(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 January 2022 (20.01.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/016029 A1

(51) International Patent Classification:
A61B 5/055 (2006.01) *G01R 33/385* (2006.01)
G01R 33/383 (2006.01) *G01R 33/48* (2006.01)

(21) International Application Number:
PCT/US2021/041916

(22) International Filing Date:
16 July 2021 (16.07.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/052,650 16 July 2020 (16.07.2020) US

(71) Applicant: THE BOARD OF REGENTS OF THE UNIVERSITY OF TEXAS SYSTEM [US/US]; 210 West 7th Street, Austin, TX 78701 (US).

(72) Inventors: JIA, Xun; 210 West 7th Street, Austin, TX 78701 (US). TIMMERMAN, Robert; 210 West 7th Street, Austin, TX 78701 (US).

(74) Agent: WOLFE, Joseph et al.; DLA Piper LLP US, 33 Arch Street, 26th Floor, Boston, MA 02110 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

(54) Title: PORTABLE INHOMOGENEOUS-FIELD MRI SYSTEM

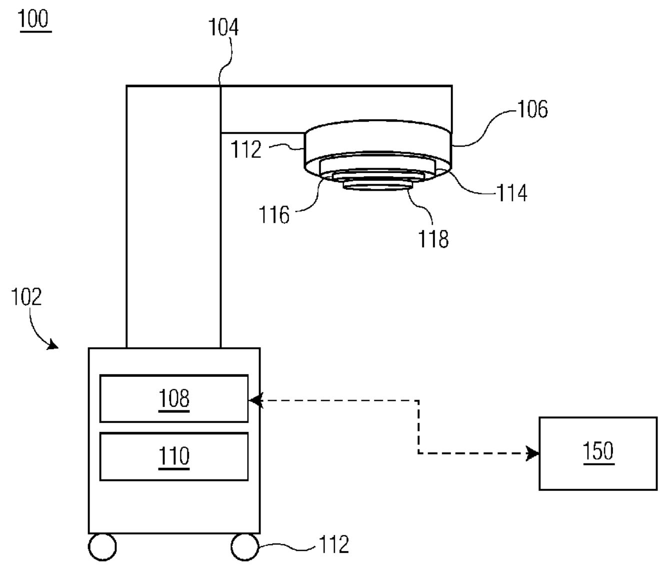

FIG. 1A

(57) Abstract: A portable magnetic resonance imaging (MRI) system is disclosed herein. The portable MRI system includes a mechanical arm and a scanner. The mechanical arm is configurable between a plurality of positions. The scanner is coupled to the mechanical arm. The scanner is configurable between a plurality of positions. The scanner includes a magnet, one or more gradient coils, and one or more radio frequency (RF) coils. The magnet is configured to generate an inhomogeneous magnetic field. The one or more gradient coils are configured to generate one or more magnetic fields to distort the inhomogeneous magnetic field. The one or more RF coils are configured to send and receive RF electromagnetic wave for imaging purposes.

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GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

PORTABLE INHOMOGENEOUS-FIELD MRI SYSTEM

Field of the Disclosure

[0001] This application claims priority to U.S. Application Serial No. 63/052,650, filed July 16, 2020, which is hereby incorporated by reference in its entirety.

Field of the Disclosure

[0002] The present disclosure generally relates to a portable magnetic resonance imaging system and, more specifically, to a portable inhomogeneous-field magnetic resonance imaging system.

Background

[0003] Magnetic resonance imaging (MRI) is one of the major medical imaging modalities for disease diagnosis and image guidance of therapeutic procedures. MRI systems are often bulky and expensive. For example, due to the size of existing MRI systems, facilities that house these MRI systems typically require a lot of space for the system itself, and also requires patients to physically come to the location in which the MRI system is located. Such a stationary system suffers from a series of limitations, most notably of which is the difficulty in travelling with an injured to sick patient from their respective care room to a location in the care facility where the MRI system is located.

Summary

[0004] In some embodiments, a portable magnetic resonance imaging (MRI) system is disclosed herein. The portable MRI system includes a mechanical arm and a scanner. The mechanical arm is configurable between a plurality of positions. The scanner is coupled to the mechanical arm. The scanner is configurable between a plurality of positions. The scanner includes a magnet, one or more gradient coils, and one or more radio frequency (RF) coils. The magnet is configured to generate an inhomogeneous magnetic field. The one or more gradient coils are configured to generate one or more magnetic fields to distort the inhomogeneous magnetic field. The one or more RF coils are configured to send and receive RF electromagnetic wave for imaging purposes.

[0005] In some embodiments, the portable MRI system further includes a structure and an electronic motor system. The structure defines an interior volume. The electronic motor system is configured to direct the portable MRI system to a location.

[0006] In some embodiments, the structure further includes one or more wheels coupled thereto. The one or more wheels are controlled by the electronic motor system.

[0007] In some embodiments, the portable MRI system includes a controller disposed in an interior volume of the structure. The controller is configured to control an amount of power delivered to at least one of the one or more gradient coils or the one or more RF coils.

[0008] In some embodiments, a first gradient coil of the one or more gradient coils is configured to generate a first spatially varying magnetic field along a first direction.

[0009] In some embodiments, a second gradient coil of the one or more gradient coils is configured to generate a second spatially varying magnetic field along a second direction.

[0010] In some embodiments, magnet is configured to generate a third spatially varying magnetic field along a third direction.

[0011] In some embodiments, the one or more RF coils are configured to facilitate MRI data acquisition by performing a number of two-dimensional scans, with varying RF frequencies.

[0012] In some embodiments, the portable MRI system may include RF shielding.

Brief Description of the Drawings

[0013] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrated only typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

[0014] Figure 1A is a block diagram illustrating a portable inhomogeneous-field MRI system, according to example embodiments.

[0015] Figure 1B is a block diagram illustrating a scanner of the portable inhomogeneous-field MRI system of Figure 1A, according to example embodiments.

[0016] Figure 2 illustrates a chart representing an illustration of image reconstruction on a set of two-dimensional surfaces, according to example embodiments

[0017] Figure 3A is a block diagram illustrating scanner positioned in a first exemplary position, according to example embodiments.

[0018] Figure 3B is a block diagram illustrating scanner positioned in a second exemplary position, according to example embodiments.

[0019] Figure 4 is a flow diagram illustrating a method of operating system, according to example embodiments

[0020] Figure 5A illustrates an example system configuration for implementing various embodiments of the present technology, according to example embodiments.

[0021] Figure 5B illustrates an example system configuration for implementing various embodiments of the present technology, according to example embodiments.

[0022] Figure 6A illustrates an exemplary view magnet assembly that utilize permanent magnets to assemble the main magnet, according to example embodiments.

[0023] Figure 6B illustrates an exemplary view magnet assembly, according to example embodiments.

[0024] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.

Detailed Description

[0025] Magnetic resonance imaging (MRI) is one of the major medical imaging modalities for disease diagnosis and image guidance of therapeutic procedures, e.g., image guided radiation therapy or image guided surgery. Currently, existing MRI technology mostly employs a highly homogenous high magnetic field. Generally, inhomogeneous-field MRI technology, low field strength, and small field of view (FOV) are typically not favored in diagnostic radiology due to the low image quality and small FOV associated therewith. Homogeneity/inhomogeneity may refer to the uniformity of a magnetic field generated by the MRI system.

[0026] Existing MRI technology suffers from a variety of limitations. For example, the cost of system development and manufacture of traditional MRIs is very high. Existing MRI technology also takes up a large footprint due to the weight and large size of the MRI scanner. This results in the MRI scanner impeding its application in certain scenarios, such as, but not limited to, point-of-care imaging to scan a patient without moving the patient to the scanner, or when using MRI scanners in an operation room where space is limited and electromagnetic or geometric interference with other medical devices is a concern.

[0027] The one or more techniques described herein improves upon conventional MRI technology by providing a design of a portable MRI scanner that employs an inhomogeneous magnetic field design. By providing a portable MRI scanner that employs an inhomogeneous magnetic field design, the present apparatus reduces the MRI scanner footprint and makes the MRI scanner more portable for targeted uses.

[0028] Figure 1A is a block diagram illustrating a portable inhomogeneous field MRI system 100 (hereinafter “system 100”), according to example embodiments. As illustrated, system 100 may include at least a body 102. Body 102 may include a mechanical arm 104, a scanner 106, and a controller 108.

[0029] Body 102 may be adapted for movement of system 100 to a location at which an MRI is needed. In some embodiments, body 102 may include an electronic motor system 110 and wheels 112. Electronic motor system 110 may be configured to direct system 100 to a desired location. In some embodiments, electronic motor system 110 may be responsive to a remote (or controller) that instructs electronic motor system 110 where to navigate. Electronic motor system 110 may be in communication with wheels 112. For example, when remote or controller instructs electronic motor system 110 to navigate to a location, electronic motor system 110 may instruct wheels 112 to turn a desired direction in order to navigate to a specific location. Electronic motor system 110 may include a battery system, configured to provide power thereto.

[0030] In some embodiments, body 102 may only include wheels 112. For example, rather than implementing an electronic motor system (e.g., electronic motor system 110), system 100 may be moved manually, relying on wheels 112.

[0031] As illustrated, mechanical arm 104 may be coupled with scanner 106. Mechanical arm 104 may be movable among a variety of positions. In this manner, operators can position system 100 such that target areas of a patient may be imaged. In some embodiments, mechanical arm 104 may be physically moved into a variety of positions by an operator. In some embodiments, mechanical arm 104 may be in communication with electronic motor system 110. For example, electronic motor system 110 may be configured to move mechanical arm 104 into a variety of positions based on instructions from controller 108 or remote. In this manner, scanner 106 may be moved into a desired position with respect to the patient. In some embodiments, mechanical arm 104 may be further configured to tilt or rotate scanner 106 at various angles with respect to the patient. In this manner, mechanical arm 104 may position scanner 106 to ensure that scanner 106 sufficiently images a patient.

[0032] Scanner 106 may include main magnet 114, one or more gradient coils 116, and one or more radio frequency (RF) coils 118. Main magnet 114 may be configured to generate an inhomogeneous magnetic field about scanner 106. For example, the inhomogeneous magnetic field may be generated such that the magnetic field may decay when moving away from main magnet 114 (e.g., in the positive z-direction). Magnet 114 may be representative of a single magnet or multiple magnets. Generally, because an inhomogeneous magnetic field is to be generated by system 100 during operation, magnet 114 may be representative of a simple magnet design, opposed to more complex magnet designs utilized to achieve field homogeneity. In some embodiments, main magnet 114 may be representative of a superconducting magnet, a resistive magnet, a permanent magnet, and the like. As illustrated, main magnet 114 may have a cylindrical body. As those in the art understand, main magnet 114 may be shaped differently to accommodate the specific needs and limitations from a clinical set up. In some embodiments, due to rotational symmetry in the design of main magnet 114, the inhomogeneous magnetic field may be rotationally symmetric in space, about the z-axis. However, the inhomogeneous magnetic field should not be limited to a rotationally symmetric magnet and magnetic field. In some embodiments, the inhomogeneous magnetic field distribution in space may be measured precisely, yielding a function $B = B(x, y, z)$ in a coordinate system defined relative to scanner 106 geometry.

[0033] In some embodiments, in lieu of or in addition to main magnet 114, system 100 may use other components to generate an inhomogeneous magnetic field. For example, system 100 may include one or more of a resistive magnet, a superconducting magnet, or other components to generate an inhomogeneous magnetic field.

[0034] Figures 6A and 6B illustrates exemplary views magnet assembly 600, according to example embodiments. Magnet assembly 600 may be an exemplary arrangement of magnets configured to act as main magnet 114. As shown, magnet assembly 600 may include a plurality of permanent magnets 602. Plurality of permanent magnets 602 may be placed on a curved surface with their orientations and positions determined by solving an optimization problem to achieve desired magnetic field properties in the imaging regions of interest. The curved shape may allow for placement of magnet 114 on the patient' body surface.

[0035] Although Figures 6A and 6B provide an exemplary magnet assembly 600, those skilled in the art understand that, when designing magnet 114, other considerations, such as reducing a fringe field to avoid electromagnetic interference with surrounding other medical devices, may be taken into considerations.

[0036] Further, while Figures 6A and 6B are exemplary, those skilled in the art understand that main magnet 114 may take on other forms. For example, main magnet 114 may be installed into a patient couch or support.

[0037] Referring back to Figure 1A, gradient coils 116 may be positioned adjacent to main magnet 114. Gradient coils can be designed using various methods, such as, target field method, on specific given surfaces, e.g. the front surface of the main magnet 114. Gradient coils 116 may be positioned between main magnet 114 and a target patient. Gradient coils 116 may be representative of two or more gradient coils configured to create spatially varying magnetic fields along the x- and y-directions (or other non-trivial directions) for spatial encoding. Note, spatial encoding along the third axis (i.e., the z-axis) that is typically required in conventional MRI systems may be achieved in system 100 using the inhomogeneous magnetic field created by main magnet 114. For example, one gradient coil 116 can generate a spatially dependent magnetic field, based on which location information can be inferred in MR imaging process. Different techniques may be used to encode three directions (x-, y-, or z-directions) for three-dimensional imaging purpose. For example, gradient coils 116 may include at least one coil configured to encode one of three directions (e.g., one of the x-, y-, or z-direction). In such example, one of the other directions would be encoded by the inhomogeneous magnetic field generated by magnet 114 and the other direction would be encoded using a combination of the single coil and a mechanical rotation. In another example, gradient coils 116 may include a first gradient coil dedicated for encoding a first direction and a second gradient coil dedicated for encoding a second direction. In such example, the inhomogeneous magnetic field generated by magnet 114 would encode the third direction.

[0038] RF coils 118 may be configured to send and receive RF electromagnetic waves for MRI data acquisition. RF coils 118 may be configured in standard MRI coil forms, e.g. body coil, surface coil, birdcage coil, or coil array. In some embodiments, it is also possible to have separate transmit and receive RF coils 118 to position the receive RF coil closer to the imaging region of interest to increase signal to noise ratio.

[0039] In some embodiments, multiple RF coils 118 may be used. For example, each RF coil 118 may cover a narrow bandwidth. Together, RF coils 118 may cover a wide bandwidth needed to scan the imaging field of view. The use of narrow bandwidth for each RF coil 118 may help reducing image noise.

[0040] In some embodiments, MRI data acquisition may be achieved by performing a number of two-dimensional scans, each with a given RF frequency. For example, for a given frequency f_0, a two-dimensional surface in space may be defined based on the relationship $\gamma f_0 = B(x, y, z)$, i.e., the iso-magnetic field surface corresponding to the frequency f_0. Once the RF signal is sent to the FOV, it may excite spins on this two-dimensional surface. The signal received by the RF coil may contain excitation information in this surface, which can be used to reconstruct the image of this surface. Using two-dimensional spatial encoding techniques achieved via gradient coils 116, a typical form of received RF signal may be expressed as

$$S = \int dxdyM\big(x, y, z(x, y)\big)e^{i(k_x x + k_y y)}$$

Where $z(x, y)$ parametrizes the surface defined implicitly by $\gamma f_0 = B(x, y, z)$. The acquired RF signals may be used to reconstruct an image defined on a two-dimensional surface using standard Fourier Transform algorithm, iterative algorithms, or other advanced algorithms.

[0041] For example, Figure 2 illustrates a chart 200 representing an illustration of image reconstruction on a set of two-dimensional surfaces, according to example embodiments. As illustrated, image pixel values at the intersection between vertical lines 202 and iso-magnetic field surface 204 may be reconstructed by controller 108 or a computing system in communication with controller 108. Repeating this procedure for a different frequency f_0 may yield a set of images defined on a set of iso-magnetic field surfaces. Following this process, controller 108 or a computing system in communication with controller 108 may apply numerical interpolation to obtain a volumetric image defined by a cartesian coordinate for clinical use.

[0042] In some embodiments, main magnet 114 may generate an inhomogeneous magnetic field extending from the front surface of scanner 106. The magnetic field may decay as it moves away from a front surface of main magnet 114 (e.g., positive z-direction). As shown in Figure 2, due to the rotational symmetry, the magnetic field may be rotationally symmetric in space, about the z-axis. Such general principles, however, may not be limited to rotationally a symmetric magnet and magnetic field. The magnetic field distribution in space can be measured precisely, e.g. using a Tesla meter, yielding a function $B = B(x, y, z)$ in a coordinate system defined relative to the scanner geometry.

[0043] In some embodiments, system 100 may further include RF shielding (not shown). RF shielding may be used to reduce interference of RF signals in the patient room to the RF acquisition system of system 100. In some embodiments, standard RF shielding techniques may be applied, such as a copper sheet (or other metal sheets) to block interfering RF signals from the RF coil and patient body.

[0044] In some embodiments, system 100 may further include magnetic shielding (not shown). Magnetic shielding may be applied to shield the magnetic field of scanner 106 from reaching the environment, thus reducing its impact on other nearby medical devices. Magnetic shielding may be achieved by using magnetic shielding materials, e.g. mu-metal, positioned around scanner 106 and the patient body.

[0045] Controller 108 may be configured to control electronic motor system 110 and an amount of power provided to one or more of gradient coils 116 and/or RF coils 118. The power needed by the gradient coils and RF coils for imaging purpose may be obtained via standard power supply system. As illustrated, controller 108 may be in communication with computing system 150.

[0046] Computing system 150 may be a separate computer system 150 in communication with controller 108. Computing system 150 may be an option component. For example, instead of utilizing computing system 150, all processes performed by computing system 150 may be performed by controller 108. Computing system 150 may be configured to reconstruct an image on a surface of an object. For example, computing system 150 may define a reconstruction surface given the RF f_0 signal and magnetic field B_0. For example, for a given frequency f_0 and magnetic field B_0, controller 108 may define a two-dimensional surface in space. In some embodiments, the two-dimensional surface in space may be defined based on the relationship $\gamma f_0 = B(x, y, z)$, i.e., the iso-magnetic field surface corresponding to the frequency f_0. Computing system 150 may reconstruct the image based on the defined reconstruction surface and an acquired RF signal. Additional operations performed by computing system 150 and/or controller 108 may be found below in conjunction with Figure 4.

[0047] Figure 1B is a block diagram illustrating scanner 106, according to exemplary embodiments. As shown, scanner 106 may include main magnet 114 and gradient coils 116. Coordinates are shown on top of scanner 106 for illustration purposes.

[0048] Figure 3A is a block diagram illustrating scanner 106 positioned in a first exemplary position, according to example embodiments. As shown, scanner 106 may be positioned directly over a sternum of patient 302.

[0049] Figure 3B is a block diagram illustrating scanner 106 positioned in a second exemplary position, according to example embodiments. As shown, scanner 106 may be positioned adjacent to patient 302. For example, mechanical arm 104 may move scanner 106 away from first position illustrated in Figure 3A, to a second position. In some embodiments, moving scanner from the first position to the second position may include tilting scanner 106 at an angle with respect to the surface of the patient.

[0050] Although scanner 106 is shown in two different positions in Figures 3A and 3B, those skilled in the art recognize that these positions are only exemplary. Scanner 106 may be positioned in a plurality of positions relative to patient 302.

[0051] Figure 4 is a flow diagram illustrating a method 400 of operating system 100, according to example embodiments. Method 400 may begin at step 402.

[0052] At step 402, system 100 may transmit an RF signal. For example, controller 108 may transmit an RF signal having a frequency, f_0. In some embodiments, the signal may be sent through an RF coil 118. RF signal may induce magnetic nuclear resonance in the imaging region.

[0053] At step 404, system 100 may input the known magnetic field distribution B_0 to the system. In some embodiments, the 3D distribution of the field B_0 may depend on the specific magnet design and construction. For a given magnet, the distribution can be known, for example by performing a measurement.

[0054] At step 406, system 100 may define a reconstruction surface given the RF f_0 signal and magnetic field B_0. For example, for a given frequency f_0 and magnetic field B_0, controller 108 may define a two-dimensional surface in space. In some embodiments, the two-dimensional surface in space may be defined based on the relationship $\gamma f_0 = B(x, y, z)$, i.e., the iso-magnetic field surface corresponding to the frequency f_0.

[0055] At step 408, system 100 may acquire an RF signal. In some embodiments, the RF signal in the imaging region after the resonance may be received by the RF coil 118.

[0056] At step 410, system 100 may reconstruct an image on a surface of an object given the defined reconstruction surface and the acquired RF signal. For example, once the RF signal is sent to the field of view, it may excite spins on this two-dimensional surface. The signal received by RF coil 118 may contain excitation information in this surface, which can be used to reconstruct the image of this surface. For example, image pixel values at the intersection between the vertical lines and an iso-magnetic field surface can be reconstructed. In some embodiments, system 100 may reconstruct an image using a Fourier transform based method. In some embodiments, system 100 may reconstruct an image using advance iterative reconstruction methods. Repeating this procedure for different frequency, e.g., f_0, may yield a set of images defined on a set of iso-magnetic field surfaces. Following these operations, numerical interpolation may be applied to obtain a volumetric image defined a conventional Cartesian coordinate for clinical use.

[0057] To obtain the volume image inside the imaging region, images on a number of surfaces may be needed. Each scan with frequency f_0 may provide an image on one surface. The scan may be repeated with different frequencies to acquire images for different surfaces. At step 412, system 100 may determine whether all frequencies have been considered. If, at step, 412, system determines that not all frequencies were considered, then method 400 reverts to step 402 and a new f_0 is selected. If, however, at step 412, system 100 determines that all frequencies were considered, then method 400 proceeds to step 414.

[0058] At step 414, system 100 may resample the images to cartesian coordinates. For example, using two-dimensional spatial encoding techniques achieved via gradient coils 116, a typical form of received RF signal may be expressed as

$$S = \int dxdyM\big(x, y, z(x, y)\big)\mathrm{e}^{i(k_x x + k_y y)}$$

where $z(x, y)$ parametrizes the surface defined implicitly by $\gamma f_0 = B(x, y, z)$. The acquired RF signals may be used to reconstruct an image defined on a two-dimensional surface using standard Fourier Transform algorithm, iterative algorithms, or other advanced algorithms.

[0059] Figure 5A illustrates a system bus computing system architecture 500, according to example embodiments. One or more components of system 500 may be in electrical communication with each other using a bus 505. System 500 may include a processor (e.g., one or more CPUs, GPUs or other types of processors) 510 and a system bus 505 that couples various system components including the system memory 515, such as read only memory (ROM) 520 and random access memory (RAM) 525, to processor 510. System 500 can include a cache of high-speed memory connected directly with, in close proximity to, or integrated as part of processor 510. System 500 can copy data from memory 515 and/or storage device 530 to cache 512 for quick access by processor 510. In this way, cache 512 may provide a performance boost that avoids processor 510 delays while waiting for data. These and other modules can control or be configured to control processor 510 to perform various actions. Other system memory 515 may be available for use as well. Memory 515 may include multiple different types of memory with different performance characteristics. Processor 510 may be representative of a single processor or multiple processors. Processor 510 can include one or more of a general purpose processor or a hardware module or software module, such as service 1 532, service 2 534, and service 3 536 stored in storage device 530, configured to control processor 510, as well as a special-purpose processor where software instructions are incorporated into the actual processor design. Processor 510 may essentially be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric.

[0060] To enable user interaction with the computing device 500, an input device 545 which can be any number of input mechanisms, such as a microphone for speech, a touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech and so forth. An output device 535 can also be one or more of a number of output mechanisms known to those of skill in the art. In some instances, multimodal systems can enable a user to provide multiple types of input to communicate with computing device 500. Communications interface 540 can generally govern and manage the user input and system output. There is no restriction on operating on any particular hardware arrangement and therefore the basic features here may easily be substituted for improved hardware or firmware arrangements as they are developed.

[0061] Storage device 530 may be a non-volatile memory and can be a hard disk or other types of computer readable media that can store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, random access memories (RAMs) 525, read only memory (ROM) 520, and hybrids thereof.

[0062] Storage device 530 can include services 532, 534, and 536 for controlling the processor 510. Other hardware or software modules are contemplated. Storage device 530 can be connected to system bus 505. In one aspect, a hardware module that performs a particular function can include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as processor 510, bus 505, display 535, and so forth, to carry out the function.

[0063] Figure 5B illustrates a computer system 550 having a chipset architecture that can be used in operating system 100. Computer system 550 may be an example of computer hardware, software, and firmware that can be used to implement the disclosed technology. System 550 can include one or more processors 555, representative of any number of physically and/or logically distinct resources capable of executing software, firmware, and hardware configured to perform identified computations. One or more processors 555 can communicate with a chipset 560 that can control input to and output from one or more processors 555. In this example, chipset 560 outputs information to output 565, such as a display, and can read and write information to storage device 570, which can include magnetic media, and solid state media, for example. Chipset 560 can also read data from and write data to RAM 575. A bridge 580 for interfacing with a variety of user interface components 585 can be provided for interfacing with chipset 560. Such user interface components 585 can include a keyboard, a microphone, touch detection and processing circuitry, a pointing device, such as a mouse, and so on. In general, inputs to system 550 can come from any of a variety of sources, machine generated and/or human generated.

[0064] Chipset 560 can also interface with one or more communication interfaces 590 that can have different physical interfaces. Such communication interfaces can include interfaces for wired and wireless local area networks, for broadband wireless networks, as well as personal area networks. Some applications of the methods for generating, displaying, and using the GUI disclosed herein can include receiving ordered datasets over the physical interface or be generated by the machine itself by one or more processors 555 analyzing data stored in storage 570 or 575. Further, the machine can receive inputs from a user through user interface components 585 and execute appropriate functions, such as browsing functions by interpreting these inputs using one or more processors 555.

[0065] It can be appreciated that example systems 500 and 550 can have more than one processor 510 or be part of a group or cluster of computing devices networked together to provide greater processing capability.

[0066] While the foregoing is directed to embodiments described herein, other and further embodiments may be devised without departing from the basic scope thereof. For example, aspects of the present disclosure may be implemented in hardware or software or a combination of hardware and software. One embodiment described herein may be implemented as a program product for use with a computer system. The program(s) of the program product define functions of the embodiments (including the methods described herein) and can be contained on a variety of computer-readable storage media. Illustrative computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory (ROM) devices within a computer, such as CD-ROM disks readably by a CD-ROM drive, flash memory, ROM chips, or any type of solid-state non-volatile memory) on which information is permanently stored; and (ii) writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or any type of solid state random-access memory) on which alterable information is stored. Such computer-readable storage media, when carrying computer-readable instructions that direct the functions of the disclosed embodiments, are embodiments of the present disclosure.

[0067] It will be appreciated to those skilled in the art that the preceding examples are exemplary and not limiting. It is intended that all permutations, enhancements, equivalents, and improvements thereto are apparent to those skilled in the art upon a reading of the specification and a study of the drawings are included within the true spirit and scope of the present disclosure. It is therefore intended that the following appended claims include all such modifications, permutations, and equivalents as fall within the true spirit and scope of these teachings.

Claims:

1. A portable magnetic resonance imaging (MRI) system, comprising:
a mechanical arm configurable between a plurality of positions; and
a scanner coupled to the mechanical arm, the scanner configurable between the plurality of positions, the scanner comprising:
a magnet configured to generate an inhomogeneous magnetic field;
one or more gradient coils configured to generate one or more magnetic fields to distort the inhomogeneous magnetic field; and
one or more radio frequency (RF) coils configured to send and receive RF electromagnetic waves for imaging purposes.

2. The portable MRI system of claim 1, further comprising:
a structure that defines an interior volume of interest for imaging; and
an electronic motor system configured direct to portable MRI system to a location.

3. The portable MRI system of claim 2, wherein the structure further comprises:
one or more wheels coupled thereto, wherein the one or more wheels are controlled by the electronic motor system.

4. The portable MRI system of claim 1, further comprising:
a controller configured to control an amount of power delivered to at least one of the one or more gradient coils or the one or more RF coils.

5. The portable MRI system of claim 1, wherein a first gradient coil of the one or more gradient coils is configured to generate a first spatially varying magnetic field along a first direction.

6. The portable MRI system of claim 5, wherein a second gradient coil of the one or more gradient coils is configured to generate a second spatially varying magnetic field along a second direction.

7. The portable MRI system of claim 6, wherein the magnet is configured to generate a third spatially varying magnetic field along a third direction.

8. The portable MRI system of claim 1, wherein the one or more RF coils are configured to facilitate MRI data acquisition by performing a number of two-dimensional scans, with varying RF frequencies.

9. The portable MRI system of claim 1, wherein a first RF coil of the one or more RF coils comprises a transmit RF coil and a second RF coil of the one or more RF coils comprises a receive RF coil.

10. A portable magnetic resonance imaging (MRI) system, comprising:

a magnet configured to generate an inhomogeneous magnetic field;

one or more gradient coils configured to generate one or more magnetic fields to distort the inhomogeneous magnetic field; and

one or more radio frequency (RF) coils configured to send and receive RF electromagnetic waves for imaging purposes.

11. The portable MRI system of claim 10, further comprising:

a structure that defines an interior volume; and

an electronic motor system configured direct to portable MRI system to a location.

12. The portable MRI system of claim 11, wherein the structure further comprises:

one or more wheels coupled thereto, wherein the one or more wheels are controlled by the electronic motor system.

13. The portable MRI system of claim 10, further comprising:

a controller configured to control an amount of power delivered to at least one of the one or more gradient coils or the one or more RF coils.

14. The portable MRI system of claim 10, wherein a first gradient coil of the one or more gradient coils is configured to generate a first spatially varying magnetic field along a first direction.

15. The portable MRI system of claim 14, wherein a second gradient coil of the one or more gradient coils is configured to generate a second spatially varying magnetic field along a second direction.

16. The portable MRI system of claim 15, wherein the magnet is configured to generate a third spatially varying magnetic field along a third direction.

17. The portable MRI system of claim 10, wherein the one or more RF coils are configured to facilitate MRI data acquisition by performing a number of two-dimensional scans, with varying RF frequencies.

18. The portable MRI system of claim 10, wherein a first RF coil of the one or more RF coils comprises a transmit RF coil and a second RF coil of the one or more RF coils comprises a receive RF coil.

19. A portable MRI system comprising:

a scanner comprising:

a magnet configured to generate an inhomogeneous magnetic field;

one or more gradient coils configured to generate one or more magnetic fields to distort the inhomogeneous magnetic field; and

one or more radio frequency (RF) coils configured to send and receive RF electromagnetic waves for imaging purposes; and

a controller coupled to the scanner, the controller configured to perform operations comprising:

transmitting a first RF signal;

defining a reconstruction surface given the RF signal and the inhomogeneous magnetic field generated the magnet;

acquiring a second RF signal; and

reconstructing an image on a surface of an object given the defined reconstruction surface and the second RF signal.

20. The portable MRI system of claim 19, wherein the operations further comprise:

resampling the image to cartesian coordinates.

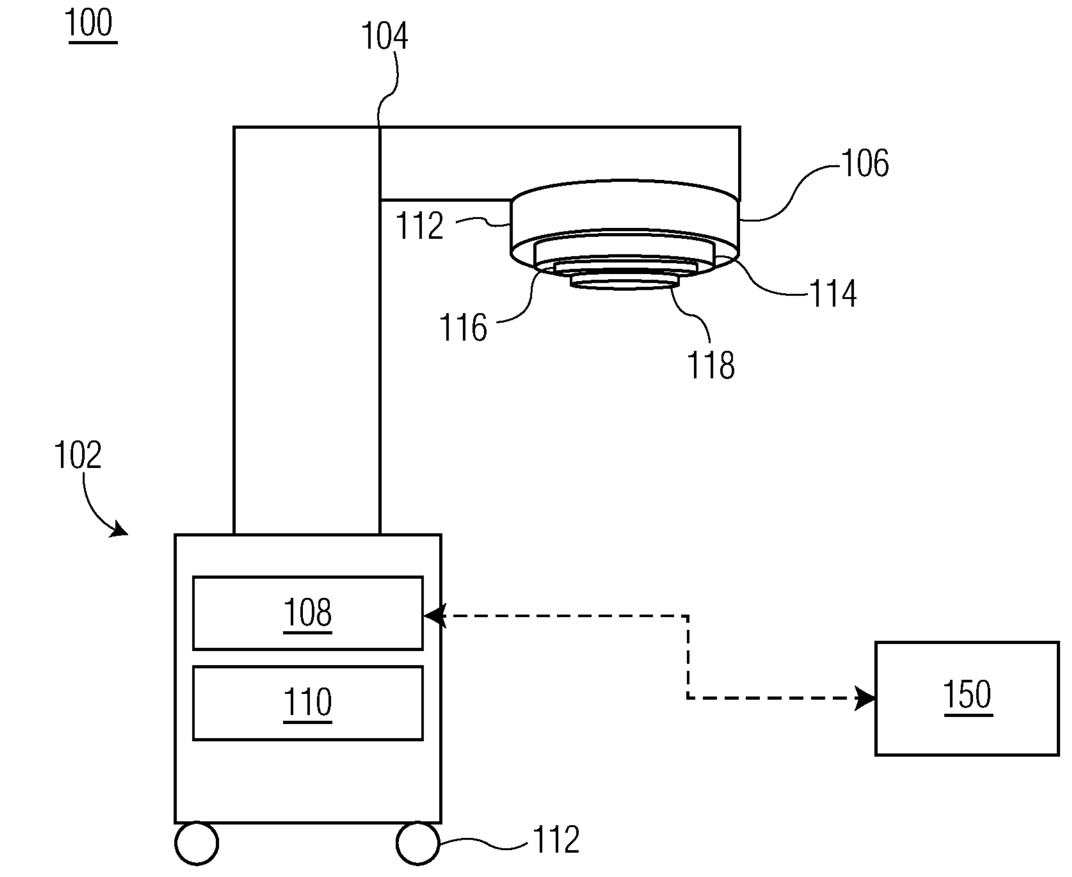

FIG. 1A

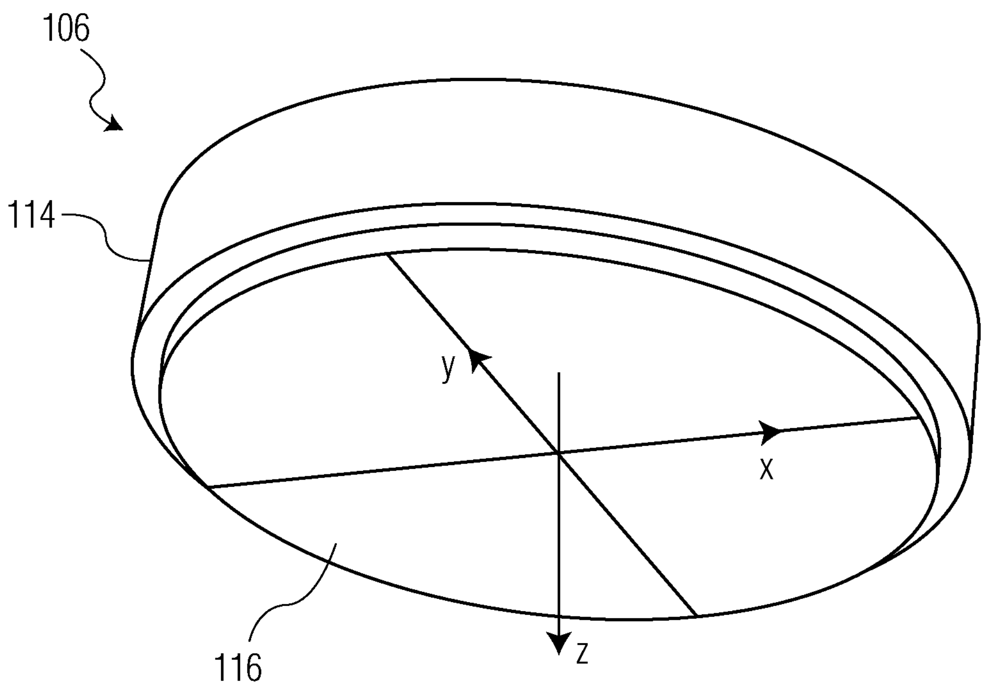

FIG. 1B

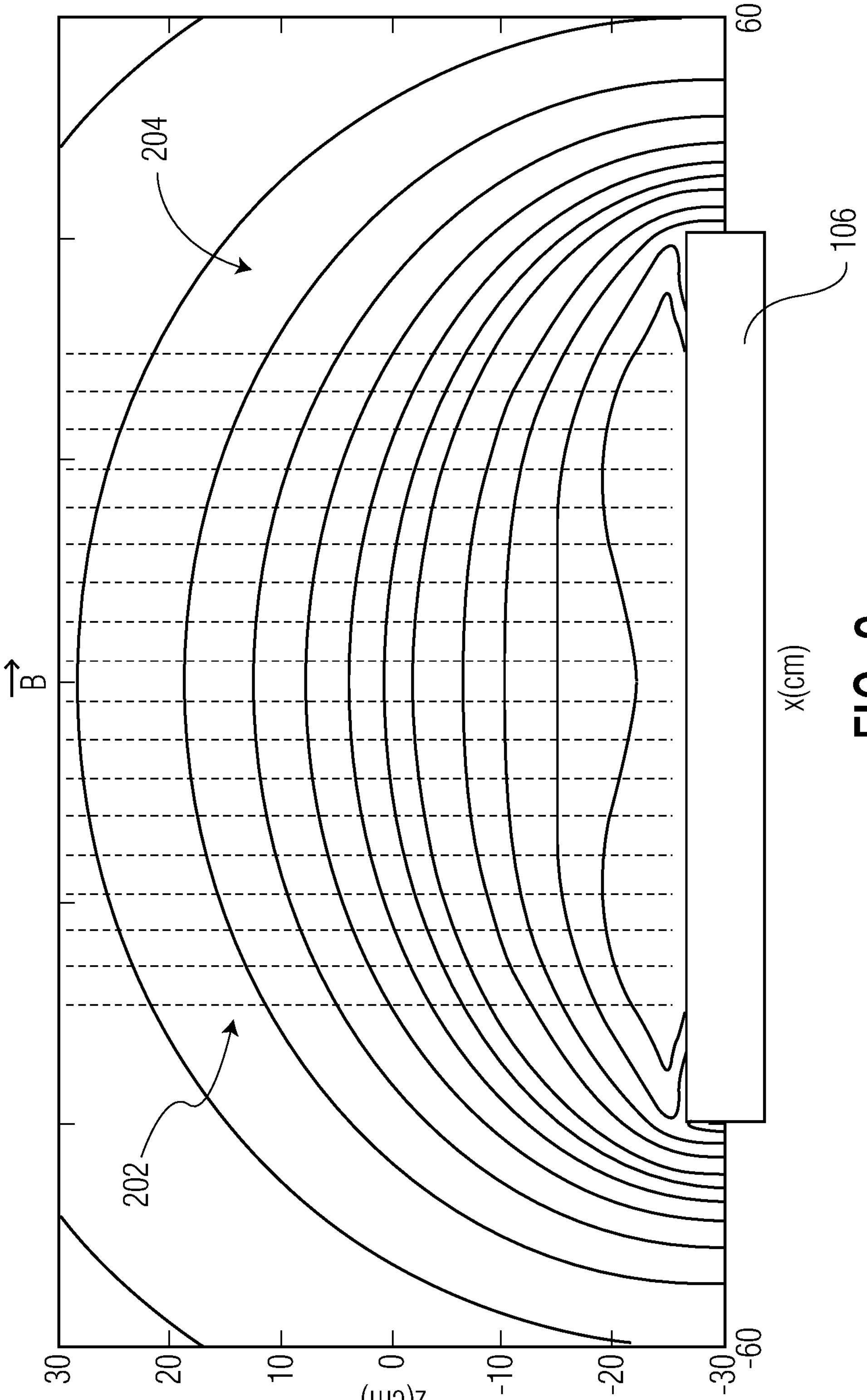

FIG. 2

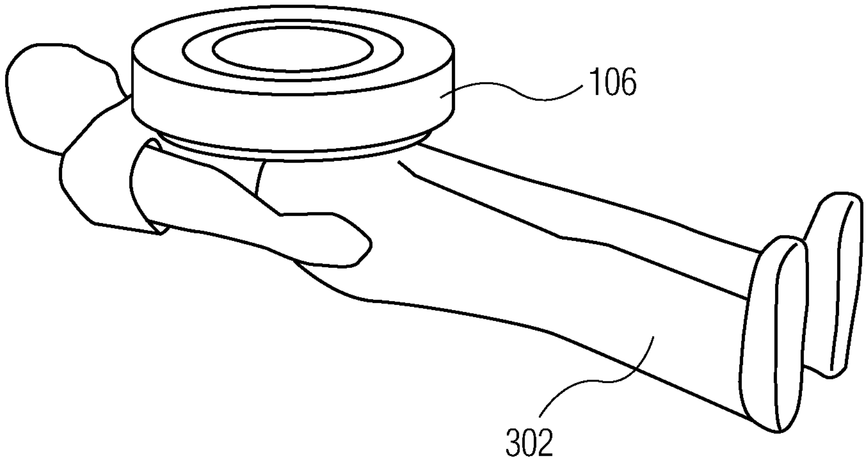

FIG. 3A

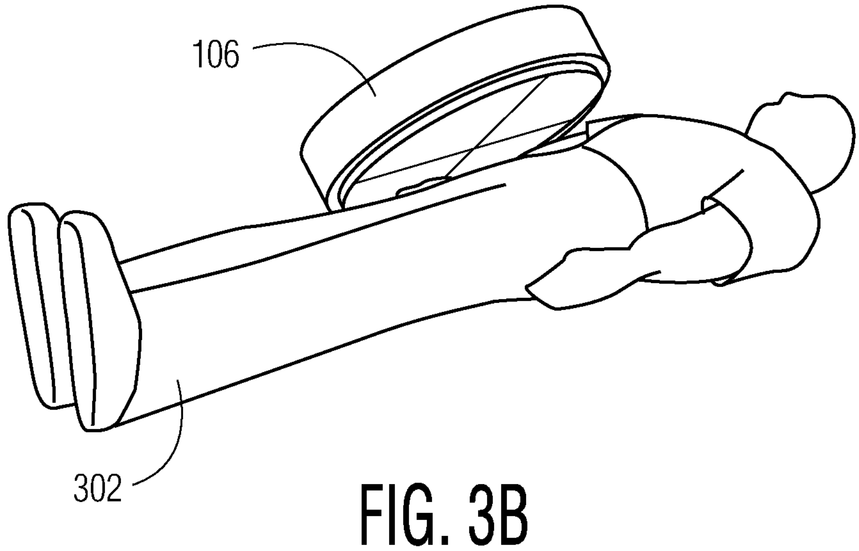

FIG. 3B

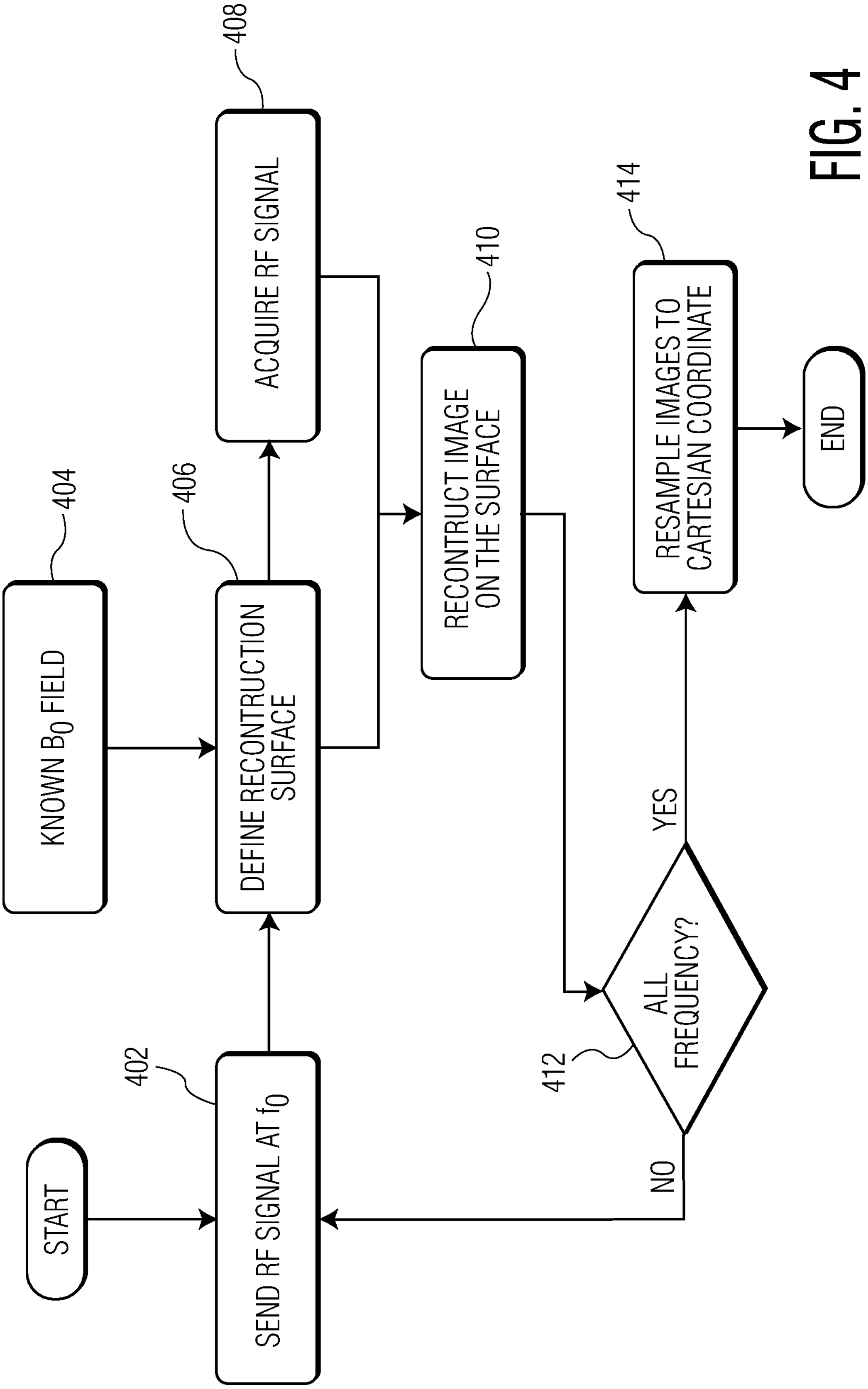
START
SEND RF SIGNAL AT f_0
402
KNOWN B_0 FIELD
404
DEFINE RECONTRUCTION SURFACE
406
ACQUIRE RF SIGNAL
408
RECONTRUCT IMAGE ON THE SURFACE
410
ALL FREQUENCY?
412
NO
YES
RESAMPLE IMAGES TO CARTESIAN COORDINATE
414
END

FIG. 4

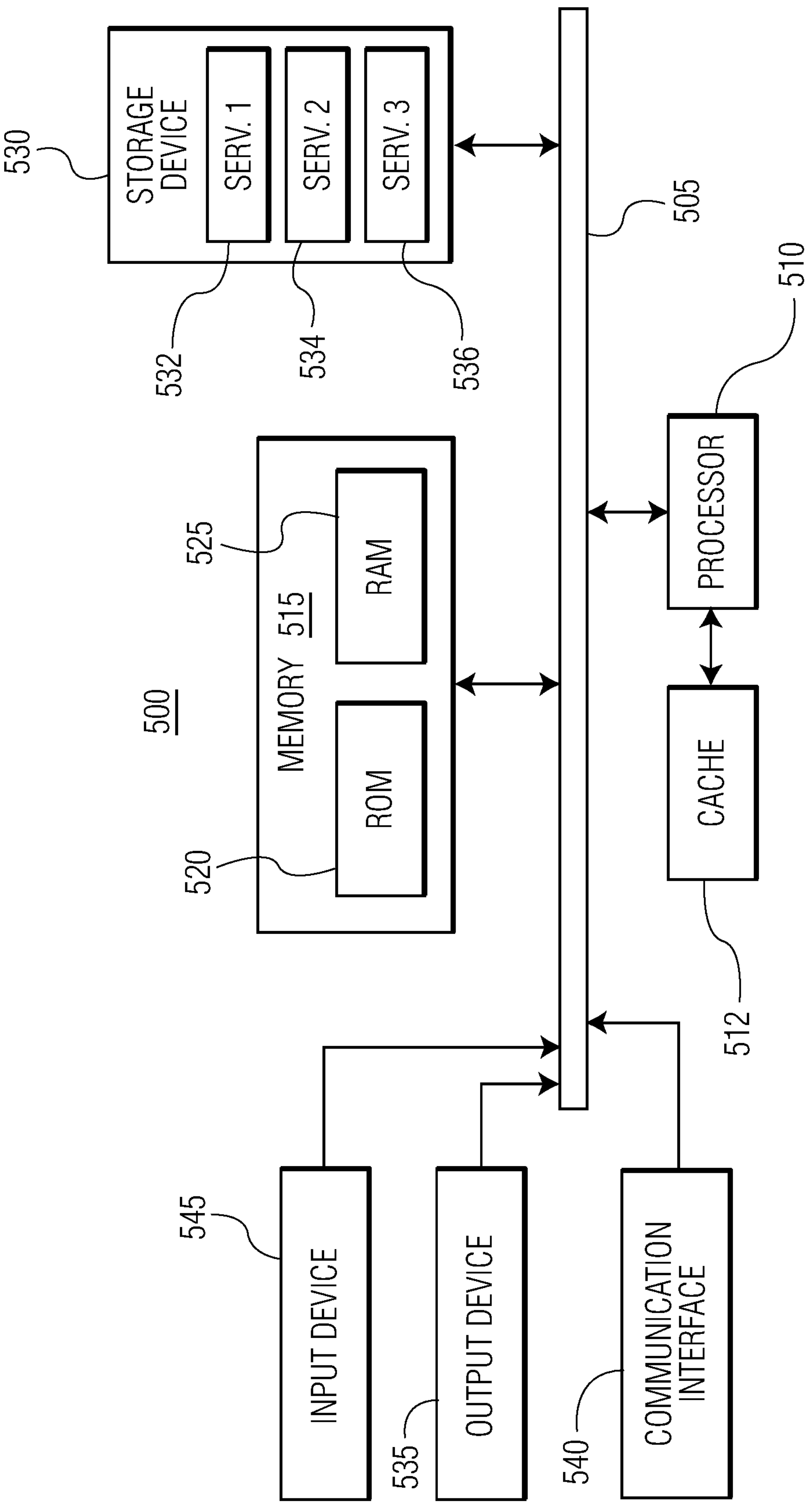
500
STORAGE DEVICE
SERV. 1
SERV. 2
SERV. 3
530
532
534
536
505
MEMORY 515
RAM
ROM
525
520
PROCESSOR
510
CACHE
512
INPUT DEVICE
545
OUTPUT DEVICE
535
COMMUNICATION INTERFACE
540

FIG. 5A

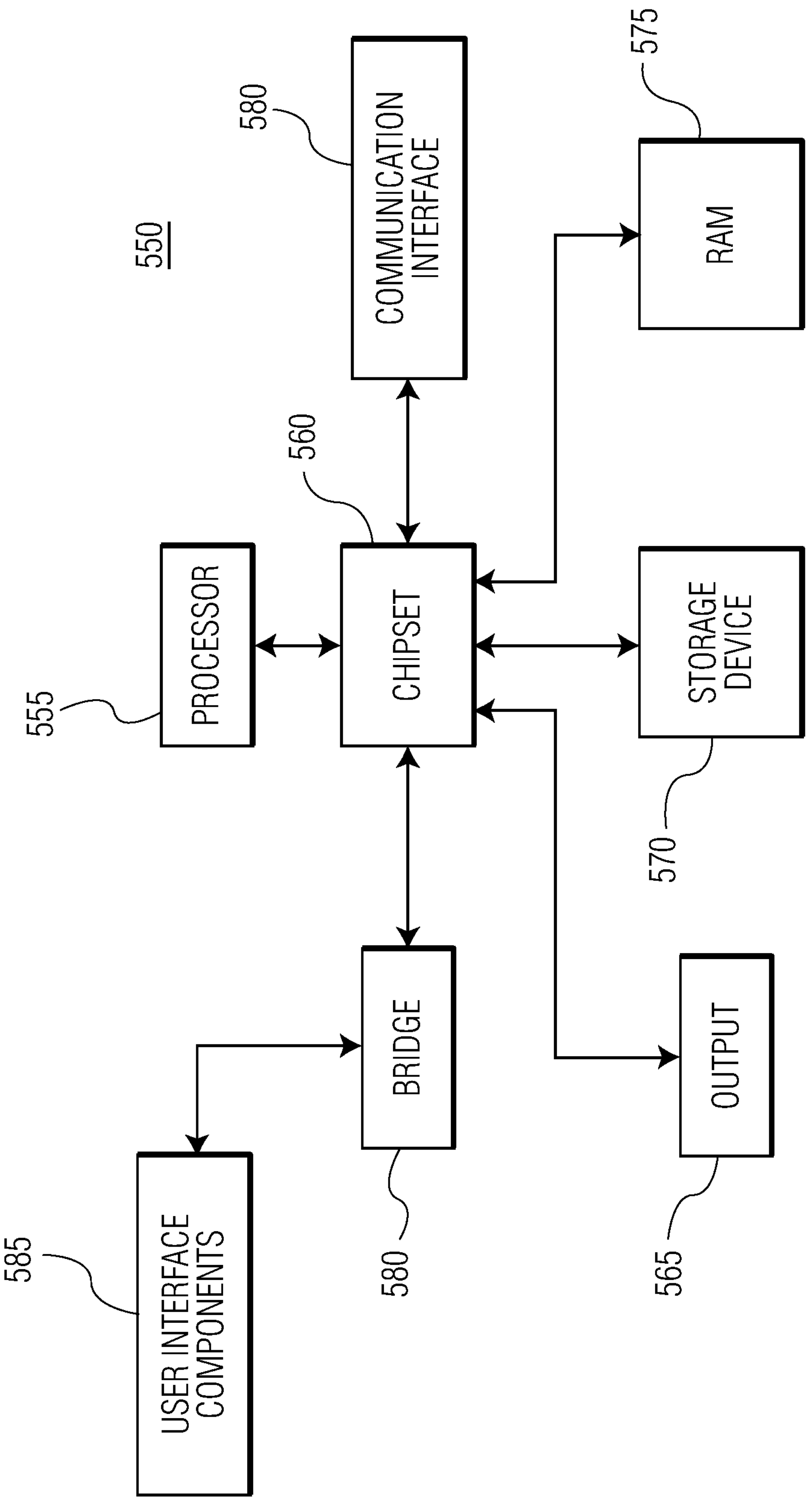
550
COMMUNICATION INTERFACE
580
575
RAM
560
555
PROCESSOR
CHIPSET
STORAGE DEVICE
570
BRIDGE
OUTPUT
585
USER INTERFACE COMPONENTS
580
565

FIG. 5B

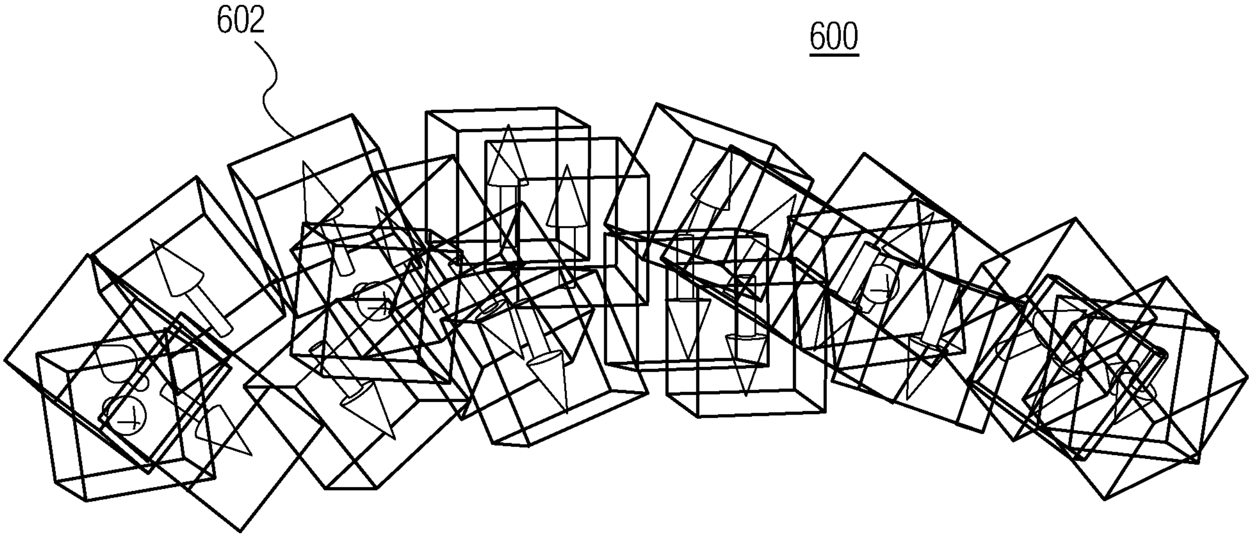

FIG. 6A

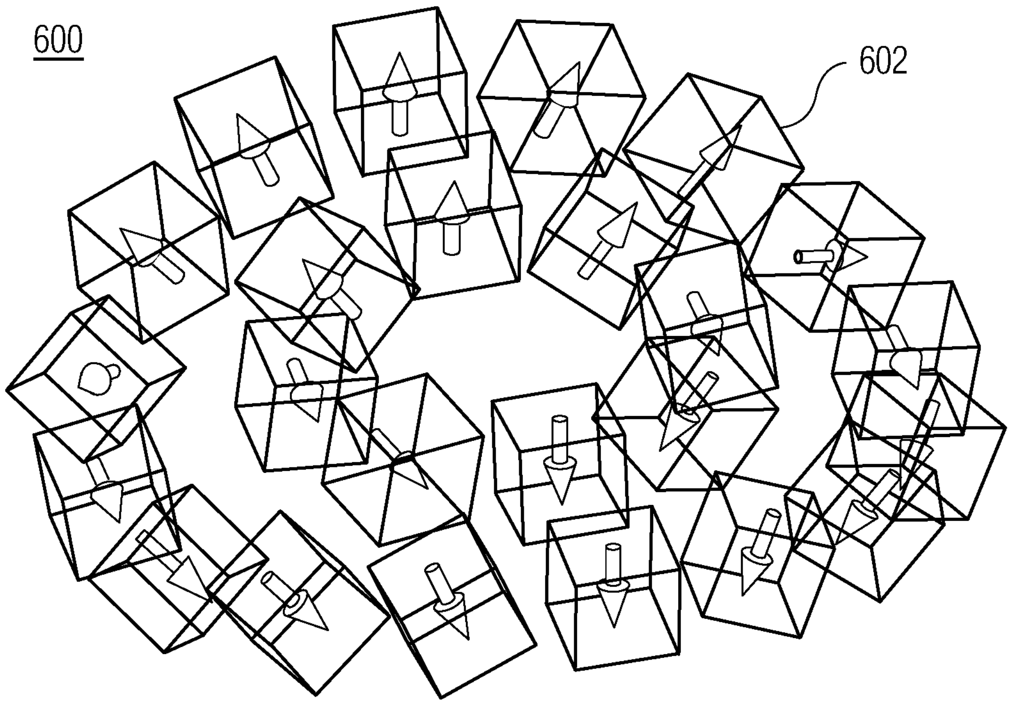

FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 21/41916

A. CLASSIFICATION OF SUBJECT MATTER
IPC - A61B 5/055; G01R 33/383; G01R 33/385; G01R 33/48 (2021.01)

CPC - A61B 6/4405; A61B 5/055; G01R 33/287; G01R 33/383; G01R 33/385; G01R 33/48

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)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 2015/0217136 A1 (UNIVERSITY HEALTH NETWORK) 06 August 2015 (06.08.2015), para [0005], [0082], [0086], [0156], [0193], [0199], [0204], [0205], [0207]-[0209]; Fig 11	1, 4, 5, 8-10, 13, 14, 17, 18 --- 2, 3, 6, 7, 11, 12, 15, 16 --- 19, 20
Y --- A	US 2018/0143274 A1 (HYPERFINE RESEARCH, INC.) 24 May 2018 (24.05.2018), para [0009], [0099], [0104], [0129], [0164], [0256]; Fig 19A, 19B	2, 3, 6, 7, 11, 12, 15, 16 --- 19, 20
A	US 2001/0009974 A1 (REISFELD) 26 July 2001 (26.07.2001), para [0010], [0041], [0045]	19, 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
"D" document cited by the applicant in the international application
"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
13 September 2021	OCT 21 2021
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriquez Telephone No. PCT Helpdesk: 571-272-4300