



(51) International Patent Classification:

G01R 33/48 (2006.01) G01R 33/38 (2006.01)
G01R 33/56 (2006.01)

(21) International Application Number:

PCT/IB2019/056725

(22) International Filing Date:

07 August 2019 (07.08.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

201841029631 07 August 2018 (07.08.2018) IN

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(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, 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, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: A DATA ACQUISITION SYSTEM AND A METHOD OF ACQUIRING DATA FOR RECONSTRUCTION OF MRI
IMAGES

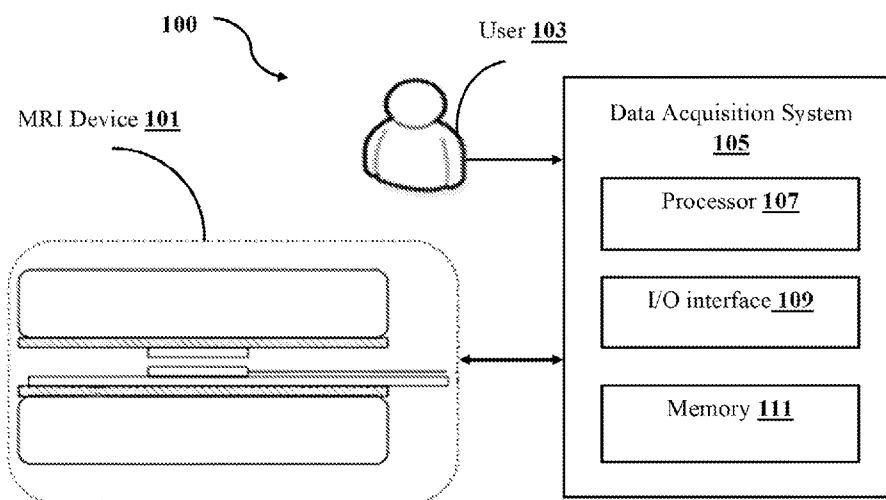


Figure 1

(57) Abstract: The present disclosure relates to a method and system for acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images. The method comprises obtaining a trajectory for acquiring magnetic gradients from identified one or more data points in scanned data, wherein the number of data points scanned by the MRI device is based on a weighing value received from a user. The method consequentially reduces the time of scanning based on the weighing value received, while maintaining the structural similarity of the reconstructed MRI image.

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))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

**TITLE: "A DATA ACQUISITION SYSTEM AND A METHOD OF
ACQUIRING DATA FOR RECONSTRUCTION OF MRI IMAGES"**

TECHNICAL FIELD

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The present subject matter is generally related to Magnetic Resonance Imaging (MRI), and more particularly, but not exclusively, to a method and system for acquiring data for reconstruction of MRI images.

BACKGROUND

- 10 Magnetic Resonance Imaging (MRI) is a Nuclear Magnetic Resonance (NMR)-based non-invasive scanning method used for the purposes of imaging. The MRI gained popularity among public mostly for its contribution to diagnostics. Further, the advantages of MRI comprise preventing exposure to radiation by using magnetic field as principle excitation source, enhanced imaging of soft tissues and provisions to obtain 3-Dimensional (3D) as well as cross-
- 15 sectional images of an area of interest in a subject had enabled MRI devices to be used for varying number of applications comprising imaging and even therapy. But one of the main disadvantages associated with a conventional MRI device is its extended time of scanning. Particularly in medical imaging applications, patients tend to prefer x-ray, Computer tomography (CT) and other radiological imaging techniques in comparison to allow themselves
- 20 to be inside a loud hollow tunnel of an MRI device for hours at a time. Some experience claustrophobia, palpitations, and other stress symptoms during the scanning process. But reduction in the time of scanning can lead to compromise in the quality of the images obtained, which may lead to misdiagnosis of the health issue. Therefore, it is necessary to strike a balance between the time of scanning and the quality of the resulting images.
- 25 An MRI mainly uses static magnetic field of the order of a few Tesla in conjunction with radio frequency waves to polarize the hydrogen ions of the water molecules in a body. The hydrogen ions tend to go back to their original state and emit the radio frequency waves during depolarization cycle. The spatial localization of the scanned data from the emitted radio frequency waves is obtained by using three linear magnetic gradients (g_x , g_y and g_z) in three
- 30 directions built in an MRI device which turn ON and OFF individually in a manner to encode the emitted signal by slice in the area of interest, frequency and phase.

The emitted radio frequency waves comprise the scanned data of multiple slices from the area of interest in k-space (frequency domain). The received scanned data in k-space of a slice comprise multiple data points distributed non-uniformly over a plane of the k-space. To obtain the gradients of individual data points, the k-space is scanned following a selected path, and the obtained gradients are used to reconstruct the scanned images of the area of interest by applying inverse Fourier Transform (IFT) to convert then to time domain and display for analysis.

The path that is followed for scanning to sample the data points in a k-space is called a trajectory. Traditionally, to construct an image, the scanner sample all the data points in the k-space in a cartesian trajectory satisfying the Nyquist criteria, and cartesian methods such as spin echo(SE) imaging, gradient Echo(GE) imaging, echo planar imaging (EPI) and the like are used to sample using a trajectory over a uniform grid. Other non-cartesian trajectories such as spiral, radial, shell, rosette etc are also being used lately for traversing along a trajectory to sample non-uniformly.

Compressed sensing (CS) theory aims to reconstruct signals and images from significantly fewer data points. The application of CS to MRI reduces the scan time significantly, wherein the under sampling adopted, violates the Nyquist criteria. The main properties for Compressed Sensing (CS) theory to be applied are sparsity and incoherence. MRI images are sparse in transform domains such as wavelet, finite differences, Discrete Cosine Transform (DCT) and the like. To achieve incoherence, random sampling is theorized. However, it is not practical to sample random points in MRI. Hence, to obtain a continuous trajectory, use of solution of Traveling Salesman Problem (TSP) was considered, which gives the shortest path between the randomly sampled points. As the trajectory does not satisfy the gradient constraints, it compromises the feasibility of application of the trajectory to the data in k-space. Further, there is a trade-off between scan time and image quality when using a CS-MRI.

There are two methods, to obtain feasible trajectory from a given arbitrarily parameterized curve: optimal control-based method and projection-based method. Optimal control-based method finds the fastest gradient curves to traverse the given reference curve. Drawback of this method is that it forces the trajectory to follow the original reference curve. This makes the trajectory take more samples near sharp edges resulting in increased scan time. Projection-based method projects the given curve onto a set of feasible curves and smoothens it. The constraint to follow the reference curve was relaxed in projection-based method. However, it suffers from the drawback that it is heavily dependent on initial parameterization of the curve. Traditional

ad-hoc trajectories outperform this method.

SUMMARY

The present disclosure discloses a method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images. The method comprises receiving by a data acquisition system associated with an MRI device, a scanned data of a predefined area of interest of a subject from the MRI device, wherein the predefined area of interest is scanned by the MRI device based on a predefined weighing value. The predefined area of interest is categorized into a plurality of slices, wherein each of the plurality of slices comprises plurality of data points distributed predominantly in a centre region of the slice. Thereafter, the method comprises, identifying, one or more data points among the plurality of data points in each of the plurality of slices for down sampling based on variable density condition. The method comprises obtaining, by the acquisition system, a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint. The method thereafter comprises acquiring data associated with magnetic gradients of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory for reconstructing the image of the predefined area of interest.

Further, the present disclosure discloses a data acquisition system. The data acquisition system comprises a processor and a memory. The memory is communicatively coupled to the processor, wherein the processor is configured to receive a scanned data of predefined area of interest of a subject from the MRI device, wherein the predefined area of interest is scanned by the MRI device based on a predefined weighing value. The predefined area of interest is categorized into a plurality of slices, wherein each of the plurality of slices comprises plurality of data points distributed predominantly in a centre region of the slice. The processor identifies one or more data points among the plurality of data points in each of the plurality of slices for down sampling based on variable density condition. The processor is further configured to obtain a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint. Thereafter the processor acquires data associated with magnetic gradients, of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory, for reconstructing the image of the predefined area of interest.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

For a better understanding of exemplary embodiments of the present invention, together with other and further features and advantages thereof, reference is made to the following description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The same numbers are used throughout the figures to reference like features and components. Some embodiments of device or system and/or methods in accordance with embodiments of the present subject matter are now described, by way of example only, and with reference to the accompanying figures, in which:

Figure 1 illustrates an exemplary architecture of data acquisition system in accordance with some embodiments of the present disclosure;

Figure 2 shows block diagram of a data acquisition system in accordance with some embodiments of the present disclosure;

Figure 3 shows a flowchart illustrating a method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images in accordance with some embodiments of the present disclosure;

Figures 4a and **4b** shows exemplary application of variable density condition to identify one or more data points for under sampling, in accordance with some embodiments of the present disclosure;

Figures 5a-5d shows a comparison between feasible trajectory curves obtained by conventional methods and the present method in accordance with some embodiments of the present disclosure; and

Figures 6(a-f) illustrates the change in the length of the trajectory obtained corresponding to a predefined weighing value denoted by λ , in accordance with some embodiments of the present disclosure.

5 It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative systems embodying the principles of the present subject matter. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and executed by a computer or processor, whether or not such
10 computer or processor is explicitly shown.

DETAILED DESCRIPTION

In the present document, the word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment or implementation of the present subject matter
15 described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

While the disclosure is susceptible to various modifications and alternative forms, specific embodiment thereof has been shown by way of example in the drawings and will be described
20 in detail below. It should be understood, however that it is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the disclosure is to cover all modifications, equivalents, and alternative falling within the spirit and the scope of the disclosure.

The terms "comprises", "comprising", or any other variations thereof, are intended to cover a
25 non-exclusive inclusion, such that a setup, device or method that comprises a list of components or steps does not include only those components or steps but may include other components or steps not expressly listed or inherent to such setup or device or method. In other words, one or more elements in a device or system or apparatus preceded by "comprises... a" does not, without more constraints, preclude the existence of other elements or additional elements in the
30 device or system or method.

The present disclosure relates to a data acquisition system and the method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images. The data acquisition system may receive a scanned data of a predefined area of interest of a subject from an MRI device.
35 The scanned data is obtained in k-space. The predefined area of interest is scanned by the MRI

device based on a predefined weighing value. The number of data points scanned by the MRI device is inversely proportional to the predefined weighing value. The predefined weighing value may be a value defined in the range $0-R+$, where $R+\geq 0$. The predefined area of interest is categorized into a plurality of slices and scanned data in k-space of each of the plurality of slices comprises plurality of data points distributed predominantly in a centre region of the slice. The data acquisition system may identify one or more data points among the plurality of data points in each of the plurality of slices for under sampling based on variable density condition. The variable density condition is implemented using at least one of rectangular grid method and variable probability function method. After identifying the one or more data points, the data acquisition system may obtain a trajectory to scan the identified one or more data points by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew rate constraint. For example, the gradient constraint is maximum gradient strength $G_{\max}$ and slew-rate constraint is the maximum slew-rate $S_{\max}$ which may vary for different models of MRI device 101. Further, for a given MRI device 101, usually the $G_{\max}$ and $S_{\max}$ are same for all three gradient axes. For example, Siemens Magnetom Prisma MRI device has $G_{\max}$ of 80 mT/m (millitesla per meter) and $S_{\max}$ of 200mT/m/ms (millitesla per meter per millisecond). Thereafter, the data acquisition system acquires data associated with magnetic gradients of the identified one or more data points by scanning the one or more data points of the slice while traversing along the obtained trajectory for reconstructing an image of the predefined area of interest. The magnetic gradients comprise information associated with slice selection, phase encoding and frequency encoding gradients. The acquired magnetic gradients are reconstructed to obtain the MRI images.

In this manner, the present disclosure obtains a trajectory to acquire data for reconstruction of MRI images and thereby reduce time of scanning while still maintaining the quality of the reconstructed MRI images.

Figure 1 illustrates an exemplary architecture 100 of data acquisition system 105 in accordance with some embodiments of the present disclosure.

The architecture 100 may include an MRI device 101, a user 103 and a data acquisition system 105. The MRI device 101 may be configured to scan a predefined area of interest of a subject based on a predefined weighing value provided by the user 103 to the data acquisition system 105. In some other embodiment, the data acquisition system 105 may be remotely associated with the MRI device 101, via a wireless communication network (not shown in Figure 1).

The data acquisition system 105 may include a processor 107, an Input/Output (I/O) interface 109 and a memory 111. The I/O interface 109 may be configured to receive a predefined weighing value from the user 103. Upon receiving the predefined weighing value, the data acquisition system 105 associated with the MRI device 101 may be configured to receive a scanned data 201 of a predefined area of interest of a subject scanned by the MRI device 101. The scanned data 201 obtained is in k-space. The predefined area of interest is categorized into a plurality of slices which comprises plurality of data points distributed predominantly in a centre region of the slice. As an example, the scanned data 201 of a slice might comprise datapoints that are distributed sparsely at the edges and densely as it progresses towards the centre. The MRI device 101 scan the predefined area of interest based on the predefined weighing value. The number of data points scanned by the MRI device 101 is inversely proportional to the predefined weighing value. As an example, the predefined weighing value may be one of 0, 10, 100, 500 and 1000. Upon receiving the scanned data 201, the processor 107 may, identify one or more data points among the plurality of data points in each of the plurality of slice for under sampling based on variable density condition. As an example, the variable density condition comprise implementation of rectangular grid method using a scaled rectangular grid of size 128 x 128 size which is as shown in **Figure 4a** and the identified data-points of the exemplified variable density condition may be as shown in **Figure 4b**. The data acquisition system 105 may also obtain a trajectory to scan the identified one or more data points by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint. The predefined reference curve comprises a 2-dimensional curve in time domain $c(t)$, $c : [0, T] \rightarrow \mathbb{R}^2$ determined by magnetic gradients of a MRI device 101 and is obtained based on equation (1) provided below:

$$c(t) = \gamma \int_0^t \dot{g}(\tau) d\tau. \quad (1)$$

where, $g(\tau)$ comprise a function representing gradient constraint and slew rate constraint.

In an exemplified embodiment, the reference $c(t)$ may be a travelling salesman problem (TSP) curve. In another exemplified embodiment, the predefined reference curve $c(t)$ comprise a spiral curve.

For example, the gradient constraint is maximum gradient strength $G_{\max}$ and slew-rate

constraint is the maximum slew-rate $S_{\max}$ which may vary for different models of MRI device 101. Further, for a given MRI device 101, usually the $G_{\max}$ and $S_{\max}$ are same for all three gradient axes. For example, Siemens Magnetom Prisma MRI device has $G_{\max}$ of 80 mT/m (millitesla per meter) and $S_{\max}$ of 200 mT/m/ms (millitesla per meter per millisecond). The data acquisition system 105 may further acquire the data associated with magnetic gradients of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory, for reconstructing the image of the predefined area of interest. The magnetic gradients comprise information associated with slice selection, phase encoding and frequency encoding gradients. For example, the scanned data 201 through the radio waves emitted by the tissue from the area of interest of a subject are received by the radio frequency coils in an MRI device 101. During this process, the scanned data 201 from the different slices and datapoints are given distinctive frequency and phase characteristics so that they can be separated from the other data points during image reconstruction. Based on the acquired magnetic gradient data 209, the scanned data 201 is reconstructed into MRI images comprising the area of interest of the subject.

In an embodiment, the time of scanning of the MRI device 101 for a predefined area of interest is reduced without any significant change in the quality or resolution of the reconstructed MRI images.

Figure 2 Shows block diagram in accordance with some embodiments of the present disclosure.

In some implementations, the data acquisition system 105 may include data and modules. As an example, the data is stored in a memory 111 configured in the data acquisition system 105 as shown in the **Figure 2**. In one embodiment, the data 200 may include a scanned data 201, a predefined weighing value data 203, identified data-points data 205, a trajectory data 207, a magnetic gradient data 209, constraints data 211 and other data 213. In the illustrated **Figure 2**, modules are described herein in detail.

In some embodiments, the data may be stored in the memory 111 in form of various data structures. Additionally, the data can be organized using data models, such as relational or hierarchical data models. The other data 213 may store data, including temporary data and temporary files, generated by the modules for performing the various functions of the data acquisition system 105.

In some embodiments, the data stored in the memory 111 may be processed by the modules of the data acquisition system 105. The modules may be stored within the memory 111. In an example, the modules communicatively coupled to the processor 107 configured in the data acquisition system 105, may also be present outside the memory 111 as shown in **Figure 2** and implemented as hardware. As used herein, the term modules may refer to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory 111 that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

In some embodiments, the modules may include, for example, a receiving module 215, a data point identifying module 217, a trajectory obtaining module 219, a data acquiring module 221 and other modules 223. The other modules 223 may be used to perform various miscellaneous functionalities of the data acquisition system 105. It will be appreciated that such aforementioned modules may be represented as a single module or a combination of different modules.

As used herein, the term module refers to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory 111 that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. In an embodiment, the other modules 223 may be used to perform various miscellaneous functionalities of the data acquisition system 105. It will be appreciated that such modules may be represented as a single module or a combination of different modules. Furthermore, a person of ordinary skill in the art will appreciate that in an implementation, the one or more modules may be stored in the memory 111, without limiting the scope of the disclosure. The said modules when configured with the functionality defined in the present disclosure will result in a novel hardware.

In an embodiment, the receiving module 215 may be configured to receive the scanned data 201 of predefined area of interest of a subject from the MRI device 101 associated with the data acquisition system 105. The predefined weighing value may be received from the user 103 and stored as the predefined weighing value data 203. The predefined weighing value 203 is communicated to the MRI device 101 associated with the data acquisition system 105. The predefined area of interest of a subject is scanned by the MRI device 101 based on the predefined weighing value.

In an embodiment, the scanned data 201 may be retrieved by the data-points identifying module 217 to implement variable density condition and identify one or more datapoints for under sampling. The identified one or more data points may be stored as identified data-points data 205. For example, the identified data-points data 205 may comprise one or more data points obtained by implementing variable density condition wherein greater number of data points may be obtained from centre region of the slice in k-space in comparison to edges. In an exemplified embodiment, the array of datapoints between $-k_{\max}$ and $+k_{\max}$ is scaled by $e^{\alpha|k|}$, $\alpha \in \mathbb{R}^+$ using scaled rectangular grid method. In an exemplified embodiment, the variable density condition is implemented by one of a class of possible variable density probability function $1/|k|^p$. In another exemplified embodiment the possible variable density probability function is $1/|k|^2$.

In another embodiment, the trajectory obtaining module 219 may be configured to obtain a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint. The trajectory obtaining module 217 may retrieve the gradient constraint and slew-rate constraint from the constraints data 211 defined based on the MRI device 101. A predefined reference curve associated with the other data 213 is also retrieved by the obtaining module 219 to obtain a trajectory. The obtained trajectory may be stored as trajectory data 207. In an exemplified embodiment a single predefined reference curve can be used to scan all kind of tissue of a subject's body. The optimization of the predefined reference curve may be performed as shown in **Figure 5(d)** by satisfying the gradient and slew-rate constraints, which implies that the maximum velocity with which the trajectory may be traversed is proportional to the maximum gradient strength $G_{\max}$ and rate of change in direction by the trajectory is proportional to the maximum slew-rate $S_{\max}$. **Figure 5(a)** discloses curves that illustrates the confinements imposed by the gradient constraint and slew-rate constraint. **Figure 5(b) & 5 (c)** disclose other curves of prior arts in dotted lines, in comparison to the present disclosure depicted in **Figure 5(d)**, wherein the reference curve $c(t)$ satisfies the gradient and slew-rate constraints.

In an exemplified embodiment, the predefined reference curve optimized to obtain the trajectory shall satisfy the main requirements of a) low scan time b) physical plausibility and c) variable density sampling in compressive sensing framework comprise solving the optimization function:

$$\begin{aligned}
 & \arg \min_{s(t)} \quad \frac{1}{2}d(c(t), s(t)) + \frac{\lambda}{2}l(s(t)) \\
 & \text{subject to} \quad |g(t)| \leq G_{\max} \\
 & \quad \quad \quad |\dot{g}(t)| \leq S_{\max}
 \end{aligned} \tag{2}$$

- Where $s(t)$ is the trajectory to be obtained, $c(t)$ is the reference curve, $d(c(t), s(t))$ is a distance operator for the curves, $l(s(t))$ indicates length of trajectory. $\lambda > 0$ is a predefined weighing value for the length of the curve. $c(t)$ is an arbitrary time function given as predefined reference curve. In an exemplified embodiment, the predefined reference curve $c(t)$ comprise one of a travelling salesman problem (TSP) curve. In another exemplified embodiment, the predefined reference curve $c(t)$ comprise a spiral curve.
- 10 The exemplified obtained trajectory in conjunction with the predefined weighing value is as shown in **Figures 6(a-f)**, where the length of the trajectory can be seen to be inversely proportional to the predefined weighing value. For example, as can be seen in **Figures 6(a-f)**, for lower predefined weighing value like 0 and 10, the length of the trajectory is more as seen in **Figure 6b and 6c**. In an exemplified embodiment, as the predefined weighing value increase to 500 in **Figure 6(e)** and 1000 in **Figure 6(f)**, the length of the trajectory is reduced and thereby the time of scanning by the scanner associated with acquiring module 221 to scan corresponding trajectories is also reduced. But as the trajectory is obtained from identified one or more data points based on variable density conditions, the reconstructed MRI images with a significantly higher predefined weighing value may comprise acceptable quality of image. In another
- 20 exemplified embodiment, the number of data points between two identified one or more data points that a trajectory traverse is more when the weighing value is less and vice versa.

In another embodiment, the data acquiring module 221 may be configured to retrieve the trajectory data 207 and the identified data-points data 205 from the memory 111. The data

25 acquiring module 221 scans the identified one more datapoints of each slice from the identified data-points data 205, along the obtained trajectory from the trajectory data 207 to acquire magnetic gradients of the one or more data points. The magnetic gradients comprise information

associated with slice selection, phase encoding and frequency encoding gradients. The acquired magnetic gradients may be stored as magnetic gradient data 209 which may be used for reconstruction of the MRI images.

- 5 **Figure 3** Shows a flowchart illustrating a method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images in accordance with some embodiments of the present disclosure.

10 As illustrated in **Figure 3**, the method 300 includes one or more blocks illustrating a method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images. The method 300 may be described in the general context of computer executable instructions. Generally, computer executable instructions can include routines, programs, objects, components, data structures, procedures, modules, and functions, which perform specific functions or implement specific abstract data types.

15 The order in which the method 300 is described is not intended to be construed as a limitation, and any number of the described method blocks can be combined in any order to implement the method. Additionally, individual blocks may be deleted from the methods without departing from the spirit and scope of the subject matter described herein. Furthermore, the method can
20 be implemented in any suitable hardware, software, firmware, or combination thereof.

At **block 301**, the method 300 may include receiving, by a data acquisition system 105 associated with an MRI device 101, a scanned data 201 of a predefined area of interest of a subject from the MRI device 101. The predefined area of interest is scanned by the MRI device
25 101 based on a predefined weighing value. The number of data points scanned by the MRI device 101 is inversely proportional to the predefined weighing value. the predefined weighing value is a value defined in the range $0-R+$, for all $R \geq 0$. The scanned data 201 is obtained in k-space. The predefined area of interest is categorized into a plurality of slices, and the scanned data 201 in k-space of each of the plurality of slices comprises plurality of data points
30 distributed predominantly in a centre region of the slice

At **block 302**, the method 300 may include identifying, by the data acquisition system 105, one or more data points among the plurality of data points in each of the plurality of slices for under sampling based on variable density condition. The variable density condition is implemented using at least one of rectangular grid method and variable density probability function method.

At **block 303**, the method 300 may include obtaining, by the data acquisition system 105, a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint.

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At **block 304**, the method 300 may include acquiring, by the data acquisition system 105, data associated with magnetic gradients of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory for reconstructing an image of the predefined area of interest.

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Computer System

Figure 7 illustrates a block diagram of an exemplary computer system 700 for implementing embodiments consistent with the present disclosure. In an embodiment, the computer system 700 may be data acquisition system 105, which is used for acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images. The computer system 700 may include a central processing unit (“CPU” or “processor”) 702. The processor 702 may comprise at least one data processor for executing program components for executing user 103 or system-generated business processes. The processor 702 may include specialized processing units such as integrated system (bus) controllers, memory management control units, floating point units, graphics processing units, digital signal processing units, etc.

The processor 702 may be disposed in communication with one or more input/output (I/O) devices (411 and 412) via I/O interface 701. The I/O interface 701 may employ communication protocols/methods such as, without limitation, audio, analog, digital, stereo, IEEE-1394, serial bus, Universal Serial Bus (USB), infrared, PS/2, BNC, coaxial, component, composite, Digital Visual Interface (DVI), high-definition multimedia interface (HDMI), Radio Frequency (RF) antennas, S-Video, Video Graphics Array (VGA), IEEE 802.n /b/g/n/x, Bluetooth, cellular (e.g., Code-Division Multiple Access (CDMA), High-Speed Packet Access (HSPA+), Global System For Mobile Communications (GSM), Long-Term Evolution (LTE) or the like), etc. Using the I/O interface 701, the computer system 700 may communicate with one or more I/O devices 511 and 712. In some implementations, the I/O interface 701 may be used by the user 103 to access the reconstructed images and provide weighing value.

In some embodiments, the processor 702 may be disposed in communication with a communication network 409 via a network interface 703. The network interface 703 may

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communicate with the communication network 409. The network interface 703 may employ connection protocols including, without limitation, direct connect, Ethernet (e.g., twisted pair 10/100/1000 Base T), Transmission Control Protocol/Internet Protocol (TCP/IP), token ring, IEEE 802.11a/b/g/n/x, etc.

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The communication network 409 can be implemented as one of the several types of networks, such as intranet or Local Area Network (LAN) and such within the organization. The communication network 409 may either be a dedicated network or a shared network, which represents an association of several types of networks that use a variety of protocols, for example, Hypertext Transfer Protocol (HTTP), Transmission Control Protocol/Internet Protocol (TCP/IP), Wireless Application Protocol (WAP), etc., to communicate with each other. Further, the communication network 409 may include a variety of network devices, including routers, bridges, servers, computing devices, storage devices, etc.

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In some embodiments, the processor 702 may be disposed in communication with a memory 705 (e.g., RAM 713, ROM 714, etc) via a storage interface 704. The storage interface 704 may connect to memory 705 including, without limitation, memory drives, removable disc drives, etc., employing connection protocols such as Serial Advanced Technology Attachment (SATA), Integrated Drive Electronics (IDE), IEEE-1394, Universal Serial Bus (USB), fiber channel, Small Computer Systems Interface (SCSI), etc. The memory drives may further include a drum, magnetic disc drive, magneto-optical drive, optical drive, Redundant Array of Independent Discs (RAID), solid-state memory devices, solid-state drives, etc.

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The memory 705 may store a collection of program or database components, including, without limitation, user 103 /application 706, an operating system 707, a web browser 708, mail client 715, mail server 716, web server 717 and the like. In some embodiments, computer system 700 may store user /application data 706, such as the data, variables, records, etc. as described in this invention. Such databases may be implemented as fault-tolerant, relational, scalable, secure databases such as OracleR or SybaseR.

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The operating system 707 may facilitate resource management and operation of the computer system 700. Examples of operating systems include, without limitation, APPLE MACINTOSH OS X, UNIXR, UNIX-like system distributions (E.G., BERKELEY SOFTWARE DISTRIBUTIONTM (BSD), FREEBSDTM, NETBSDTM, OPENBSDTM, etc.), LINUX DISTRIBUTIONTM (E.G., RED HATTM, UBUNTUTM, KUBUNTUTM,

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etc.), IBMTM OS/2, MICROSOFTTM WINDOWSTM (XPTM, VISTATM/7/8, 10 etc.),
APPLER IOSTM, GOOGLER ANDROIDTM, BLACKBERRYR OS, or the like. A user
interface may facilitate display, execution, interaction, manipulation, or operation of program
components through textual or graphical facilities. For example, user interfaces may provide
5 computer interaction interface elements on a display system operatively connected to the
computer system 500, such as cursors, icons, check boxes, menus, windows, widgets, etc.
Graphical User Interfaces (GUIs) may be employed, including, without limitation, APPLE
MACINTOSH operating systems, IBMTM OS/2, MICROSOFTTM WINDOWSTM
(XPTM, VISTATM/7/8, 10 etc.), UnixR X-Windows, web interface libraries (e.g., AJAXTM,
10 DHTMLTM, ADOBE® FLASHTM, JAVASCRIPTTM, JAVATM, etc.), or the like.

Furthermore, one or more computer-readable storage media may be utilized in implementing
embodiments consistent with the present invention. A computer-readable storage medium
refers to any type of physical memory on which information or data readable by a processor
15 may be stored. Thus, a computer-readable storage medium may store instructions for execution
by one or more processors, including instructions for causing the processor(s) to perform steps
or stages consistent with the embodiments described herein. The term "computer-readable
medium" should be understood to include tangible items and exclude carrier waves and
transient signals, i.e., non-transitory. Examples include Random Access Memory (RAM),
20 Read-Only Memory (ROM), volatile memory, non-volatile memory, hard drives, Compact
Disc (CD) ROMs, Digital Video Disc (DVDs), flash drives, disks, and any other known
physical storage media.

The terms "an embodiment", "embodiment", "embodiments", "the embodiment", "the
25 embodiments", "one or more embodiments", "some embodiments", and "one embodiment"
mean "one or more (but not all) embodiments of the invention(s)" unless expressly specified
otherwise.

The terms "including", "comprising", "having" and variations thereof mean "including but not
limited to", unless expressly specified otherwise. The enumerated listing of items does not
30 imply that any or all the items are mutually exclusive, unless expressly specified otherwise.

The terms "a", "an" and "the" mean "one or more", unless expressly specified otherwise.

A description of an embodiment with several components in communication with each other
35 does not imply that all such components are required. On the contrary, a variety of optional

components are described to illustrate the wide variety of possible embodiments of the invention.

When a single device or article is described herein, it will be clear that more than one device/article (whether they cooperate) may be used in place of a single device/article. Similarly, where more than one device or article is described herein (whether they cooperate), it will be clear that a single device/article may be used in place of the more than one device or article or a different number of devices/articles may be used instead of the shown number of devices or programs. The functionality and/or the features of a device may be alternatively embodied by one or more other devices which are not explicitly described as having such functionality/features. Thus, other embodiments of the invention need not include the device itself.

Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the invention be limited not by this detailed description. Accordingly, the disclosure of the embodiments of the invention is intended to be illustrative, but not limiting, of the scope of the invention.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting.

Advantages of the present disclosure:

The present disclosure allows a user to control the time of scanning of an area of interest of a subject based on the predefined weighing value.

The present disclosure obtains a feasible trajectory satisfying gradient constraint and slew-rate constraint for the trajectory.

The present disclosure provides reconstruction of the MRI images with shorter scanning time.

In the present disclosure, a reduced time of scanning of 89 ms due to a weighing value of “1” constitute a reconstructed image with structural similarity of 0.9161 for a 256 x 256 brain image.

Referral Numerals:

Reference Number	Description
100	Architecture
101	MRI Device
103	User
105	Data Acquisition System
107	Processor
109	I/O Interface
111	Memory
200	Data
201	Scanned data
203	Weighing value data
205	Identified data-points data
207	Trajectory Data
209	Magnetic Gradient Data
211	Constraints data
213	Other data
215	Receiving Module
217	Identifying Module
219	Obtaining Module
221	Acquiring Module
223	Other Modules
700	Exemplary computer system
701	I/O Interface of the exemplary computer system
702	Processor of the exemplary computer system
703	Network interface
704	Storage interface
705	Memory of the exemplary computer system
706	User /Application
707	Operating system
708	Web browser
409	Communication network

411	Input devices
412	Output devices
713	RAM
714	ROM
415	Mail Client
416	Mail Server
417	Web Server

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We claim:

1. A method of acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images, the method comprising:
 - receiving, by a data acquisition system associated with an MRI device, a scanned
5 data of a predefined area of interest of a subject from the MRI device, wherein the predefined area of interest is scanned by the MRI device based on a predefined weighing value, wherein the predefined area of interest is categorized into a plurality of slices, wherein each of the plurality of slices comprises plurality of data points distributed predominantly in a center region of the slice;
 - 10 identifying, by the data acquisition system, one or more data points among the plurality of data points in each of the plurality of slices for down sampling based on variable density condition;
 - obtaining, by the data acquisition system, a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified
15 one or more data points, a gradient constraint and a slew-rate constraint, wherein the gradient constraint comprise maximum gradient strength ($G_{\max}$) and maximum slew-rate ($S_{\max}$) of an MRI device; and
 - acquiring, by the data acquisition system, data associated with magnetic
20 gradients of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory for reconstructing an image of the predefined area of interest.
2. The method as claimed in claim 1, wherein the scanned data is obtained in k-space.
3. The method as claimed in claim 1, wherein number of data points scanned by the MRI
25 device is inversely proportional to the predefined weighing value.
4. The method as claimed in claim 1, wherein the predefined weighing value is in the range 0-R, wherein R is a real number greater than or equal to 0.
- 30 5. The method as claimed in claim 1, wherein the variable density condition is implemented using at least one of rectangular grid method and variable density probability function method.

6. The method as claimed in claim 1, wherein the magnetic gradients comprise information associated with slice selection, phase encoding and frequency encoding gradients.
7. A data acquisition system for acquiring data for reconstruction of Magnetic Resonance Imaging (MRI) images, the acquisition system comprising:
 - a processor;
 - a memory communicatively coupled to the processor, wherein the processor is configured to:
 - receiving a scanned data of predefined area of interest of a subject from the MRI device, wherein the predefined area of interest is scanned by the MRI device based on a predefined weighing value, wherein the predefined area of interest is categorized into a plurality of slices; wherein each of the plurality of slices comprises plurality of data points distributed predominantly in an center region of the slice;
 - identifying one or more data points among the plurality of data points in each of the plurality of slices for down sampling based on variable density condition;
 - obtaining a trajectory to scan the identified one or more data points, by optimizing a predefined reference curve based on the identified one or more data points, a gradient constraint and a slew-rate constraint, wherein the gradient constraint comprise maximum gradient strength ($G_{\max}$) and maximum slew-rate ($S_{\max}$) of an MRI device; and
 - acquiring data associated with magnetic gradients, of the identified one or more data points, by scanning the one or more data points of the slice while traversing along the obtained trajectory, for reconstructing the image of the predefined area of interest.
8. The data acquisition system as claimed in claim 7, wherein the scanned data is obtained in k-space.
9. The data acquisition system as claimed in claim 7, wherein number of data points scanned by the MRI device is inversely proportional to the predefined weighing value.
10. The data acquisition system as claimed in claim 7, wherein the predefined weighing value is in the range 0-R, wherein R is a real number greater or equal 0.

11. The data acquisition system as claimed in claim 7, wherein the processor implements the variable density condition using at least one of rectangular grid method and variable density probability function method.
- 5 12. The data acquisition system as claimed in claim 7, wherein the magnetic gradients comprise information associated with slice selection, phase encoding and frequency encoding gradients.

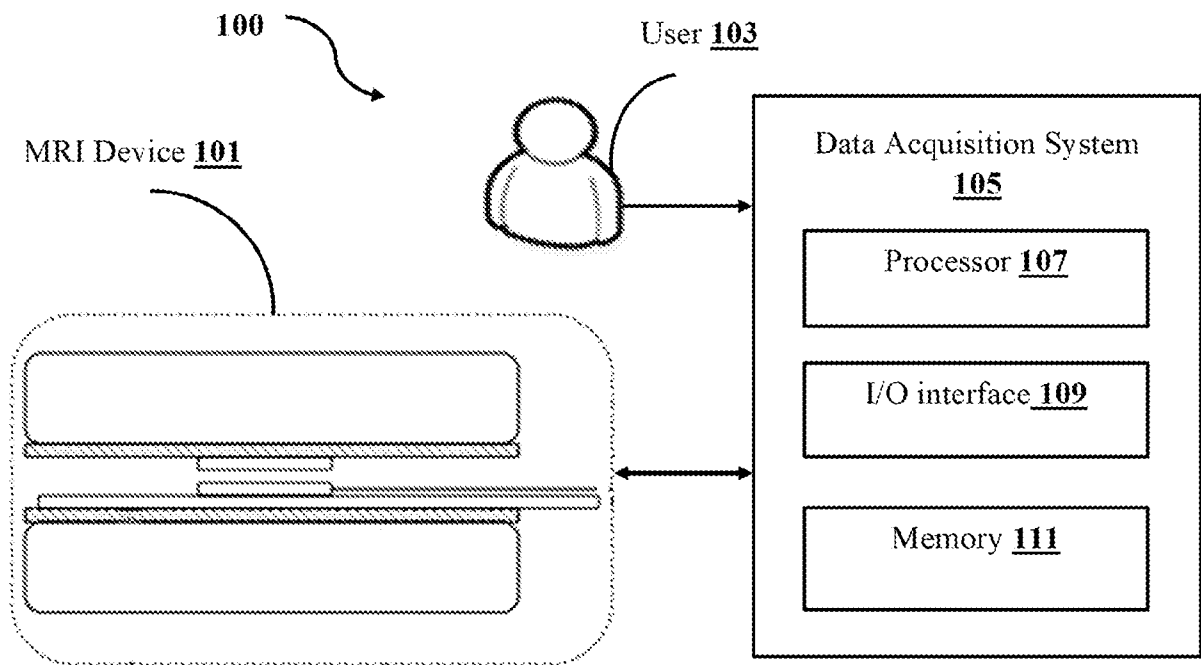


Figure 1

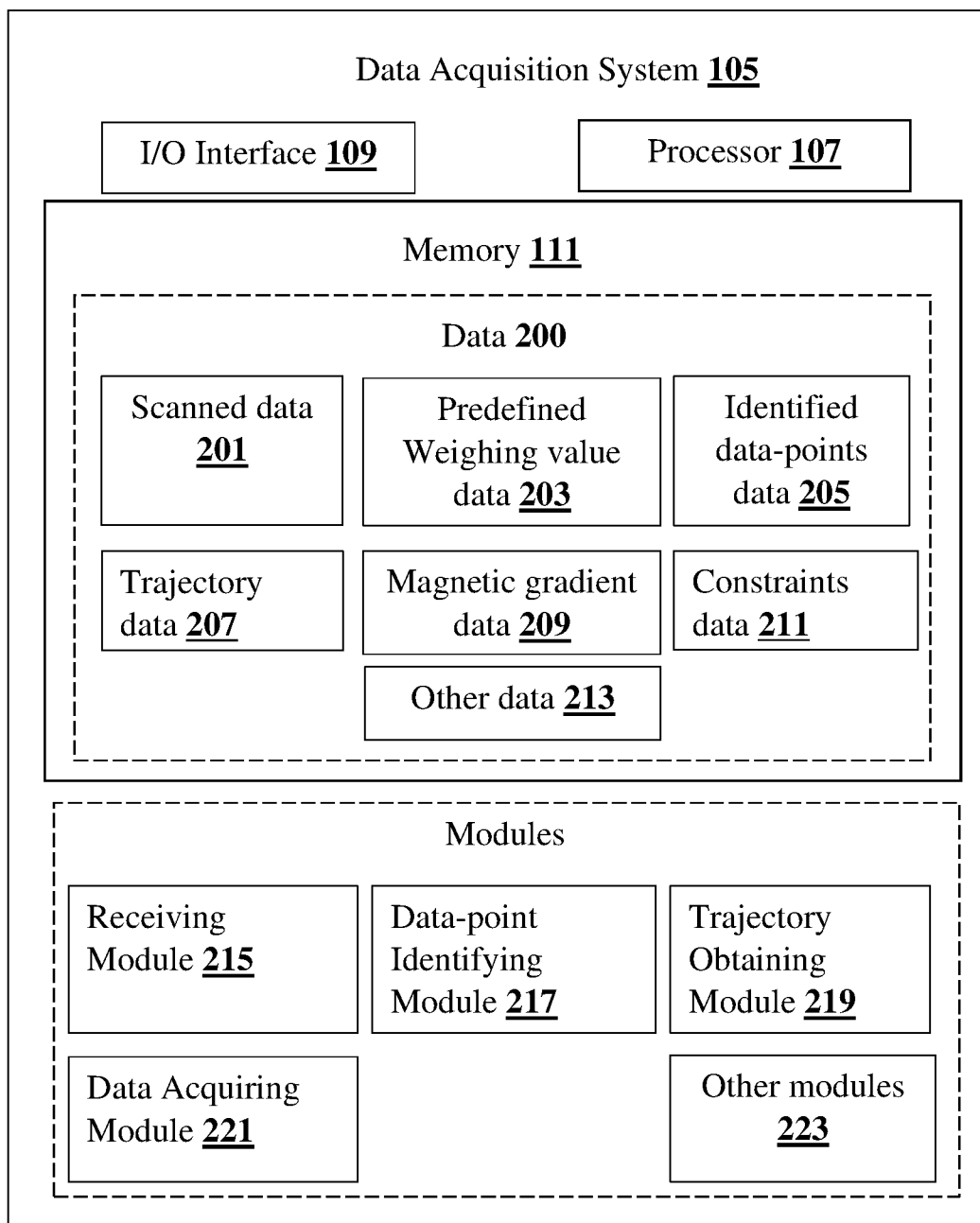


Figure 2

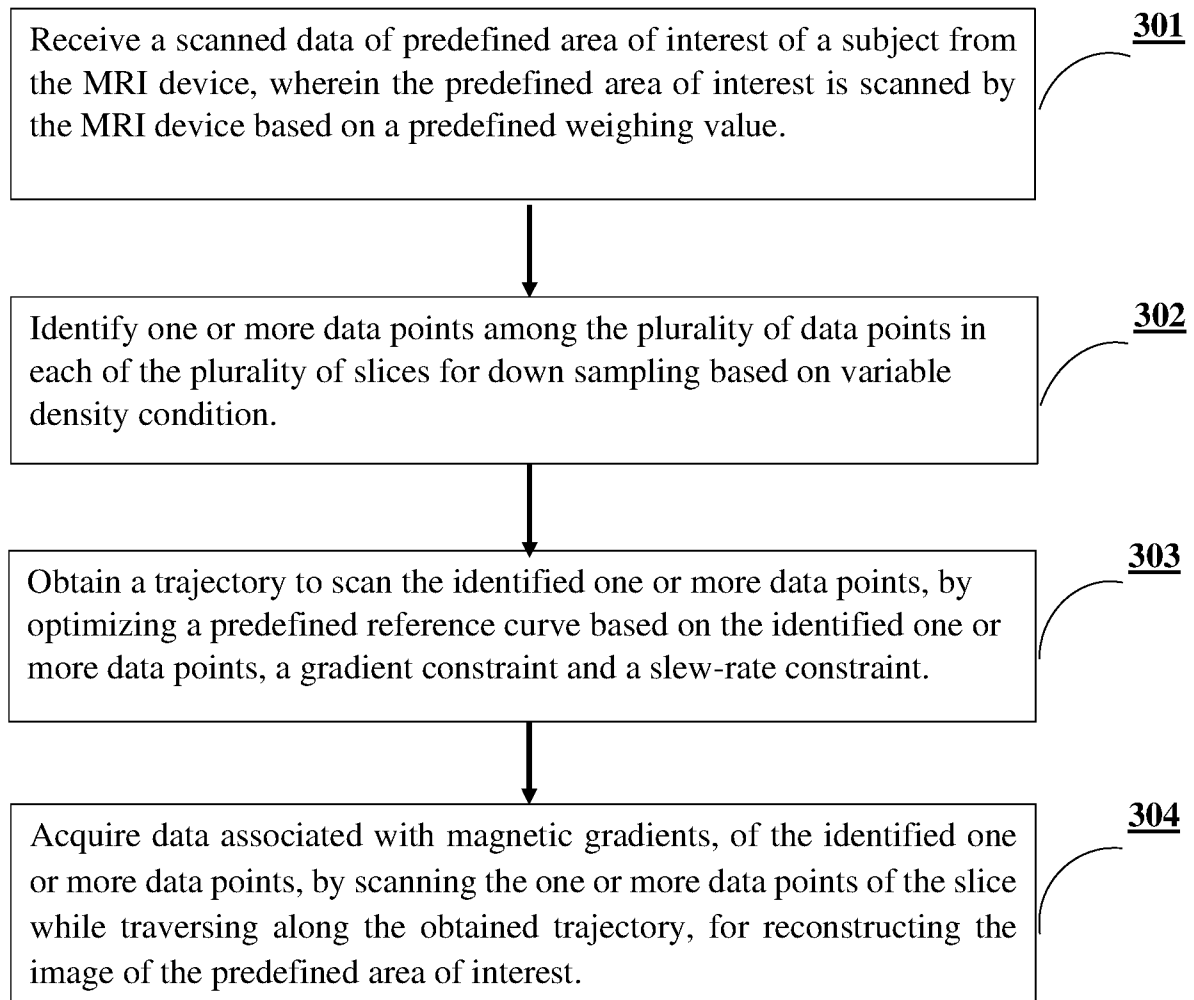


Figure 3

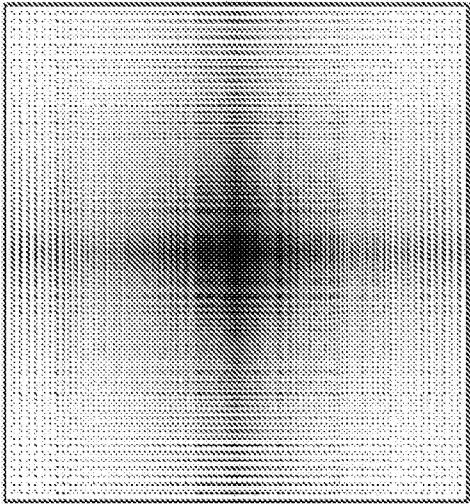
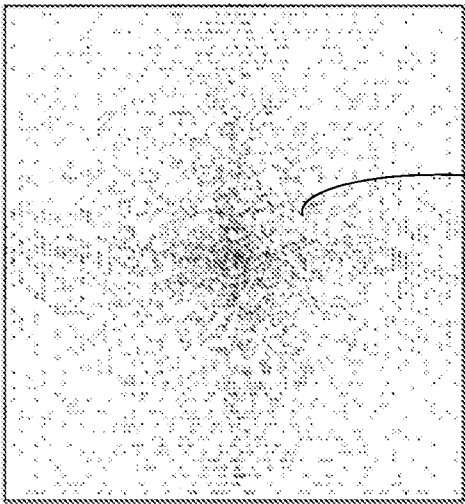


Figure 4a



Data Points

Figure 4b

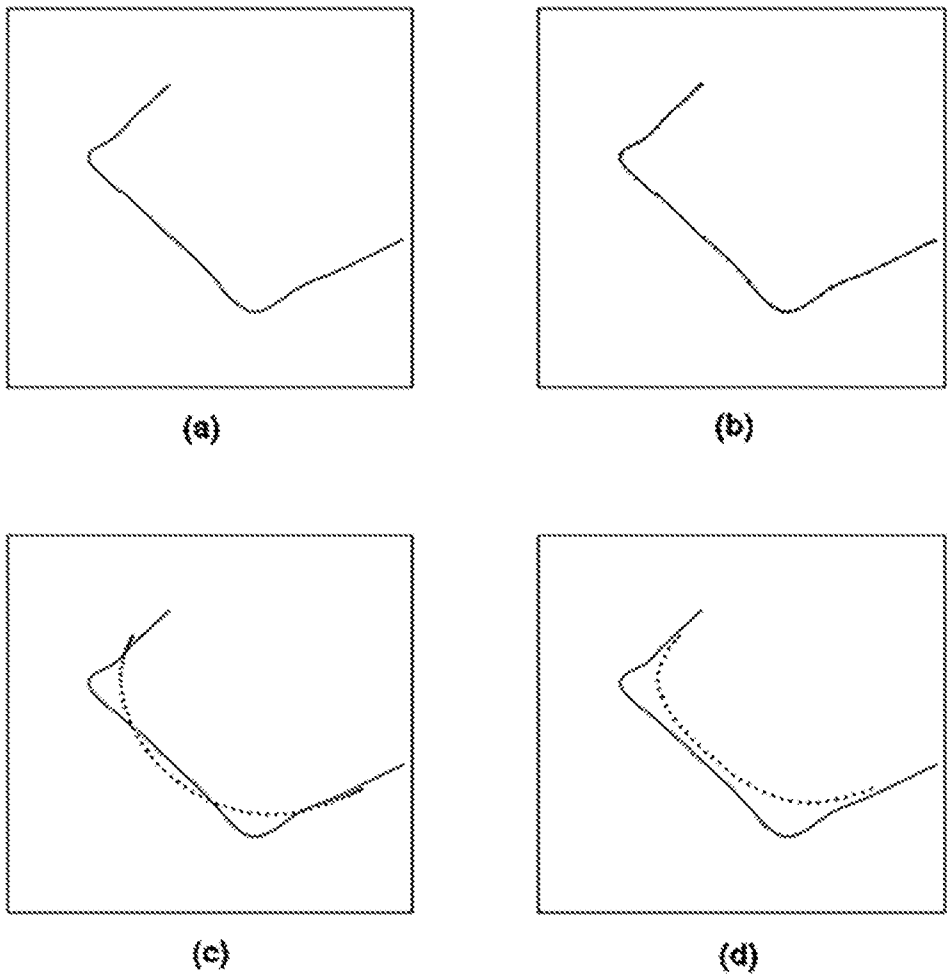


Figure 5

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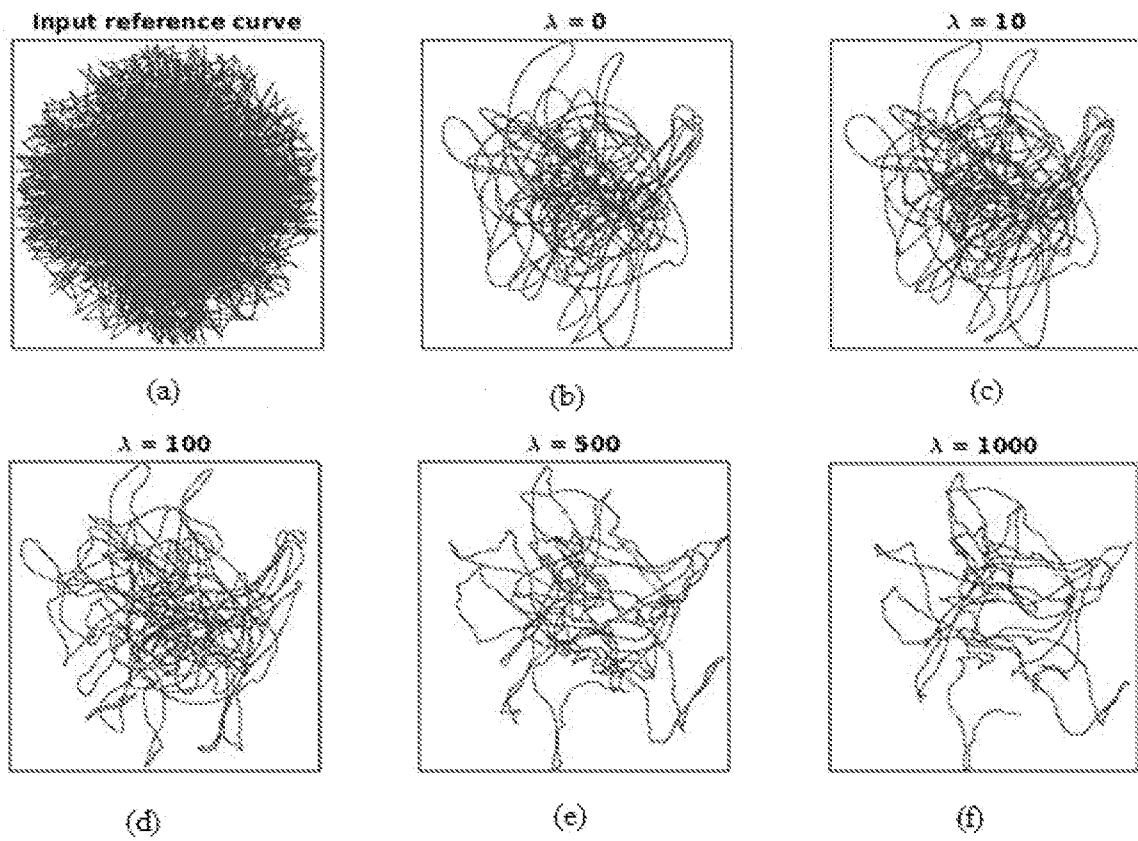


Figure 6

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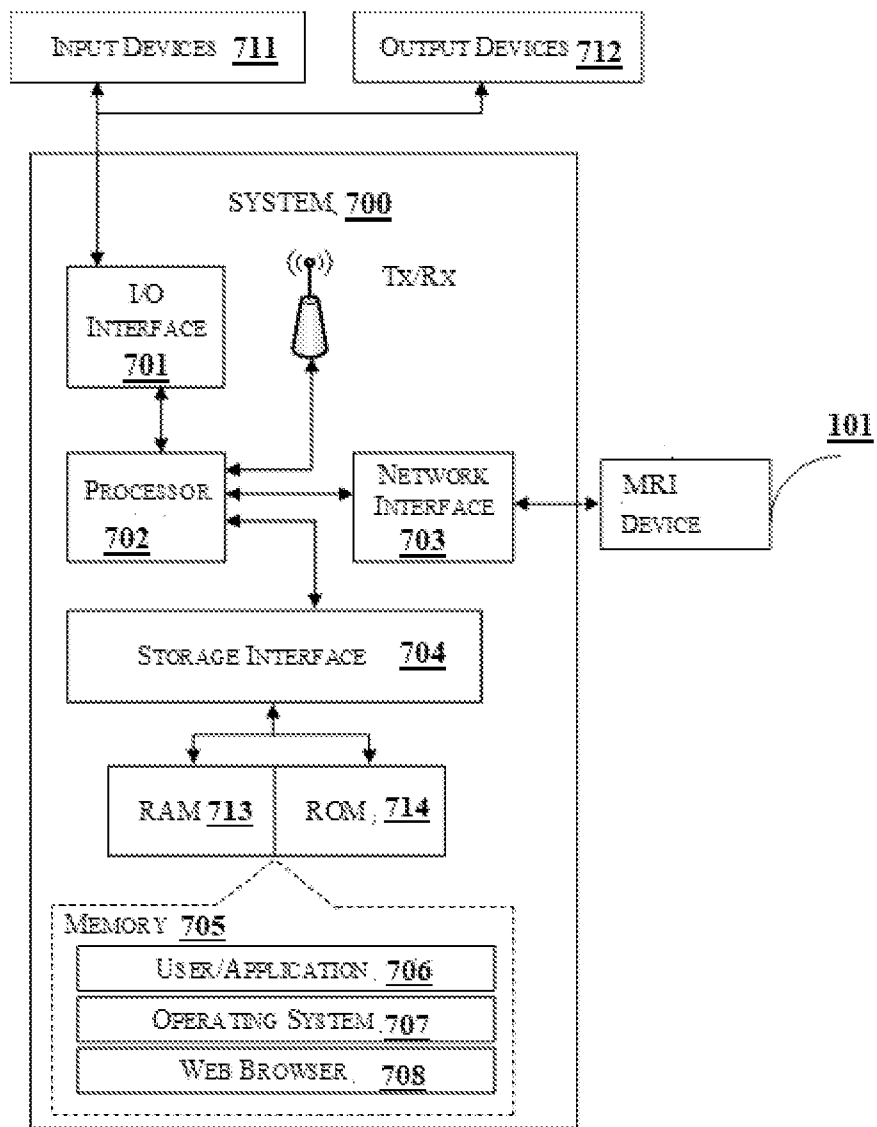


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2019/056725

A. CLASSIFICATION OF SUBJECT MATTER

G01R33/48, G01R33/56, G01R33/38 Version=2019.01

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)

G01R

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

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

Databases: Total Patent One, IPO Internal Database, google patents

Keywords: Scan, trajectory, area of interest, data points, slice

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US20140103928A1 (SIEMENS HEALTHCARE GMBH) 17 APRIL 2014 (17-04-2014) PARAGRAPHS [0002], [0005], [0008], [0017], [0019]-[0020], [0031], [0036], [0037], [0046] - [0047]; CLAIMS 1, 2, 7	1, 2, 7, 8
Y	ABSTRACT; PARAGRAPHS [0029]-[0030]	3- 6, 9 - 12
Y	US20120262172A1 (GENERAL ELECTRIC CO, WISCONSIN ALUMNI RESEARCH FOUNDATION) 18 OCTOBER 2012 (18-10-2012) PARAGRAPHS [0020], [0036], [0043]-[0047]; FIG 3; CLAIM 6	3 - 6, 9 - 12

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

☒ See patent family annex.

* Special categories of cited documents:

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"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

22-11-2019

Date of mailing of the international search report

22-11-2019

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/IB2019/056725

Citation	Pub.Date	Family	Pub.Date
US 20140103928 A1	17-04-2014	JP 2014076359 A	01-05-2014
		DE 102012218422 B3	27-02-2014
		CN 103728580 A	16-04-2014
US 20120262172 A1	18-10-2012	US 9103898 B2	11-08-2015