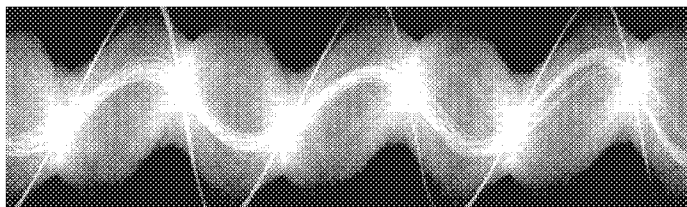


Fig. 4

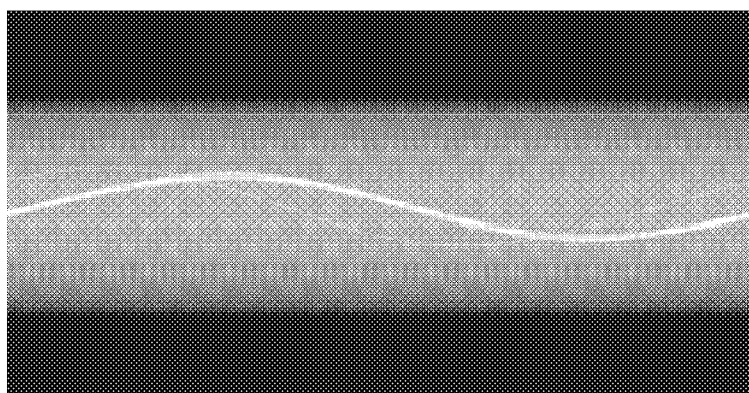


Fig. 5

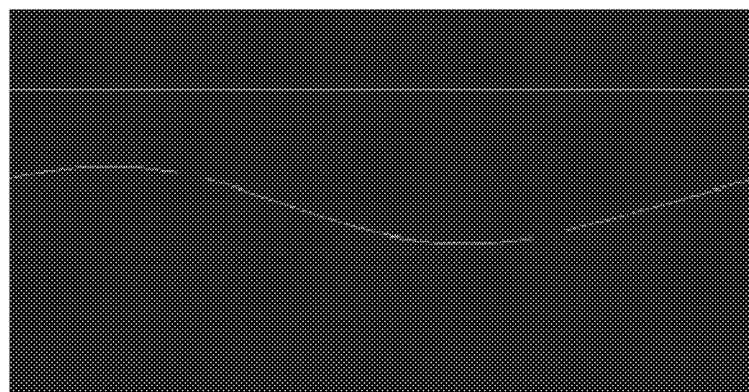


Fig. 6

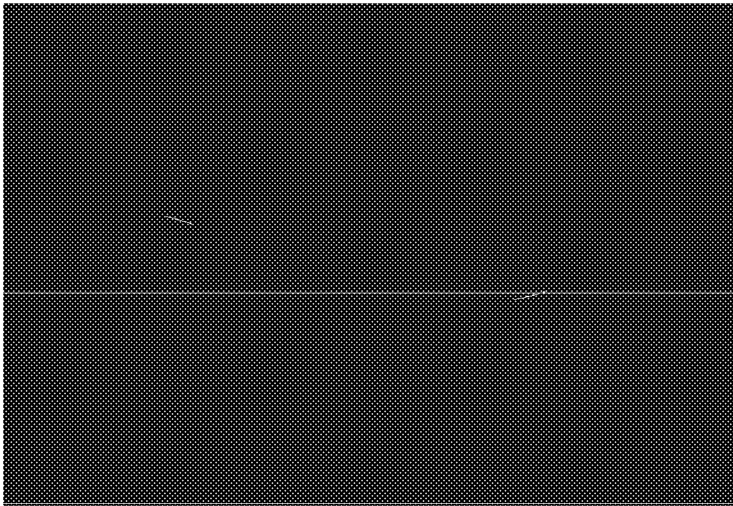


Fig. 7

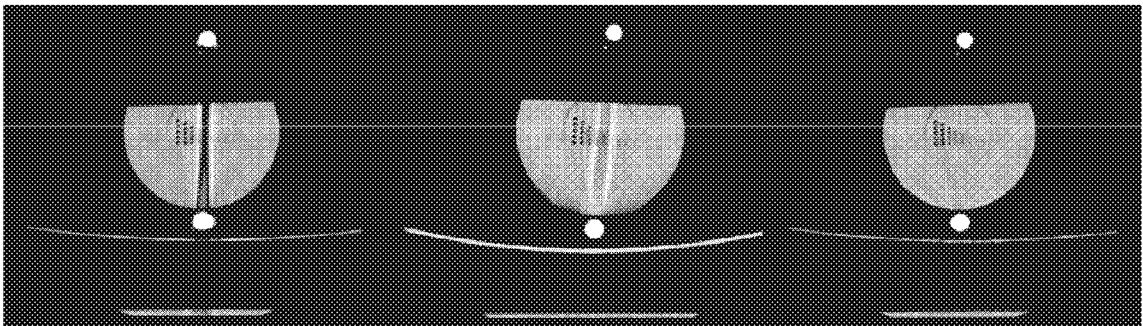


Fig. 8

Fig. 9A

Fig. 9B

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Fig. 10

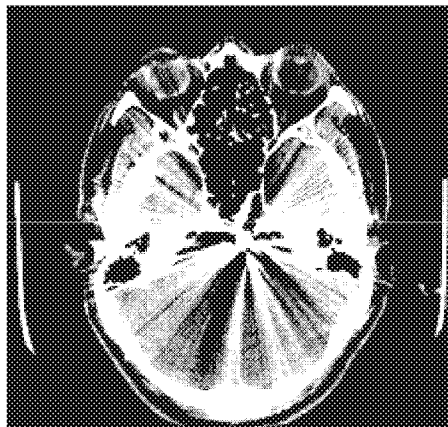


Fig. 11

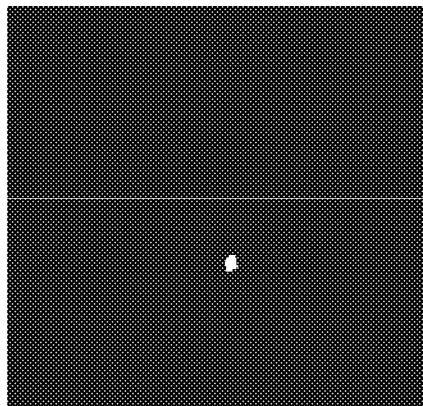


Fig. 12

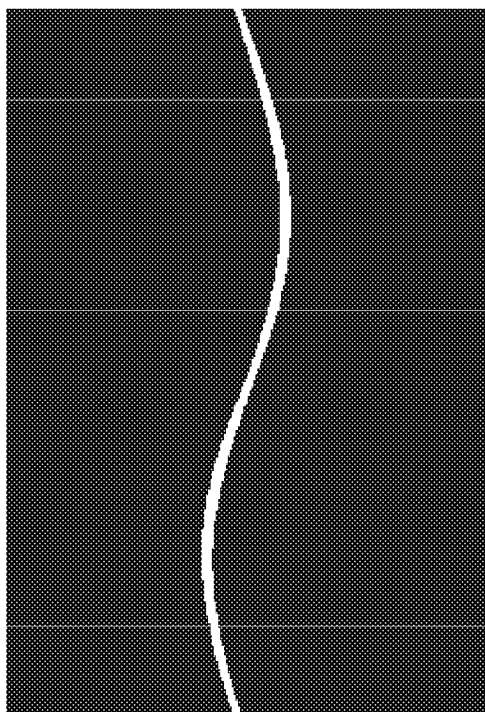


Fig. 13

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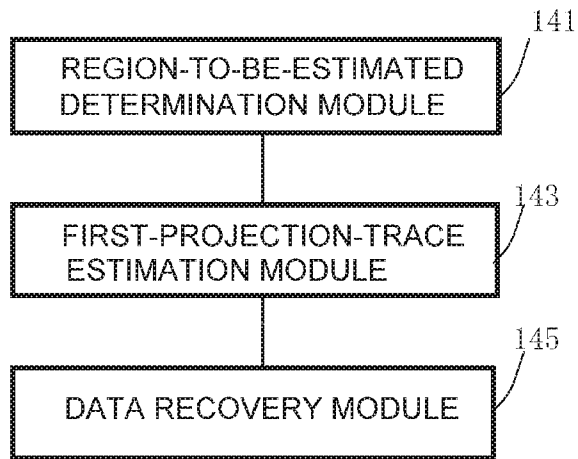


Fig. 14

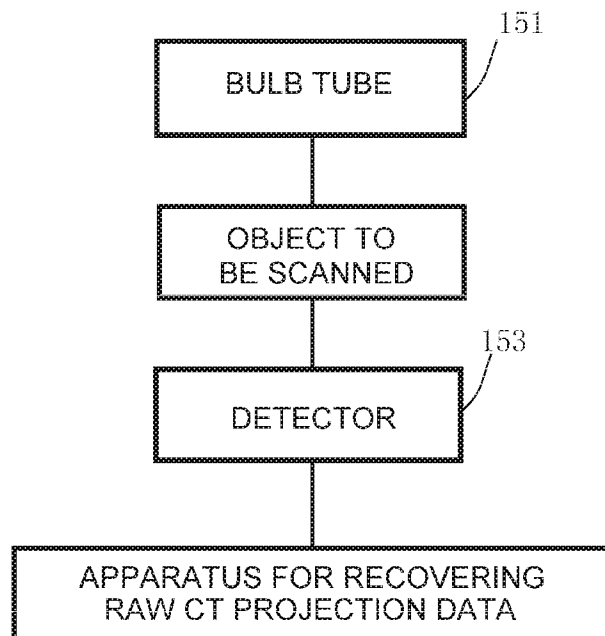


Fig. 15

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US16/38470

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 6/02; G01T 1/29; G06T 11/00 (2016.01)

CPC - A61B 6/027, 6/5235, 6/5258; G01T 1/2985; G06T 11/005

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): A61B 6/02; G01T 1/29; G06T 11/00 (2016.01)

CPC: A61B 6/027, 6/5235, 6/5241, 6/5258; G01T 1/2985; G06T 11/005, 2211/40, 2211/424

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

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

PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google Scholar; EBSCO; KEYWORDS: data recovery CT projection data interpolation estimate pixel points reconstructed image overlapped region projection tracks texture orientation trace trajectory

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 2008/0056437 A1 (PACK, J. et al.) March 6, 2008; figures 1-2; paragraphs [0028, 0039-0040, 0043, 0045-0046, 0048]	1-2, 4, 6-9, 11, 13-14, 15/8-15/9, 15/11, 15/13-15/14 ----- 3, 5, 10, 12, 15/10, 15/12
A	US 2013/0308745 A1 (GOSHEN, L.) November 21, 2013; figure 3; paragraphs [0031-0037]	3, 5, 10, 12, 15/10, 15/12
A	US 2007/0248255 A1 (CHEN, G.) October 25, 2007; figures 6, 10; paragraphs [0025-0037]	5, 12, 15/12

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

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Date of the actual completion of the international search

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Date of mailing of the international search report

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Name and mailing address of the ISA/

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