

METHOD AND APPARATUS FOR CENTRE-OF-ROTATION DETERMINATION IN COMPUTED TOMOGRAPHY IMAGES

FIELD OF THE INVENTION

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This invention relates to a method and system for automated determination of the axis of rotation in a computed tomography (CT) scanning independent of the practical scanning manner and the object position. More specifically, the method and system determines the centre of rotation for scans such as offset scan, high-

10 magnification scan, normal scan, offset-plus-high-magnification scan, and the like.

BACKGROUND OF THE INVENTION

Central ray is the projection of the centre-of-rotation on the detector. It must be a known parameter for all reconstruction algorithms. Error in central ray generally leads to
15 artifacts and distortion in the reconstructed images which sometimes are very difficult to identify. The current methods used for central ray determination are discussed.

FIG. 1A illustrates a conventional system 110 for determining central ray utilizing a wire phantom 116. The sinogram of the projection data of the wire phantom is used to determine the central ray. A wire phantom 116 is scanned in the system 110 first to
20 generate a sinogram of the wire from which the central ray can be determined. A wire phantom is actually a small straight wire fixed at the centre of a plastic tube. The wire is made of heavy metal such as tungsten. It must be small enough so that it can be treated as a point to meet the requirement for certain accuracy. In the system 110, a source 112 for projecting a projection beam 114 towards the wire phantom 116 and
25 detected by a digital detector 120. A manipulator and rotator 122 rotates the wire phantom about a rotation of axis 118. FIG. 1A illustrates the situation where a wire phantom is scanned and FIG. 1B is a typical sinogram 130 of this scan showing the scanning of the wire phantom. In many medical check X-ray CT systems, the centre of rotation is always fixed and usually only need to be calibrated once a year, for example. For this system,
30 because a resolution of about sub-millimeter is acceptable, there is no high accuracy requirement about the central ray. However, the use of a fixed centre of rotation is only applicable to medical X-ray CT system because all micro-CT systems for industry applications need to adjust the magnification and scanning position of the object according to the size, shape of the object and the requirement for different resolution.

Calibration with a calibration unit like a wire phantom is currently a common practice in many existing commercially available systems. However, this method requires one more scanning which greatly slow down the whole inspection process. It also presents significant calibration error in high-magnification scanning due to the mechanical movement involved.

FIG. 2 illustrate another conventional approach uses a look-up table 140. A look-up table is actually a relationship between the central ray and the scanning position. It is usually established by scanning a calibration unit such as a wire phantom with the rotation axis placed at different positions. Once a lookup table is created, the central ray in a particular scan is read from it according to the actual object position. Using a lookup table is straightforward but in practice this is simply not reliable because of the high requirement for the accuracy and repeatability of the manipulation system. Considering the large area of movement and several movement degrees of freedom, the look up table approach is only used for low-accuracy or low-resolution inspection applications.

FIG. 3A illustrates another conventional approach 150, using a geometrical relationship of the scanning. This method makes use of the property that during the scanning the boundary of the sinogram is generated always by the point that has the longest distance to the centre of rotation. With the knowledge of the central channel 162, one actually can unambiguously determine the central ray 164 from the left and right boundary points 158,160, where the object rotation axis 152 and tangential points 154,156 are determined. FIG. 3B shows a sinogram and boundary detection 170. Using the geometrical relationship of the scanning, the method is developed to overcome the drawback of the previous methods that require pre-calibration of the CT system. Instead, the geometrical method directly uses the projection data of the object to determine the central ray. The boundary curves are identified of the sinogram of one object slice and determine the central ray based on the geometrical relationship. The geometrical method has been proven to be an effective method which eliminates the need for extra scan and is able to provide a comparable accuracy to other methods such as calibrating with a wire phantom. However, this method generally only works with normal scan which require object to be fully covered in the X-ray fan beam. Besides, this method encounters a certain difficulty if large fluctuation in X-ray intensity occurs during the scanning process or poor image contrast is observed.

There is thus a need for a system and method that alleviates the problems associated with the above procedures.

SUMMARY OF THE INVENTION

In accordance with an aspect of the invention there is provided a method for
 5 determining the central ray projection of the centre of rotation on a detector within
 a computed tomography (CT) system with the CT scanning data of an object, comprising
 receiving CT scanning data of a scanned object; reconstructing the scanning data to form
 at least two CT images of the same object cross section; and determining the central ray
 projection of the centre of rotation on the detector by measuring a mismatching level of
 10 the two CT images within reconstructed with views in the range of (0 degree to α
 degree) ($\alpha \leq 180$) and the range of (180 degree to $180 + \alpha$) ($\alpha < 180$) respectively,
 with a scan less than or equal to 360 degree and an angular scanning step.

In accordance with an aspect of the invention there is provided an apparatus for
 determining the central ray projection of the centre of rotation on a detector within
 15 an computed tomography (CT) system with the CT scanning data of an object, the
 system comprising a source for generating a projection beam for scanning the object; a
 rotary unit for mounting and rotating the object relative to the beam; and a detector for
 detecting the beam, the detector receiving CT scanning data of at least one image of a
 scanned object; the apparatus comprising a processor for receiving CT scanning data of
 20 a scanned object processing the central ray projection by reconstructing the scanning
 data to form at least two CT images of the same object cross-section and determining the
 central ray projection of the centre of rotation on the detector by measuring a mismatching
 level of the two CT images within reconstructed with views in the range of (0 degree to
 α degree) ($\alpha \leq 180$) and the range of (180 degree to $180 + \alpha$) ($\alpha < 180$) respectively,
 25 with a scan less than or equal to 360 degree and an angular scanning step.

In accordance with an aspect of the invention there is provided a computed tomography
 system for determining the central ray projection of the centre of rotation on a
 detector with the CT scanning data of an object, comprising a source for generating a
 projection beam for scanning the object; a rotary unit for mounting and rotating the object
 30 relative to the beam; a detector for detecting the beam, the detector receiving CT
 scanning data of at least one image of a scanned object; and a processor for receiving
 CT scanning data of a scanned object processing the central ray projection by
 reconstructing the scanning data to form at least two CT images of the same object
 cross-section and determining the central ray projection of the centre of rotation on the
 35 detector by measuring a mismatching level of the two CT images within reconstructed
 with views in the range of (0 degree to α degree) ($\alpha \leq 180$) and the range of (180

degree to $180 + \alpha$ ($\alpha < 180$) respectively, with a scan less than or equal to 360 degree and an angular scanning step .

5 BRIEF DESCRIPTION OF THE DRAWINGS

In order that the present invention may be fully understood and readily put into practical effect, there shall now be described by way of non-limitative example only embodiments of the present invention, the description being with reference to the accompanying illustrative drawings:

FIG. 1A-B show a schematic drawing of a system of the prior art using a wire phantom (FIG. 1A), and a resulting typical sinogram of scanning a wire phantom of the prior art (FIG. 1B);

FIG. 2 is a table of the central ray determination using a lookup table of the prior art; FIG. 3A-B show a schematic drawing of the prior art using the geometrical method (FIG. 3A), and a resulting typical sinogram and boundary detection of the central ray determination using the geometrical method of the prior art (FIG. 3B);

FIG. 4A is a schematic diagram of a system in accordance with an embodiment of the invention;

FIG. 4B is a flow chart of a method in accordance with an embodiment of the invention;

FIG. 5A-E show observations about a reconstructed image with an error in the central ray, specifically, an image of an examination object (FIG. 5A), a 2-dimensional image of the examination object of FIG. 5A (FIG. 5B), a measurement graph obtained in a search round for an estimate of the central ray (FIG. 5C), a graph of the results of a fine searching for determining the central ray (FIG. 5D), and a reconstructed image with the central ray value identified (FIG. 5E) in accordance with an embodiment of the invention;

FIG. 6A-F show a reconstructed slice with an acceptable central ray value with (1-180) views (FIG. 6A), a reconstructed slice image with (181-360) views (FIG. 6B), a difference of FIG. 6A and 6B (FIG. 6C), the same slice reconstructed with a bad central ray with (1-180) views (FIG. 6D), the same slice as shown in FIG. 6D with (181-360) views (FIG. 6E), and a difference of FIG. 6D and 6E (FIG. 6F) in accordance with an embodiment of the invention;

FIG. 7 shows a flow chart of an embodiment of the invention;

FIG. 8 shows a flow chart of an embodiment of the invention;

FIG. 9A-D shows graphical representation of different steps of an embodiment of the invention demonstrating the performance for normal scanning (FIG. 9A), complete

sinogram (FIG. 9B), results of a fine search (FIG. 9C), and a reconstructed slice (FIG. 9D) in accordance with an embodiment of the invention;

FIG. 10A-D shows graphical representation of different steps of an embodiment of the invention demonstrating the performance for high-magnification scanning (FIG. 10A),

5 sinogram without boundary data (FIG. 10B), results of fine search (FIG. 10C), and a reconstructed slice (FIG. 10D) in accordance with an embodiment of the invention;

FIG. 11A-D shows graphical representation of different steps of an embodiment of the invention demonstrating the performance for offset scanning (FIG. 11A), sinogram with missing data (FIG. 11B), results of fine search (FIG. 11C), and a reconstructed slice (FIG.

10 11D) in accordance with an embodiment of the invention; and

FIG. 12A-D shows graphical representation of different steps of an embodiment of the invention demonstrating the performance for planar object reconstruction with preferred orientation for various scanning modes including high-magnification scanning mode and offset scanning mode, with same slice as shown in FIG. 10 with dimensions aligned (FIG.

15 12A) data process and results with left and right boundaries of scanned objects and shadow width (FIG. 12 B and 12 C), and a reconstructed slice with central ray as determined by results shown in FIG. 12B and 12C (FIG. 12D) in accordance with an embodiment of the invention.

20 DETAILED DESCRIPTION

A system, method and apparatus for centre-of-rotation determination in computed tomography (CT) images is disclosed. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It is apparent to one skilled in the art, however,

25 that the present invention may be practiced without these specific details or with equivalent arrangements. In some instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the present invention. This invention provides a method and algorithm that can automatically determine the central ray with the projection data of the object to be scanned. This

30 method is applicable to various scanning technologies such as 1) normal scan where object is fully covered by the X-ray beam; 2) high-magnification scan where object is put very close to the source and only the interesting area is covered by the X-ray beam during the scanning; 3) offset scan with which the centre of rotation is placed far away from the centre of the detector so that an almost doubled field of view can be achieved; 4) Offset

35 plus high-magnification scan which places the object very close to the source and at the same time the rotation centre is located far away from the detector centre. Another

objective of the invention is to provide a reliable and robust central ray determination method which is insensitive to intensity variation of the X-ray.

An embodiment of the invention provides a measurement method for the quality of the reconstructed images in computed tomography

- 5 An embodiment of the invention provides a method that allows a planar object to be reconstructed with preferred orientation for the above mentioned various scanning technologies.

An embodiment of the invention may be suitable for all CT systems that allow an adjustable centre of rotation. There is a very high probability for X-ray micro CT
10 equipment makers to find an embodiment of the invention useful to adopt and apply in the central ray determination and reconstructed image quality measurement.

Referring to FIG. 4A, a CT system in accordance with an embodiment of the invention is shown. FIG. 4 illustrates the general concept of a CT system which comprises of a source 12, a direct digital detector (DDD) detector 20, a rotary unit 22
15 and an examination subject 16, for example an integrated circuit (IC) chip. The source 12 of the CT system may generate a perspective projection beam 14 or fan-beam projections, cone-beam or perspective projection beam, or the like. The rotary unit may rotate the subject around a rotation axis 18 to generate multiple projections for various angles which then are used for CT reconstruction. The CT system 10 is
20 controlled by the processing system 24 which includes processor 26 responsive to input commands direct from input by a user and/or stored in memory 25 to process data received from detector 20 or input 27 to control rotator 22 of the rotary unit, source 12, and to render a desired output of the data such as a CT image on display 29. The object 16 is mounted on the rotary unit 22 and is rotatable in at least the
25 direction of rotation 28 indicated. After CT scanning of the sample 16, a certain number of slices are then reconstructed. These slices are then combined to form a volume representation of the object, with which the internal structure of the examination object can be visualized and interpreted.

Using the scanned data of the object a sinogram of one cross-section of the object
30 16 is created. In this embodiment, the position data of the sinogram undergoes several different transformations for further processing, depending on whether a fan-beam or a cone-beam reconstruction algorithm is used. Taking the fan-beam back projection algorithm as an example, the fan beam projections are converted to

non-uniform parallel-beam or perspective projections, and then to uniform parallel-beam projections.

FIG. 4B shows a flow chart of an embodiment of a method 30 in accordance with the invention for determining the central ray projection of the centre of rotation on a detector within an computed tomography (CT) system with a 360-degree (1 degree per projection) CT scanning data of an object, comprising receiving CT scanning data 32 of a scanned object; creating the sinogram of one slice 34, converting fan-beam projections to parallel-beam projection 36, defining a search range and a search step size 38, performing Fourier Transform and reconstructing the slice with an assumed central ray in the search range with views from 1 to 1+N (N<=180) (CT image A) 40, reconstructing the same slice with the same assumed central ray with views from 181 to 181+N (CT image B) 40, Measuring the difference of the two reconstructed CT images using

$$M = \sum_{(x,y) \in S} (A(x,y) - B(x,y))^2, \quad \text{or}$$

$$M = \sum_{(x,y) \in S} \text{abs}(A(x,y) - B(x,y)), \quad \text{where } (x,y) \text{ are the pixel positions in the two}$$

images, S is a part or the whole image area; repeating steps 40 to 44 if the search range is not reached, otherwise plotting the measurement over the assumed central ray values and identifying central ray value corresponding to the minimum measurement 46, using the identified central ray as the new search center to define a new search range which is usually twice that of the step size in round one and a new step size which is much smaller than the step size in round one 38, repeating steps 40 to 44 if the new search range is not reached, otherwise, plot the measurement of round two and identifying the central ray corresponding to the minimum measurement 46. This identified central ray will be used as the central ray of the scanning for subsequent real slice reconstruction work.

FIG. 5A-E illustrates the process described in FIG. 4B, FIG. 5A shows an examination object 50 made of aluminum foam material. Fig. 5B is one of its 2D projections 52. FIG. 5C shows the measurement graph 54 obtained in the first search round. The central ray value corresponding to the minimum measurement 53 is identified as 704. This round uses a search range of (550 pixel – 850 pixel) and the step size is 5 pixels. FIG. 5D is the result 56 of searching in a range of (699 pixel to 709 pixel) centered at 704 with a step size of 0.5 pixel. The pixel number corresponding to the minimum measurement 55 is determined as the final central ray that will be later used for real slice reconstruction. One may also find that actually a curve fitting can be applied to the measured data and the minimum of the fitted curve may be used as the final central ray, instead of the

measured one. However, almost in all tested cases, the measured result and the curve fitted results have very small difference and are both thought as reliable. FIG. 5E is a reconstructed CT slice 58 with the central ray identified in FIG. 5D.

FIG. 6A-F show observation about the reconstructed image respectively with a good central ray and a bad central ray in accordance with an embodiment of the invention. FIG. 6A shows a reconstructed slice 60 with an acceptable central ray value (central ray = 357.1) with (1-180) views. FIG. 6B shows a reconstructed image with (181-360) views 61. FIG. 6C shows the difference of FIG. 6A and FIG. 6B 62. However, if an error is introduced to the central ray, the reconstructed image now becomes as shown in FIG. 6D-F. FIG. 6D shows the same slice reconstructed with a bad central ray of 352 with (1-180) views 63. FIG. 6E shows the same slice with this central ray with (181 - 360) views 64. FIG. 6F shows their difference 65..

The measurement presented in an embodiment of the invention may be described as following:

suppose that the two reconstructed images are $A(x, y)$ and $B(x, y)$ and have a size of S , where Area s is a part of A or just equals A , then,

$$\text{Measurement} = M = \sum_{(x,y) \in S} (A(x, y) - B(x, y))^2$$

When performing the search process, either a two-step or one-step search strategy can be used. With the two-step search approach, a rough search is taken in a large search range with a large search step size. The central ray value identified in this round will give a good estimate of the real central ray and allows us to conduct the second search in a very small range with a small step size. This two-step process enables us to obtain a good result with a relatively short time compared with the one-step approach, given that they possess the same accuracy. To a certain extent the final accuracy is only associated with the step size of the final search. However, this is still limited by the accuracy of the scanning system and cannot be improved unlimitedly.

When the search range is defined, usually the search center is set first. There are several ways to determine the search center. The first method 70 is to simply use the center of the detector 72. FIG. 7 shows the flow chart with this method 72-79. Defining the search center in this way is normally good enough when the specimen is scanned around a point located near the midline of the system. In this case, the real central ray will not be far away from the center of the detector. However, when an offset scan is

adopted with which the rotation axis is far away from the system midline, or when the specimen is scanned at a place very close to the source with which any small shifting in the horizontal direction would cause a big shifting of the central ray on the detector, using the center of the detector as the search center would need a relatively large
 5 search range in order not to miss the real central ray. As a consequence, the whole computation time will be much longer.

FIG. 8 presents another embodiment of the invention 80 which make use of the system's geometrical relationship 82. This is similar to create a lookup-table as shown and discussed above with reference to FIG. 2 and an embodiment with the invention.

10 Because the source and detector are always fixed in many micro-CT systems, we can establish the relationship between the central ray and the position of the rotator. In practice, this can be accomplished by scanning a wire phantom at different positions and calibrated their corresponding central rays using one of the traditional methods. With the calibration data obtained, one can either create a lookup table or derive a
 15 formula for calculating the estimate of the central ray with the actual scanning position of the rotator in a particular scan. In this way, we can define the search center and the search range much more efficiently than the center-of-detector method, regardless of the particular scanning position 84-89.

FIG. 9A-D demonstrate the performance of an embodiment of the invention for normal CT scan 210. With a normal CT scan 210 in FIG. 9A, the whole object is required to be fully
 20 covered by the fan-beam X-ray as shown in FIG. 9B where a complete sinogram is obtained 212. FIG. 9C shows the results of the fine search with a step size of 0.5 pixel 214. FIG. 9D shows one reconstructed slice 216 with the central ray identified as the position corresponding to the minimum measurement .

25 FIG. 10A-D demonstrates the performance of an embodiment of the invention for high-magnification CT scan 220. With a high-magnification CT scan 220 in FIG. 10A, only the part interested is kept within the fan-beam X-ray during scanning as shown in FIG. 10B where some boundary data can not be seen in the sinogram 222. Fig. 10C shows the results of the fine search with a step size of 0.5 pixel 224. The graph itself
 30 demonstrates that with this kind of scanning, the central ray can be well determined accurately without any ambiguity. FIG. 10D shows one reconstructed slice 226 with the central ray identified as the position corresponding to the minimum measurement. Note that with a high-magnification scanning, after reconstruction, only the central part of the reconstructed image is clear.

FIG. 11A-D demonstrates the performance of an embodiment of the invention for offset CT scan 230. With an offset CT scan 230 in FIG. 12A, the central ray is located near the edge of the detector. This allows either the field of view to be doubled at a given height, or the scanning resolution to be doubled with a given field of view. Fig. 11B shows a typical sinogram of this scanning type 232. Fig. 11C is the result of the fine search 234. FIG. 11 D is one reconstructed slice 236.

Also it is not demonstrated here, an embodiment of the invention may also work with the high-magnification-plus-offset scanning mode. With this mode, the object is put very close to the source and the central ray is located at one side of the detector.

FIG. 12A-D demonstrates the performance of an embodiment of the invention in reconstructing a planar object reconstruction with a preferred orientation for both high-magnification scanning mode and offset scanning mode. FIG. 12A shows the same slice as that shown in FIG. 10 but reconstructed with the dimensions of the object cross section well aligned with the dimensions of the reconstruction matrix 240. FIG. 12B and 12C shows the major data process and results with left and right boundaries of scanned objects and shadow width that enables the automatic determination of the object scanning orientation 242, 242. FIG. 12D shows a reconstructed slice 246 with central ray of 152.3 as determined by results shown in FIG. 12B and FIG. 12C.

It will be appreciated that an embodiment of the invention provides an automated central ray determination method directly using the projection data of the object to be inspected. The system may be applied to all major scanning technologies such as normal scanning, high-magnification scanning, offset scanning and the like. Conveniently, the system is reliable and robust due to its insensitivity to x-ray intensity variation and the poor contrast of the projection, and empirical testing has shown that the performance of the system is more accurate than previously achievable. The system may be used as a measurement of the reconstructed image quality that requires no additional scanning, and adds no significant computing effort and time within the system.

It will be appreciated that an embodiment of the invention stems from the usage of the unique mismatching property of the object images reconstructed respectively by a part of the projection views and the rest of the views when there is an error to the critical parameter-central ray. Additionally, the unique algorithm developed can unambiguously measure the central ray with a high accuracy. Furthermore, a feature utilized can also be used as the measurement of the quality of the reconstructed image.

Conveniently, identification of all the available methods for central ray determination may be employed by either using any one or a combination of approaches to identify the minimum approximation of the central ray identified prior to determining the optimal approximation of the true central ray in accordance with an embodiment of the invention.

It is to be understood that the embodiments, as described with respect to FIG. 4A-12D, are for exemplary purposes, as many variations of the specific hardware used to implement the disclosed exemplary embodiments are possible. For example, the functionality of the devices and the subsystems of the embodiments may be implemented via one or more programmed computer system or devices. To implement such variations as well as other variations, a single computer system may be programmed to perform the functions of one or more of the devices and subsystems of the exemplary systems. On the other hand, two or more programmed computer systems or devices may be substituted for any one of the devices and subsystems of the exemplary systems. Accordingly, principles and advantages of distributed processing, such as redundancy, replication, and the like, also may be implemented, as desired, for example, to increase robustness and performance of the exemplary systems described with respect to FIG. 4A-12D.

The exemplary systems described with respect to FIG. 4A-12D may be used to store information relating to various processes described herein. This information may be stored in one or more memories, such as hard disk, optical disk, magneto-optical disk, RAM, and the like, of the devices and sub-systems of the embodiments. One or more databases of the devices and subsystems may store the information used to implement the exemplary embodiments. The databases may be organized using data structures, such as records, tables, arrays, fields, graphs, trees, lists, and the like, included in one or more memories, such as the memories listed above.

All or a portion of the exemplary systems described with respect to FIG. 4A-12D may be conveniently implemented using one or more general-purpose computer systems, microprocessors, digital signal processors, micro-controllers, and the like, programmed according to the teachings of the disclosed exemplary embodiments. Appropriate software may be readily prepared by programmers of ordinary skill based on the teachings of the disclosed exemplary embodiments. In addition, the exemplary systems may be implemented by the preparation of application-specific integrated circuits or by interconnecting an appropriate network of component circuits.

Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without
5 departing from the present invention.

CLAIMS:

1. A method for determining the central ray projection of the centre of rotation on a detector within a computed tomography (CT) system with the CT scanning data of an object, comprising:

5 receiving CT scanning data of a scanned object;

reconstructing the scanning data to form at least two CT images of the same object cross section; and

determining the central ray projection of the centre of rotation on the detector by measuring a mismatching level of the two CT images within reconstructed with views in
10 the range of (0 degree to α degree) ($\alpha \leq 180$) and the range of (180 degree to $180 + \alpha$ ($\alpha < 180$) respectively, with a scan less than or equal to 360 degree and an angular scanning step.

2. The method according to claim 1 wherein measuring of the mismatching level is calculated from a sum of the difference square, or a sum of the absolute value of the
15 difference of the two CT images used for the measurement.

3. The method according to claim 2 wherein measuring of the mismatching level the difference-square-sum or the absolute difference-sum is conducted over the entire reconstructed image.

4. The method according to claim 2 wherein measuring of the mismatching level the difference-square-sum or the absolute difference sum is conducted over a part of the
20 reconstructed image.

5. The method according to claim 2 wherein measuring of the mismatching level the difference-square-sum or the absolute difference-sum is conducted over selected points of the reconstructed image.

25 6. The method according to any one of the preceding claims wherein measuring of the mismatching level is determined with the minimum of the measurement is an indicator of the best quality of the reconstruction image.

7. The method according to any one of the preceding claims wherein determining the central ray is determined as the pixel position on the detector / sinogram corresponding
30 to the minimum of the direct measurement.

8. The method according to any one of the preceding claims wherein determining the central ray is determined as the pixel position on the detector / sinogram corresponding to minimum of a curve-fitted measurement results.

5 9. The method according to any one of the preceding claims wherein reconstructing the scanning data further comprises defining a search center that is assumed for the reconstruction and the central ray is determined by establishing the relationship between the measurement and a guessed central ray within a certain range and with a certain step length.

10 10. The method according to any one of the preceding claims wherein determining the central ray comprises measuring within a first search range and a first step size to obtain an estimate of the central ray, and a second search range and a second step size, the second search range being larger than twice that of the first step size and the second step size being smaller than the first step size, in obtaining an accurate value of the central ray.

15 11. The method according to any one of claims 1-8 wherein determining the central ray comprises using the center of the detector as a search center of a first search range to obtain an estimate of the central ray with a first step size, and using the obtained central ray to define a second search range and a second step size, the second search range being larger than twice of the first step size, and the second step size being smaller
20 than the first step size, in obtaining an accurate value of the central ray.

12. The method according to any one of claims 1-8 wherein determining the central ray comprises using a lookup table calibrated previously for the relationship between the central ray and the rotary unit position to obtain an estimate of the central ray and using the lookup table to define a search center of a first search range to obtain an estimate of
25 the central ray with a first step size, and using the obtained central ray to define the second search range and a second step size, the second search range being larger than twice of the first step size, and second step size being smaller than the first step size, in obtaining an accurate value of the central ray.

30 13. The method according to any one of claims 1-8 wherein determining the central ray comprises using a geometrical relationship among the detector, the rotary unit and the source to obtain an estimate of the central ray for each particular scanning and using this estimate of central ray as the search center of a first search range to obtain an

estimate of the central ray with a first step size, and using the obtained central ray to define a second search range and a second step size, the second search range being larger than twice of the first step size, and the second step size being smaller than the first step size, in obtaining an accurate value of the central ray.

- 5 14. The method according to any one of claims 1-13 wherein receiving scanning data that is received start angle is identified and used for reconstruction of the object with a preferred orientation.

15. The method according to claim 14 wherein scanning start angle is determined by finding the narrowest projection width of the object.

- 10 16. An apparatus for determining the central ray projection of the centre of rotation on a detector within an computed tomography (CT) system with the CT scanning data of an object, the system comprising a source for generating a projection beam for scanning the object; a rotary unit for mounting and rotating the object relative to the beam; and a detector for detecting the beam, the detector receiving CT scanning data of at least one
15 image of a scanned object; the apparatus comprising a processor for receiving CT scanning data of a scanned object processing the central ray projection by reconstructing the scanning data to form at least two CT images of the same object cross-section and determining the central ray projection of the centre of rotation on the detector by measuring a mismatching level of the two CT images within reconstructed with views in
20 the range of (0 degree to α degree) ($\alpha \leq 180$) and the range of (180 degree to $180 + \alpha$ ($\alpha < 180$) respectively, with a scan less than or equal to 360 degree and an angular scanning step.

- 25 17. The apparatus according to claim 16 wherein measuring of the mismatching level is calculated from a sum of the difference square of the two images used for the measurement.

18. The apparatus according to claim 17 wherein measuring of the mismatching level the difference-square-sum is conducted over the entire reconstructed image.

19. The apparatus according to claim 17 or 18 wherein measuring of the mismatching level the difference-square-sum is conducted over a part of the reconstructed image.

- 30 20. The apparatus according to any one of claims 17 to 19 wherein measuring of the mismatching level the difference-square-sum is conducted over selected points of the reconstructed image.

21. The apparatus according to claim 16 wherein measuring of the mismatching level is calculated from a sum of the absolute value of the difference of the two images used for the measurement.

22. The apparatus according to claim 21 wherein measuring of the mismatching level the absolute difference-sum is conducted over the entire reconstructed image.

23. The apparatus according to claim 21 or 22 wherein measuring of the mismatching level the absolute difference-sum is conducted over a part of the reconstructed image.

24. The apparatus according to any one of claims 21 to 23 wherein measuring of the mismatching level the absolute difference-sum is conducted over selected points of the reconstructed image.

25. The apparatus according to any one of claims 16 to 24 wherein measuring of the mismatching level is determined with the minimum of the measurement is an indicator of the best quality of the reconstruction image.

26. The apparatus according to any one of claims 16 to 25 wherein the processor determines the central ray is determined as the minimum of the direct measurement.

27. The apparatus according to any one of claims 16 to 26 wherein determining the central ray is determined as the minimum of a curve-fitted measurement results.

28. The apparatus according to any one of claims 16 to 27 wherein the processor for reconstructing the scanning data further comprises defining a seed assumed for the reconstruction and the central ray is determined by establishing the relationship between the measurement and the guessed central ray within a certain range and with a certain step length.

29. The apparatus according to any one of claims 16 to 28 wherein the processor determines the central ray by measuring within a first search range and a first step size to obtain an estimate of the central ray, and a second search range and a second step size, the second search range and second step size being smaller than the first search range and the first step size, in obtaining an accurate value of the central ray.

30. The apparatus according to any one of claims 16 to 23 wherein the processor determines the central ray by using a wire-phantom method with a first search range and a first step size to obtain an estimate of the central ray, and a second search range and a second step size, the second search range and the second step size being smaller

than the first search range and the first step size, in obtaining an accurate value of the central ray.

31. The apparatus according to any one of claims 16 to 23 wherein the processor determines the central ray by a lookup table using a first search range and a first step size to obtain an estimate of the central ray, and a second search range and a second step size, the second search range and the second step size being smaller than the first search range and first step size, in obtaining an accurate value of the central ray.

32. The apparatus according to any one of claims 16 to 23 wherein the processor determines the central ray by a geometrical method using a first search range and a first step size to obtain an estimate of the central ray, and a second search range and a second step size, the second search range and the second step size being smaller than the first search range and first step size, in obtaining an accurate value of the central ray.

33. The apparatus according to any one of claims 16 to 28 wherein the scanning data that is received, the start angle is identified and used for reconstruction of the object with a preferred orientation.

34. The apparatus according to claim 33 wherein scanning start angle is determined by finding the narrowest projection width of the object.

35. A computed tomography system for determining the central ray projection of the centre of rotation on a detector with the CT scanning data of an object, comprising:

a source for generating a projection beam for scanning the object;

a rotary unit for mounting and rotating the object relative to the beam;

a detector for detecting the beam, the detector receiving CT scanning data of at least one image of a scanned object; and

a processor for receiving CT scanning data of a scanned object processing the central ray projection by reconstructing the scanning data to form at least two CT images of the same object cross-section and determining the central ray projection of the centre of rotation on the detector by measuring a mismatching level of the two CT images within reconstructed with views in the range of (0 degree to α degree) ($\alpha \leq 180$) and the range of (180 degree to $180 + \alpha$) ($\alpha < 180$) respectively, with a scan less than or equal to 360 degree and an angular scanning step.