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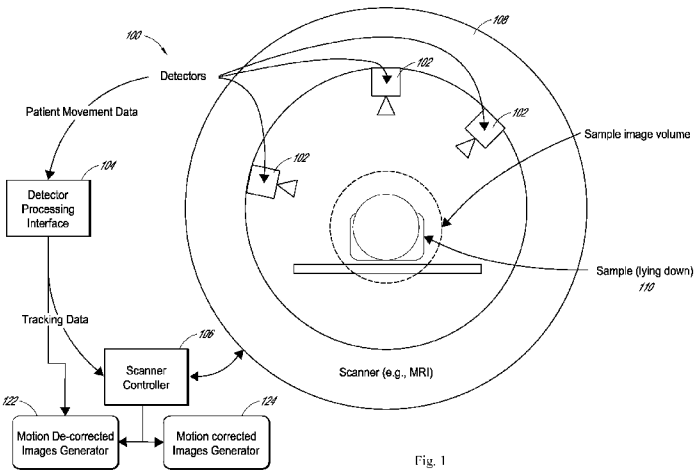

Fig. 1

(57) Abstract: The disclosure herein provides methods, systems, and devices for removing prospective motion correction from medical imaging scans. In an embodiment, a computer-implemented method for removing motion correction from biomedical imaging scan data comprises tracking, by a computer system, motion of an object being scanned; generating, by the computer system, motion tracking data; adjusting, by the computer system, a biomedical imaging scanner, using the motion tracking data, to compensate in real time for object motion, such that raw image data generated by the scanner can be reconstructed into motion-corrected images; inverting, by the computer system, the motion tracking data; and applying, by the computer system, the inverted motion tracking data to the raw image data to generate de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de- corrected image data can be reconstructed into de-corrected images, wherein the computer system comprises an electronic memory and a computer processor.

WO 2015/148391 A1

SYSTEMS, METHODS, AND DEVICES FOR REMOVING PROSPECTIVE MOTION CORRECTION FROM MEDICAL IMAGING SCANS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/969,765, filed March 24, 2015, and titled SYSTEMS, METHODS, AND DEVICES FOR REMOVING PROSPECTIVE MOTION CORRECTION FROM MEDICAL IMAGING SCANS, which is hereby incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED R&D

[0001] This invention was made with government support under Grant Number R01-DA021146 awarded by the National Institutes of Health. The government has certain rights to this invention

BACKGROUND

Field

[0002] The disclosure relates generally to the field of medical imaging, and more specifically to systems, methods, and devices for removing prospective motion correction from medical imaging scans.

Description

[0003] Medical imaging scans are required for various medical treatments and/or diagnoses. Some medical imaging scan technologies require that a patient be scanned for an extended period of time, and any motion by the patient during this extended period of time can introduce motion artifacts and other errors into the resulting images. Accordingly, motion compensation techniques have been developed to compensate for patient motion during a scan. Although motion compensation techniques can in many instances improve clarity of images, among other benefits, such techniques are not without deficiencies.

SUMMARY

[0004] The disclosure herein provides systems, methods, and devices for removing prospective motion correction from medical imaging scans. For purposes of

this summary, certain aspects, advantages, and novel features of the invention are described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

[0005] In certain embodiments, a system for generating motion de-corrected images in conjunction with a biomedical imaging scan comprises: a biomedical image scanner; one or more detectors configured to capture motion data for an object being scanned by the biomedical image scanner; a detector processing interface configured to generate motion tracking data from the captured motion data, the motion tracking data indicating the position of the object being scanned by the biomedical image scanner; a scanner controller configured to adjust the biomedical image scanner using the motion tracking data to compensate in real time for object motions, such that the raw image data generated by the scanner can be reconstructed into motion-corrected images; and an image processing interface comprising: a motion-corrected images generator configured to reconstruct images based on the raw image data generated by the scanner; and a motion de-corrected images generator configured to generate, based on the raw image data and the motion tracking data, de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de-corrected image data can be reconstructed into de-corrected images.

[0006] In some embodiments, the motion de-corrected images generator generates de-corrected images by inverting the motion tracking data generated by the detector processing interface and applying the inverted motion tracking data to the raw image data to generate de-corrected image data. In some embodiments, the imaging processing interface is further configured to reconstruct images based on the de-corrected image data. In some embodiments, the image processing interface is further configured to: transmit motion-corrected images and the de-corrected images to an electronic display for simultaneous display to a user. In some embodiments, the motion-corrected images and the de-corrected images are displayed on an electronic display device. In some embodiments, the motion de-corrected images are generated using a regridding process to remove the effects of compensating for motions of the object being scanned. In some

embodiments, the motion de-corrected images generator uses a SENSE algorithm to de-correct the raw image data using the motion tracking data. In some embodiments, the system further comprises a marker coupled to the object being scanned, wherein the detector processing interface is configured to track the motion of the marker to generate motion tracking data. In some embodiments, the detector processing interface further comprises a tracking combination component configured to combine two or more sets of tracking data to generate a position of the object being scanned. In some embodiments, the one or more detectors are at least partially embedded in a wall of the biomedical imaging scanner. In some embodiments, the biomedical imaging scanner comprises a wall positioned between an MRI magnet and a bore for positioning therein of a patient, the wall comprising a first side proximal to the bore and a second side distal to the bore, wherein the one or more detectors are positioned in a cavity adjacent the second side of the wall. In some embodiments, the scanner is one of an MRI or a CT scanning system.

[0007] In certain embodiments, a system for generating motion de-corrected images in conjunction with a biomedical imaging scan comprises: a magnetic resonance imaging (MRI) scanner; one or more detectors configured to capture motion data for an object being scanned by the MRI scanner; a detector processing interface configured to generate motion tracking data from the captured motion data, the motion tracking data indicating the position of the object being scanned by the MRI scanner; a scanner controller configured to adjust the MRI scanner using the motion tracking data to compensate in real time for object motions, such that the raw image data generated by the scanner can be reconstructed into motion-corrected images; and an image processing interface comprising: a motion-corrected images generator configured to reconstruct images based on the raw image data generated by the scanner; and a motion de-corrected images generator configured to generate, based on the raw image data and the motion tracking data, de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de-corrected image data can be reconstructed into de-corrected images.

[0008] In certain embodiments, a computer implemented-method for generating motion de-corrected images in conjunction with a biomedical imaging scan comprises: tracking, by a computer system, motion of an object being scanned by a scanner; generating, by the computer system, motion tracking data indicating the position of the object being scanned; adjusting, by the computer system, a biomedical imaging

scanner, using the motion tracking data, to compensate in real time for object motion, such that raw image data generated by the scanner can be reconstructed into motion-corrected images; inverting, by the computer system, the motion tracking data to generated inverted motion tracking data; and applying, by the computer system, the inverted motion tracking data to the raw image data to generate de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de-corrected image data can be reconstructed into de-corrected images, wherein the computer system comprises an electronic memory and a computer processor.

[0009] In some embodiments, the computer-implemented method further comprises, reconstructing, by the computer system, images based on the de-corrected image data. In some embodiments, the computer-implemented method further comprises: reconstructing, by the computing system, images based on the raw image data generated by the scanner; and transmitting, by the computer system, the motion-corrected images and the de-corrected images to an electronic display for simultaneous display to a user. In some embodiments, the computer-implemented method further comprises: transmitting, by the computer system, data enabling display, simultaneously with the motion-corrected and de-corrected images, of a pictorial representation of the tracked motion. In some embodiments, tracking motion of an object being scanned comprises tracking motion of a marker coupled to the object. In some embodiments, tracking motion of an object being scanned comprises combining two or more sets of tracking data to generate a position of the object being scanned. In some embodiments, compensating in real time for object motion further comprises updating geometric parameters of the scanner based on an updated position of the object being scanned. In some embodiments, the scanner generates raw image data using a process comprising: exciting, by the biological image scanner, nuclei within the object being scanned; applying, by the biomedical image scanner, a magnetic field gradient across the object being scanned; and receiving, at a receiver coil, radiofrequency signals indicating one or more features of the object being scanned.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The foregoing and other features, aspects, and advantages of the present invention are described in detail below with reference to the drawings of various

embodiments, which are intended to illustrate and not to limit the invention. The drawings comprise the following figures in which:

[0011] FIG. 1 depicts an embodiment of a schematic diagram illustrating a biomedical imaging motion compensation system.

[0012] FIG. 2 is a block diagram depicting another embodiment of a biomedical imaging motion compensation system.

[0013] FIG. 3 depicts an embodiment of a process flow diagram illustrating an example of a motion correction removal process.

[0014] FIG. 4 depicts another embodiment of a process flow diagram illustrating an example of a motion correction removal process.

[0015] FIGS. 5A and 5B depict additional embodiments of a process flow diagram illustrating examples of motion correction removal processes.

[0016] FIGS. 6A and 6B depict additional embodiments of a process flow diagram illustrating examples of motion correction removal processes.

[0017] FIG. 7 depicts an embodiment of a process flow diagram illustrating an example of removing motion correction from raw imaging data.

[0018] FIGS. 8A and 8B illustrate motion traces depicting data obtained during a motion tracking process.

[0019] FIGS. 9A-9D depict various images from a medical imaging scan with and without motion correction.

[0020] FIG. 10 is a block diagram depicting an embodiment of a computer hardware system configured to run software for implementing one or more embodiments of the systems described herein.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0021] The disclosure herein provides systems, methods, and devices for removing prospective motion correction from medical imaging scans. Medical imaging scans are required for various medical treatments and/or diagnoses. A variety of biomedical imaging scan technologies are available, such as magnetic resonance imaging (MRI), computed tomography (CT), and the like. Some medical imaging scan technologies require that a subject be scanned for an extended period of time. During a scan, any motion of the patient or object being scanned can introduce motion artifacts and other errors into the resulting images. For example, if a patient is having their brain scanned in an MRI machine, the resulting images may have motion artifacts and/or be

blurry if the user or patient moves his or her head during scan. Motion compensation systems provide techniques for removing or preventing motion artifacts from showing up in a scan.

[0022] Although motion compensation systems can be beneficial in removing motion artifacts from medical imaging scans, some deficiencies in motion tracking and compensation systems exist. Because of potential deficiencies in compensation systems, some users of a medical imaging scanner, such as an MRI scanner operator, may not trust that the motion-compensated images are better than what would have been produced without motion compensation. Further, in some instances, such as, for example, when a patient did not move at all during a scan, a motion-compensated image may actually be of worse quality than if motion correction had not been applied. Accordingly, it can be beneficial to generate two or more sets of image data, some sets being motion-corrected, and other sets not being motion-corrected, so that a user can view the two or more sets of data to determine which is better to use and/or to instill a level of comfort that the motion-corrected data is better than the non-motion corrected data.

[0023] Further, many medical devices require clearance from the FDA. In achieving such clearance, the applicant may be required to show that a system works as intended. Accordingly, to achieve clearance for a motion compensation system, it can be useful to be able to generate both motion-corrected images and non-motion corrected images to show that the motion-corrected data is better or at least within requirements of the FDA.

[0024] Prospective motion correction can enable a medical imaging scanner to adjust itself in real time in response to tracking of patient motion. Prospective motion correction can thus enable images to be as accurate as possible. However, if prospective motion correction is applied, meaning the source data created by the scanner has already been compensated for motion, a problem arises in being able to provide non-motion corrected data. In such a case, non-motion corrected data was never acquired by the scanner; thus, if non-motion corrected data is to be presented to a user, in some embodiments it can be derived from the motion corrected data.

[0025] Various technologies have been developed to enable compensation for subject motion during a scan. For example, in some embodiments, a motion compensation system is configured to track movement or motion of an object being scanned and to adjust the scanner in real time to compensate for that motion. Examples

of such technology may be found in U.S. Patent No. 8,121,361, entitled MOTION TRACKING SYSTEM FOR REAL TIME ADAPTIVE IMAGING AND SPECTROSCOPY, filed on May 18, 2007 ('361 Patent), Patent Cooperation Treaty Application No. PCT/US2014/013546, entitled MOTION TRACKING SYSTEM FOR REAL TIME ADAPTIVE MOTION COMPENSATION IN BIOMEDICAL IMAGING, filed on January 29, 2014 ('546 Application), U.S. Patent Application No. 13/594563, entitled METHODS, SYSTEMS, AND DEVICES FOR INTRA-SCAN MOTION CORRECTION, filed on August 24, 2012 ('563 Application), and Patent Cooperation Treaty Application No. PCT/US2014/012806, entitled SYSTEMS, DEVICES, AND METHODS FOR TRACKING AND COMPENSATING FOR PATIENT MOTION DURING A MEDICAL IMAGING SCAN, filed on January 23, 2014 ('806 Application). Each of the forgoing patents and applications is hereby incorporated by reference herein in its entirety. In some embodiments, motion compensation can be in real time, meaning the raw image data outputted from a scanner has already been compensated for motion. This is sometimes termed prospective motion correction (PMC). For example, the system may record the orientation of the subject while performing the scan and store the raw imaging data according to the orientation of the subject and scanner. In other embodiments, motion compensation can be after the fact, such as by converting raw non-compensated scanner data into motion-compensated data through post-processing of the raw scanner data in conjunction with motion tracking data. In some embodiments described herein, a motion correction removal system is configured to remove motion compensation from data generated as part of a prospective motion correction system. However, in some embodiments, similar concepts may also be applied to a post-processing system.

[0026] One potential option for creating non-motion corrected data and motion corrected data for comparison is to run a first scan with the motion correction and a second scan without motion correction. For example, a second scan may be performed while a patient is instructed to remain as still as possible to compare with motion corrected images of the same or a different patient. Alternatively, the second scan may utilize a phantom object instead of a patient. During the second scan, the tracked motion data from the first scan can be used to simulate the motion of the patient in the first scan. This can therefore introduce motion artifacts into the second scan similar to what would have occurred in the first scan if PMC had not been used during the first scan. Such a

process has deficiencies. For example, the resulting images from the second scan will not be of the same scan as the first scan. Further, this process requires that the patient in the second scan remain as still as possible. If the patient moves, even through involuntary movements such as breathing, twitching, or other movement, the non-motion corrected data will be flawed. Another deficiency is that the patient may be required to undergo two scans, exposing the patient to further, for example, MRI emissions, extending the time required to conduct an MRI scan, and reducing the overall quality of treatment.

[0027] Unlike the two-scan process described above, embodiments of systems, methods, and devices disclosed herein enable both motion-corrected and non-motion corrected imaging data to be created from a single imaging scan. This reduces the number of scans that must be performed increasing the efficiency of the process. Accordingly, the system is configured to enable faster acquisition, processing, and displaying of both motion corrected and motion de-corrected images from a biomedical imaging scan. In addition, the reduced number of scans exposes a subject to reduced radiation. In some embodiments, the non-motion corrected data is referred to as de-corrected imaging data. For example, a system can be configured to acquire motion-compensated imaging data using prospective motion compensation, and to then de-correct that imaging data utilizing the tracked motion of the patient to provide a second de-corrected motion set that simulates what the scan would have produced had prospective motion correction not been used.

[0028] The de-correction process may start with raw imaging data from a scanner, which was acquired using prospective motion correction. The raw imaging data may include (or otherwise be associated with) tracking or motion data indicating the position and/or movement of the subject during the scanning process. To de-correct the raw imaging data, the system may invert the position and/or motion data of the user. The inverted motions can then be applied to the raw imaging data to generate a set of de-corrected raw imaging data. The de-corrected raw imaging data can then be reconstructed into de-corrected images for review by a user and comparison to motion-corrected images reconstructed from the original raw imaging data.

[0029] Although several embodiments, examples, and illustrations are disclosed, it will be understood by those of ordinary skill in the art that the inventions described herein extends beyond the specifically disclosed embodiments, examples, and illustrations and includes other uses of the inventions and obvious modifications and

equivalents thereof. Embodiments of the inventions are described with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The terminology used in the description presented herein is not intended to be interpreted in any limited or restrictive manner simply because it is being used in conjunction with a detailed description of certain specific embodiments of the inventions. In addition, embodiments of the inventions can comprise several novel features and no single feature is solely responsible for its desirable attributes or is essential to practicing the inventions herein described.

[0030] The embodiments and examples described herein are generally discussed in the context of patient scanning, in particular with an MRI scanner. However, the scope of the disclosure is not limited to scanning with an MRI, medical imaging scanning, or otherwise. The system may incorporate a variety of scanning systems or types in addition to, or instead of, an MRI scanner. Additionally, while the example embodiments are discussed in the context of a human patient, a scanning system incorporating the features disclosed herein may be used to scan humans, animals, plants, inanimate objects, and/or the like.

[0031] The embodiment of a motion compensation system 100 illustrated in FIG. 1 is not shown to scale, but is rather shown at a scale that helps facilitate illustration of the system. Other figures are also not shown to scale. Additionally, most embodiments illustrated in these figures and described in this specification comprise a motion compensation system operating in real time or substantially in real time to correct a scanner for motion of a patient or object. However, in other embodiments, a motion compensation system can be configured to operate by processing images using post-processing after they have been created by a scanner to remove any motion artifacts.

Motion De-Correction Systems

[0032] FIG. 1 is an embodiment of a schematic diagram illustrating a motion tracking system 100. The motion tracking system 100 comprises one or more detectors 102, a detector processing interface 104, a scanner controller 106, and a scanner 108. In an embodiment, the one or more detectors 102 are positioned generally within an interior volume of the scanner 108 (one of ordinary skill in the art will appreciate that the one or more detectors can be positioned in other locations, for example, outside the volume of the scanner, embedded at least partially in a wall or magnet of the scanner, and/or the like) and positioned to each have a different viewpoint from which to view the subject 110 or

to detect information describing at least one feature or quality of the subject 110. For example, features or qualities of the subject 110 that may be detected by various detectors 102 include but are not limited to a visual image or depiction of the subject 110 or a portion of the subject 110, a distance of the subject 110 or a portion of the subject 110 to the detector 102, a surface texture of the subject 110 or a portion of the subject 110, an indentation or protrusion of the subject, an opening or orifice of the subject, a structural outline of the subject or a portion of the subject, another anatomical landmark or feature of the subject, or a marker attached to the subject. Various embodiments may be configured to employ various numbers of detectors 102 (including a single detector, two detectors, three detectors, or more detectors), and the detectors 102 can be positioned places other than within an interior volume of a scanner, as long at the detectors 102 are positioned to enable viewing the subject 110 or detecting information describing at least one quality of the subject 110 (for example, "patient movement data").

[0033] During an imaging scan, the detectors 102 are configured to acquire patient movement data and send the data to the detector processing interface 104. The detector processing interface 104 is configured to analyze the patient movement data using one or more tracking controllers or filters and to create tracking data describing movement or motion of the patient/object of interest in detector and/or scanner reference or coordinate frames. The tracking data is sent from the detector processing interface 104 to the scanner controller 106, the motion de-corrected images generator 122, and the motion corrected images generator 120. The scanner controller 106 is configured to adjust the scanner 108 in real time based on patient/object of interest movement described in the tracking data to enable creation of scanned images with no or few motion artifacts. For example, the scanner controller 106 can be configured to adjust scan planes, locations, and/or orientations of the scanner 108 in real time.

[0034] In some embodiments, the tracking data generated by the detector processing interface 104 is used to compensate for motion during image reconstruction or post-processing, rather than to directly adjust the scanner 108. In some embodiments, tracking data is used to both compensate for motion during image reconstruction and to directly adjust the scanner 108.

[0035] The motion de-corrected images generator 122 receives raw imaging data from the scanning controller 106 and movement data from the detector processing interface 104. The de-corrected images generator then uses the motion data to generate

images as they would have been without motion compensation. For example, in some embodiments, the motion data may indicate a position of a patient's head, which the scanner controller 106 used to adjust the scanner 108 to capture data in the correct orientation while scanning. The de-corrected images generator 122 may then use the motion data to adjust the raw imaging data to the orientation the scanner would have seen if not for the compensation. The de-corrected images generator 122 then generates images based on the adjusted raw imaging data. The motion-corrected images generator 124 uses the raw imaging data to generate motion compensated images. In some embodiments, the motion data is used by the motion-corrected images generator 124 in a post-processing technique to compensate the raw imaging data based on a record of the patient's movement. In such embodiments, the de-corrected images generator may not use the motion data, but instead generate images based directly on the raw imaging data from the scan that taken while not compensating for motion.

[0036] The term "detector" as used herein is a broad term, and unless otherwise indicated the term can include within its meaning, without limitation, a camera (either digital or analog, and either capable of capturing still images or movies) that can detect the visible spectrum or other portions of the electromagnetic spectrum, a proximity sensor, an ultrasonic sensor, a radar sensor, a laser-based sensors, time-of-flight cameras, or any other kind of detector. In embodiments where the detector is positioned within the bore of a medical imaging device, the term "detector" includes within its meaning a detector that is configured to not interfere or only comprises components that do not interfere with the imaging capability of the medical imaging device, for example, the detector does not generate electrical or magnetic interference that could cause artifacts in the images generated by the medical imaging device. In some embodiments one or more of the detectors may be fully or partially disposed within the wall of a scanner. For example, the detectors may be located in a cavity of scanning system. For example, an MRI scanner may comprise a cylindrical magnet that is positioned around a bore for positioning therein of a patient. In some embodiments, one or more detectors or cameras may be positioned at least partially within such magnet. In some embodiments, the magnet is at least partially positioned within a cavity of a housing. In some embodiments, the one or more detectors may be positioned at least partially within that housing. In some embodiments, the housing comprises a wall that separates the bore for positioning therein of the patient from the magnet. In some embodiments, the one or more detectors

may be positioned in, on, or adjacent to such wall. In some embodiments, the detectors may be positioned adjacent to a surface of the wall that is distal to the patient bore. In some embodiments, the detectors are positioned within a cavity at least partially defined by the wall, the detectors are configured to view the patient bore area through a hole or other at least partially transparent portion of the wall.

[0037] Various embodiments of motion tracking systems can be configured to use various types of detectors. In some embodiments, the detectors 102 are all cameras, with each detector 102 being configured to continuously record a partial or full view of the object of interest, such as a subject's face in the case of tracking a patient's head. Recording the partial or full views from various detector vantage points can enable increased accuracy and/or redundancy of various tracking techniques. In some embodiments, the detectors 102 may be cameras, laser-based sensors, projection-based sensors, radar sensors, ultrasonic sensors, other remote sensors, or any combination thereof.

[0038] The various components illustrated in FIG. 1 may be integrated into a biomedical scanning system or may be an add-on feature. For example, each of the components may be built directly into a scanning system during original manufacture. In some other embodiments, the components may be added onto an existing biomedical scanning system. For example, the detectors may be installed into a cavity within the biomedical scanner separately. In addition, in some embodiments, the processing is performed by the already existing computer systems specific to a biomedical scanning system. However, in some embodiments, additional computing system may be installed to perform the motion de-correction processes described herein.

[0039] FIG. 2 is a block diagram depicting an embodiment of a motion tracking system 200. The motion tracking system 200 comprises one or more detectors 102, a detector processing interface 104, a scanner controller 106, and a scanner 108, and an image processing interface 120. The detector processing interface further comprises several tracking controllers or filters 202 and a tracking combination interface 204. In the motion tracking system 200, the one or more detectors 102 send patient movement data (for example, camera images, distance estimates, signals, or the like) to the detector processing interface 104, and each of the several tracking controllers or filters 202 uses the patient movement data (or a portion of the patient movement data) to generate an estimate of movement of the patient/object of interest (for example, describing all six

degrees of freedom or fewer than six degrees of freedom). The tracking combination interface 204 is configured to receive each tracking controller's individual estimate and to combine them (or to select one of them) to create tracking data comprising a single or unitary movement estimate to send to the scanner controller 106. The tracking combination interface 204 may also be configured to send no motion updates to the scanner controller 106, for example, to retain the most recent motion data, if the difference in motion or amount or magnitude of tracked motion does not exceed a predetermined threshold. The scanner controller 106 is configured to update one or more parameters of the scanner 108 in real time based on this tracking data received from the detector processing interface 104. The image processing interface 120 further comprises a motion-corrected images generator 124 and a motion de-corrected images generator 122, which generate two sets of images, one with motion compensation and one with non-motion compensated images.

[0040] Several possible tracking controllers or filters 202, as shown in FIG. 2, either in isolation or in combination, can be configured to track the object of interest. One embodiment of a tracking controller or filter 202, for example Tracking Controller 1 shown in FIG. 2, is configured to track the position and orientation of anatomical features or "landmarks" during subject movement, and uses this information to derive the object of interest's (for example, the subject's head) movement. For example, when tracking a subject's head, if the position of the subject's two eyes and the position of the tip of the subject's nose are known in detector coordinates, then the three translations and three rotations of the subject's head can be derived by means of triangulation or other methods. In general, accuracy of such a tracking controller or filter 202 can be improved by tracking a greater number of anatomical features. For example, if the position of a subject's nostrils and/or the bridge of the nose are tracked in addition to the nose tip and the eyes, then tracking of the subject's head can be generally more accurate. Tracking accuracy can also be improved by utilizing a greater number of detectors 102 and/or positioning the detectors 102 to view the subject's head from a variety of angles. Furthermore, in some embodiments, a single tracking controller or filter can be configured to provide data for less than all six degrees of freedom, i.e. less than three translations and three rotations, in which case information from one or more other tracking controllers or filters may be used to complete the tracking of all six degrees of freedom.

[0041] Another embodiment of a tracking controller or filter 202, for example Tracking Controller 2 shown in FIG. 2, is configured to create a three-dimensional surface model of the object of interest (for example, a subject's head), and to calculate motion tracking information based on changes to the three-dimensional surface model as it is updated when the subject moves. A three-dimensional surface model tracking controller or filter can be configured to employ various types of detectors 102 and modeling methods. For example, the controller or filter is configured to create a surface model based on a surface texture of the object as detected by a detector or as detected by the scanner. In an embodiment, the controller or filter is configured to create a surface model based on changes in lighting and/or shading of the object of interest.

[0042] Some embodiments of tracking controllers or filters 202, for example Tracking Controller 3 shown in FIG. 2, are configured to use estimates of a distance of the object of interest (or a portion or portions of the object of interest) to one or more of the detectors 102. The position of the object of interest can then be estimated or derived by combining the distance estimates from multiple detectors 102 and/or by monitoring changes in the distance estimates from an individual detector 102. Some distance estimation controller embodiments are configured to utilize, for example, range imaging, stereo triangulation, interferometry, or the like.

[0043] Other embodiments of tracking controllers or filters 202, for example Tracking Controller 4 shown in FIG. 2, are configured to track changes in a known pattern, for example, a regular grid, projected onto the object of interest. A projector projects one or more patterns onto the object of interest from one or more projection locations, and one or more detectors 102 detect images of the pattern projected onto the object of interest. The tracking controller or filter 202 is configured to analyze deformations and/or changes to the projection(s) as the subject 110 moves to derive an estimate of the object of interest's positioning.

[0044] Some embodiments of tracking controllers or filters 202 are configured to track light reflected from reflective and/or absorbent particles suspended or contained in a compound applied to a subject's skin. The compound can be, for example, a paste, a cream, a glue, a temporary tattoo, an ink, and the like. The compound can be painted, smeared, drawn, brushed, or otherwise applied to the subject's skin. The reflective particles can be configured to reflect light in different directions as the subject moves or rotates the skin area having the compound applied. For example, the reflective particles

can be prisms that refract light in a known fashion, glitter particles, or the like. The absorbent particles can also be configured to absorb light in different directions as the subject moves or rotates the skin area having the compound applied. For example, the absorbent particles can be dark spheres that absorb light in a known fashion, or the like. This embodiment of a tracking controller or filter 202 is configured to analyze images detected by the detectors 102 to track light reflections and/or alterations from the various reflective and/or absorbent particles in order to determine movement of the object of interest. In some embodiments, the tracking controller or filter 202 is configured to track reflections and/or absorption of ambient light. In some embodiments, the tracking controller or filter 202 is configured to track reflections and/or absorptions of an auxiliary light source directed generally toward the reflective and/or absorbent particles.

[0045] In some embodiments, various embodiments of tracking controllers or filters 202 (including those described above and those using various other techniques) can be used either independently or in combination with other tracking controllers or filters, including markerless tracking controllers or filters, and modules utilizing markers for motion tracking (for example, markers placed on the subject or object being scanned, markers held by the object or subject being scanned, and/or the like). A tracking combination interface, such as the tracking combination interface 204 shown in FIG. 2, can be configured to receive position or movement estimates from a variety of tracking controllers or filters 202 and to either select one of the estimates to send to the scanner controller 106 or to combine one or more of the estimates to form a single or unitary, more accurate estimate to send to the scanner controller 106. In some embodiments, the position or movement estimates received by the tracking combination interface 204 each describe six degrees of freedom (for example, three translations and three rotations). In some embodiments, the position or movement estimates received by the tracking combination interface 204 each describe fewer than six degrees of freedom. In some embodiments, some of the position or movement estimates received by the tracking combination interface describe six degrees of freedom, while others describe fewer than six degrees of freedom. Tracking combination interface 204 can be configured to combine estimates from tracking controllers or filters 202. In some embodiments, a tracking combination interface can be configured to send no motion updates to the scanner controller if the difference in motion or an amount or magnitude of tracked

motion does not exceed a predetermined threshold. In some embodiments, only a single tracking technique is utilized, and no tracking combination interface is used.

[0046] In some embodiments, all or some of the tracking controllers or filters 202 can be configured to use the same technique, but with different configurations. For example, a detector processing interface 104 can comprise multiple tracking controllers or filters 202 utilizing anatomical landmark tracking, with each tracking controller or filter 202 being configured to track a different anatomical landmark or set of anatomical landmarks. Additionally, in some embodiments, tracking controllers or filters 202 can be configured to utilize more than one tracking technique. For example, a tracking module 202 can be configured to utilize both anatomical landmark tracking and three-dimensional surface model tracking, but to send one unitary tracking estimate based on a combination of both methods to the tracking combination interface 204 for combination with the estimates of other tracking controllers or filters 202.

[0047] The motion de-corrected images generator 122 can in some embodiments be configured to use the motion data generated by the tracking combination interface 204 to de-correct the raw imaging data provided by the scanner 108 during the scanning process. The motion data may, for example, indicate a position of the patient or a movement of the patient since the last set of data was taken by the scanner 108. For example, the raw imaging data generated by the scanner may comprise (or otherwise be associated with) a set of data including position or location data corresponding to specific readings for the scanner. For example, the data may include scan planes, locations, or orientations of the scanner. The motion data may then indicate the position of the patient when a specific scan was taken by the scanner. In order to de-correct the raw imaging data, the de-corrected images generator 122 may be configured to, in some embodiments, adjust the orientation, location, and/or other parameter (or simulate such adjustment) associated with a reading to the position or configuration it would have been in if not for prospective motion compensation. The motion de-corrected images generator 122 may then generate images from the de-corrected raw imaging data. The motion-corrected images generator 124 generates images based on the raw imaging data. The images generated by both the de-corrected images generator 122 and the motion-corrected images generator 124 may be electronically stored for later review or one or both sets of images may be presented on a display screen. Example processes of generating de-corrected images are discussed further below with reference to FIGS. 3-9.

Motion De-correction Processes

[0048] FIG. 3 illustrates an embodiment of a process flow diagram depicting a process for generating both motion corrected and de-corrected images from a single medical imaging scan. At block 302, raw imaging data is provided by a scanner controller, such as the scanner controller 106. In this embodiment, the raw imaging data provided by the scanner controller has been corrected for patient motion using prospective motion correction. At block 304, the raw imaging data is reconstructed by, for example, the motion-corrected images generator 124 to produce motion-corrected images 306 for viewing by, for example, a radiologist.

[0049] At block 308, subject motion tracking data is provided. For example, the detector processing interface 104 can be configured to provide object orientation tracking data to the motion de-corrected images generator 122. In some embodiments, the motion tracking data is provided with and/or embedded in the raw imaging data. In some embodiments, the motion tracking data is associated with and or correlated with the raw imaging data, enabling the system to determine how specific portions of the motion tracking data correspond to specific portions of the raw imaging data. At block 310, the motion de-corrected images generator can be configured to invert the motion tracking data. For example, the motion tracking data may indicate that a patient rotated his or her head to the left. The system can be configured to invert this information such that the data for use in removing motion correction would indicate that the motion is to the right instead of to the left. For clarity, this is a relatively simple example, but one of skill in the art will recognize that inverting the data may be a relatively complex mathematical operation, involving in some embodiments inversion of data describing motion, orientation, or pose in, for example, six degrees of freedom. In some embodiments, block 310 is not used and the effects of motion compensation are removed directly using the motion data.

[0050] At block 312, the inverted motion data is utilized to remove the effects of prospective motion correction from the raw imaging data. For example, the motion de-corrected images generator 122 can be configured to utilize regridding or other processes or algorithms to remove the effects of prospective motion correction from the imaging raw data prior to image reconstruction. Gridding is a method of interpolating data from an arbitrary sampling pattern to a uniform grid. The results of block 312 in some embodiments is raw imaging data similar to the raw imaging data provided at block 302,

but created as if prospective motion correction had not been utilized during scan. At block 314, the system can be configured to reconstruct the raw imaging data with PMC removed to generate de-corrected images. The reconstruction process in block 314 may be the same or similar to as is used in block 304. For example, the de-corrected raw imaging data may be in the same format as the raw imaging data and may be compatible for reconstruction by the same system. At block 316, the de-corrected images are provided. In some embodiments, the system can be configured to display the de-corrected images next to the motion corrected images so that a user can compare the two to see which image is better and/or to prove that the motion corrected images are better.

[0051] FIG. 4 illustrates another embodiment of a process flow depicting a motion de-correcting process. In this example, the process is similar to the process flow illustrated in FIG. 3. However, unlike in FIG. 3, the imaging data is received using a parallel imaging technique. For example, the scanner may generate raw imaging data with spatial encoding based on sampling in parallel from an array of RF coils. In this case, based on the algorithm being used to generate the raw imaging data, the effect of the prospective motion correction is removed during the reconstruction from the raw imaging data. At block 402, raw imaging data generated with prospective motion correction applied is provided, for example by scanner controller 106. At block 404, the system is configured to reconstruct the raw imaging data into motion-corrected images, which are provided at block 406. At block 408, subject motion tracking data is provided. At block 410, the subject motion tracking data is inverted to be used in de-correcting the raw image data.

[0052] At block 412, the imaging raw data is de-corrected and reconstructed into de-corrected images using the inverted subject motion data. For example, the motion de-corrected images generator 122 can be configured to utilize the SENSE technique or algorithm with the inverted subject motion data to generate de-corrected images and/or de-corrected imaging raw data. SENSE is a parallel imaging reconstruction technique utilized in magnetic resonance imaging. Although in this embodiment the SENSE technique or algorithm is used, various other processes or algorithms could be used in de-correcting raw image data using subject motion tracking data or inverted subject motion tracking data. For example, the system may be configured to use SENSE, SMASH, GRAPPA, AUTO-SMASH, compressed sensing, and/or the like. Further these or similar

techniques may be used as applied to imaging technologies other than MRI. At block 414, the de-corrected images are provided.

[0053] FIG. 5A illustrates a process flow of an example of embodiments of one or more methods of de-correcting image data generated using prospective motion control. Beginning in block 502, the system acquires movement data from a plurality of detectors (or in some embodiments, one or more detectors) in the scanning environment. In block 504, the system analyzes the movement data to generate tracking data for prospective updating of geometric parameters (and/or other parameters) for use when acquiring scanning data. The tracking data may include a position or pose of the subject in comparison to a baseline position, motion of the subject in comparison to a previous position of the subject, and/or the like. The position and/or motion data generated by the system is also, in some embodiments, stored in a database for access later when generating de-corrected images. For example, the detector processing interface 104 may generate motion or position data of a subject using one or more tracking controllers 202 and a tracking combination interface 204 as discussed above. The prospective updates may be used by the scanner controller 106 in real time to direct the slices of imaging data taken by the scanner 108. In some embodiments, the geometric updates are made immediately prior to radiofrequency pulses are applied in order to accurately determine the position of readings that are taken by the scanner. By updating the geometry parameters and/or slice planes immediately prior to all radiofrequency pulses, a line-by-line correction of motion between successive excitations is possible. In other words, signals throughout the entire measurement can be aligned in position.

[0054] Moving on to block 506 and 508 the scanner performs raw imaging data acquisition. In block 506 the system initiates the scanner in preparation to take a set of scans. For example, in an MRI scanning system, the scanner may apply an RF pulse to excite nuclei in the subject. Then in block 508 the scanning device acquires raw imaging data at one or more receivers. The raw imaging data is acquired with compensation for any motion by the subject during the scanning process. Thus, in block 510, the images can be reconstructed directly from the raw imaging data acquired in block 508 to generate motion corrected images. The process used in block 510 may be one based on traditional imaging technologies or based on parallel processing techniques.

[0055] In block 512, the system accesses the motion or position data of the subject corresponding to the scanning process. For example, the position of the subject

used to generate geometric updates for use by the scanner may be stored in a matrix with position data corresponding to the data acquired by the scanner at the same time. The position and/or motion data may indicate the position of the subject in up to six degrees of freedom. The corresponding image data may be stored correlated with the motion or position or tracking data that was used to adjust the scanner during data acquisition.

[0056] In block 514, the system de-corrects the raw imaging data to remove the effect of the prospective motion control. In some embodiments, the system may de-correct the data, by inverting the positions and/or motions of the subject during the scanning process. For example, if the position of the subject during one step of scanning indicates that the subject was rotated 5 degrees to the left, the system may invert the position to rotate the position of the data 5 degrees to the right. Similar corrections can be made for rotations, translations, or other motions of the subject. For example, if the patient moved 5cm to the left and rotated 5 degrees to the right, the system may de-correct the corresponding imaging data by updating the position 5cm to the right and rotating it 5 degrees to the left.

[0057] In some embodiments, the tracking data associated with the position and/or motion data is used to de-correct the raw imaging data. For example, instead of inverting the positions and/or motions of the subject being scanned received from a detector processing interface, the system may invert the raw motion tracking data from the one or more detectors to then generate new inverted position and/or motion data associated with the scan. In some embodiments, generating the de-corrected raw imaging data is performed using the same processes that are used in a post-processing motion-correction system. For example, the inverted position and/or motion data may be applied to the raw imaging data in a post-processing motion-correction system, however, the inverted positions and/or motion data generates de-corrected raw imaging data when the original raw imaging data was generated using prospective motion correction.

[0058] In block 516, the system reconstructs and outputs the de-corrected images. The reconstruction process may be the same performed in block 510 and may be performed by the same systems or modules, however, the raw data has been updated to remove the effects of the prospective motion compensation used when acquiring the raw imaging data. The motion corrected and de-corrected images may be presented together for comparison. For example, the images may be presented on a display screen, printed, or stored for later access. In some embodiments, a pictorial or visual representation of the

tracked motion may also be displayed or otherwise presented along with the images. Such representation may be similar to as shown in, for example, FIGS. 18 and 21-23C of the '546 Application.

[0059] In some embodiments the de-corrected and motion-corrected images may be displayed (side by side or otherwise) for slice by slice comparison to the scanner operator or doctor or other user of the system. For example, the system may be configured to enable a doctor to scroll through a synchronized set of images or slices, such that the de-corrected and motion-corrected images or slices from the same corresponding point in time are always displayed together.. In some embodiments, the system may be configured to enable the user to scroll through the images or slices independently such that the de-corrected and motion-corrected images or slices may be from a different point in time.

[0060] In some embodiments, the system displays the motion-corrected and de-corrected images with a label indicating which set of imaging data is being shown. For example, the de-corrected images could be displayed with a label that states it is de-corrected imaging data. When comparing the images, the operator or doctor or other use may be enabled to save the better imaging data (or to indicate a preference for the motion-corrected or de-corrected data). In some embodiments, the doctor saves the entire 2D or 3D representation of the scanned area; however, in some embodiments, the doctor can also save slices individually to generate composite data, wherein the best image quality is used from each individual slice. In such embodiments, each individual slice may be labelled such that the individual slices of the composite scanned images are identified as motion-corrected or de-corrected. For example, the system may be configured to enable a user to generate a composite or merged set of scanned data or images that is created by interlacing or merging motion corrected and motion de-corrected images or slices into the same set of data (which may be created as a new set of data, or may be an edited version of existing data). In some embodiments, the system is configured to change the stored data by removing and/or adding individual slices. In some embodiments, the system is configured to generate a new set of data that comprises at least one of a motion corrected or de-corrected slice or image for each point in time of the subject scan. In some embodiments, the system is configured to generate or update header information for the dataset and/or individual images or slices, such as to indicate that a composite data set is being used, whether each slice or image has been motion corrected, and/or the like.

[0061] FIG. 5B illustrates a process flow of an example of embodiments of one or more methods of generating corrected and de-corrected images without prospective motion compensation by using, for example, post-processing techniques. The process is similar to the process described in reference to FIG. 5A. For example, blocks 502, 506, and 508 may each be performed in the same or a similar manner as described in reference to the processes in FIG. 5A. In block 505, the system uses the motion tracking data provided in block 502 to generate position and/or motion data about the subject. This data is stored for post-processing motion correction alongside (or otherwise associated with) the corresponding raw imaging data acquired by the scanner.

[0062] In blocks 506 and 508, the scanner scans the subject to acquire raw imaging data about the subject. Then, moving on to block 511, the system reconstructs the raw imaging data into final images. The reconstruction of the raw imaging data in this case generates de-corrected (or uncorrected) images because the scanning controller did not apply prospective motion control to the scanner while acquiring data. Therefore, motion artifacts from the process may be present in the reconstructed images.

[0063] In block 512, the system accesses motion and/or position data of the subject stored by the system in block 505. For example, the position of the subject may be stored as each scanning step is performed by the scanner. Moving to block 515, the raw imaging data is processed to remove the effects of the motion of the subject using one or more of a variety of potential processing algorithms. For example, if the position of the subject is shown to be 5 degrees rotated clockwise with respect to a baseline position, the raw image data may be processed, either before reconstruction or concurrently with reconstruction, to compensate for that positioning, eliminating or reducing any motion artifacts that would otherwise appear in the reconstructed images. When applied to each scan in the raw imaging data, a motion corrected set of raw imaging data is generated. In block 517, the system reconstructs and outputs the corrected images using the corrected raw imaging data. As noted above, in some embodiments, image reconstruction may occur concurrently with motion correction or compensation. The motion corrected and de-corrected images may be provided together for review.

[0064] FIGS. 6A and 6B illustrate more detailed embodiments of processes for generating de-corrected images during a scanning process. Beginning in blocks 602 and 612, the scanning process and motion compensation processes begin. In starting the motion compensation process, a baseline position of the subject may be taken, from

which the position of the subject during the scanning process can be compared. In block 610, one or more detectors acquire raw movement or tracking data indicating the movements and/or position of a subject (for example, one or more images created by one or more cameras, distance measurements, and/or a variety of other pieces of information that may be used to track object motion, as described in more detail above). The movement or tracking data may then be used by a detector processing interface in block 614 to determine the position of the subject compared to a baseline position. For example the detector processing interface may be as described with reference to FIGS. 1 and 2 above, and may include one or more tracking controllers and tracking combination interfaces to determine a position of the subject. In block 616, the detector processing interface outputs the position of the subject compared to the baseline position. The position may, for example, be stored as a matrix showing the position compared to the baseline, may be stored according to translations and rotations of the subject compared to the baseline, and/or may be stored in another format. The output including the position is stored in a motion database 615 for later use. The position data is also used by a scanner controller in block 618 to adjust the scanner to compensate for the updated position or motion of the subject. The scanner controller can then direct the scanner to acquire prospective motion compensated raw imaging data based on the position of the subject.

[0065] In block 604, the scanner acquires raw imaging data. The acquired data is compensated based on the tracked position of the subject by the scanner controller. Therefore, 2D or 3D data is generated with the position stored with respect to the position within the patient or subject instead of just to the position of the scanner. The raw imaging data is stored in a raw imaging database 605. The processes performed in blocks 610, 614, 616, and 618 are repeated by the system for each iteration of the scanner acquiring raw imaging data in block 604. For example, after outputting the position and/or motion data in block 616, and the scanning controller adjust the scanner in block 618, the system determines if the imaging scan is complete in block 620. If the scan is complete, the system moves on to block 622. If the scan is not complete, the motion compensation system repeats the processes of acquiring and analyzing the movement and/or position data of the subject.

[0066] In block 622, the image processing interface receives raw imaging data from raw imaging database 605. The raw imaging data was generated by the scanner with

prospective motion compensation. As such, in block 624, the image processing interface reconstructs and outputs motion-corrected images directly from the raw imaging data.

[0067] In block 626, the image processing interface accesses position and/or motion data of the subject from motion database 615. Moving on to block 628, the image processing interface removes the effects of the prospective motion control from the raw imaging data. For example, the positions used to compensate the scanning acquisition process may be inverted by the motion de-corrected images generator. The inverted positions may then be used to change the positions in the raw imaging data to remove the effect of the previously made corrections. Another example process for de-correcting images is described further below with reference to FIG. 7. In block 630, the image processing interface reconstructs the de-corrected images from the de-corrected raw imaging data.

[0068] In some embodiments, the processes shown in FIG. 6A may include fewer or additional steps. For example, the system may only generate de-corrected images and not motion corrected images. In addition, the processes performed in blocks 622 and 624 may be performed in parallel with those performed in block 626, 628, and 630, to reconstruct motion corrected and motion de-corrected images at the same time. Furthermore, while the processes illustrated in FIG. 6A illustrate reconstruction and/or de-correction of raw imaging data occurring after the scanning process has been completed, in some embodiments, the processes may occur in parallel. For example, as the scanner is scanning images with prospective motion correction, the image processing interface may be reconstructing the images into motion-corrected images in block 624, and performing the processes to generate de-corrected images.

[0069] FIG. 6B illustrates similar processes to those shown in FIG. 6A, only without using prospective motion control. The processes used for acquiring tracking data, generating motion and/or position data, and storing that information are the same as in FIG 6B. The first difference in the processes is in block 619. The scanner controller in FIG. 6B does not compensate for the updated position of the subject. Instead, in block 604, when the scanner acquires raw imaging data, the data is not compensated for motion.

[0070] The next difference from the processes performed in the embodiment illustrated in FIG. 6A, is the processing of the raw imaging data in blocks 623, 625, 627, 629, and 631 of Fig. 6B. In block 623, the image processing interface receives raw imagine data without prospective motion correction. The raw imaging data is then

reconstructed in block 625 as de-corrected or uncorrected images, potentially having one or more motion artifacts based on the subject's movements. In block 627, the image processing interface accesses position and/or motion data of the subject, which in block 629 is used to remove the effects of the subjects movement from the raw imaging data. In block 631, the motion corrected raw imaging data is reconstructed into motion corrected images to provide to a user. The reconstructed motion corrected and de-corrected images may be provided together for comparison and/or review.

[0071] FIG. 7 illustrates a process for generating de-corrected images from raw imaging data as used in some embodiments. In block 702, the system acquires raw imaging data. For example, raw imaging data is provided to the image processing system by a scanning device. The raw imaging data received has been generated with prospective motion compensation such that when reconstructed motion artifacts should be minimized. In block 704, the system acquires position and/or motion data from a motion database. The position data may be stored in a separate database from the raw imaging data or it may be stored in the same database, file, or location. For example, in some embodiments, each iteration of a scan from the scanner may include data of the corresponding position of the subject. The position of the subject indicated by the position data may in some embodiments be based on the change in position compared to a baseline position. For example the data may have information related to or describing the subject's movement in up to 6 degrees of freedom from the original position when scanning began.

[0072] In block 706, the system generates inverse motion data for each position or motion recorded in the motion database. For example, if the position of the subject corresponding to a scan indicates the position of the subject was rotated or translated in one direction, the system may generate inverse motion data indicating that the subject was rotated or translated in the opposite direction. This inverse motion data can then be used to reverse the effects of the prospective motion control from the scan.

[0073] As an example, in some embodiments, the rotational component of a subject's motion data may be stored as a matrix of values indicating the subject's movements. In one embodiment, the system stores the position of the subject as a set of quaternion rotation matrices. Taking the inverse of the quaternion matrix then provides inverse motion data which can be used to de-correct the prospective motion compensation from the raw imaging data. While using quaternion matrices has advantages, rotation matrices may provide a similar mechanism for de-correcting the raw imaging data. For

example, for a given unit quaternion (qr,qx,qy,qz)=(q1,q2,q3,q4) the corresponding rotation matrix dcm (discrete cosine matrix) is calculated using the following definition.

```
dcm(1,1) = q(1).^2 + q(2).^2 - q(3).^2 - q(4).^2;
dcm(1,2) = 2.*(q(2).*q(3) - q(1).*q(4));
dcm(1,3) = 2.*(q(2).*q(4) + q(1).*q(3));
dcm(2,1) = 2.*(q(2).*q(3) + q(1).*q(4));
dcm(2,2) = q(1).^2 - q(2).^2 + q(3).^2 - q(4).^2;
dcm(2,3) = 2.*(q(3).*q(4) - q(1).*q(2));
dcm(3,1) = 2.*(q(2).*q(4) - q(1).*q(3));
dcm(3,2) = 2.*(q(3).*q(4) + q(1).*q(2));
dcm(3,3) = q(1).^2 - q(2).^2 - q(3).^2 + q(4).^2;
```

[0074] Thus, as an example, the quaternion encoding a pure sagittal slice orientation `Orientation[0]=( -0.500000 0.500000 -0.500000, 0.500000)` as in the log file and (qr,qx,qy,qz)=(`0.500000 ,-0.500000 ,0.500000 ,-0.500000`) is transformed to the following rotation matrix:

$$R = \begin{pmatrix} 0 & 0 & 1 \\ -1 & 0 & 0 \\ 0 & -1 & 0 \end{pmatrix}$$

[0075] In block 708, the system applies the inverse motion data to the corresponding raw imaging data to generate de-corrected raw imaging data. For example, the position of each scan, slice, or other imaging data may be rotated or translated according to the inverse motion data associated with the imaging data. The imaging data is therefore placed in a position approximating the position it would have corresponded to if not for the prospective motion control. Then, in block 710 de-corrected images are generated from the de-corrected raw imaging data. The reconstruction process may occur as it normally would for any raw imaging data received from a scanner.

Testing of a Motion De-correction System

[0076] FIGS 8-9 illustrate an example of a test performed utilizing one embodiment of a motion de-correction or motion compensation removal system. In this test, three MPRAGE scans (1.3x1.3x1.3 mm3, TR=2000ms, TI=900ms,) were acquired. In two of the scans the subject continuously performed nodding and shaking motion. FIGS. 8A and 8B display the motion traces (translations only) during a 6 minute scan with maximum amplitude around 20mm and similar pattern for both scans. For a third and last scan the subject was told not to move and prospective motion correction was turned on (not shown). This serves as a baseline scan approximating what a clean scan would look like for each of the tests.

[0077] For the first scan with head motion (FIG. 8A) prospective motion correction was enabled. For the second scan (head motion according to FIG. 8B) prospective motion correction not applied, but the system was continuously logging the tracking, positions, and/or motion data of the subject and the camera frame numbers.

[0078] Results from the test can be seen in FIGS. 9A-9D. In FIG. 9A the base line image acquired from a stationary head pose is shown. In this first image, prospective motion correction was applied and resulted in a clean scan showing clear details. FIG. 6B illustrates an image from a scan with prospective motion correction applied, but with movement from the subject. In this example, the movement shown in FIG. 8A has been removed using prospective motion correction. FIG. 9D shows the case of a scan where the subject moved and prospective motion correction was not applied during the scanning process. The slow but rather pronounced head motion shown in FIG. 8B results in dramatic degradation of the image quality up to a point where it becomes non-diagnostic or cannot be used for gray/white matter segmentation.

[0079] The motion traces from FIG. 8A were then used to undo the effects of the prospective motion correction with the result (FIG. 9C) showing how the image would have looked if prospective motion correction switched off. In some embodiments, the "undoing" process can be similar to the processes illustrated in FIGS. 3-9, as further described above. The "de-corrected" reconstruction in FIG. 9C shows similar artifacts as the uncorrected image in FIG. 9D. The different motion traces of both runs are likely to be responsible for the differences in the artifacts visible. That is, because the motion of the subjects was not exactly the same, the degradation in the uncorrected images shown in FIG. 9D and the degradation of the de-corrected images shown in FIG. 9C are not exactly the same.

Computing System

[0080] FIG. 10 is a block diagram depicting an embodiment of a computer hardware system configured to run software for implementing one or more embodiments of the motion correction removal systems described herein.

[0081] In some embodiments, the computer clients and/or servers described above take the form of a computing system 1000 illustrated in FIG. 10, which is a block diagram of one embodiment of a computing system that is in communication with one or more computing systems 1017 and/or one or more data sources 1019 via one or more networks 1016. The computing system 1000 may be used to implement one or more of

the systems and methods described herein. In addition, in one embodiment, the computing system 1000 may be configured to manage access or administer a software application. While FIG. 10 illustrates one embodiment of a computing system 1000, it is recognized that the functionality provided for in the components and modules of computing system 1000 may be combined into fewer components and modules or further separated into additional components and modules.

Motion Correction Removal System Module

[0082] In one embodiment, the computing system 1000 comprises a motion correction removal system 1006 that carries out the functions described herein with reference to removing prospective motion correction from images, including any one of techniques described above. The motion correction removal system 1006 and/or other modules may be executed on the computing system 1000 by a central processing unit 1002 discussed further below.

[0083] In general, the word "module," as used herein, refers to logic embodied in hardware or firmware, or to a collection of software instructions, possibly having entry and exit points, written in a programming language, such as, for example, COBOL, CICS, Java, Lua, C or C++. A software module may be compiled and linked into an executable program, installed in a dynamic link library, or may be written in an interpreted programming language such as, for example, BASIC, Perl, or Python. It will be appreciated that software modules may be callable from other modules or from themselves, and/or may be invoked in response to detected events or interrupts. Software instructions may be embedded in firmware, such as an EPROM. It will be further appreciated that hardware modules may be comprised of connected logic units, such as gates and flip-flops, and/or may be comprised of programmable units, such as programmable gate arrays or processors. The modules described herein are preferably implemented as software modules, but may be represented in hardware or firmware. Generally, the modules described herein refer to logical modules that may be combined with other modules or divided into sub-modules despite their physical organization or storage.

Computing System Components

[0084] In one embodiment, the computing system 1000 also comprises a mainframe computer suitable for controlling and/or communicating with large databases, performing high volume transaction processing, and generating reports from large

databases. The computing system 1000 also comprises a central processing unit ("CPU") 1002, which may comprise a conventional microprocessor. The computing system 1000 further comprises a memory 1004, such as random access memory ("RAM") for temporary storage of information and/or a read only memory ("ROM") for permanent storage of information, and a mass storage device 1008, such as a hard drive, diskette, or optical media storage device. Typically, the modules of the computing system 1000 are connected to the computer using a standards based bus system. In different embodiments, the standards based bus system could be Peripheral Component Interconnect (PCI), Microchannel, SCSI, Industrial Standard Architecture (ISA) and Extended ISA (EISA) architectures, for example.

[0085] The computing system 1000 comprises one or more commonly available input/output (I/O) devices and interfaces 1012, such as a keyboard, mouse, touchpad, and printer. In one embodiment, the I/O devices and interfaces 1012 comprise one or more display devices, such as a monitor, that allows the visual presentation of data to a user. More particularly, a display device provides for the presentation of GUIs, application software data, and multimedia presentations, for example. In one or more embodiments, the I/O devices and interfaces 1012 comprise a microphone and/or motion sensor that allow a user to generate input to the computing system 1000 using sounds, voice, motion, gestures, or the like. In the embodiment of FIG. 10, the I/O devices and interfaces 1012 also provide a communications interface to various external devices. The computing system 1000 may also comprise one or more multimedia devices 1010, such as speakers, video cards, graphics accelerators, and microphones, for example.

Computing System Device/Operating System

[0086] The computing system 1000 may run on a variety of computing devices, such as, for example, a server, a Windows server, a Structure Query Language server, a Unix server, a personal computer, a mainframe computer, a laptop computer, a tablet computer, a cell phone, a smartphone, a personal digital assistant, a kiosk, an audio player, an e-reader device, and so forth. The computing system 1000 is generally controlled and coordinated by operating system software, such as z/OS, Windows 95, Windows 98, Windows NT, Windows 2000, Windows XP, Windows Vista, Windows 7, Windows 8, Linux, BSD, SunOS, Solaris, Android, iOS, BlackBerry OS, or other compatible operating systems. In Macintosh systems, the operating system may be any available operating system, such as MAC OS X. In other embodiments, the computing

system 1000 may be controlled by a proprietary operating system. Conventional operating systems control and schedule computer processes for execution, perform memory management, provide file system, networking, and I/O services, and provide a user interface, such as a graphical user interface ("GUI"), among other things.

Network

[0087] In the embodiment of FIG. 10, the computing system 1000 is coupled to a network 1016, such as a LAN, WAN, or the Internet, for example, via a wired, wireless, or combination of wired and wireless, communication link 1014. The network 1016 communicates with various computing devices and/or other electronic devices via wired or wireless communication links. In the embodiment of FIG. 10, the network 1016 is communicating with one or more computing systems 1017 and/or one or more data sources 1019.

[0088] Access to the motion correction removal system 1006 of the computer system 1000 by computing systems 1017 and/or by data sources 1019 may be through a web-enabled user access point such as the computing systems' 1017 or data source's 1019 personal computer, cellular phone, smartphone, laptop, tablet computer, e-reader device, audio player, or other device capable of connecting to the network 1016. Such a device may have a browser module that is implemented as a module that uses text, graphics, audio, video, and other media to present data and to allow interaction with data via the network 1016.

[0089] The browser module may be implemented as a combination of an all points addressable display such as a cathode-ray tube (CRT), a liquid crystal display (LCD), a plasma display, or other types and/or combinations of displays. In addition, the browser module may be implemented to communicate with input devices 1012 and may also comprise software with the appropriate interfaces which allow a user to access data through the use of stylized screen elements such as, for example, menus, windows, dialog boxes, toolbars, and controls (for example, radio buttons, check boxes, sliding scales, and so forth). Furthermore, the browser module may communicate with a set of input and output devices to receive signals from the user.

[0090] The input device(s) may comprise a keyboard, roller ball, pen and stylus, mouse, trackball, voice recognition system, or pre-designated switches or buttons. The output device(s) may comprise a speaker, a display screen, a printer, or a voice synthesizer. In addition a touch screen may act as a hybrid input/output device. In

another embodiment, a user may interact with the system more directly such as through a system terminal connected to the score generator without communications over the Internet, a WAN, or LAN, or similar network.

[0091] In some embodiments, the system 1000 may comprise a physical or logical connection established between a remote microprocessor and a mainframe host computer for the express purpose of uploading, downloading, or viewing interactive data and databases on-line in real time. The remote microprocessor may be operated by an entity operating the computer system 1000, including the client server systems or the main server system, an/or may be operated by one or more of the data sources 1019 and/or one or more of the computing systems 1017. In some embodiments, terminal emulation software may be used on the microprocessor for participating in the micro-mainframe link.

[0092] In some embodiments, computing systems 1017 who are internal to an entity operating the computer system 1000 may access the motion correction removal system 1006 internally as an application or process run by the CPU 1002.

User Access Point

[0093] In an embodiment, a user access point or user interface comprises a personal computer, a laptop computer, a tablet computer, an e-reader device, a cellular phone, a smartphone, a GPS system, a Blackberry® device, a portable computing device, a server, a computer workstation, a local area network of individual computers, an interactive kiosk, a personal digital assistant, an interactive wireless communications device, a handheld computer, an embedded computing device, an audio player, or the like.

Other Systems

[0094] In addition to the systems that are illustrated in FIG. 10, the network 1016 may communicate with other data sources or other computing devices. The computing system 1000 may also comprise one or more internal and/or external data sources. In some embodiments, one or more of the data repositories and the data sources may be implemented using a relational database, such as DB2, Sybase, Oracle, CodeBase and Microsoft® SQL Server as well as other types of databases such as, for example, a flat file database, an entity-relationship database, and object-oriented database, and/or a record-based database.

[0095] Conditional language, such as, among others, "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context

as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment. The headings used herein are for the convenience of the reader only and are not meant to limit the scope of the inventions or claims.

[0096] Although these inventions have been disclosed in the context of certain preferred embodiments and examples, it will be understood by those skilled in the art that the present inventions extend beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the inventions and obvious modifications and equivalents thereof. Additionally, the skilled artisan will recognize that any of the above-described methods can be carried out using any appropriate apparatus. Further, the disclosure herein of any particular feature, aspect, method, property, characteristic, quality, attribute, element, or the like in connection with an embodiment can be used in all other embodiments set forth herein. For all of the embodiments described herein the steps of the methods need not be performed sequentially. Thus, it is intended that the scope of the present inventions herein disclosed should not be limited by the particular disclosed embodiments described above.

WHAT IS CLAIMED IS:

1. A system for generating motion de-corrected images in conjunction with a biomedical imaging scan, the system comprising:

a biomedical image scanner;

one or more detectors configured to capture motion data for an object being scanned by the biomedical image scanner;

a detector processing interface configured to generate motion tracking data from the captured motion data, the motion tracking data indicating the position of the object being scanned by the biomedical image scanner;

a scanner controller configured to adjust the biomedical image scanner using the motion tracking data to compensate in real time for object motions, such that the raw image data generated by the scanner can be reconstructed into motion-corrected images; and

an image processing interface comprising:

a motion-corrected images generator configured to reconstruct images based on the raw image data generated by the scanner; and

a motion de-corrected images generator configured to generate, based on the raw image data and the motion tracking data, de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de-corrected image data can be reconstructed into de-corrected images.

2. The system of Claim1, wherein the motion de-corrected images generator generates de-corrected images by inverting the motion tracking data generated by the detector processing interface and applying the inverted motion tracking data to the raw image data to generate de-corrected image data.

3. The system of Claim1, wherein the imaging processing interface is further configured to reconstruct images based on the de-corrected image data.

4. The system of Claim3, wherein the image processing interface is further configured to:

transmit motion-corrected images and the de-corrected images to an electronic display for simultaneous display to a user.

5. The system of Claim4, wherein the motion-corrected images and the de-corrected images are displayed on an electronic display device.

6. The system of Claim 1, wherein the motion de-corrected images are generated using a regridding process to remove the effects of compensating for motions of the object being scanned.

7. The system of Claim 1, wherein the motion de-corrected images generator uses a SENSE algorithm to de-correct the raw image data using the motion tracking data.

8. The system of Claim 1, further comprising a marker coupled to the object being scanned, wherein the detector processing interface is configured to track the motion of the marker to generate motion tracking data.

9. The system of Claim 1, wherein the detector processing interface further comprises a tracking combination component configured to combine two or more sets of tracking data to generate a position of the object being scanned.

10. The system of Claim 1, wherein the one or more detectors are at least partially embedded in a wall of the biomedical imaging scanner.

11. The system of Claim 1, wherein the biomedical imaging scanner comprises a wall positioned between an MRI magnet and a bore for positioning therein of a patient, the wall comprising a first side proximal to the bore and a second side distal to the bore, wherein the one or more detectors are positioned in a cavity adjacent the second side of the wall.

12. The system of Claim 1, wherein the scanner is one of an MRI or a CT scanning system.

13. A computer implemented-method for generating motion de-corrected images in conjunction with a biomedical imaging scan, the computer implemented-method comprising:

tracking, by a computer system, motion of an object being scanned by a scanner;

generating, by the computer system, motion tracking data indicating the position of the object being scanned;

adjusting, by the computer system, a biomedical imaging scanner, using the motion tracking data, to compensate in real time for object motion, such that raw image data generated by the scanner can be reconstructed into motion-corrected images;

inverting, by the computer system, the motion tracking data to generated inverted motion tracking data; and

applying, by the computer system, the inverted motion tracking data to the raw image data to generate de-corrected image data representative of what the scanner would produce had the scanner not compensated for motion, wherein the de-corrected image data can be reconstructed into de-corrected images,

wherein the computer system comprises an electronic memory and a computer processor.

14. The computer-implemented method of Claim 13, further comprising, reconstructing, by the computer system, images based on the de-corrected image data.

15. The computer-implemented method of Claim 14, further comprising:

reconstructing, by the computing system, images based on the raw image data generated by the scanner; and

transmitting, by the computer system, the motion-corrected images and the de-corrected images to an electronic display for simultaneous display to a user.

16. The computer-implemented method of Claim 15, further comprising:

transmitting, by the computer system, data enabling display, simultaneously with the motion-corrected and de-corrected images, of a pictorial representation of the tracked motion.

17. The computer-implemented method of Claim 13, wherein tracking motion of an object being scanned comprises tracking motion of a marker coupled to the object.

18. The computer-implemented method of Claim 13, wherein tracking motion of an object being scanned comprises combining two or more sets of tracking data to generate a position of the object being scanned.

19. The computer-implemented method of Claim 13, wherein compensating in real time for object motion further comprises updating geometric parameters of the scanner based on an updated position of the object being scanned.

20. The computer-implemented method of Claim 13, wherein the scanner generates raw image data using a process comprising:

exciting, by the biological image scanner, nuclei within the object being scanned;

applying, by the biomedical image scanner, a magnetic field gradient across the object being scanned; and

receiving, at a receiver coil, radiofrequency signals indicating one or more features of the object being scanned.

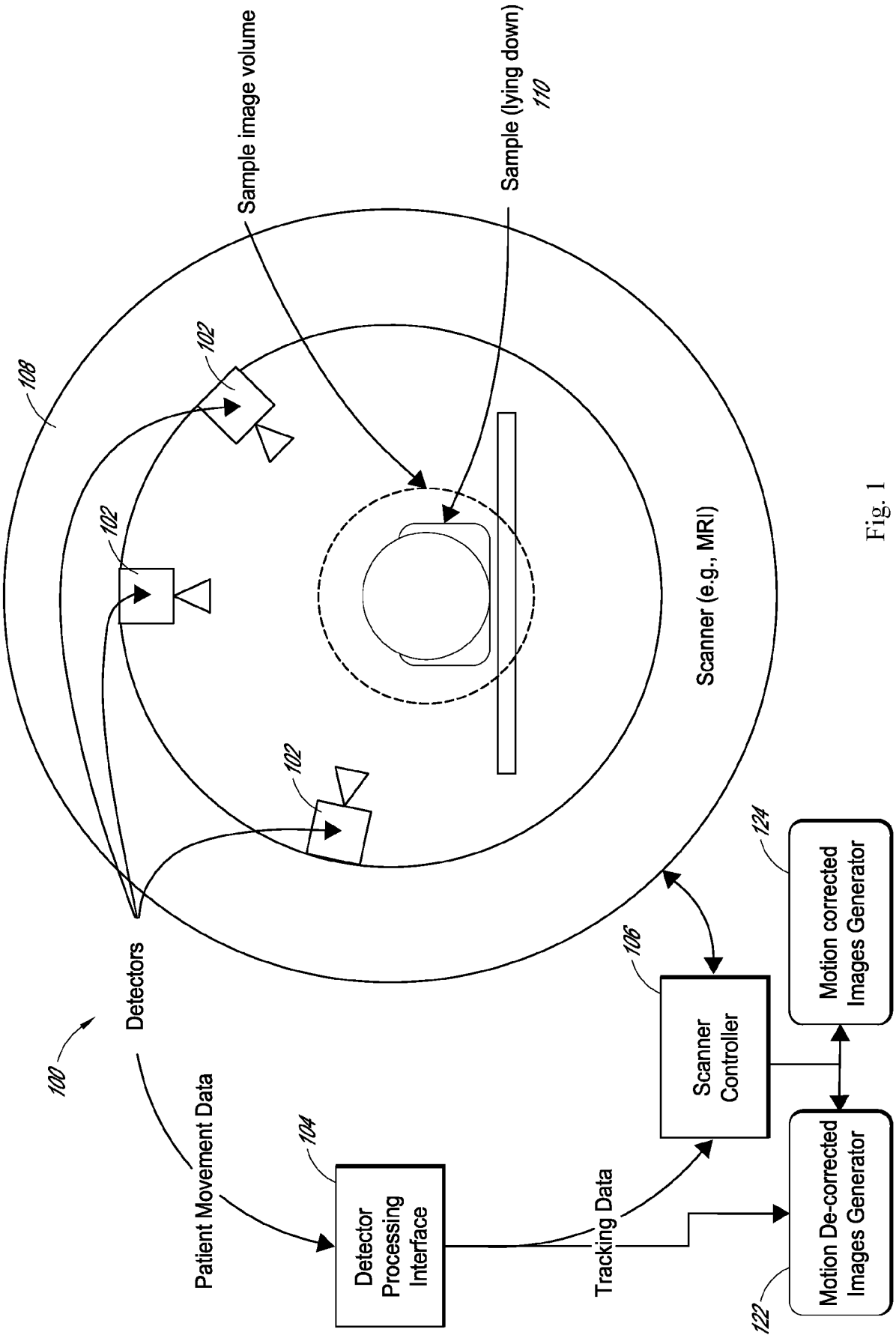
Sample image volume
Sample (lying down)
110
108
102
102
102
Scanner (e.g., MRI)
100
Detectors
Patient Movement Data
104
Detector Processing Interface
Tracking Data
106
Scanner Controller
124
Motion corrected Images Generator
122
Motion De-corrected Images Generator

Fig. 1

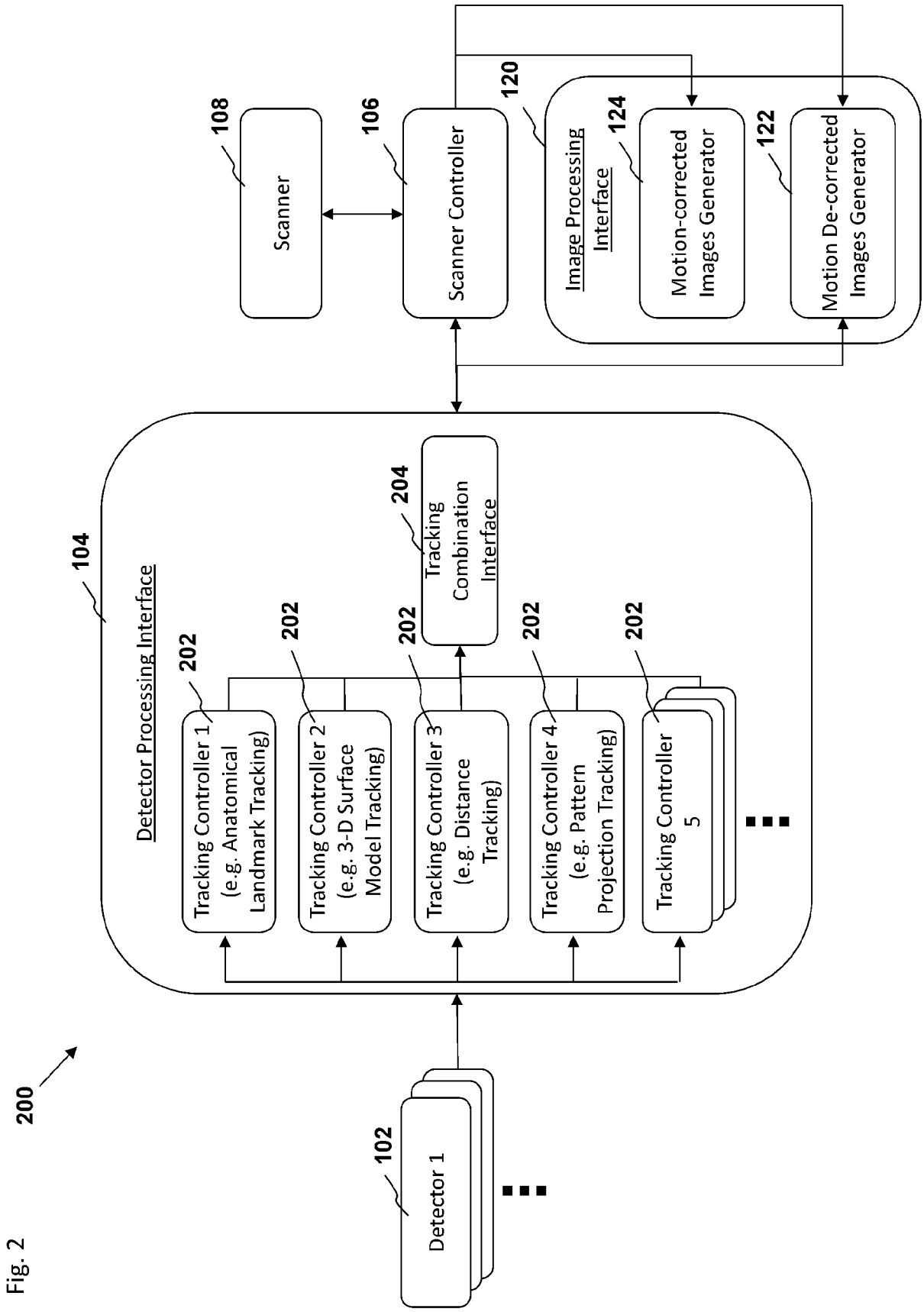
200
Detector 1
102
Detector Processing Interface
104
Tracking Controller 1 (e.g. Anatomical Landmark Tracking)
Tracking Controller 2 (e.g. 3-D Surface Model Tracking)
Tracking Controller 3 (e.g. Distance Tracking)
Tracking Controller 4 (e.g. Pattern Projection Tracking)
Tracking Controller 5
202
Tracking Combination Interface
204
Scanner
108
Scanner Controller
106
Image Processing Interface
120
Motion-corrected Images Generator
124
Motion De-corrected Images Generator
122

Fig. 2

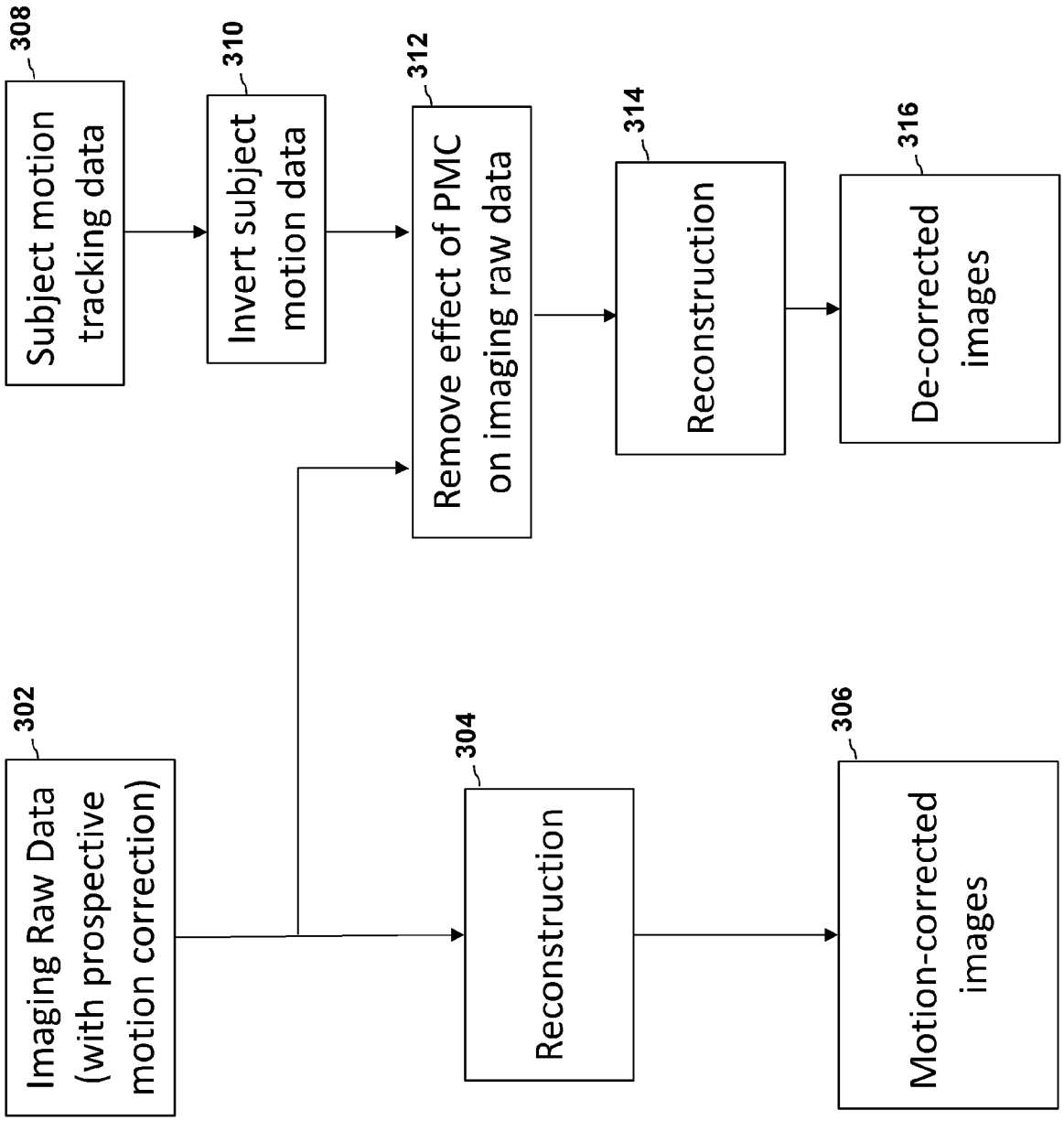
308
Subject motion tracking data
310
Invert subject motion data
312
Remove effect of PMC on imaging raw data
314
Reconstruction
316
De-corrected images
302
Imaging Raw Data (with prospective motion correction)
304
Reconstruction
306
Motion-corrected images

Fig. 3

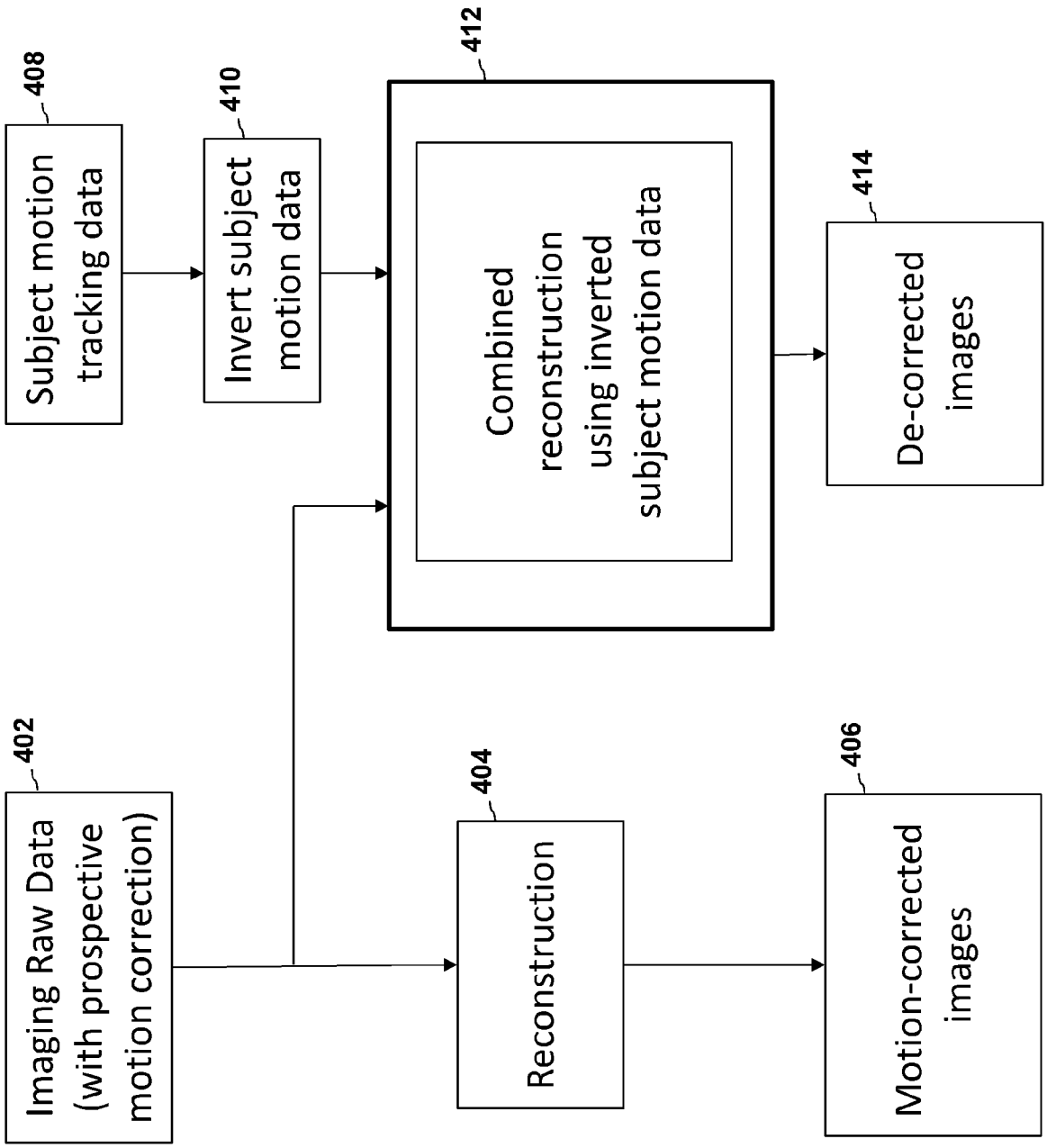
408
Subject motion tracking data
410
Invert subject motion data
412
Combined reconstruction using inverted subject motion data
414
De-corrected images
402
Imaging Raw Data (with prospective motion correction)
404
Reconstruction
406
Motion-corrected images

Fig. 4

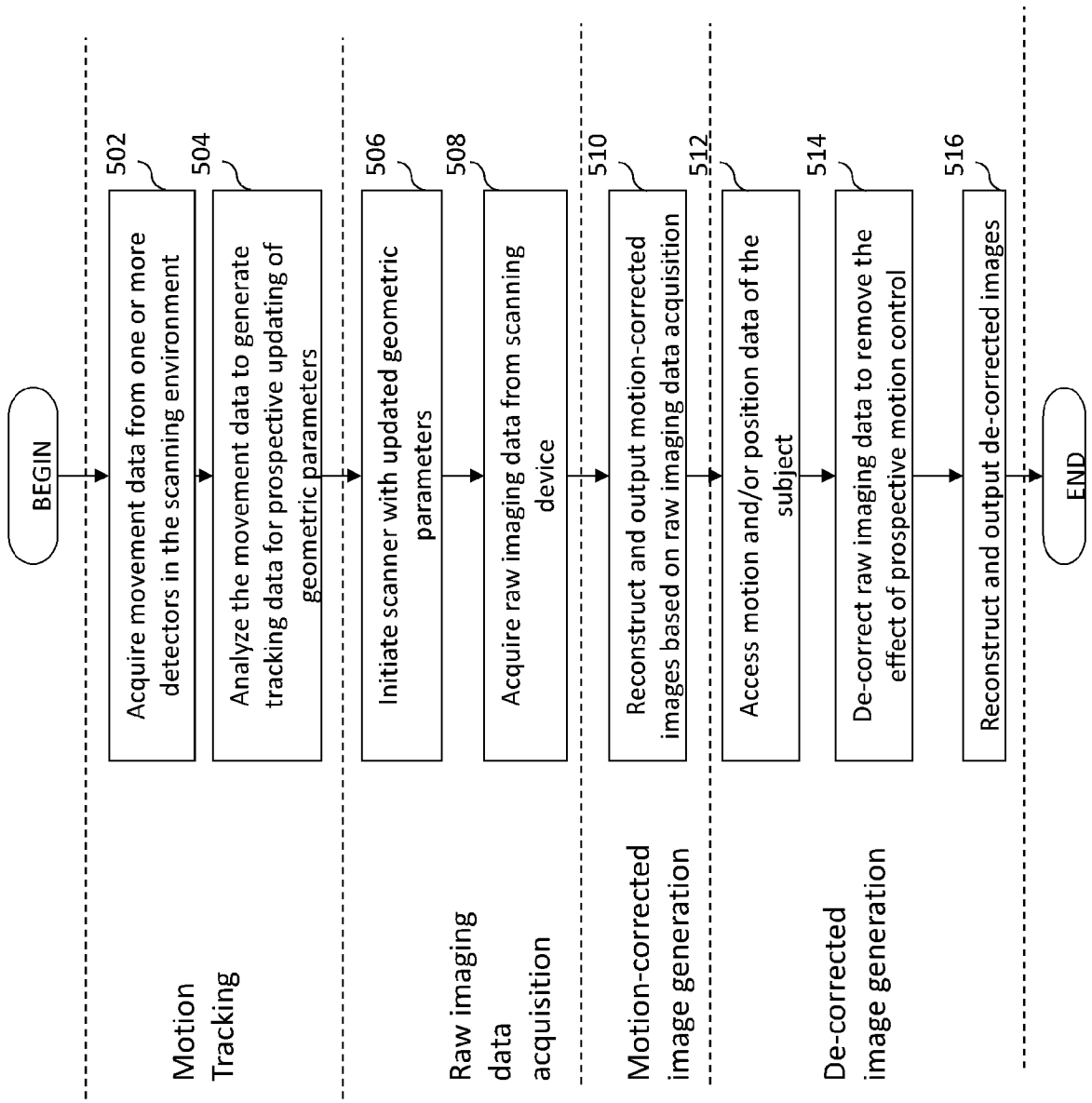
BEGIN
Acquire movement data from one or more detectors in the scanning environment
502
Analyze the movement data to generate tracking data for prospective updating of geometric parameters
504
Initiate scanner with updated geometric parameters
506
Acquire raw imaging data from scanning device
508
Reconstruct and output motion-corrected images based on raw imaging data acquisition
510
Access motion and/or position data of the subject
512
De-correct raw imaging data to remove the effect of prospective motion control
514
Reconstruct and output de-corrected images
516
END
Motion Tracking
Raw imaging data acquisition
Motion-corrected image generation
De-corrected image generation

Fig. 5A

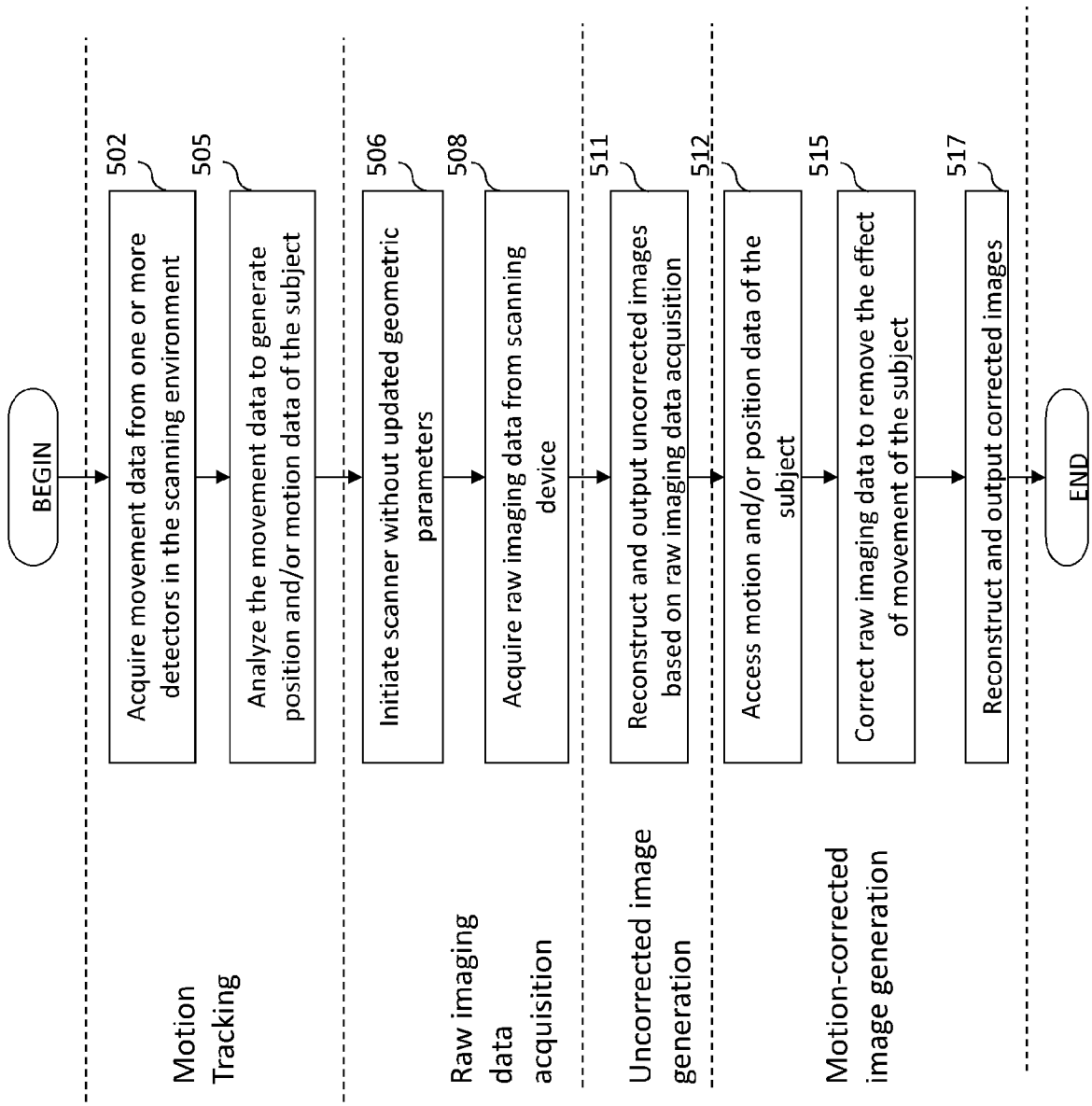
BEGIN
Motion Tracking
502
Acquire movement data from one or more detectors in the scanning environment
505
Analyze the movement data to generate position and/or motion data of the subject
Raw imaging data acquisition
506
Initiate scanner without updated geometric parameters
508
Acquire raw imaging data from scanning device
Uncorrected image generation
511
Reconstruct and output uncorrected images based on raw imaging data acquisition
Motion-corrected image generation
512
Access motion and/or position data of the subject
515
Correct raw imaging data to remove the effect of movement of the subject
517
Reconstruct and output corrected images
END

Fig. 5B

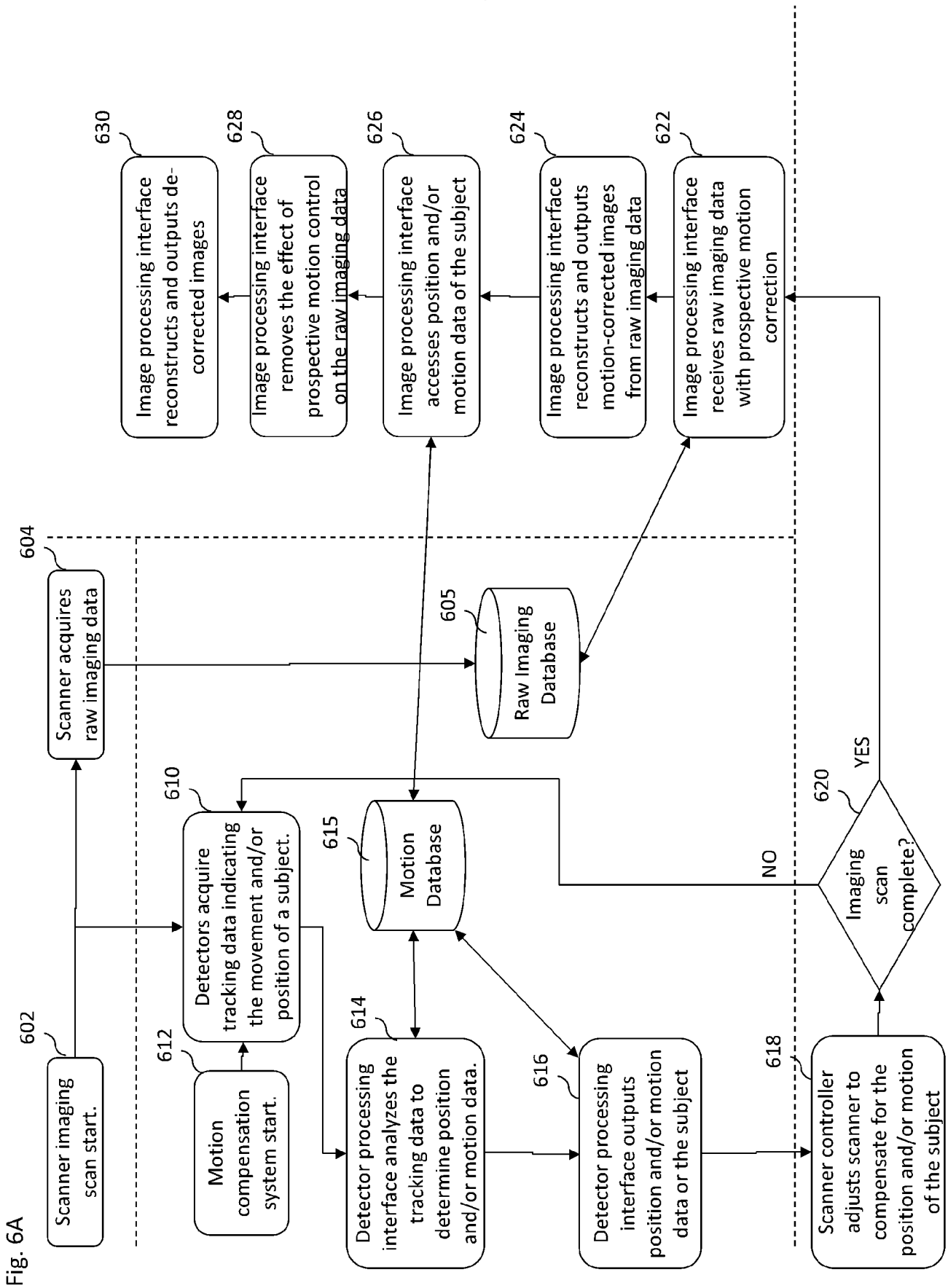
Scanner imaging scan start.
602
Scanner acquires raw imaging data
604
Motion compensation system start.
612
Detectors acquire tracking data indicating the movement and/or position of a subject.
610
Detector processing interface analyzes the tracking data to determine position and/or motion data.
614
Detector processing interface outputs position and/or motion data or the subject
616
Scanner controller adjusts scanner to compensate for the position and/or motion of the subject
618
Imaging scan complete?
620
YES
NO
Raw Imaging Database
605
Motion Database
615
Image processing interface receives raw imaging data with prospective motion correction
622
Image processing interface reconstructs and outputs motion-corrected images from raw imaging data
624
Image processing interface accesses position and/or motion data of the subject
626
Image processing interface removes the effect of prospective motion control on the raw imaging data
628
Image processing interface reconstructs and outputs de-corrected images
630

Fig. 6A

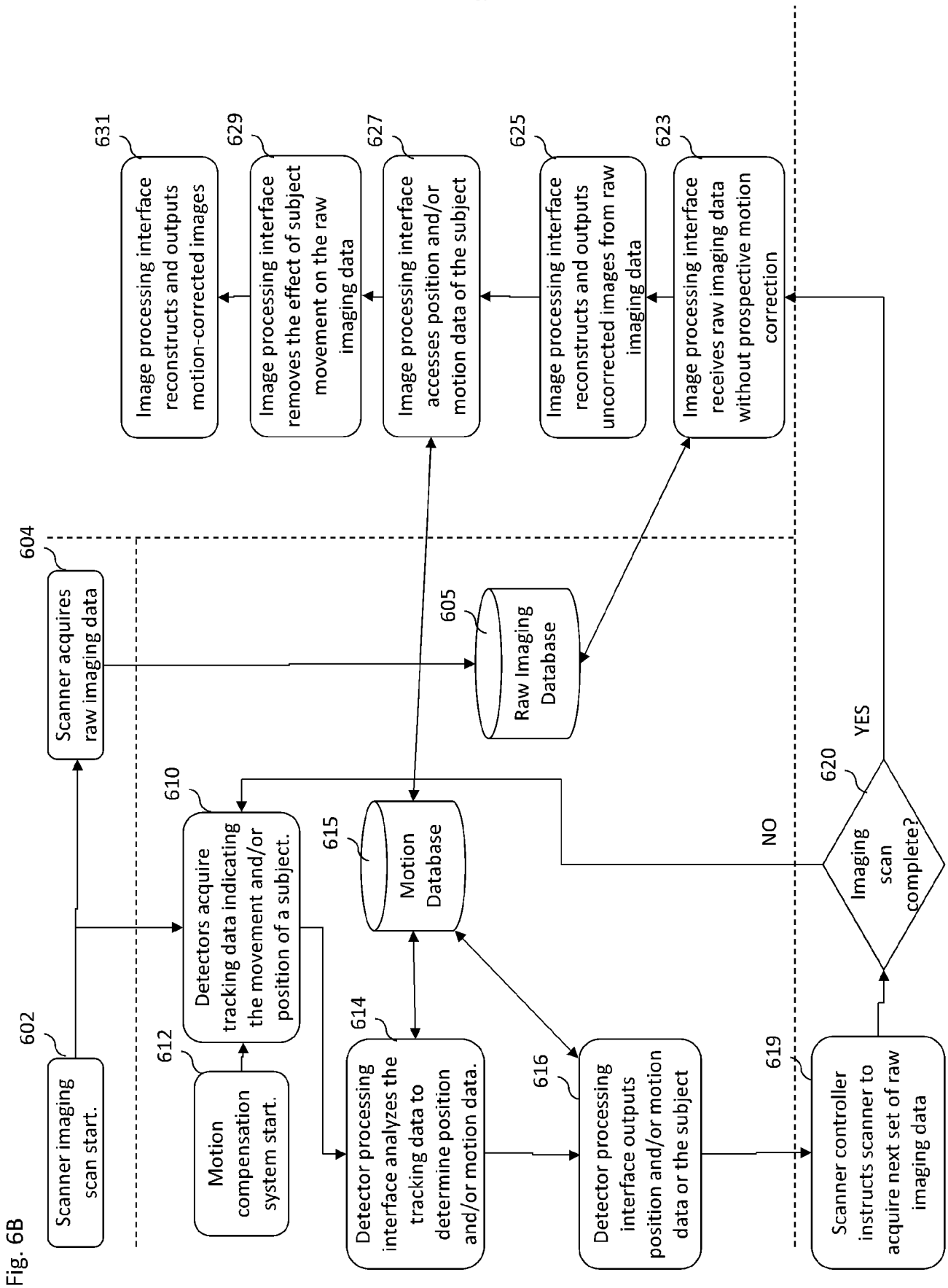
602
Scanner imaging scan start.
604
Scanner acquires raw imaging data
605
Raw Imaging Database
610
Detectors acquire tracking data indicating the movement and/or position of a subject.
612
Motion compensation system start.
614
Detector processing interface analyzes the tracking data to determine position and/or motion data.
615
Motion Database
616
Detector processing interface outputs position and/or motion data or the subject
619
Scanner controller instructs scanner to acquire next set of raw imaging data
620
Imaging scan complete?
YES
NO
623
Image processing interface receives raw imaging data without prospective motion correction
625
Image processing interface reconstructs and outputs uncorrected images from raw imaging data
627
Image processing interface accesses position and/or motion data of the subject
629
Image processing interface removes the effect of subject movement on the raw imaging data
631
Image processing interface reconstructs and outputs motion-corrected images

Fig. 6B

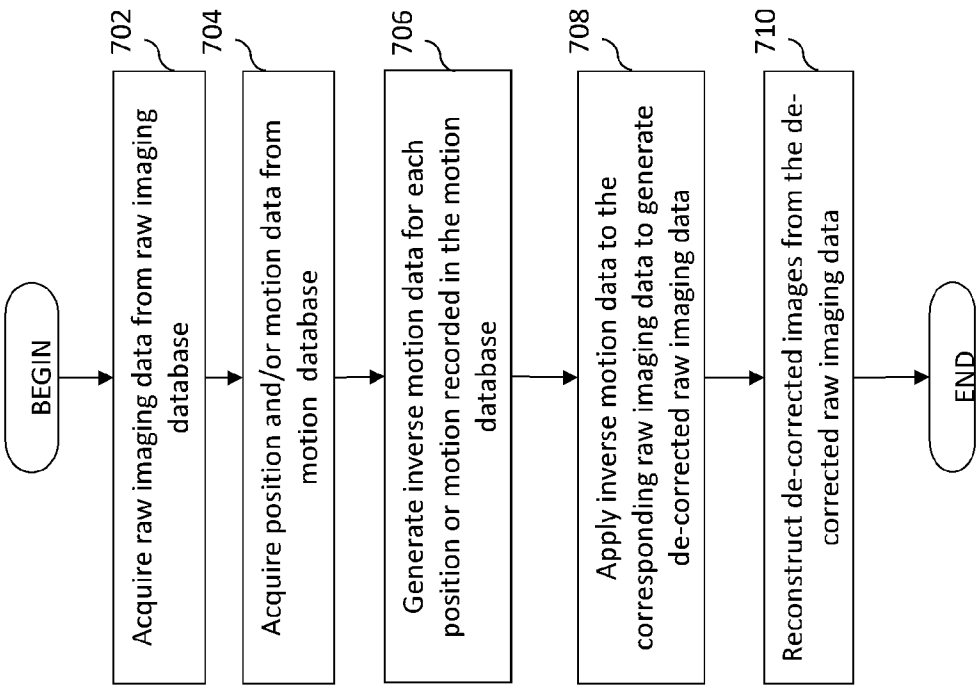
BEGIN
702
Acquire raw imaging data from raw imaging database
704
Acquire position and/or motion data from motion database
706
Generate inverse motion data for each position or motion recorded in the motion database
708
Apply inverse motion data to the corresponding raw imaging data to generate de-corrected raw imaging data
710
Reconstruct de-corrected images from the de-corrected raw imaging data
END

Fig. 7

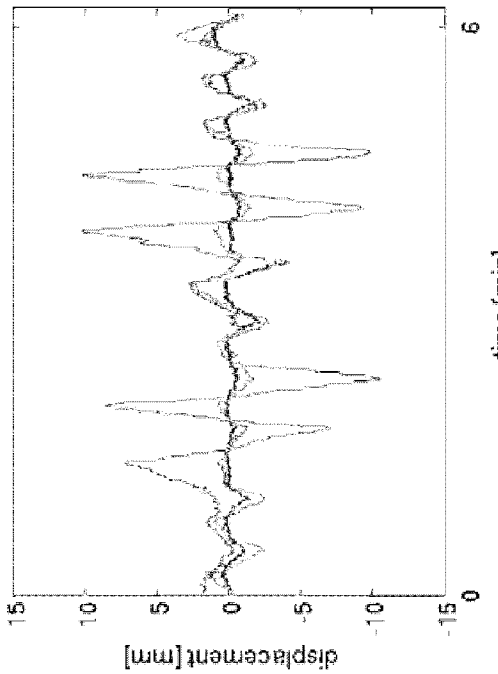
b Translations PMC off
displacement [mm]
time [min]
15
10
5
0
-5
-10
-15
0
6

Fig. 8B

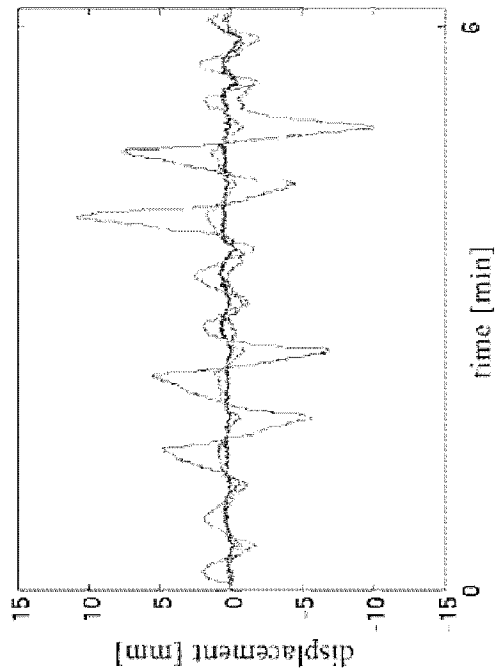
a Translations PMC
displacement [mm]
time [min]
15
10
5
0
-5
-10
-15
0
6

Fig. 8A

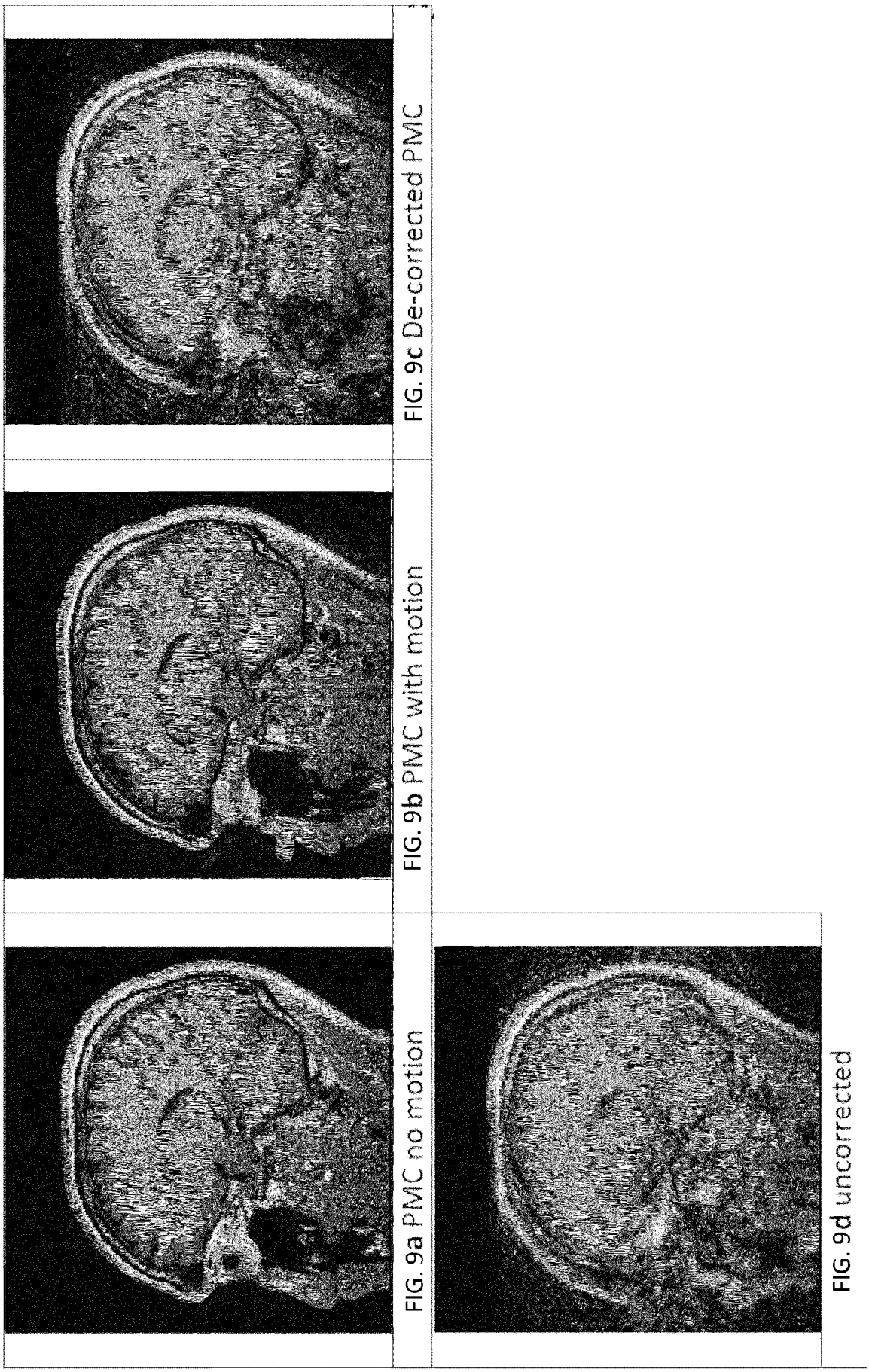

FIG. 9a PMC no motion

FIG. 9b PMC with motion

FIG. 9c De-corrected PMC

FIG. 9d uncorrected

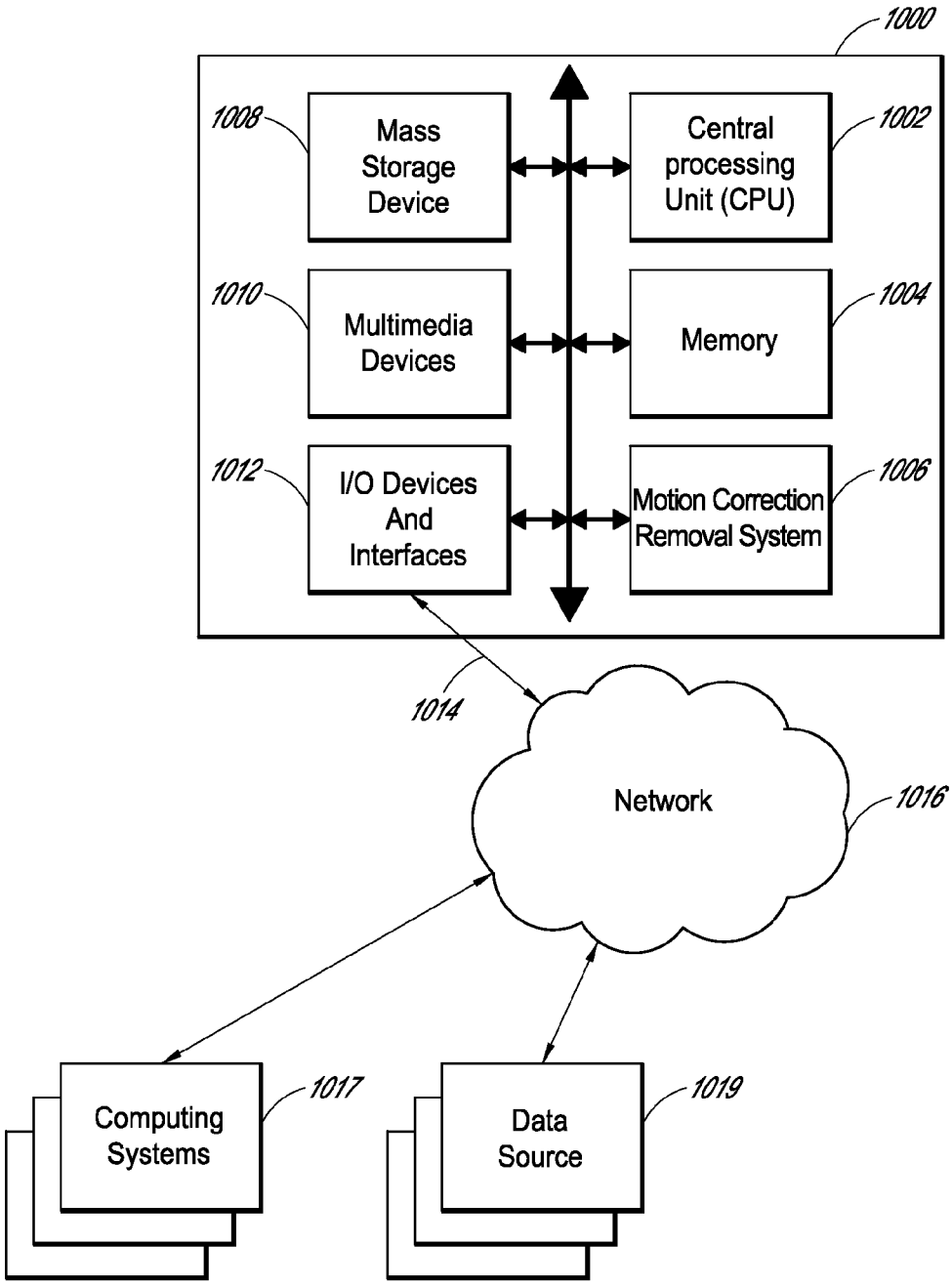
1000
1008
Mass Storage Device
Central processing Unit (CPU)
1002
1010
Multimedia Devices
Memory
1004
1012
I/O Devices And Interfaces
Motion Correction Removal System
1006
1014
Network
1016
Computing Systems
1017
Data Source
1019

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/022041

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/055(2006.01)i, A61B 6/03(2006.01)i, G06T 7/20(2006.01)i

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 5/055; A61B 5/05; A61B 6/00; G06K 9/00; G06T 7/20; G06T 5/00; A61B 5/00; A61B 6/03

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: scanner, MRI, motion, correct, tracking, camera, detector

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2014-005178 A1 (THE STATE OF QUEENSLAND ACTING THROUGH ITS DEPARTMENT OF HEALTH) 09 January 2014 See abstract, paragraphs [0024], [0051]-[0057] and figures 1a, 3.	1-20
A	US 2011-0201916 A1 (JEFF DUYN et al.) 18 August 2011 See abstract, paragraphs [0025]-[0059] and figures 1-5.	1-20
A	US 2013-0102879 A1 (JULIAN MACLAREN et al.) 25 April 2013 See abstract, paragraphs [0037]-[0050] and figures 1-4.	1-20
A	US 2003-0130574 A1 (PETER N R STOYLE) 10 July 2003 See abstract, paragraphs [0051]-[0061] and figures 1, 2.	1-20
A	US 2013-0281818 A1 (ALEXANDER HANS VIJA et al.) 24 October 2013 See abstract, paragraphs [0022]-[0062] and figures 1-3.	1-20

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"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
26 June 2015 (26.06.2015)	**29 June 2015 (29.06.2015)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
KIM, Tae Hoon
Telephone No. +82-42-481-8407

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/022041

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014-005178 A1	09/01/2014	AU 2013-286807 A1	29/01/2015
		US 2015-0139515 A1	21/05/2015
US 2011-0201916 A1	18/08/2011	EP 2283377 A1	16/02/2011
		WO 2009-129457 A1	22/10/2009
US 2013-0102879 A1	25/04/2013	WO 2011-127942 A1	20/10/2011
US 2003-0130574 A1	10/07/2003	AT 317576 T	15/02/2006
		AU 2002-347356 A1	23/06/2003
		AU 2002-347356 A8	23/06/2003
		CA 2469031 A1	19/06/2003
		DE 60209141 D1	20/04/2006
		DE 60209141 T2	26/10/2006
		EP 1451777 A2	01/09/2004
		EP 1451777 B1	08/02/2006
		GB 0129465 D0	30/01/2002
		JP 2005-511224 A	28/04/2005
		JP 4481648 B2	16/06/2010
		US 6777933 B2	17/08/2004
		WO 03-050761 A2	19/06/2003
		WO 03-050761 A3	04/12/2003
US 2013-0281818 A1	24/10/2013	None	