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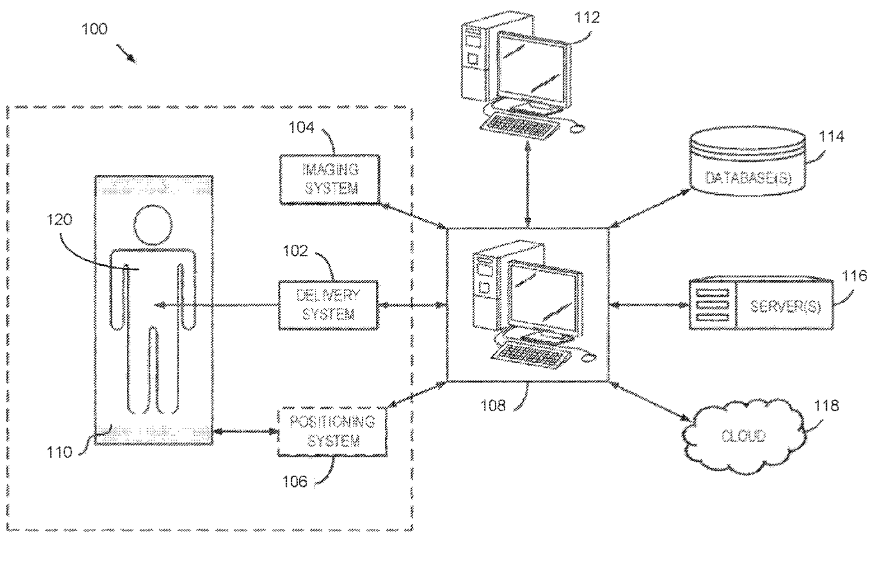

FIG. 1

(57) Abstract: A method for generating electron density maps of a region of interest of a subject for adaptive radiation therapy using a magnetic resonance (MR) linear accelerator (Linac) radiation treatment system includes receiving a radiation treatment plan associated with the region of interest of the subject, acquiring a plurality of projections using one or more X-ray beams from a linear accelerator and a flat panel detector of the MR-Linac system, reconstructing one or more projection images based on the one or more projections, generating one or more electron density maps based on the one or more projection images, and generating an updated radiation treatment plan associated with the region of interest of the subject based on the one or more electron density maps.

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SYSTEM AND METHOD FOR GENERATING ELECTRON DENSITY MAPS FOR MRI-LINAC

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on, claims priority to, and incorporates herein by reference in its entirety U.S. Serial No. 63/527,558 filed July 18, 2023, and entitled "iMREDI – MV Relative Electron Density Imager for MRI-Linac."

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] N/A

FIELD

[0003] The present disclosure relates generally to radiation treatment systems and, in particular, to systems and methods for generating electron beam maps of a region of interest of a subject using magnetic resonance (MR) linear accelerator (Linac) radiation treatment systems.

BACKGROUND

[0004] Adaptive radiotherapy (ART) has been an active area of research over the last two decades, leading to significant scientific advances towards improved personalized treatments. The integration of magnetic resonance imaging (MRI) with linear accelerators (Linac) has been recently introduced and has the advantages of improved soft-tissue contrast compared with kilovoltage (kV) and megavoltage (MV) imaging, reduced radiation burden to the patient, and the ability to provide real-time, in-treatment imaging. MR-Linac systems have been increasingly utilized for real-time imaging in adaptive treatments worldwide.

[0005] Despite the advantages of real-time imaging and adaptive planning, there are potential limitations related to electron density calculation, image registration, and time requirements that have not yet been fully addressed. Gas cavities and bones create small MR signals that can reduce the accuracy of electron density maps generated using synthetic CT methods. In the daily workflow, for example in patients undergoing treatment in the pelvic area, air cavities in the MR images require additional contouring on the day of treatment. The process is laborious and may contribute to increased planning times and introduces the potential for error. Challenges in MR representation of air cavities and subsequent estimation of electron density maps impede planning efficiency and may lead to dose calculation uncertainties.

SUMMARY

[0006] In accordance with an embodiment, a system for generating electron density maps of a region of interest of a subject using a magnetic resonance (MR) linear accelerator (Linac) radiation treatment system includes a magnetic resonance imaging apparatus configured to acquire magnetic resonance images, a gantry, a linear accelerator coupled to the gantry and comprising a radiation source configured to generate one or more X-ray beams, a flat panel X-ray detector configured to detect radiation from the one or more X-ray beams after the one or more X-ray beams pass thorough the region of interest of the subject, and a processor device. The processor device is coupled to the linear accelerator and the flat panel detector and is configured to generate one or more projection images based on the detected radiation, to generate one or more electron density maps based on the one or more projection images and to generate an updated radiation treatment plan based on the one or more electron density maps.

[0007] In accordance with another embodiment, a method for generating electron density maps of a region of interest of a subject for adaptive radiation therapy using a magnetic resonance (MR) linear accelerator (Linac) radiation treatment system includes receiving a radiation treatment plan associated with the region of interest of the subject, acquiring a plurality of projections using one or more X-ray beams from a linear accelerator and a flat panel detector of the MR-Linac system, reconstructing one or more projection images based on the one or more projections, generating one or more electron density maps based on the one or more projection images, and generating an updated radiation treatment plan associated with the region of interest of the subject based on the one or more electron density maps.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present disclosure will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements.

[0009] FIG. 1 is a schematic diagram of an example radiation treatment system in accordance with an embodiment;

[0010] FIG. 2 is a cross-sectional view of a MR-Linac system in accordance with an embodiment;

[0011] FIG. 3 illustrates a method for generating electron density maps of a region of interest of a subject for adaptive radiation therapy using an MR-Linac system in accordance with an embodiment;

[0012] FIG. 4 illustrates a method for removing of shim patterns from projection images acquired with an MR-Linac system in accordance with an embodiment; and

[0013] FIG. 5 is a block diagram of an example computer system in accordance with an embodiment.

DETAILED DESCRIPTION

[0014] The present disclosure describes systems and methods for generating electron density maps of a region of interest of a subject using a plurality of projections acquired with a MR-Linac system treatment beam (e.g., a megavoltage (MV) treatment beam). In some embodiments, the MR-Linac system can include a flat panel detector (or imager) for acquiring the plurality of projections that can be used to generate the electron density maps. Accordingly, in some embodiments, MV imaging can be used to construct electron density maps. In some embodiments, the reconstructed electron density map can be a three dimensional (3D) map that can be used, for example, for dose calculation for treatment planning and adaptive radiation therapy. Advantageously, the described systems and methods can reduce errors and uncertainty, as well as the time of the patient in the MR-Linac radiation treatment machine. Integration of the flat-panel detector (or imager) with an MR-Linac can provide accurate and precise electron density maps while the subject (e.g., a patient, a phantom, etc.) is on a treatment table without the need for image registration, synthetic-CT, and manual contouring/checks, all of which adds significant time to the radiation treatment workflow and can introduce errors at each step. In some embodiments, the disclosed system and method can enable adaptive radiation treatments (or adaptive radiotherapy, or adaptive radiation therapy), optimization of daily workflow, and minimization of sources of uncertainty and errors during adaptive radiation treatments.

[0015] FIG. 1 is a schematic diagram of an example radiation treatment system in accordance with an embodiment. In some embodiments, the radiation treatment system 100 may be used to perform one or more aspects of the methods described herein. The radiotherapy system 100 may generally include a delivery system 102, an imaging system 104, and a positioning system 106, each in communication with a treatment console 108. The delivery system 102 can be configured to generate and direct radiation to a patient or subject 120 positioned on a treatment table 110, in accordance with a radiation treatment plan, where the treatment table 110 can be movable. The imaging system 104 may be configured to image the patient before, during or after treatment. Although shown in FIG. 1 as a separate system, in some embodiments, the imaging system 104 may be part of, or combined with, the delivery system 102. For example, the radiation treatment system 100 may be a magnetic resonance (MR) linear accelerator (MR-Linac) radiation treatment system as discussed further below with respect to FIG. 2. For an MR-Linac system, the imaging system 104 is a magnetic resonance imaging (MRI) system and the delivery system 102 is a linear accelerator (Linac) that can be integrated into the MRI system. The positioning system 106 may be configured to position and orient the treatment table 110. In addition, the positioning system 106 may also be configured to move the patient to the imaging system 104. In some embodiments, the treatment console 108 may be implemented as a computer system, for example, computer system 500 described below with respect to FIG. 5. In addition, various aspects of the delivery system 102, imaging system 104 and positioning system 106 may be implemented using one or more processors (e.g., as described below with respect to FIG. 5).

[0016] The treatment console 108, or another suitable controller, may be configured to receive a radiation treatment plan from a planning workstation 112, or another location, such as a database 114, server 116, or cloud 118. Thereafter, the treatment console 108 may control the delivery system 102, imaging system 104, and optionally positioning system 106 to execute the radiation treatment plan. During treatment, the delivery system 102 builds radiation dose inside a patient to achieve dose distributions in accordance with the radiation treatment plan. The plan may include a number of treatment fields having various beam numbers, beam shapes or fluences, beam energies, beam orientations relative to the patient or subject, and durations of exposure. The delivery system 102, for example, a linear accelerator (Linac) can be moved about the patient on the treatment table 110. In some embodiments, the radiation treatment plan may also be executed using a combination of table 110 and delivery system 102 movements.

[0017] The planning workstation 112 may be utilized to generate a radiation treatment plan based on dosimetric prescriptions and imaging information obtained from a subject. In some embodiments, generating the treatment plan includes selecting appropriate treatment fields, which can vary in number, duration, shape or fluence, energy and orientation relative to the patient, to optimize patient outcomes. In some embodiments, the planning workstation 112 may be implemented on a computer system, for example, computer system 500 described below with respect to FIG. 5.

[0018] As mentioned, the radiation treatment system 100 can be a MR-Linac system that combines a MRI system and a linear accelerator (Linac) in the same machine. FIG. 2 is a cross-sectional view of a MR-Linac system in accordance with an embodiment. Advantageously, the MR-Linac system 200 can be configured to deliver treatment radiation beams and monitor the target area (or target site or region of interest) in a subject at the same time. In some embodiments, an MR-Linac system 200 can be used to, for example, treat cancers through the body, with specific advantages for tumors located inside soft tissue. The MR-Linac system 200 can also enable adaptive radiotherapy (or adaptive radiation therapy) where treatment plans can be modified based on, for example, the subject's daily anatomy. In some embodiments, the MR-Linac 200 can be a perpendicular beam-field system.

[0019] In some embodiments, MR-Linac system 100 includes various hardware elements to implement an MRI system including, for example, a magnet 202, a shim tray array 204, passive shims 206, as well as various hardware components that are not shown in FIG. 2 for simplicity and clarity such as, for example, radio frequency (RF) coils, gradient coils, shielding coils, etc. The MRI components of the MR-Linac system 200 can be used to acquire 2D or 3D MR images of the subject before, during, and/or after a treatment session, for example, using known MR acquisition protocols and techniques. In some embodiments, the magnet 202 is a superconducting magnet configured to generate a primary or main magnetic field for magnetic resonance imaging. In some embodiments, for example, as shown in FIG. 2, the magnet 202 can be cylindrical in shape and can surround a cylindrical bore 208. The magnet 202 can be a low magnetic field strength magnet such as for example, 0.35 T, 0.5 T, etc. Low field strengths can be advantageous for image homogeneity and reduced electron return effects in tissue-air interfaces. MR-Linac system 200 may also include one or more shielding coils that can be configured to cancel or reduce any magnetic field outside of the magnet 202. One or more gradient coils (not shown) may be configured to generate a gradient magnetic field that allows spatial encoding of magnetic resonance signals so that their position can be determined. One or more RF coils (not shown) can be used to generate RF pulses and to receive magnetic resonance signals from the subject.

[0020] The MR-Linac system 200 also includes a linear accelerator (Linac) 212, a gantry 210, and a flat panel X-ray detector 214. The Linac 214 can be positioned on the gantry at a source-to-isocenter distance 220 between the Linac 202 and the isocenter 218. The Linac 212 can include a radiation source (not shown) and a collimator (not shown) and can be configured to produce and shape a beam 224 of radiation (e.g., an X-ray) and direct it toward a target area within a subject in accordance with a radiation treatment plan. In some embodiments, the Linac 212 can be configured to deliver a beam 224 without a flattening filter (FF). In some embodiments, the radiation (or treatment) beam 224 can be a pencil beam. In some embodiments, the radiation (e.g., X-ray) source of the Linac 212 can be a megavoltage (MV) radiation source. In some embodiments, the ionizing radiation produced by the Linac 212 can be between 4 MV and 6 MV. The collimator in the Linac 212 can be positioned in the path of the radiation beam 224 to define and contour the shape of the radiation beam 224 profile. The collimator in the Linac 212 can be, in some embodiments, a multi-leaf collimator (MLC). In some embodiments, the collimator can be a multi-leaf collimator without jaws. An MLC can comprise multiple leaves that move independently to form a beam shape. A MLC controller (e.g., as part of delivery system 102 or treatment console 108, both shown in FIG. 1) can be used to control the movement of each of the leaves. The leaves of the MLC may be formed out of a radiation absorbing material (e.g., lead, tungsten, etc.).

[0021] A computer system (e.g., treatment console 108 shown in FIG. 1) can be in communication with the Linac 212 and can be configured to, for example, selectively control the Linac 212. The Linac 212 can be coupled to and supported by a gantry 210 that is moveable such that when the gantry 210 moves the Linac 212 moves with the gantry 210. For example, the gantry 210 may be configured such that it (and the Linac) can be rotated about an isocenter 108. In this way, the radiation source of the Linac 212 can be rotatable around the subject so that the treatment beam 224 can be applied from different angles around the gantry 210. The gantry 210 can be implemented in different ways. For example, in some embodiments, the gantry 210 can be a cylinder gantry, a ring gantry, a C-arm gantry, etc. The positioning of the gantry 210 can be controlled by, for example, the treatment console 108 shown in FIG. 1.

[0022] As mentioned, a flat panel X-ray detector (or imager) 214 can be advantageously integrated into the MR-Linac system 200 to perform imaging of MV relative electron density. The flat panel detector 214 can be positioned diametrically opposed to the Linac 212 and at a distance 222 from the isocenter 218. The flat panel detector 214 can be suitable for, and can be configured to detect the intensity of radiation which has passed through the subject. For example, in some embodiments, the Linac 212 can generate an x-ray beam 224 (e.g., an MV X-ray beam) that can be directed along an X-ray source axis 226 that is centered along the isocenter 208. The beam 224 can then impinge upon the flat panel X-ray detector 214 after passing through a target (not shown) which may be, for example, a subject (e.g., subject 120 shown in FIG. 1), a portion of a subject, an imaging phantom, etc. Data acquired by the flat panel detector 206 may be provided to a computer system in communication with the flat panel detector 214, for example, the treatment console 108 shown in FIG. 1, which can be configured to reconstruct projection images that may be used to generate electron density maps during an adaptive radiation therapy process as described further below with respect to FIG. 3. In some embodiments, the flat panel detector 214 can also be used for enhanced QA and dose delivery estimation.

[0023] A treatment table (e.g., treatment table 110 shown in FIG. 1) may be positioned in the bore 208 and between the Linac 212 and the flat panel X-ray detector 214. During a radiotherapy treatment session, a patient or subject may be positioned on a treatment table (e.g., treatment table 110 shown in FIG. 1). The treatment table may then be moved into the bore 208 of the MR-Linac system 200.

[0024] In some embodiments, the MR system hardware (e.g., magnet 202, gradient coils, RF coils, etc.) in the MR-Linac system 200 can be configured to allow the radiation (e.g., beam 224) from the Linac 212 to pass through with as little attenuation as possible and such that the dose at the target (e.g., a tumor) is predictable. For example, in some embodiments, the magnet 202 may include one or more coil(s) (not shown) that may be spaced such that there is an area free of coils or the coil(s) may be thin enough or of reduced density such that they are substantially transparent to radiation of the wavelength generated by the Linac 212. In some embodiments the magnet 202 can have a spit design with the Linac 212 rotating between the two magnet bores.

[0025] The MR-Linac system 200 can also include a plurality of passive shims 206 positioned in a shim tray assembly 204. In some embodiments, the shims 206 cand be passive iron shims. The plurality of passive shims 206 may be used to, for example, compensate for or remove inhomogeneities from the main magnetic field generated by the magnet 202 and to stabilize the magnetic field within the bore 208. As illustrated in FIG. 2, one or more of the plurality of shims 206 in the shim tray assembly 204 can be positioned before the flat panel detector 214 along the path of the beam 224 from the Linac 212.

[0026] FIG. 3 illustrates a method for generating electron density maps of a region of interest of a subject using an MR-LINAC system in accordance with an embodiment. Although the blocks of the process are illustrated in a particular order, in some embodiments, one or more blocks may be executed in a different order than illustrated in FIG 3 or may be bypassed. The generated electron density maps can be utilized for adaptive radiation therapy so that the radiation treatment of a subject can be continually adjusted to account for changes taking place within the subject's body, with the goal of administering the most accurate radiation dose possible. Radiation therapy can often take several days or weeks to complete, and certain anatomical and physiological changes can occur during that time, whether due to the treatment itself or other factors.

[0027] At block 302, a radiation treatment plan for a region of interest of a subject (e.g., a patient) may be received. Known methods for treatment planning, which typically occurs before beginning a course of radiation treatment, may be used to generate the radiation treatment plan. In some embodiments, the region of interest can include a target site (e.g., a tumor), one or more anatomical landmarks (e.g., for tracking), etc. In some embodiments, the region of interest can be larger than the target site, one or more anatomical landmarks, etc. The radiation treatment plan can include a number of beam paths (e.g., a first beam path, a second beam path, etc.) each of which is defined from a radiation source and to the target site. In some embodiments, CT images (e.g., cone beam CT images) and MR images may be acquired from a subject and/or simulated during the treatment planning process to plan a subject's course of treatment. In addition, electron density may also be obtained during the radiation treatment planning process (e.g., by deformable registration of a simulated CT image to an acquired planning MR image). In some embodiments, the acquired or synthesized CT and MR images and the initial electron density determination from the treatment planning process may also be received with the radiation treatment plan. In some embodiments, the radiation treatment plan (and acquired and/or synthesized images, electron density, etc.) can be retrieved from data storage (or memory) of the radiation treatment system (e.g., database 114 shown in FIG. 1) or data storage of other computer systems (e.g., storage device 516 of computer system 500 shown in FIG. 5).

[0028] At block 304, prior to a treatment fraction (or radiation therapy session) of a fractional adaptive radiation treatment process, a plurality of projections of the region of interest of the subject may be acquired using an MV beam from the LINAC 212 and the flat panel detector 214 of the MR-Linac system 200. In some embodiments, the plurality of projections may be acquired at a 1-degree step size over a full 360 degrees of rotation to acquire a total of 360 projections. In some embodiments, each projection can be generated using 10^{10} X-rays. At block 306, one or more projection images may be reconstructed from the acquired plurality of projections using known reconstructions methods. For example, in some embodiments, the projection image(s) may be reconstructed using the Feldkamp, Davis, and Kress (FDK) algorithm. In another example, an iterative reconstruction technique may be used to reconstruct projection image(s) from the acquired plurality of projections.

[0029] At block 308, shim patterns in the acquired projection images can be removed. Passive shimming (e.g., using the plurality of passive shims 206 of an MR-Linac system 200 shown in FIG. 2) for magnetic field homogeneity and stabilization in the MR-LINAC will affect the MV projections (or projection images) because the shims will be in the beam path (as illustrated in FIG. 2). For example, beam attenuation through passive shims 206 (shown in FIG. 2) can produce dark patches on the projection images. An example method for removing shim patterns from the projection images is discussed further below with respect to FIG. 4. At block 310, one or more relative electron density maps of the region of interest of the subject may be generated by applying a calibration curve on the reconstructed projection image(s). In some embodiments, the calibration curve can be a Hounsfield Unit (HU) to relative electron density curve. In some embodiments, a calibration curve can be associated with a particular beam energy. In some embodiments, the calibration curve may be generated during the treatment planning process. For example, in some embodiments, the calibration curve may be generated by acquiring projections of an appropriate phantom that contains different material inserts. Images can be reconstructed from the projections acquired from the phantom and a calibration curve can be established that relates the CT number at each material insert with the corresponding material mass density and/or relative electron density. The relative electron density is the electron density of a material divided by the electron density of water. In some embodiments, the electron density map(s) are

3D maps of the target area or site (e.g., the treatment area). As mentioned, the electron density map(s) are advantageously generated using the projections (e.g., 2D projections) acquired using the MV beam 224 of the MR-Linac system 200.

[0030] At block 312, the electron density maps(s) generated from the acquired projection images can be used to determine (or calculate) dose. In some embodiments, the dose can be determined using, for example, a treatment planning system (e.g., planning workstation 112 described above with respect to FIG. 1). In an example, a treatment planning system or similar software application, can utilize the generated electron density map(s) to assign specific X-ray attenuation and absorption properties to each voxel of the map. The dose can be estimated through the calculation of energy absorption on each voxel. At block 314, the radiation treatment plan for the subject may be updated (e.g., recalculated and/or optimized) based on the generated electron density map(s). In some embodiments, the electron density maps generated based on the acquired projection images can be compared to the electron density from the treatment planning process to determine if there have been any changes, for example, the percent relative difference between the electron density map(s) generated at block 310 and the electron density determined from the treatment planning process. At block 316, the updated radiation treatment plan may be stored in data storge of the radiation treatment system (e.g., database 114 shown in FIG. 1). The updated radiation treatment plan can then be implemented using the MR-Linac system 200 for the radiation treatment fraction. Advantageously, the projections acquired with the MV beam 224 of the MR-Linac 200 at block 304 (e.g., on a daily basis before each treatment fraction of the radiation therapy) can provide the information needed for accurate relative electron density and dose calculation without the need for image registration or synthetic CT calculations.

[0031] As mentioned with respect to block 308 of FIG. 3, shim patterns can be removed from the acquired projection images. FIG. 4 illustrates a method for removing shim patterns from projection images acquired with an MR-LINAC system in accordance with an embodiment. Although the blocks of the process are illustrated in a particular order, in some embodiments, one or more blocks may be executed in a different order than illustrated in FIG 4 or may be bypassed.

[0032] At block 402, the projection images generated from the 2D projections acquired using the MV beam of the MR-Linac system 200 (e.g., as described above with respect to blocks 304 and 306 of FIG. 3) can be normalized. In some embodiments, the projection images may be log normalized. For example, the projection image can be log normalized with a full-field images (or full field projections). The full field image (or flood field image) can be a projection acquired without any subject in the beam path from the radiation source (e.g., Linac 212) to the detector (e.g., flat panel X-ray detector 214), i.e., all the X-rays emitted from the radiation source hit the detector. In some embodiments, the full field image can be acquired during calibration of the imaging device (e.g., the MR-Linac system 200). In some embodiments, a full field image can be acquired daily to take into account detector pixel variations that can occur over time. In some embodiments, an air normalization process may also be used on the projection images. At block 404, an inpainting process may be performed on the normalized projection images to remove the shim patterns. Inpainting can be applied to the impaired images (i.e., the projection images with the shim patterns) to restore missing or damaged parts of the image to their original state. As mentioned, beam attenuation through the shims 206 of the MR-Linac system 200 can produce dark patched on the acquired projection images. In an example, these dark patches can be treated as damaged parts of projection image and corrected by an inpainting algorithm. In one example, the inpainting algorithm can search for optimal pattern patches within the projection image based on the pixel values and can then replace the target patch pixels. In some embodiment, the patch size can be heuristically determined and the patch fill priority can be tensor based. In some embodiments, more elaborate, iterative pattern correction techniques can be used in addition to or as an alternative to the inpainting process. At block 406, the projection images with the shim patterns removed may be stored in data storge of the radiation treatment system (e.g., database 114 shown in FIG. 1). The use of normalization and inpainting can effectively remove the shim patterns (i.e., reconstruction artifacts) without affecting noise linearity.

[0033] FIG. 5 is a block diagram of an example computer system in accordance with an embodiment. Computer system 500 may be used to implement the systems and methods described herein. In some embodiments, the computer system 500 may be a workstation, a notebook computer, a tablet device, a mobile device, a multimedia device, a network server, a mainframe, one or more controllers, one or more microcontrollers, or any other general-purpose or application-specific computing device. The computer system 500 may operate autonomously or semi-autonomously, or may read executable software instructions from the memory or storage device 516 or a computer-readable medium (e.g., a hard drive, a CD-ROM, flash memory), or may receive instructions via the input device 520 from a user, or any other source logically connected to a computer or device, such as another networked computer or server. Thus, in some embodiments, the computer system 500 can also include any suitable device for reading computer-readable storage media.

[0034] Data, such as data acquired with an imaging system (e.g., a magnetic resonance imaging (MRI) system) may be provided to the computer system 500 from a data storage device 516, and these data are received in a processing unit 502. In some embodiment, the processing unit 502 includes one or more processors. For example, the processing unit 502 may include one or more of a digital signal processor (DSP) 504, a microprocessor unit (MPU) 506, and a graphics processing unit (GPU) 508. The processing unit 502 also includes a data acquisition unit 510 that is configured to electronically receive data to be processed. The DSP 504, MPU 506, GPU 508, and data acquisition unit 510 are all coupled to a communication bus 512. The communication bus 512 may be, for example, a group of wires, or a hardware used for switching data between the peripherals or between any components in the processing unit 502.

[0035] The processing unit 502 may also include a communication port 514 in electronic communication with other devices, which may include a storage device 516, a display 518, and one or more input devices 520. Examples of an input device 520 include, but are not limited to, a keyboard, a mouse, and a touch screen through which a user can provide an input. The storage device 516 may be configured to store data, which may include data such as, for example, radiation treatment plans, projections, projection images, electron density maps, etc. whether these data are provided to, or processed by, the processing unit 502. The display 518 may be used to display images and other information, such as magnetic resonance images, patient health data, and so on.

[0036] The processing unit 502 can also be in electronic communication with a network 522 to transmit and receive data and other information. The communication port 514 can also be coupled to the processing unit 502 through a switched central resource, for example the communication bus 512. The processing unit can also include temporary storage 524 and a display controller 526. The temporary storage 524 is configured to store temporary information. For example, the temporary storage 524 can be a random access memory.

[0037] Computer-executable instructions for generating electron density maps for MRI-LINAC according to the above-described methods may be stored on a form of computer readable media. Computer readable media includes volatile and nonvolatile, removable, and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer readable media includes, but is not limited to, random access memory (RAM), read-only memory (ROM), electrically erasable programmable ROM (EEPROM), flash memory or other memory technology, compact disk ROM (CD-ROM), digital volatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired instructions and which may be accessed by a system (e.g., a computer), including by internet or other computer network form of access

[0038] The present technology has been described in terms of one or more preferred embodiments, and it should be appreciated that many equivalents, alternatives, variations, and modifications, aside from those expressly stated, are possible and within the scope of the invention.

CLAIMS

1. A system for generating electron density maps of a region of interest of a subject using a magnetic resonance (MR) linear accelerator (Linac) radiation treatment system, the system comprising:

a magnetic resonance imaging apparatus configured to acquire magnetic resonance images;

a gantry;

a linear accelerator coupled to the gantry and comprising a radiation source configured to generate one or more X-ray beams;

a flat panel X-ray detector configured to detect radiation from the one or more X-ray beams after the one or more X-ray beams pass thorough the region of interest of the subject;

a processor device coupled to the linear accelerator and the flat panel detector and configured to generate one or more projection images based on the detected radiation, to generate one or more electron density maps based on the one or more projection images and to generate an updated radiation treatment plan based on the one or more electron density maps.

2. The system according to claim 1, wherein the one or more X-ray beams are megavoltage (MV) X-ray beams.

3. The system according to claim 1, further comprising a plurality of passive shims.

4. The system according to claim 3, wherein the processor device is further configured to remove a shim pattern from the one or more projection images.

5. The system according to claim 1, wherein the linear accelerator comprises a radiation source and a collimator.

6. The system according to claim 5. wherein the collimator is a multi-leaf collimator (MLC).

7. The system according to claim 1, wherein the one or more electron density maps are three dimensional (3D) electron density maps.

8. The system according to claim 1, wherein the one or more electron density maps are associated with a radiation treatment fraction.

9. A method for generating electron density maps of a region of interest of a subject for adaptive radiation therapy using a magnetic resonance (MR) linear accelerator (Linac) radiation treatment system, the method comprising:

receiving a radiation treatment plan associated with the region of interest of the subject;

acquiring a plurality of projections using one or more X-ray beams of a linear accelerator and a flat panel detector of the MR-Linac system;

reconstructing one or more projection images based on the one or more projections;

generating one or more electron density maps based on the one or more projection images; and

generating an updated radiation treatment plan associated with the region of interest of the subject based on the one or more electron density maps.

10. The method according to claim 9, further comprising removing a shim pattern from the one or more reconstructed projection images.

11. The method according to claim 10, wherein removing a shim pattern from the one or more reconstructed projection images comprises:

performing normalization of the one or more projection images to generate one or more normalized projection images; and

performing inpainting on the one or more normalized projection images to remove the shim pattern.

12. The method according to claim 11, wherein the normalization is a log normalization.

13. The method according to claim 9, wherein the one or more X-ray beams are megavoltage (MV) X-ray beams.

14. The method according to claim 9, further comprising calculating dose based on the one or more electron density maps.

15. The method according to claim 9, wherein the one or more electron density maps are three dimensional (3D) electron density maps.

16. The method according to claim 9, wherein the one or more electron density maps are associated with a radiation treatment fraction.

17. The method according to claim 9, wherein generating one or more electron density maps based on the one or more projection images comprising applying a calibration curve to the one or more projection images.

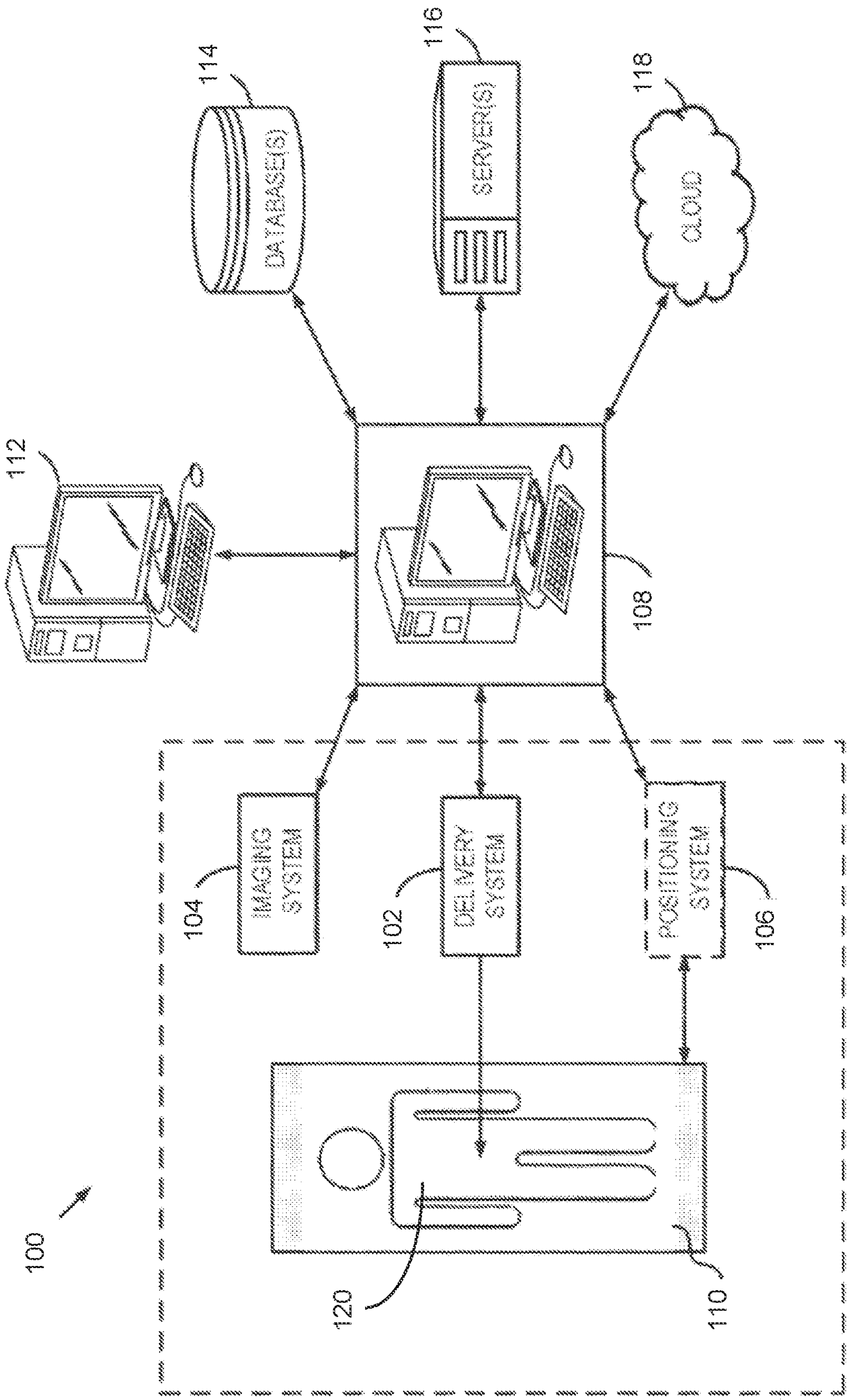
100
112
114
DATABASE(S)
116
SERVER(S)
118
CLOUD
108
104
IMAGING SYSTEM
102
DELIVERY SYSTEM
POSITIONING SYSTEM
106
120
110

FIG. 1

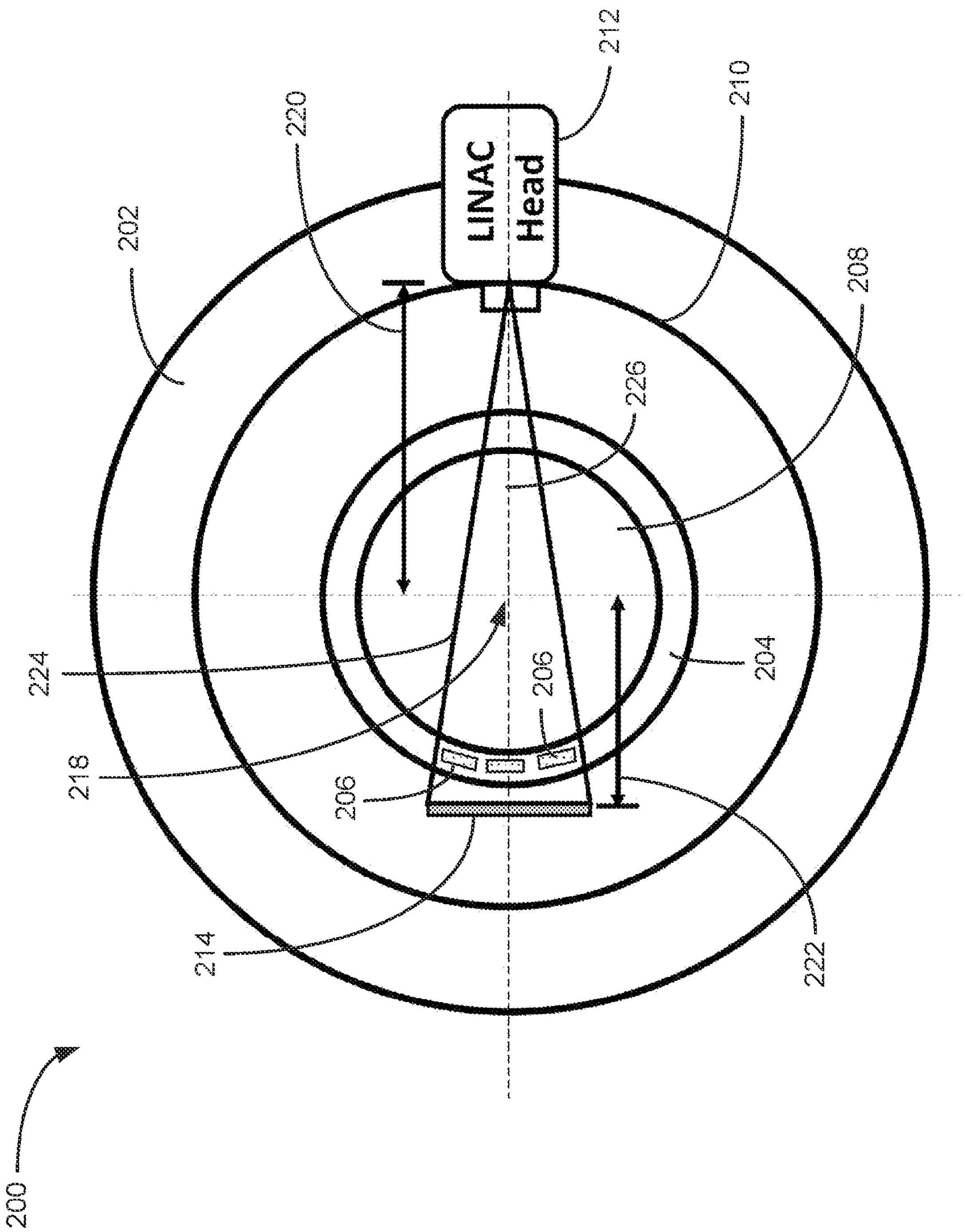
LINAC
Head
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FIG. 2

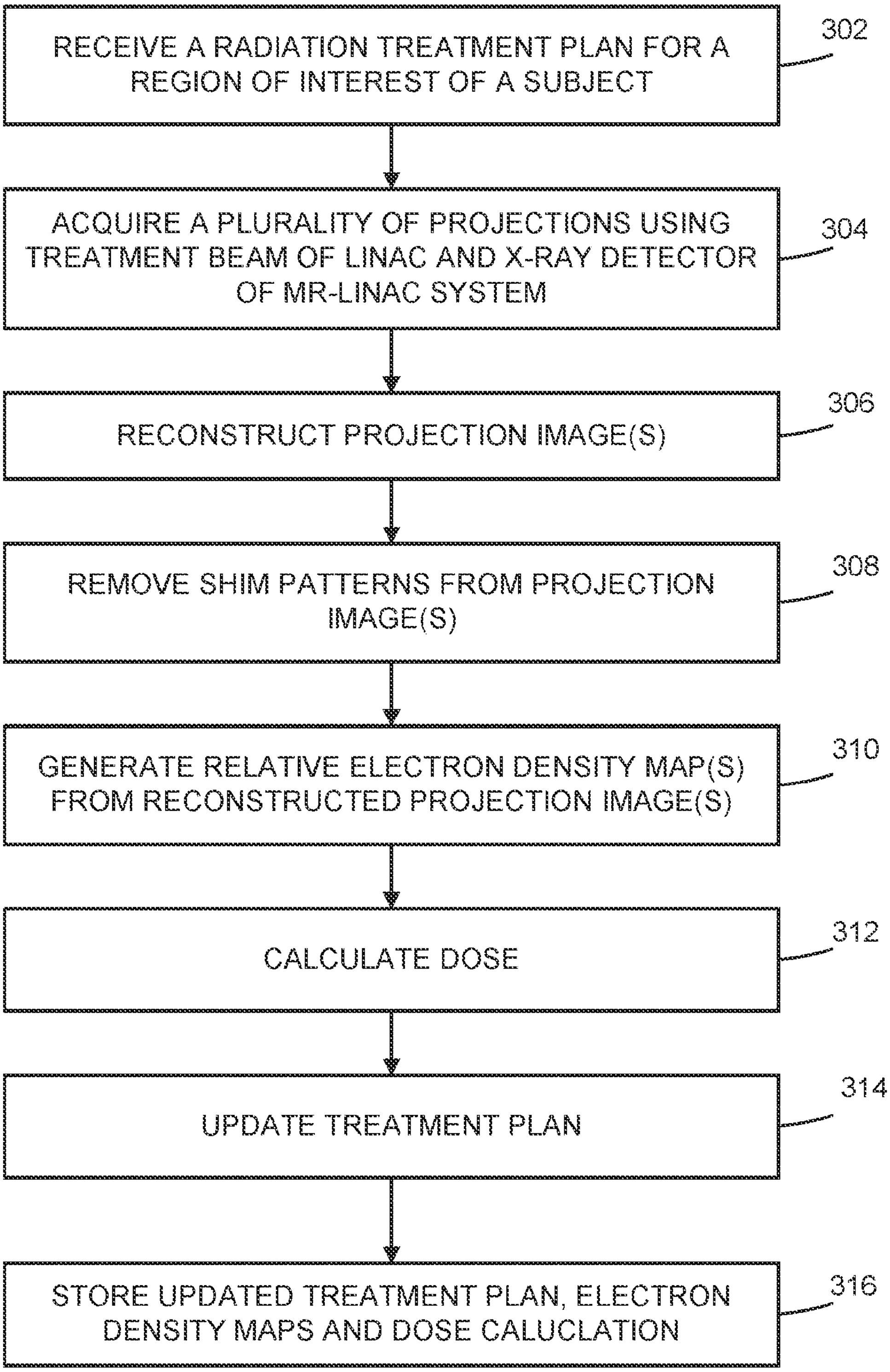
RECEIVE A RADIATION TREATMENT PLAN FOR A REGION OF INTEREST OF A SUBJECT
302
ACQUIRE A PLURALITY OF PROJECTIONS USING TREATMENT BEAM OF LINAC AND X-RAY DETECTOR OF MR-LINAC SYSTEM
304
RECONSTRUCT PROJECTION IMAGE(S)
306
REMOVE SHIM PATTERNS FROM PROJECTION IMAGE(S)
308
GENERATE RELATIVE ELECTRON DENSITY MAP(S) FROM RECONSTRUCTED PROJECTION IMAGE(S)
310
CALCULATE DOSE
312
UPDATE TREATMENT PLAN
314
STORE UPDATED TREATMENT PLAN, ELECTRON DENSITY MAPS AND DOSE CALUCLATION
316

FIG. 3

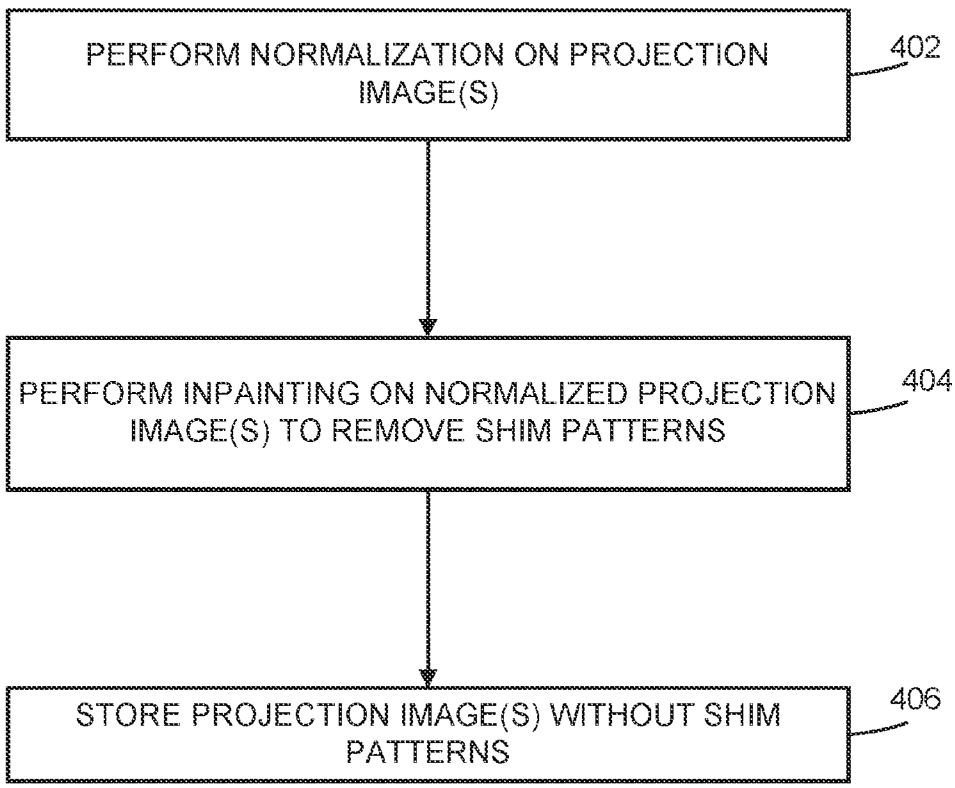
PERFORM NORMALIZATION ON PROJECTION IMAGE(S)
402
PERFORM INPAINTING ON NORMALIZED PROJECTION IMAGE(S) TO REMOVE SHIM PATTERNS
404
STORE PROJECTION IMAGE(S) WITHOUT SHIM PATTERNS
406

FIG. 4

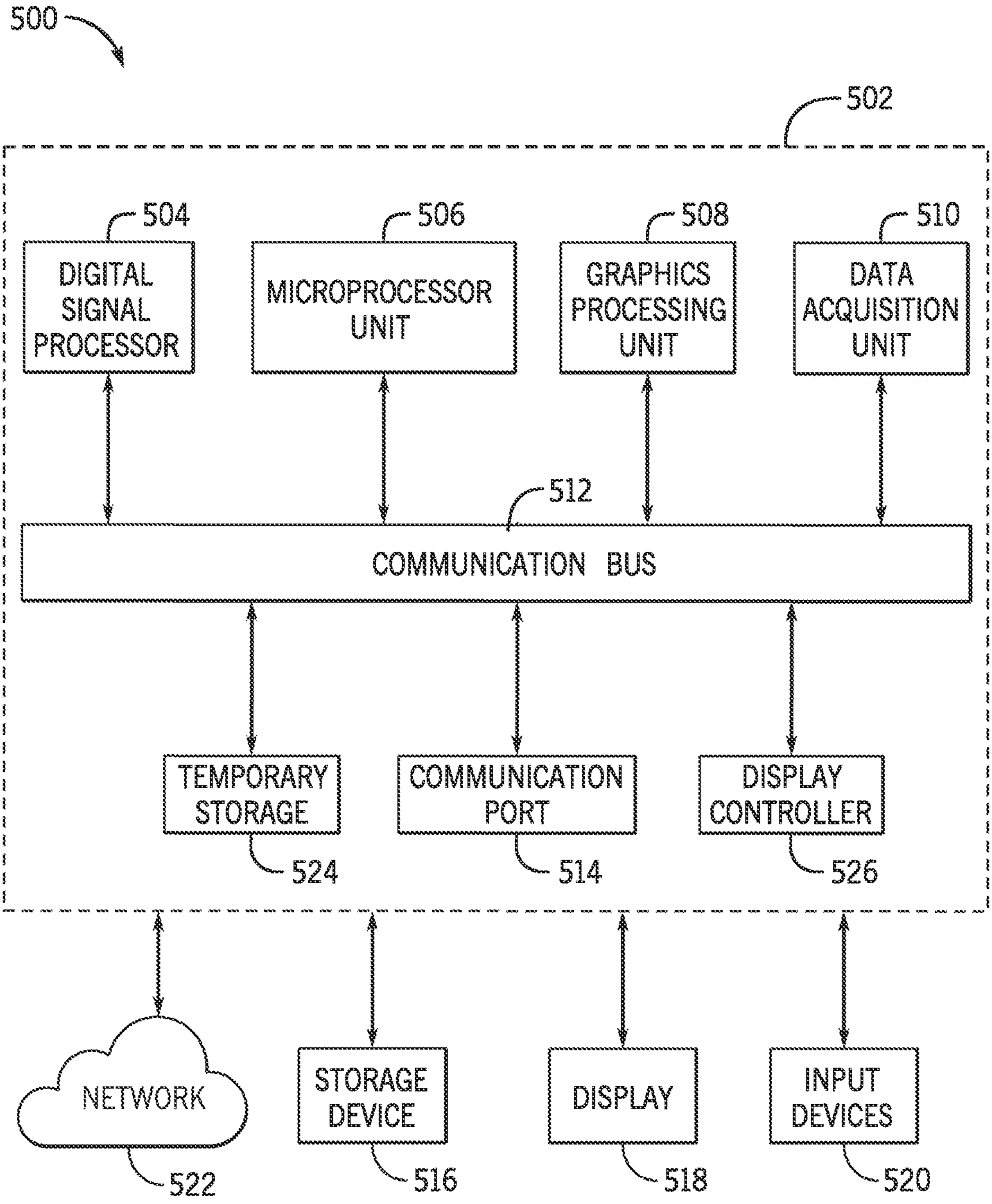
500
502
504
DIGITAL SIGNAL PROCESSOR
506
MICROPROCESSOR UNIT
508
GRAPHICS PROCESSING UNIT
510
DATA ACQUISITION UNIT
512
COMMUNICATION BUS
TEMPORARY STORAGE
524
COMMUNICATION PORT
514
DISPLAY CONTROLLER
526
NETWORK
522
STORAGE DEVICE
516
DISPLAY
518
INPUT DEVICES
520

FIG. 5