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(71) Applicant *(for all designated States except US)*: **KONINKLIJKE PHILIPS ELECTRONICS N. V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MOVASSAGHI, Babak** [DE/NL]; c/o High Tech Campus 44, NL-5656 AE Eindhoven (NL). **MANZKE, Robert** [DE/NL]; c/o High Tech Campus 44, NL-5656 AE Eindhoven (NL). **GARCIA, Joel Alberto** [DO/NL]; c/o High Tech Campus 44, NL-5656 AE Eindhoven (NL).

(74) Agent: **SCHOUTEN, Marcus, M.**; High Tech Campus 44, NL-5656 AE Eindhoven (NL).

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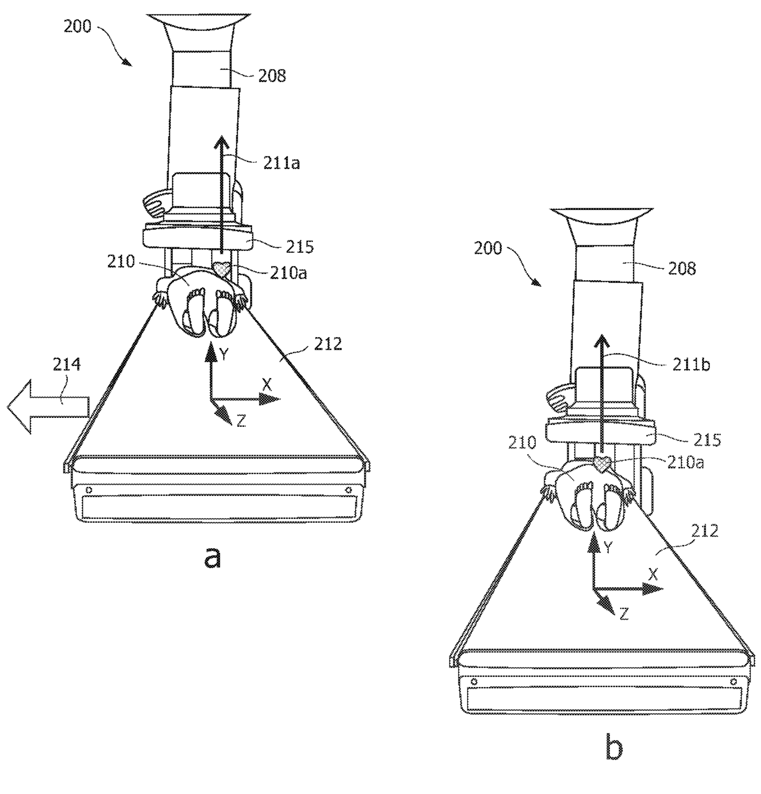

(57) Abstract: It is described a method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (310) by means of an X-ray imaging apparatus (100) having a rotatable scanning unit (301). In order to increase the angular range of the scanning unit (301), when a region of interest (HOa) located not in the center of the object (310) is examined the object under examination (310) is shifted such that the region of interest is temporarily positioned outside the center of rotation. By coupling the rotational movement of the scanning unit (301) with the translative movement of the object (310) in a synchronized manner a collision between the scanning unit (301) and the object (310) can be effectively avoided. By employing an automated motorized object table (312) a precise pre-determined movement of the object (310) can be achieved during the data acquisition. By using an appropriate phantom based calibration procedure carried out with the same table movements known three-dimensional reconstruction algorithm can be directly applied in order to generate a three-dimensional representation of the region of interest (110a).

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SHIFTING AN OBJECT FOR COMPLETE TRAJECTORIES IN ROTATIONAL X-RAY IMAGING

The present invention relates to the field of rotational X-ray imaging. In particular the present invention relates to a method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit. Thereby, the rotatable X-ray scanning unit comprises an X-ray source, which is adapted for emitting a radiation beam, and an X-ray detector, which is adapted for detecting the radiation beam after the radiation beam has passed the object under examination.

The present invention further relates to a data processing device and to a medical X-ray imaging apparatus for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of a rotatable X-ray scanning unit.

Furthermore, the present invention relates to a computer-readable medium and to a program element having instructions for executing the above-mentioned method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of a rotatable X-ray scanning unit.

In the recent years three-dimensional rotational angiography has been introduced where a C-arm X-ray imaging system rotates around the patient while acquiring projection images from a region of interest located within an object under examination. The most common applications are currently in the field of interventional neurology, with a growing interest in the field of interventional cardiology. In both cases contrast filled agent is injected into the vessel structure of a patient under examination while acquiring two-dimensional (2D) X-ray angiograms during a rotational run of the C-arm system. The acquired projection images can then be used for diagnostic purposes, and/or can be utilized to make a three-dimensional (3D) reconstruction of the region of interest.

In order to limit the radiation exposure of a patient under examination to the designated region of interest within the body of the patient there are known various way to perform an appropriate positioning of the patient with respect to a beam of X-rays or even to a beam of particles. Thereby, a beam of particles is typically used for treating carcinogenic tissue. By contrast thereto, an X-ray beam may be used both for diagnostic and for therapeutic purposes.

US2004/0184583 A1 discloses a device for positioning a patient relative to a particle beam, which is used for irradiating a tumor in the body of the patient. The patient positioning device comprises (a) an X-ray emission device for emitting X-rays along a beam line in front of a particle beam irradiation section, (b) an X-ray image capturing device for receiving the X-rays and processing an X-ray image and (c) a display unit for displaying a current image of the tumor in accordance with a processed image signal. The patient positioning device further comprises (d) a display unit for displaying a reference X-ray image of the tumor, which is prepared in advance, and (e) a positioning data generator for executing pattern matching between a first comparison area being a part of the reference X-ray image and a second comparison area being a part of the current image. Thereby, data for positioning the patient by moving a patient's couch are produced during the particle beam irradiation.

US2005/0256390 A1 discloses a medical imaging examination apparatus with an automatic patient positioning. The medical imaging examination apparatus comprises (a) an image acquisition device, (b) a patient bed, (c) a control device to control the image acquisition means and to move the patient bed as well as (d) a monitor connected with the control device for image output. In an examination image of the patient shown on the monitor that has been acquired with a first patient bed position with the imaging medical examination apparatus, an operator can designate on the monitor a desired new patient bed position for implementation of further examinations. The control device automatically determines the position data of the defined bed position and controls movement of the bed dependent on the determined position data such that the bed subsequently assumes the desired new position.

US2005/0218341 A1 discloses a method of positioning a treatment target to the iso-center of a treatment system for irradiating a tumor of a patient with a particle beam being generated by a linear particle accelerator. The method includes a simulation process and a real treatment positioning process. The simulation process includes positioning the treatment target to an iso-center of a simulation system and marking intersection points where laser beams intersect with an exterior of the patient's body. The real treatment positioning process includes (a) determining the position of the intersection points marked on the exterior of the patient body, (b) determining a treatment position for positioning the patient such that the treatment target is aligned with the iso-center of the rea1 treatment system and (c) positioning the patient to the treatment position.

With respect to rotational X-ray imaging by means of a C-arm X-ray imaging system a proper positioning of the object under examination is essential in order to allow for a high quality 3D reconstruction of the object. Thereby, a region of interest within the object under examination is positioned within the center of rotation of the C-arm system. In particular when a region of interest is examined, which region is not located in the center of the object, a precise positioning of the object is essential in order to avoid a collision between parts of the C-arm system and the object.

There may be a need for providing a method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit, which method allows for a proper positioning of the object under examination during the X-ray data acquisition at different projection angles.

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

According to a first aspect of the invention there is provided a method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having an X-ray scanning unit. The provided method comprises the steps of (a) rotating the X-ray scanning unit around a rotational axis such that the object under examination is scanned under different projection angles, and (b) moving the object under examination relative to the rotational axis, wherein the movement of the object under examination is coupled to the rotation of the X-ray scanning unit.

This aspect of the invention is based on the idea that a predetermined translative movement of the object during the X-ray data acquisition allows to compensate for spatial restrictions which may be caused if the object under examination is originally not located in the center respectively the iso-center of the X-ray imaging apparatus. Thereby, a collision between the scanning unit and an outer part of the object being located outside the iso-center may be avoided. Without such a translative shift of the object such a collision might occur at a certain angular position of the scanning unit. The iso-center is defined by the intersection of the rotational axis and the optical axis of the scanning unit.

The employed X-ray scanning unit comprises an X-ray source such as an X-ray tube and an X-ray detector, preferably a flat detector having a spatial resolution. The X-ray source and the X-ray detector may be attached to a gantry such as a holder of a C-arm. However, the X-ray source and the X-ray detector may also be attached to a self-contained holder which is used e.g. in computed tomography systems.

The described method provides the advantage that the angular range of the X-ray scanning unit might be increased in particular for voluminous objects, which are originally located outside the iso-center of the X-ray imaging apparatus. An original positioning of the object under examination outside the iso-center is in particular beneficial when a region of interest within the object is supposed to be examined, which region of interest is located not in the center of the object. This allows for a proper positioning of the region of interest within the iso-center of the X-ray scanning unit.

By shifting the object such that the region of interest is temporarily positioned outside the center of rotation, a collision between the scanning unit and the object can be effectively avoided and the possible angular range of the scanning unit can be widened. Of course, by shifting the object under examination the region of interest is at least temporarily not located in the iso-center. However, compared to a collision-restricted range of projection angles, additional X-ray attenuation data, which have been acquired with the region of interest being located offset from the iso-center, provide nonetheless further useful information about the region of interest. Of course, this requires a sufficient large cross sectional area of the X-radiation beam extending from the X-ray source to the X-ray detector at the iso-center such that at least eccentric X-rays penetrate the region of interest. This condition can be fulfilled easily by employing a flat X-ray detector having a comparatively large area.

According to an embodiment of the invention the object under examination is moved in a direction transversal to the rotational axis. In this respect it has to be mentioned that the direction of the transversal movement of the object may be either inclined or perpendicular to the rotational axis. Anyway, it is important that the object or at least a part of the object is moved out of the iso-center of the X-ray imaging apparatus.

According to an embodiment of the invention the method further comprises the steps of (a) rotating the X-ray scanning unit to a first predefined angular position, whereby the object under examination is located at a first translative position, (b) moving the object under examination from the first translative position to a second translative position, and (c) rotating the X-ray scanning unit to a second predefined angular position. Such a horizontal shuttle movement after reaching a certain angular position may provide the advantage that in a wide angular range the data acquisition may be carried out with the object being located at one and the same translative position.

According to a further embodiment of the invention the method further comprises the steps of (a) moving the object under examination from the second translative position back to the first translative position, and (b) further rotating the X-ray scanning unit. This may provide the advantage that the object is located at the second translative position only when a collision between the X-ray scanning unit and the object has to be avoided. For angular positions of the scanning unit, where there is no risk for a collision, the object under examination may be located at the original first translative position such that a region of interest within the object may be located in the iso-center even if the this region of interest is located off-center in the whole object.

Preferably, the further rotation is carried out until the X-ray scanning unit is situated again in the first predefined angular position. Thereby, a complete 360° cycle of the scanning unit including an intermediate translative shift of the object is defined. This may provide the advantage that the object under examination may be scanned with a plurality of rotational cycles. Thereby, by combining the X-ray attenuation data acquired at different revolutions the quality of the corresponding X-ray images obtained at different projection angles may be enhanced.

It has to be mentioned that of course during one rotational cycle the object might also be shifted stepwise to a variety of different second translative positions. Thereby, for each angular position of the X-ray scanning unit the shift of the object is solely as big as it is necessary to avoid a collision between the scanning unit and the object.

According to a further embodiment of the invention the movement of the object under examination is carried out during a time period in which the rotation of the X-ray scanning unit is temporarily stopped. This means that the data acquisition is carried out exclusively at discrete translative positions of the object under examination. This may provide the advantage that images at different projection angles can be compared comparatively easy because only a limited number of different object positions have to be considered.

A further advantage may be provided if the X-ray projection data obtained at various different angular positions are combined in order to reconstruct a three-dimensional (3D) representation of the object under examination. By momentarily stopping the rotation of the X-ray scanning unit a corresponding reconstruction procedure is more reliable because the number of different translative object positions is limited such that the overall uncertainty about of the correct translative position is reduced.

According to an alternative embodiment of the invention the movement of the object under examination is carried out during a time period in which the X-ray scanning unit is rotated from the first predefined angular position to the second predefined angular position. This may provide the advantage that it is not necessary to stop the data acquisition during the translative movement of the object under examination such that the overall acquisition time can effectively be reduced.

According to a further embodiment of the invention the object under examination is situated at a support element, which support element is coupled to a drive means for generating the movement of the object under examination. Preferably, the support element is a table, which may be moved at least along a direction transversal to the rotational axis. However, the table may also be driven along further directions such that a proper positioning of the object under examination may be achieved. Since patient tables used in medical X-ray imaging apparatuses are typically movable in all three directions is space, the described data acquisition method can be easily implemented in current used medical X-ray imaging apparatuses.

By using an automated motorized table a precise positioning of the object can be achieved. This may provide the advantage that the uncertainty of the exact object position is reduced such that projection data acquired both under different angular positions of the scanning unit and at different translative positions of the object may be combined by means of a reliable reconstruction procedure leading to a 3D representation of the object under examination.

According to a further embodiment of the invention the object under examination is at least a region of interest of a body of a patient. This has the advantage that in medical X-ray imaging the described method may be used to effectively increase the angular range of an X-ray imaging apparatus such as a C-arm system in particular when thick patients have to be examined.

According to a further embodiment of the invention the region of interest is an organ of the patient, which organ is located off-center within the body of the patient, in particular the region of interest is the heart of the patient.

Preferably, during a first phase of the X-ray data acquisition, when the patient's body is located within the first translative position, the organ is located in the iso-center of the medical X-ray imaging apparatus. This means that the patient's body as a whole is located off-center. In order to avoid a collision between the scanning unit and the patient's body at a subsequent angular position of the scanning unit, the patient is moved in due time to the second translative position. Thereby, the patient's body as a whole is moved at least towards the iso-center whereby the organ of the patient is moved away from the iso-center. This allows for a further rotation of the X-ray scanning unit.

At this point it has to be mentioned that the size of the flat X-ray detector of the scanning unit has to be big enough in order to ensure, that the off-center organ is still within the cross section of the X-ray beam extending between the X-ray source and the X-ray detector. If this would be not the case the increase of the collision free angular range of the scanning unit would not be useful because no further X-ray attenuation data of the organ can be acquired. However, in most current used C-arm systems the cross section of the X-ray beam is big enough in order to allow also an X-ray imaging of organs, which are not located in the iso-center of the employed C-arm system.

According to a further embodiment of the invention the method further comprises the step of inserting a contrast agent into the body of a patient. This may provide the advantage that the internal vessel structure of the patient may be illustrated very clearly by means of a rotational angiography. Due to the increased collision free angular range of the scanning unit the known problem of foreshortening the length of vessel sections, which are oriented almost parallel to the optical axis of the X-ray scanning unit, is eliminated. When using the described method it will be possible to acquire X-ray images also at other angular positions, wherein these vessel sections are oriented at least almost perpendicular to the optical axis of the X-ray scanning unit.

According to a further embodiment of the invention the method further comprises the step of reconstructing a three-dimensional representation of the object under examination based on the acquired series of two-dimensional X-ray attenuation data, whereby the movement of the object under examination is taken into account. Thereby, the movement of the object under examination causes a shift of the relevant attenuation data on the flat X-ray detector. Of course, this spatial data shift depends on the angle θ between the direction of the translative movement and the detector plane. Specifically, the spatial data shift ΔS is given by the expression $\Delta S = \Delta x \cdot \cos\theta$, wherein Δx is the moving distance of the object under examination.

According to a further embodiment of the invention the method further comprises the step of carrying out a calibration procedure for registering the movement of the object under examination with the rotation of the X-ray scanning unit. Preferably, the calibration procedure is carried out by using an appropriate phantom in order to register the translative movement of the phantom respectively the object with the rotational movement of X-ray scanning unit. Of course, both the movement of the object under examination and the trajectory of the X-ray scanning unit have to be reproducible such that the real data acquisition can be carried out under the same conditions, which conditions have been available already for calibration procedure.

In case of a accomplishing a 3D reconstruction of the object under examination this may provide the advantage that the motion compensation of the acquired projection data due to the translative movement of the object and the acquired X-ray attenuation data can be directly applied to commercially utilized 3D reconstruction algorithms.

According to a further aspect of the invention there is provided a data processing device for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit. The data processing device comprises (a) a data processor, which is adapted for controlling exemplary embodiments of the above-described method, and (b) a memory for storing the series of acquired two-dimensional X-ray attenuation data.

According to a further aspect of the invention there is provided a medical X-ray imaging apparatus for acquiring a series of two-dimensional X-ray attenuation data of an object under examination. The medical X-ray imaging apparatus is in particular a so-called C-arm system, which comprises an X-ray scanning unit being rotatable around a rotational axis. The X-ray scanning unit itself comprises an X-ray source, which is adapted for emitting a radiation beam, and an X-ray detector, which is adapted for detecting the radiation beam after the radiation beam has passed the object under examination. The medical X-ray imaging apparatus further comprises the above described a data processing device.

According to an embodiment of the invention the medical X-ray imaging apparatus further comprises (a) a support element for supporting the object under examination and (b) a drive means, which is coupled to the support element and which is adapted for generating the transversal movement of the object under examination. As has already been mentioned above, the support element may be a movable table, which allows for a precise and reproducible positioning of the object under examination.

According to a further embodiment of the invention the medical X-ray imaging apparatus further comprises a control unit, which is coupled to the drive means and which is adapted to control the movement of the support element. This has the advantage that a fully automated motorized support element may be realized such that a precise and reproducible positioning of the object can be achieved. Preferably, the control unit is also directly or indirectly coupled to a motor for generating the rotational movement of the scanning unit. Thereby, a perfect synchronization between the rotational movement of the scanning unit and the translative movement of the object may be realized.

It has to be mentioned that the control unit may be realized by means of a computer program respectively software. However, the invention may also be realized by means of one ore more specific electronic circuits respectively hardware. Furthermore, the invention may also be realized in a hybrid form, i.e. in a combination of software modules and hardware modules.

According to a further aspect of the invention there is provided a computer-readable medium on which there is stored a computer program for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit. The computer program, when being executed by a data processor, is adapted for controlling exemplary embodiments of the above-described method.

According to a further aspect of the invention there is provided a program element for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit. The program element, when being executed by a data processor, is adapted for controlling exemplary embodiments of the above-described method.

The computer program element may be implemented as a computer readable instruction code in any suitable programming language, such as, for example, JAVA, C++, and may be stored on a computer-readable medium (removable disk, volatile or non-volatile memory, embedded memory/processor, etc.). The instruction code is operable to program a computer or other programmable device to carry out the intended functions. The computer program may be available from a network, such as the WorldWideWeb, from which it may be downloaded.

It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claims is considered to be disclosed with this application.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Figure 1a shows a side view of a medical C-arm system, which is adapted to carry out a translative motion of an object under examination, wherein the translative motion is coupled to a rotational movement of the scanning unit.

Figure 1b shows a perspective view of the C-arm depicted in Figure 1a.

Figure 2a shows a patient under examination positioned within a C-arm system, whereby the patient's body as a whole is positioned in the iso-center of the C-arm.

Figure 2b shows the patient depicted in Figure 2a in a position, whereby the patient's heart is positioned in the iso-center of the C-arm.

Figures 3a-3k illustrate the synchronized combination of a rotational movement of a C-arm with a horizontal movement of a patient table in order to avoid collisions between an X-ray detector of the C-arm with a shoulder of the patient.

Figure 4 shows a data processing device, which is adapted to perform an above-described method for acquiring a series of X-ray attenuation data of an object under examination by means of a rotatable X-ray scanning unit.

The illustration in the drawing is schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which are different from the corresponding reference signs only within the first digit.

Referring to Figures 1a and 1b of the drawing, a medical X-ray imaging system 100 according to a further embodiment of the invention is a so called C-arm system. The C-arm system 100 comprises a swing arm scanning system 101 supported proximal a patient table 112 by a robotic arm 108. Housed within the swing C-arm 101, there is provided an X-ray scanning unit comprising an X-ray tube 105 and an X-ray detector 115. The X-ray detector 115 is arranged and configured to detect X-rays 107, which have passed through an object under examination 110. Typically, the object under examination is a patient 110.

The X-ray detector 115 is adapted to generate an electrical signal representative of the spatial intensity distribution of the detected X-rays 107 on the X-ray detector. By moving the swing arm 101, the X-ray tube 105 and the X-ray detector 115 can be placed at any desired angular orientation relative to the patient 110.

The C-arm system 100 further comprises a table drive means 113, which is adapted to move the table 112 along all three directions in space. Thereby, the patient 110 being supported by the table 112 may be positioned in the iso-center of the C-arm 101. It has to be mentioned that depending on a region of interest 110a within the patient's body, which may not be located in the center of the patient's body, the patient may be positiened slightly offset from the iso-center in order to allow that the region of interest 110a is located exactly in the iso-center.

However, if the region of interest 110a is not located in the center of the longitudinal axis of the patient 110, i.e. the region of interest 110a is shifted in the direction of an x-axis being perpendiculat both to the depicted y-axis and the depicted z-axis, a collision between in particular the X-ray detector 115 and the patient's body might occur at some angular positions of the C-arm 101, when the region of interest 110a is located in the iso-center. Such a collision would restrict the possible angular range of the C-arm 101 movement. In order to increase this angular range the patient 110 is shifted predominately along the x-axis such that the region of interest 110a is temporarily positioned outside the iso-center and the body of the patient 110 as a whole is positioned at least aproximately within the iso-center. This means that by coupling the rotational movement of the C-arm 101 with the translative movement of the patient 110 in a synchronized manner a collision between in particular the X-ray detector 115 and in particular a shoulder of the patient 110 can be effectively avoided.

Furthermore, the C-arm system 100 comprises a control unit 121 and a data processing device 125, which are both accomodetaed within a workstation or a personal computer 120. The control unit 121 is adapted to control both the rotational movement of the swing arm scanning system 101 and the translative motion of the table 112. The data processing device 125 is adapted for performing a three-dimensional (3D) reconstruction of the region of interest 110a based on a set of acquired X-ray attenuation data obtained at different angular positions of the C-arm 101.

Figure 2a shows a patient under examination 210 positioned within a C-arm system 200. The patient 210 is supported by a movable table 212, which table can be shifted along the x-axis, along the y-axis and along the z-axis. The C-arm system 200 comprises a robotic arm 208, at which a not visible C-arm is attached in a rotatable manner. A not visible X-ray source and an X-ray detector 215 are attached to the C-arm. The C-arm is capable of rotating around a z-axis such that the X-ray source and the X-ray detector 215 rotate around the patient 210 within a plane being oriented parallel to the x-axis as well as to the y-axis.

According to the embodiment described here the heart 210a of the patient 210 is examined. Since the heart 210a is located within the left side of the patient's body, the heart 210a will not be located in the iso-center of the C-arm if the patient's body as a whole is positioned within the iso-center. In Figure 2a the offset positioning of the heart 210a with respect to the iso-center is indicated by the arrow 211a. The arrow 211a is not aligned with an optical axis of the X-ray detector 215. In order to move the region of interest 210a into the iso-center, the table 212 has to be moved along the x-axis in a negative direction i.e. to the left side. Such a table movement is indicated by the arrow 214.

Figure 2b shows the patient 210 within the C-arm system 200, whereby the patient's heart 210a is positioned in the iso-center. The iso-centering is indicated by the arrow 211b, which is aligned with the optical axis of the X-ray detector 215. In that case, the patient's body as a whole is shifted to the left compared to the iso-center of the C-arm.

Figures 3a-3k illustrate the combination of a rotational movement of a C-arm 301, which rotational movement is coupled in a synchronized manner with a horizontal movement of a patient table 312 in order to avoid a collision between an X-ray detector 315 of the C-arm 301 with a shoulder of the patient 310. The C-arm 301 is attached in a rotatable manner to a ceiling of an examination laboratory by means of a robotic arm 308.

In the beginning of the rotational movement of the C-arm 301 the patient 310 is positioned in such a manner that the patient's heart is located in the iso-center of the C-arm 301. This situation is depicted in Figures 3a, 3b and 3c, which illustrate a first phase of the rotational movement of the C-arm 301. The C-arm 301 rotates in a counter-clockwise direction. Thereby, the X-ray source 305 of the C-arm 301 is moved in a rotatable manner underneath the patient 310. Consequently, the X-ray detector 315 is moved in a rotatable manner above the patient 310.

When the X-ray detector 315 approaches the right shoulder of the patient 310, the table 312 is shifted to the right such that the heart of the patient is offset from the iso-center. This table movement is indicated in Figure 3d by the arrow 314d. Thereby, the right shoulder of the patient 310 is also moved to the right such that a collision between the X-ray detector 315 and the shoulder can be avoided. In other words, the accessible angular range of the C-arm 301 is increased such that further X-ray attenuation data may be acquired at more extreme projection angles.

As can be seen from Figures 3e, 3f, 3g, 3h and 3i, when the heart of the patient is located offset from the iso-center, the X-ray detector 315 of the C-arm 301 can be rotated around the shoulder of the patient 310 without having the risk of a collision.

When the X-ray detector 315 is positioned below the shoulder, the table 312 is shifted back to its original position such that the patient's heart is again located in the iso-center of the C-arm 301. This table movement to the left is indicated in Figure 3j by the arrow 314f.

In order to complete a full cycle of the C-arm 301 the C-arm is further rotated to its original angular position. This situation is shown in Figure 3k.

The intermediate table movement synchronized has the advantage, that the total accessible angular range can be increased in particular when thick patients are examined. By employing the described horizontal table movement the full angular range of a C-arm system can be exploited. For example the C-arm system FD20 Allura developed by Philips is capable of a C-arm propeller rotation from 120° left anterior oblique (LAO) to 185° right anterior oblique (RAO). Thereby, the projection angle is defined with respect to the view of a patient being positioned within the C-arm system.

Without employing the described horizontal table movement the C-arm system FD20 Allura cannot be used for cardiac applications because this full angular range cannot be used in particular for larger respectively thicker patients. Therefore, depending on the patient size, the C-arm movement would be limited to approximately 60° RAO only. Currently, the acquisition protocols for 3D coronary reconstruction require a C-arm propeller movement from 120° LAO to 60° RAO propeller movement.

In this respect it is pointed out that a rotation angle of 180° plus the angle of the beam spread of the X-ray beam is necessary in order to accomplish a 3D reconstruction procedure using known filtered back projection techniques.

By employing the described horizontal table movement it is possible to apply the acquisition protocols for 3D coronary reconstruction with currently available C-arm systems also for larger patients. Moreover, the above-mentioned C-arm system FD20 Allura has the ability to do extreme RAO projections that aid in the reconstruction process. Further, the described horizontal table movement unleashes capabilities already present but underutilized in currently available imaging systems, which capabilities are not limited to the reconstruction process. Furthermore, optimal view maps of coronary segments show that the acquisition of angular views between 60° RAO and 180° RAO are highly appreciated to generate projection images with a minimum of vessel shortening and vessel overlap. Such a reduced vessel shortening and vessel overlap increases the quality of two-dimensional (2D) angiograms and the resulting reconstructed and/or modeled 3D images significantly.

If a programmable and motorized patient table is available the above described horizontal table movement can carried out by executing the following steps:

1. Determination of an acquisition protocol for a rotational run acquisition. For example a 180° propeller rotation starting from 90° LAO to 90° RAO is appropriate.

2. Determination of the angular start point for the table shuttle movement. For example 30° LAO is appropriate.

3. Calibration of the C-arm rotational movement including the horizontal table movement.

4. Acquisition of patient data and if needed 3D reconstruction of the data after calibration.

Figure 4 shows a data processing device 425, which is adapted to perform an above-described method for acquiring a series of X-ray attenuation data of an object under examination by means of a rotatable X-ray scanning unit. The data processing device 425 comprises a central processing unit (CPU) or image processor 461. The image processor 461 is connected to a memory 462 for temporally storing acquired X-ray attenuation data. Via a bus system 465 the image processor 461 is connected to a plurality of input/output network or diagnosis devices of the C-arm system described above. Furthermore, the image processor 461 is connected to a display device 463, for example a computer monitor, for displaying information or one or more images reconstructed by the image processor 461. An operator or user may interact with the image processor 461 via a keyboard 464 and/or any other output devices, which are not depicted in Figure 4.

It should be noted that the term “comprising” does not exclude other elements or steps and the “a” or “an” does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

In order to recapitulate the above described embodiments of the present invention one can state:

It is described a method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination by means of an X-ray imaging apparatus having a rotatable scanning unit. In order to increase the angular range of the scanning unit, when a region of interest is examined, which region is located not in the center of the object but which region is originally positioned in the center of rotation of the scanning unit, the object under examination is shifted such that the region of interest is temporarily positioned outside the center of rotation. By coupling the rotational movement of the scanning unit with the translative movement of the object in a synchronized manner a collision between the scanning unit and the object can be effectively avoided. By employing an automated motorized object table a precise pre-determined movement of the object can be achieved during the data acquisition. By using an appropriate phantom based calibration procedure carried out with the same table movements known three-dimensional reconstruction algorithm can be directly applied in order to generate a three-dimensional representation of the region of interest.

LIST OF REFERENCE SIGNS:

100	medical X-ray imaging system / C-arm system
101	X-ray scanning unit / swing arm scanning system / C-arm
105	X-ray source / X-ray tube
107	X-ray beam
108	robotic arm
110	object under examination / patient
112	table
113	table drive means
115	X-ray detector
120	workstation / personal computer
121	control unit
125	data processing device
200	C-arm system
208	robotic arm
210	object under examination / patient
210a	region of interest / organ / heart
211a	arrow indicating offset x-position of the heart
211b	arrow indicating iso-centered x-position of the heart
212	table
214	arrow indicating table movement
215	X-ray detector
301	C-arm
305	X-ray source / X-ray tube
308	robotic arm
310	object under examination / patient
312	table
314d	arrow indicating table movement to the right
314j	arrow indicating table movement to the right
315	X-ray detector
425	data processing device

461	central processing unit / image processor
462	memory
463	display device
464	keyboard
465	bus system

CLAIMS:

1. A method for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (110, 310) by means of an X-ray imaging apparatus (100) having an X-ray scanning unit (101, 310), the method comprising the steps of

rotating the X-ray scanning unit (101, 301) around a rotational axis such that the object under examination (110, 310) is scanned under different projection angles, and

moving the object under examination (110, 310) relative to the rotational axis, wherein the movement of the object under examination (110, 310) is coupled to the rotation of the X-ray scanning unit (101, 301).

2. The method according to claim 1, whereby

the object under examination (110, 310) is moved in a direction transversal to the rotational axis.

3. The method according to claim 1, further comprising the steps of

rotating the X-ray scanning unit (101, 301) to a first predefined angular position, whereby the object under examination (110, 310) is located at a first translative position,

moving the object under examination (110, 310) from the first translative position to a second translative position, and

rotating the X-ray scanning unit (101, 301) to a second predefined angular position.

4. The method according to claim 3, further comprising the steps of

moving the object under examination (110, 310) from the second translative position back to the first translative position, and further rotating the X-ray scanning unit (101, 301).

5. The method according to claim 3, wherein
the movement of the object under examination (110, 310) is carried out during a time period in which the rotation of the X-ray scanning unit (101, 301) is temporarily stopped.

6. The method according to claim 3, wherein
the movement of the object under examination (110, 310) is carried out during a time period in which the X-ray scanning unit (101, 301) is rotated from the first predefined angular position to the second predefined angular position.

7. The method according to claim 1, wherein
the object under examination (110, 310) is situated at a support element (112, 312), which support element (112, 312) is coupled to a drive means (113) for generating the movement of the object under examination (110, 310).

8. The method according to claim 1, wherein
the object under examination (110, 310) is at least a region of interest (110a, 210a) of a body of a patient.

9. The method according to claim 8, wherein
the region of interest is an organ (110a, 210a) of the patient (110, 310), which organ (110a, 210a) is located off-center within the body of the patient (110, 310), in particular the region of interest is the heart (110a, 210a) of the patient (110, 310).

10. The method according to claim 8, further comprising the step of
inserting a contrast agent into the body of a patient (110, 310).

11. The method according to claim 1, further comprising the step of

reconstructing a three-dimensional representation of the object under examination (110, 310) based on the acquired series of two-dimensional X-ray attenuation data, whereby the movement of the object under examination (110, 310) is taken into account.

12. The method according to claim 1, further comprising the step of carrying out a calibration procedure for registering the movement of the object under examination (110, 310) with the rotation of the X-ray scanning unit (101, 301).

13. A data processing device for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (110, 310) by means of an X-ray imaging apparatus having a rotatable X-ray scanning unit (101, 301),
the data processing device (425) comprising
a data processor (461), which is adapted for controlling the method as set forth in claim 1, and
a memory (462) for storing the series of acquired two-dimensional X-ray attenuation data.

14. A medical X-ray imaging apparatus, in particular a C-arm system (100), for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (110, 310), the medical X-ray imaging apparatus (100) comprising
an X-ray scanning unit (101, 301) being rotatable around a rotational axis, wherein the X-ray scanning unit (101, 301) comprises
- an X-ray source (105), which is adapted for emitting a radiation beam (107), and
- an X-ray detector (115), which is adapted for detecting the radiation beam (107) after the radiation beam (107) has passed the object under examination (110, 310),
a data processing device (425) according to claim 13.

15. The medical X-ray imaging apparatus according to claim 14, further comprising

a support element (112, 312) for supporting the object under examination (110, 310) and

a drive means (113), which is coupled to the support element (112, 312) and which is adapted for generating the transversal movement of the object under examination (110, 310).

16. The medical X-ray imaging apparatus according to claim 15, further comprising

a control unit (121), which is coupled to the drive means (113) and which is adapted to control the movement of the support element (112, 312).

17. A computer-readable medium on which there is stored a computer program for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (110, 310) by means of an X-ray imaging apparatus (100) having a rotatable X-ray scanning unit (101, 301),
the computer program, when being executed by a data processor (461), is adapted for controlling the method as set forth in claim 1.

18. A program element
for acquiring a series of two-dimensional X-ray attenuation data of an object under examination (110, 310) by means of an X-ray imaging apparatus (100) having a rotatable X-ray scanning unit (101, 301),
the program element, when being executed by a data processor (461), is adapted for controlling the method as set forth in claim 1.

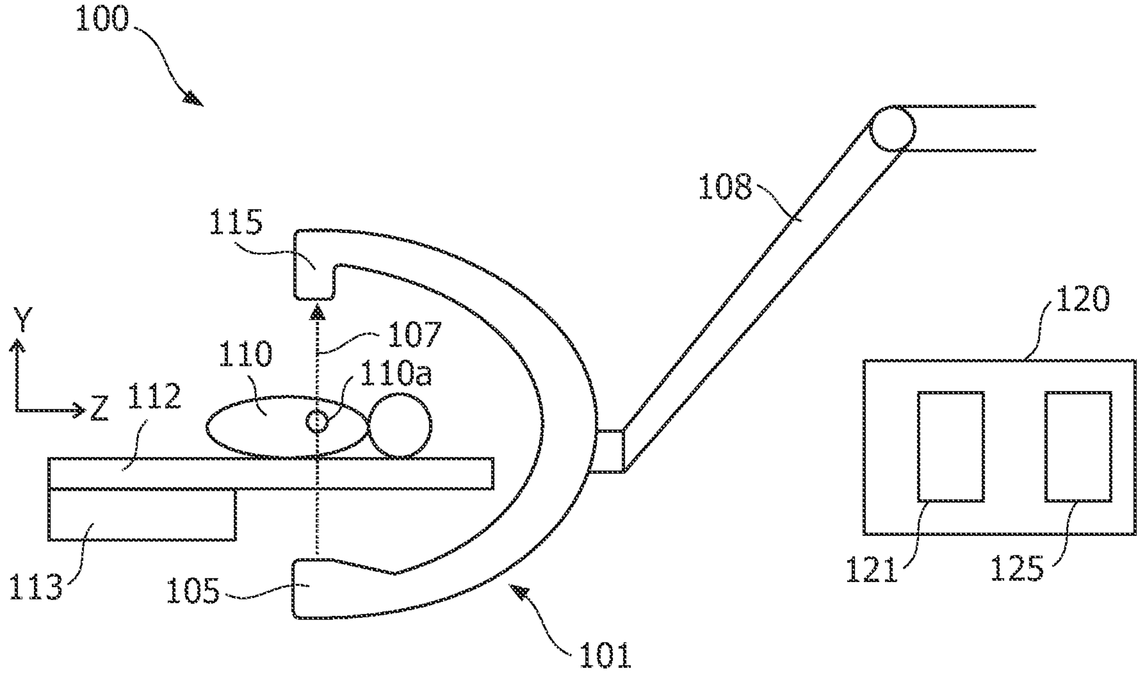
100
108
115
120
Y
107
110
110a
Z
112
121
125
113
105
101

FIG. 1a

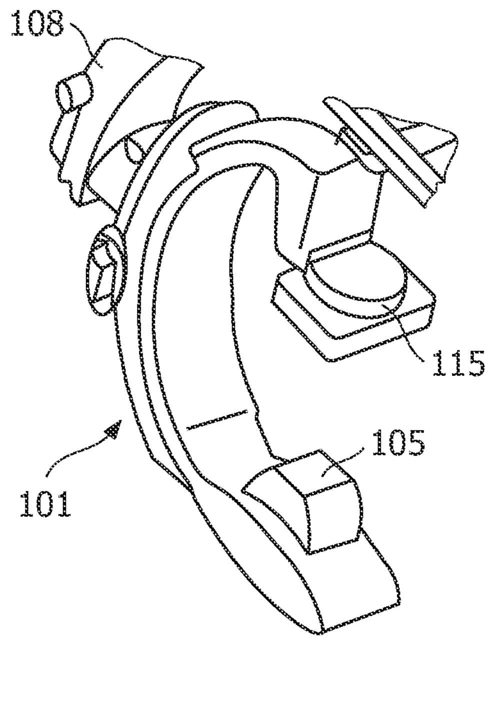
108
115
105
101

FIG. 1b

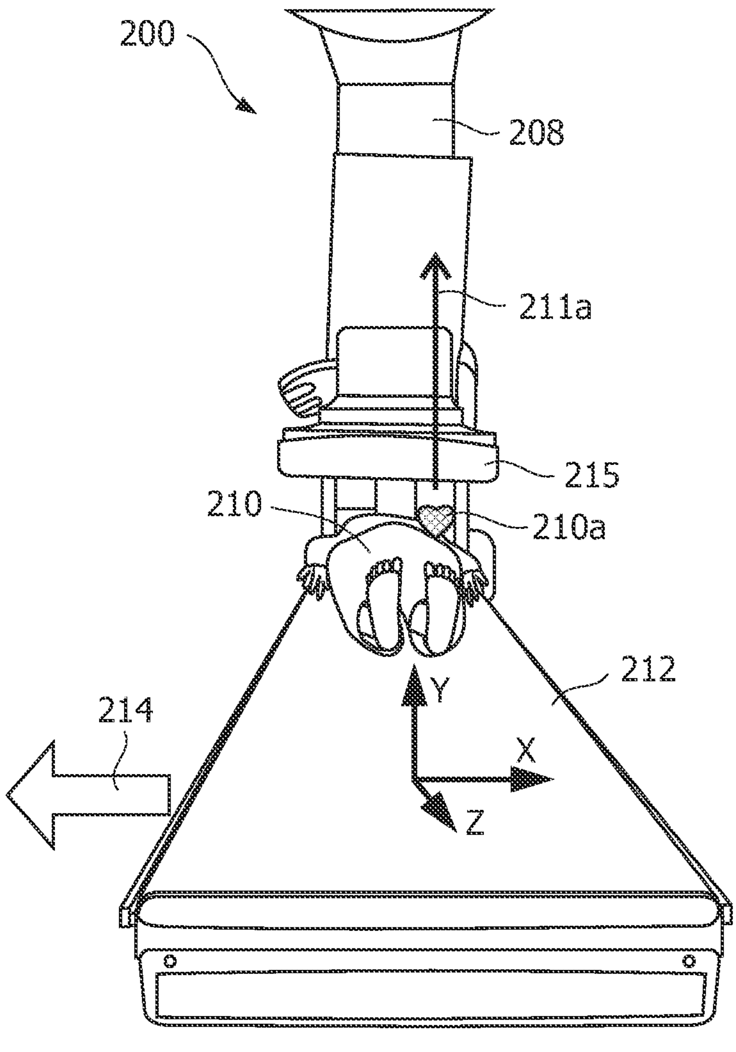

FIG. 2a

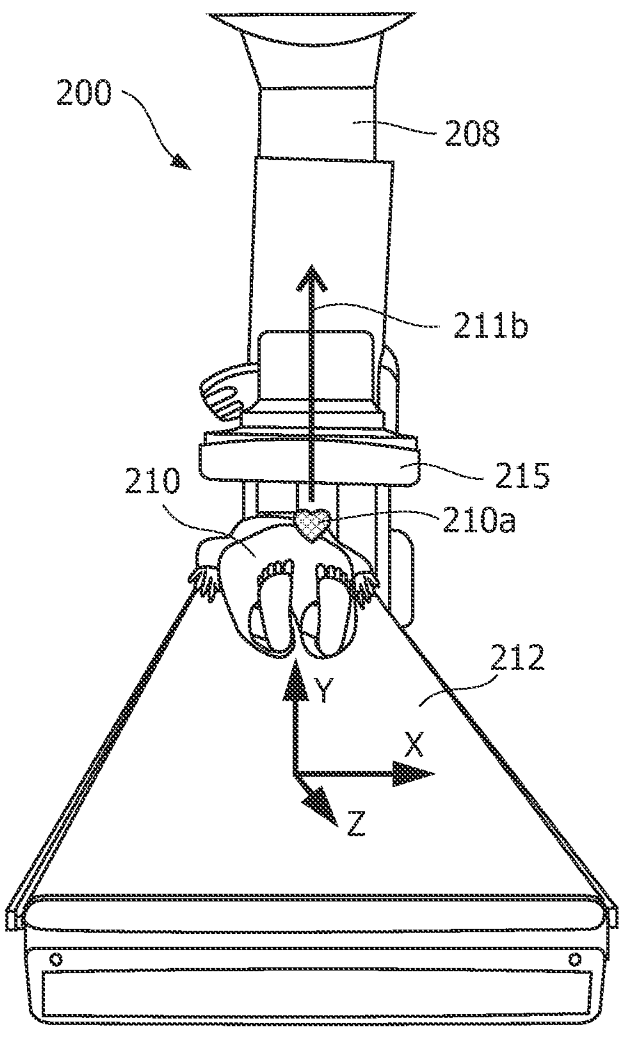

FIG. 2b

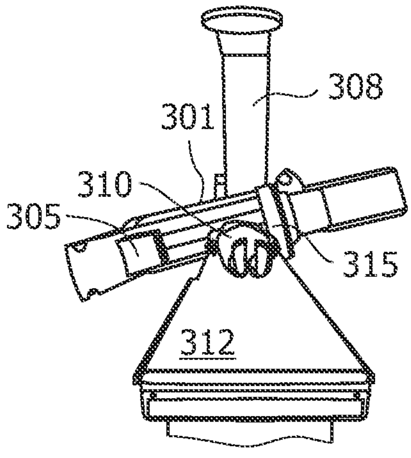

FIG. 3a

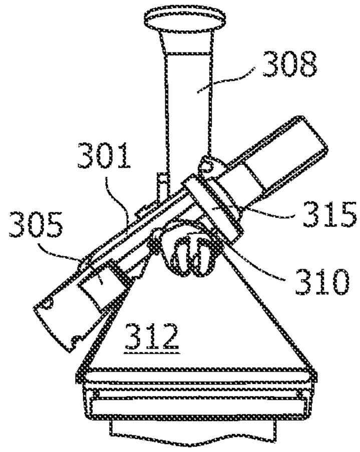

FIG. 3b

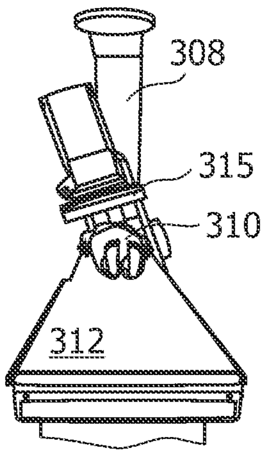

FIG. 3c

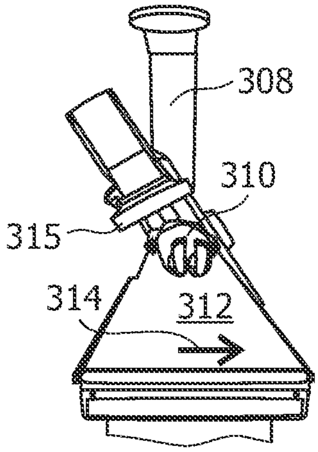

FIG. 3d

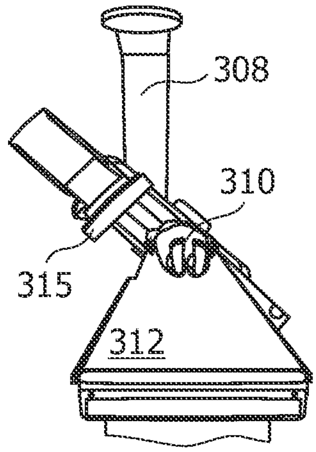

FIG. 3e

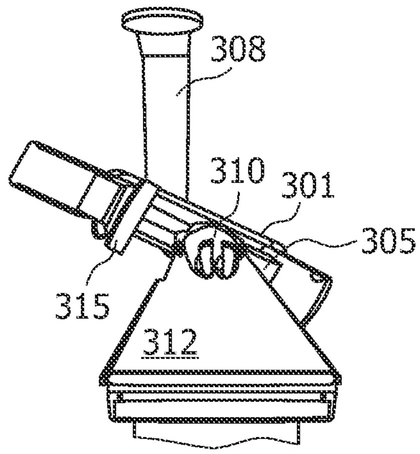

FIG. 3f

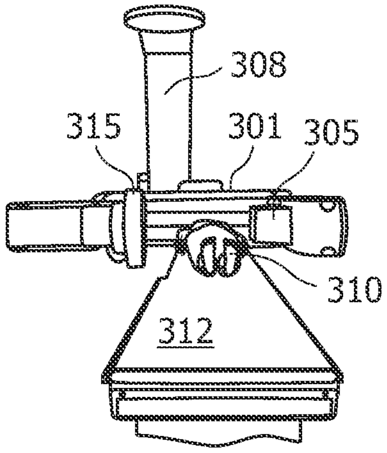

FIG. 3g

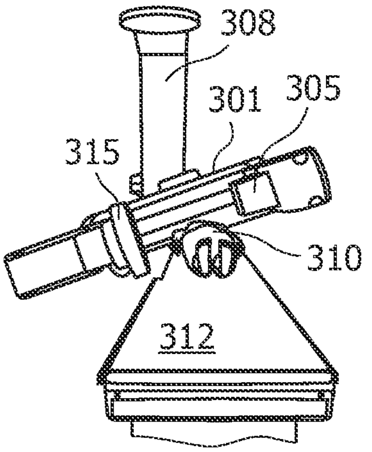

FIG. 3h

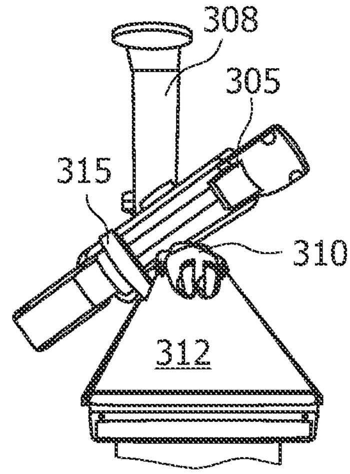

FIG. 3i

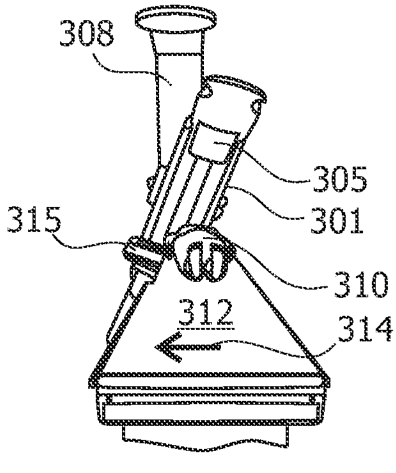

FIG. 3j

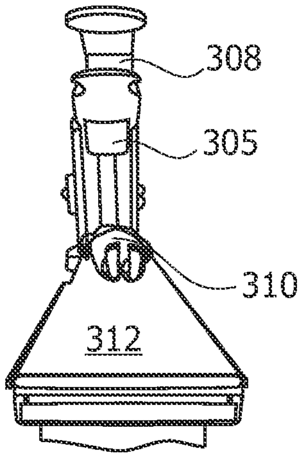

FIG. 3k

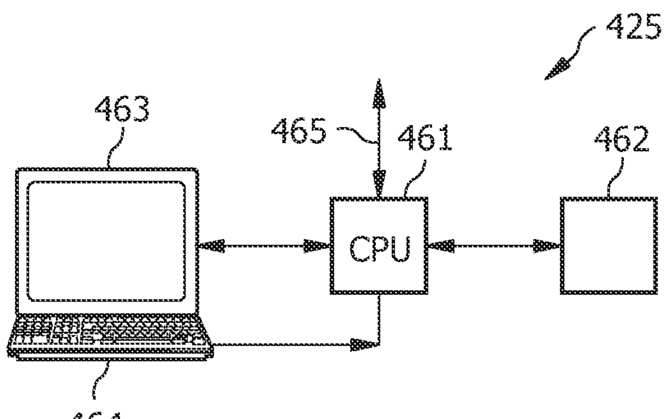

FIG. 4

TIONAL SEARCH REPORT

International application No
PCT/IB2007/053744

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/00 A61B6/04

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)
A61B

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/090058 A1 (YASUDA MITSUNORI [JP] ET AL) 11 July 2002 (2002-07-11) paragraphs [0010], [0016] paragraph [0038] - paragraph [0059] figures 1-3	1-3,5-7, 10,11, 13-18
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Y		4,12
X	US 5 930 328 A (NAKAMURA MASATO [JP] ET AL) 27 July 1999 (1999-07-27) column 4, line 12 - column 5, line 49	1

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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 document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2008	04/03/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Görlach, Tobias

International application No
PCT/IB2007/053744

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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TIONAL SEARCH REPORT

on on patent family members

International application No

PCT/IB2007/053744

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US 2003069499	A1	10-04-2003	NONE			