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(54) DATA PROCESSING APPARATUS, MAGNETIC RESONANCE IMAGING APPARATUS, AND DATA PROCESSING METHOD

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(57) **ABSTRACT**

A data processing apparatus according to an embodiment includes processing circuitry. The processing circuitry is configured to output first complementary data by inputting, to a first neural network, first partial sampling data resulting from performing a partial sampling process; to obtain first corrected data, by performing a process to improve a consistency degree between the first complementary data and the first partial sampling data; to generate second partial sampling data, on the basis of the first corrected data and the first partial sampling data; and to output second complementary data, by inputting the second partial sampling data to a second neural network.

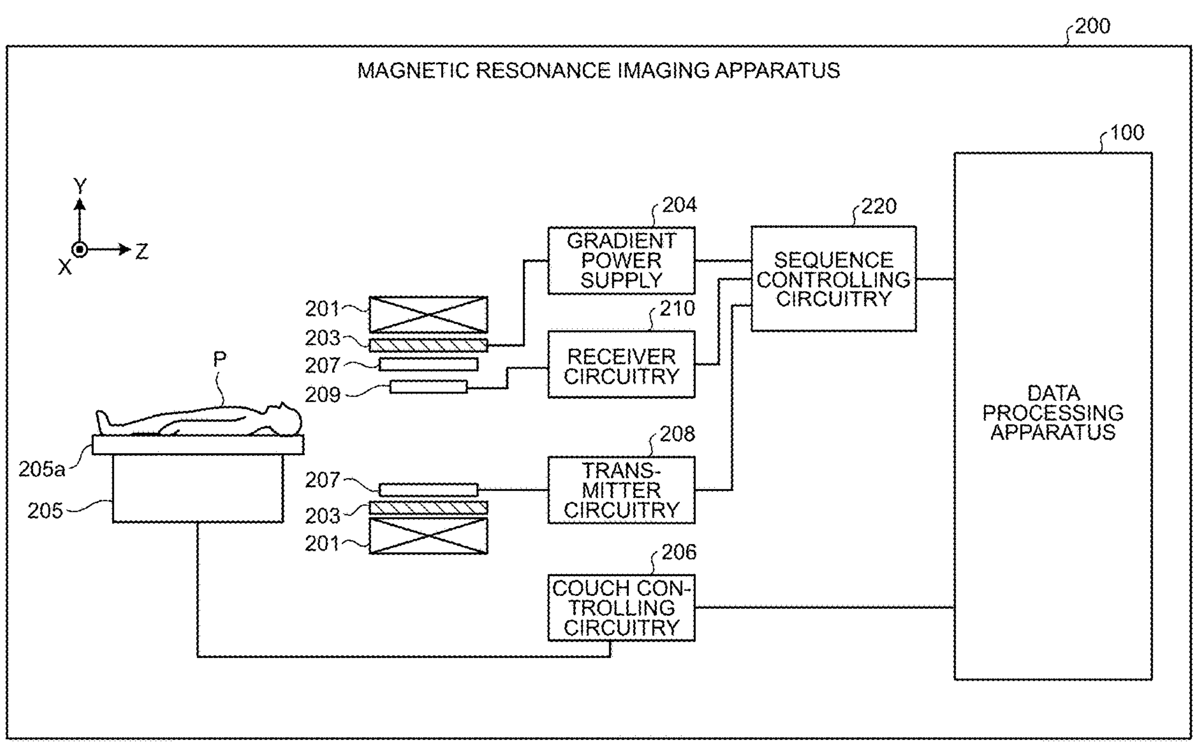


FIG.1

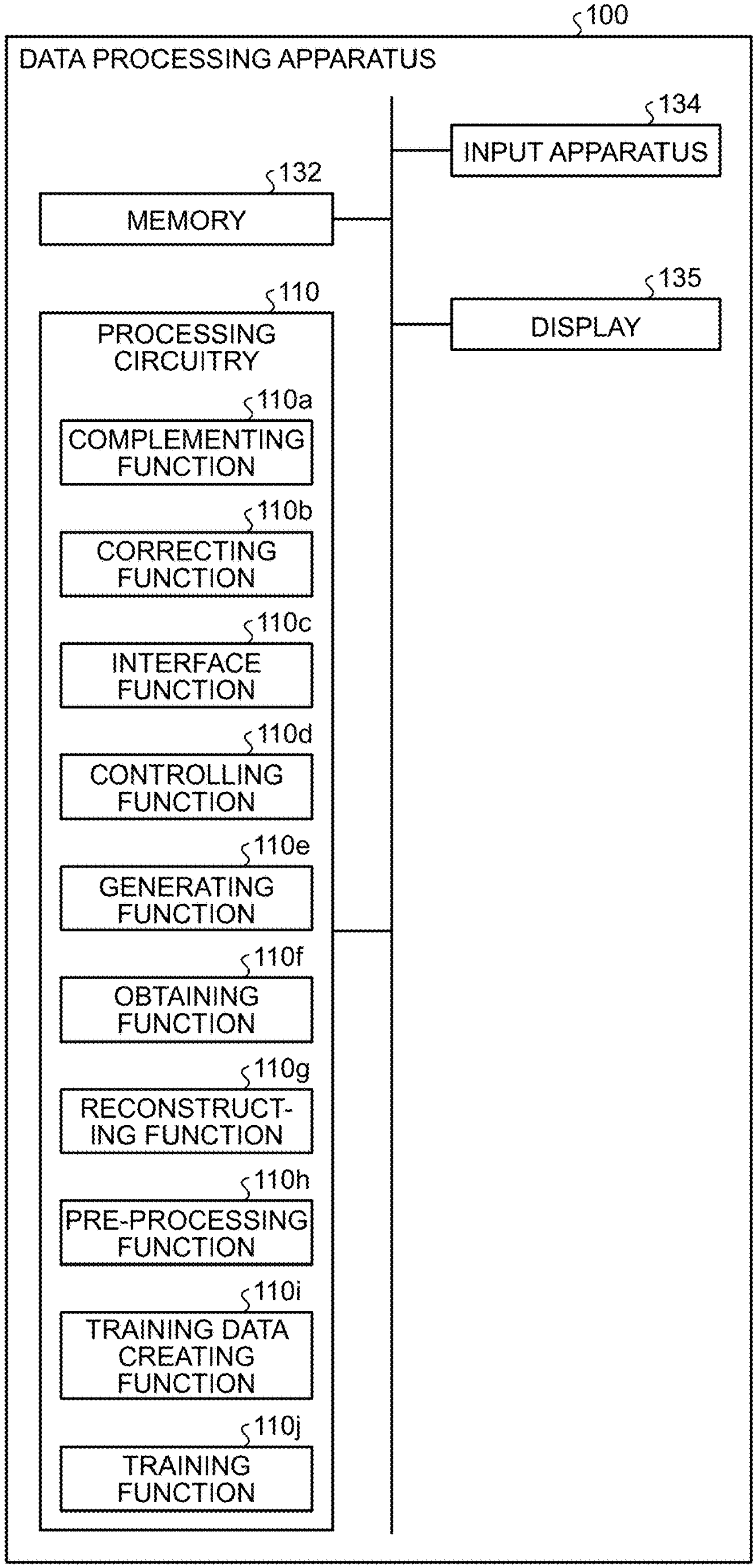

100
DATA PROCESSING APPARATUS
134
INPUT APPARATUS
132
MEMORY
135
DISPLAY
110
PROCESSING CIRCUITRY
110a
COMPLEMENTING FUNCTION
110b
CORRECTING FUNCTION
110c
INTERFACE FUNCTION
110d
CONTROLLING FUNCTION
110e
GENERATING FUNCTION
110f
OBTAINING FUNCTION
110g
RECONSTRUCTING FUNCTION
110h
PRE-PROCESSING FUNCTION
110i
TRAINING DATA CREATING FUNCTION
110j
TRAINING FUNCTION

FIG.2

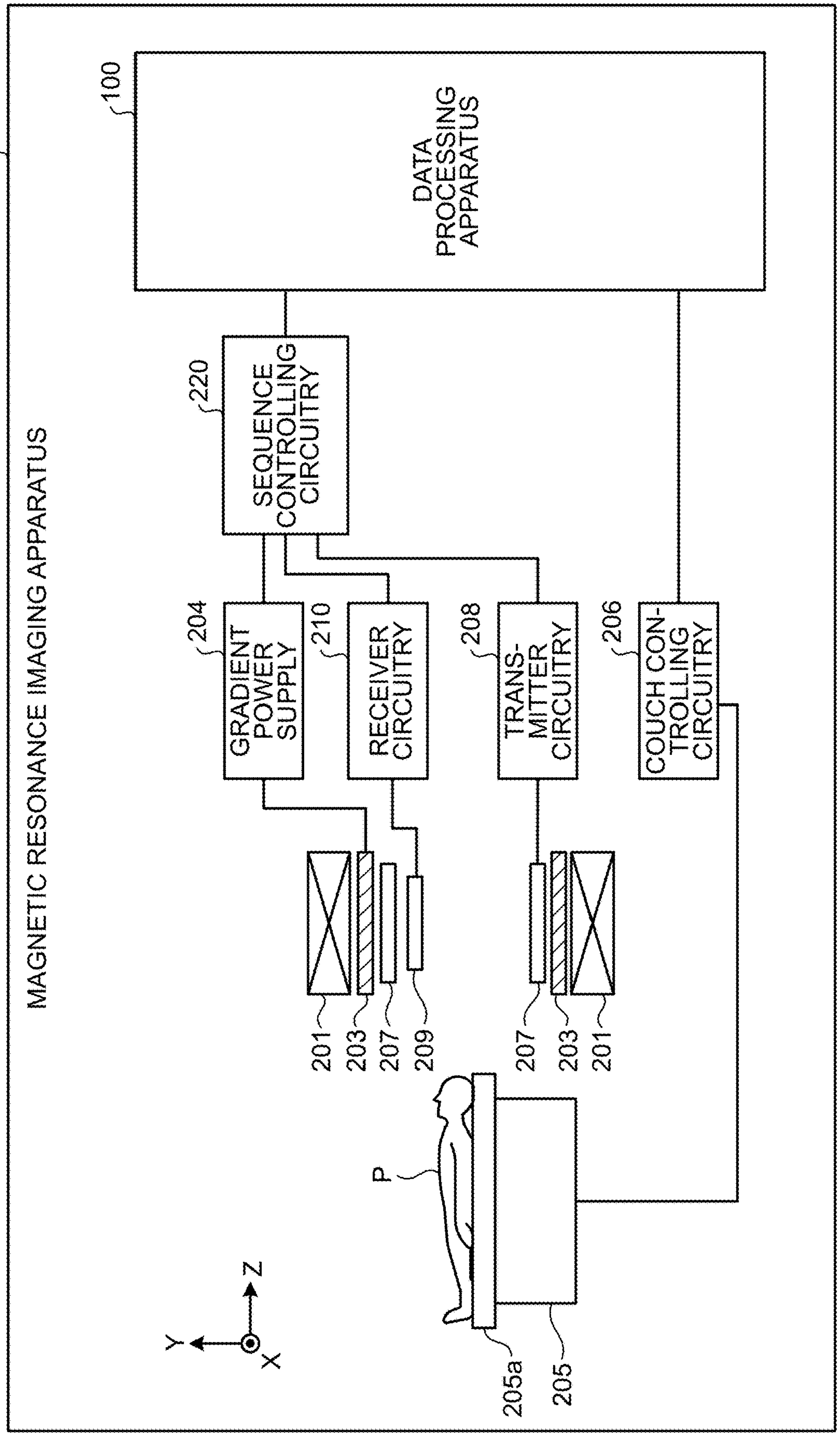

200
MAGNETIC RESONANCE IMAGING APPARATUS
100
DATA PROCESSING APPARATUS
220
SEQUENCE CONTROLLING CIRCUITRY
204
GRADIENT POWER SUPPLY
210
RECEIVER CIRCUITRY
208
TRANS-MITTER CIRCUITRY
206
COUCH CON-TROLLING CIRCUITRY
201
203
207
209
207
203
201
P
Z
Y
X
205a
205

FIG.3

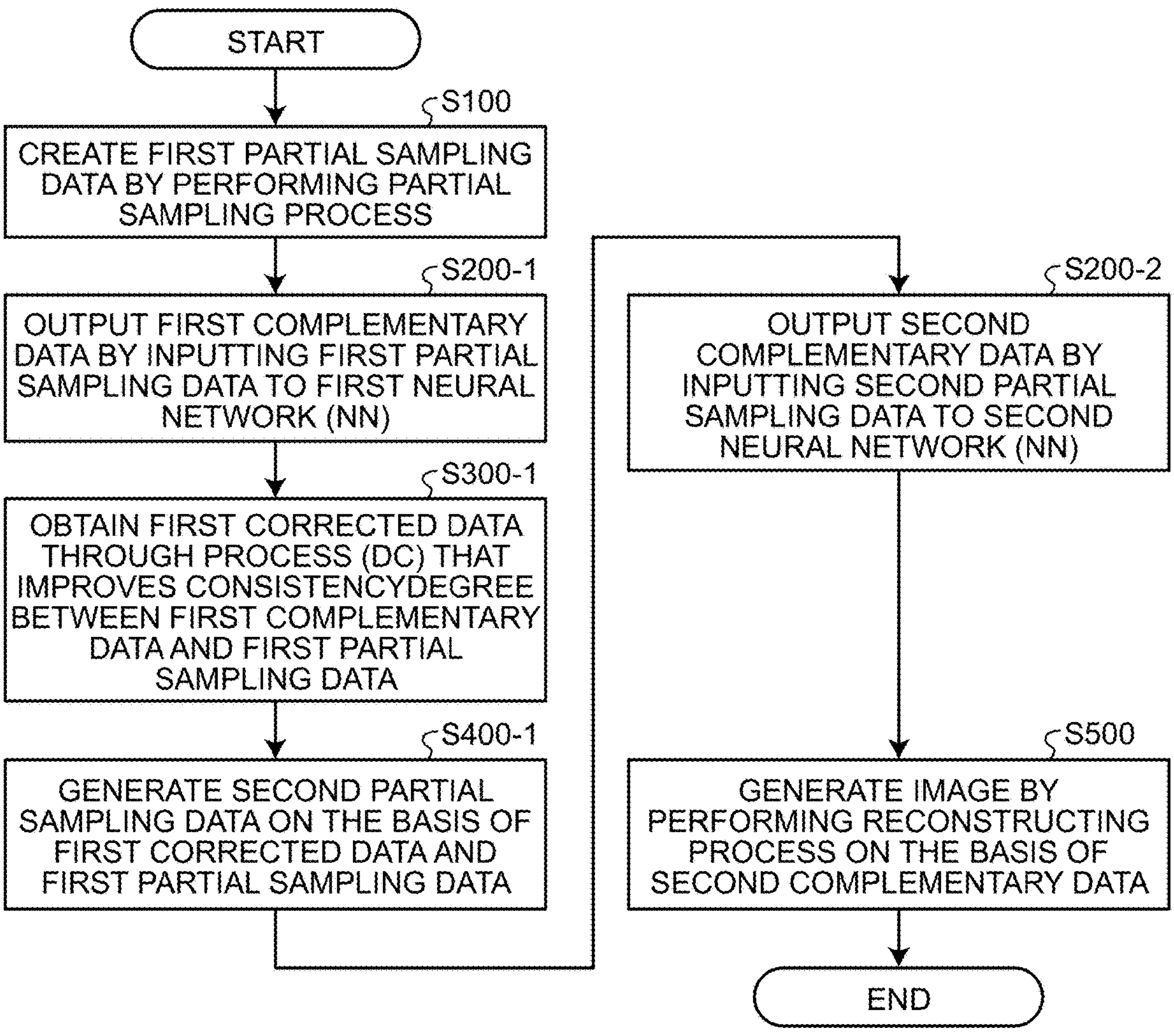

START
S100
CREATE FIRST PARTIAL SAMPLING DATA BY PERFORMING PARTIAL SAMPLING PROCESS
S200-1
OUTPUT FIRST COMPLEMENTARY DATA BY INPUTTING FIRST PARTIAL SAMPLING DATA TO FIRST NEURAL NETWORK (NN)
S300-1
OBTAIN FIRST CORRECTED DATA THROUGH PROCESS (DC) THAT IMPROVES CONSISTENCYDEGREE BETWEEN FIRST COMPLEMENTARY DATA AND FIRST PARTIAL SAMPLING DATA
S400-1
GENERATE SECOND PARTIAL SAMPLING DATA ON THE BASIS OF FIRST CORRECTED DATA AND FIRST PARTIAL SAMPLING DATA
S200-2
OUTPUT SECOND COMPLEMENTARY DATA BY INPUTTING SECOND PARTIAL SAMPLING DATA TO SECOND NEURAL NETWORK (NN)
S500
GENERATE IMAGE BY PERFORMING RECONSTRUCTING PROCESS ON THE BASIS OF SECOND COMPLEMENTARY DATA
END

FIG.4

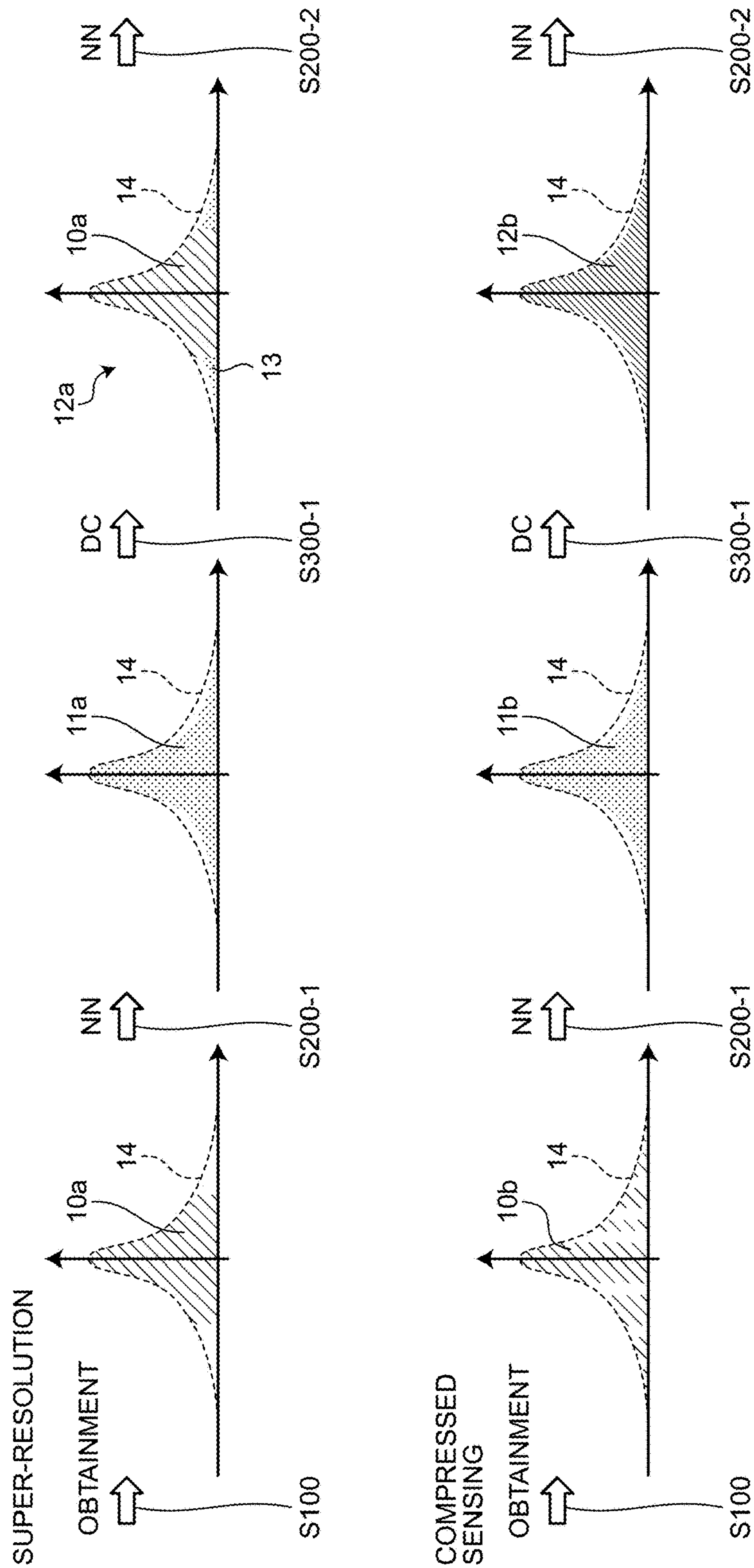

SUPER-RESOLUTION
OBTAINMENT
S100
10a
14
NN
S200-1
11a
14
DC
S300-1
12a
10a
14
13
NN
S200-2
COMPRESSED SENSING
OBTAINMENT
S100
10b
14
NN
S200-1
11b
14
DC
S300-1
12b
14
NN
S200-2

FIG.5

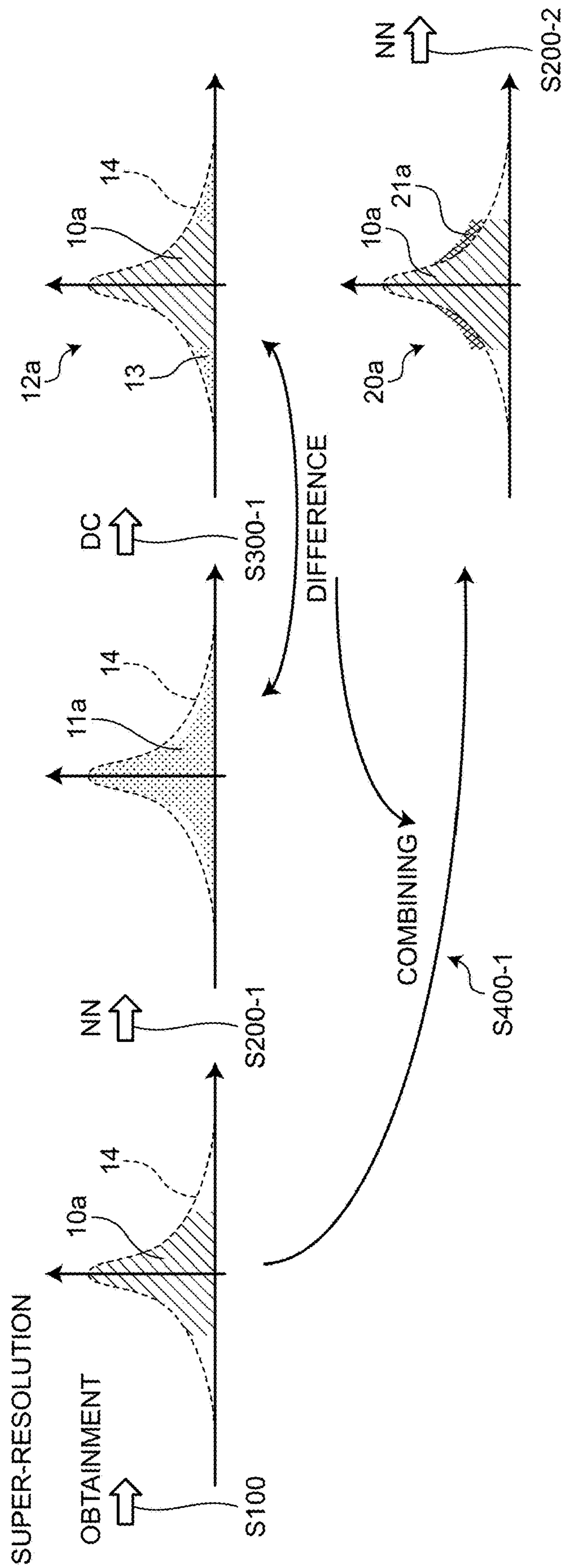
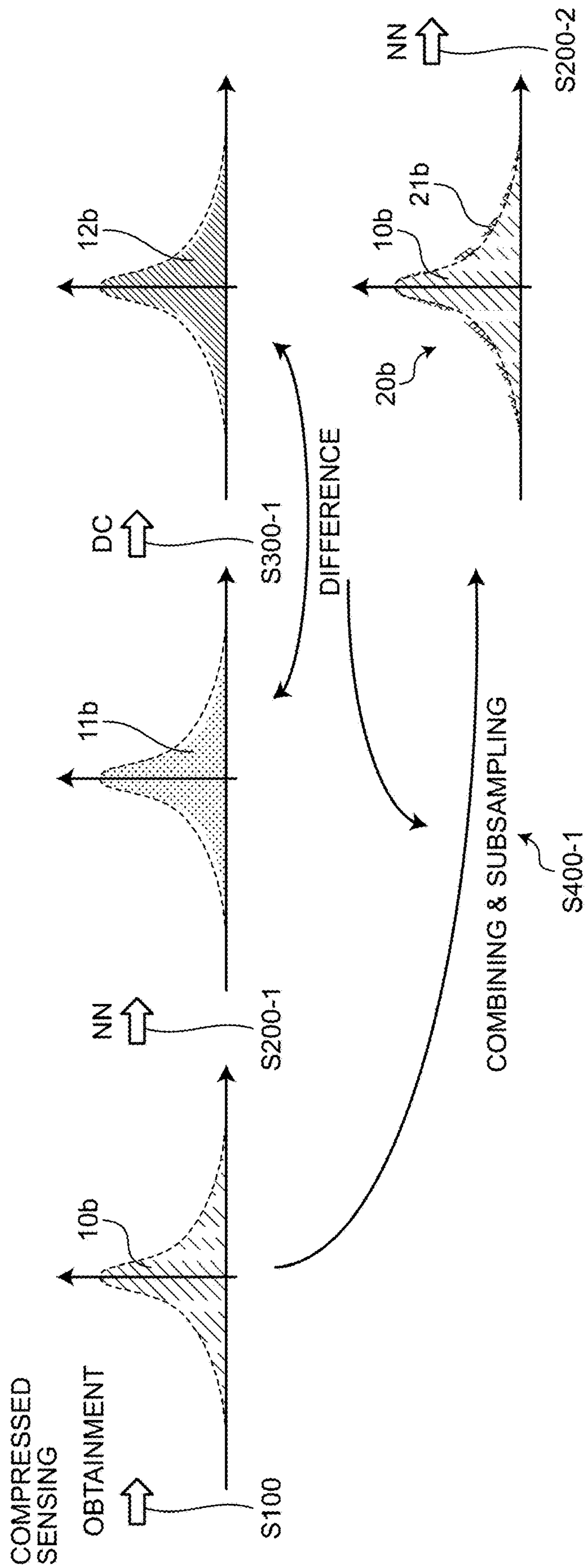

SUPER-RESOLUTION
OBTAINMENT
S100
10a
14
NN
S200-1
11a
14
DC
S300-1
12a
13
10a
14
DIFFERENCE
COMBINING
S400-1
20a
10a
21a
NN
S200-2

FIG.6



COMPRESSED SENSING
OBTAINMENT
S100
10b
NN
S200-1
11b
DC
S300-1
12b
DIFFERENCE
COMBINING & SUBSAMPLING
S400-1
20b
10b
21b
NN
S200-2

FIG.7

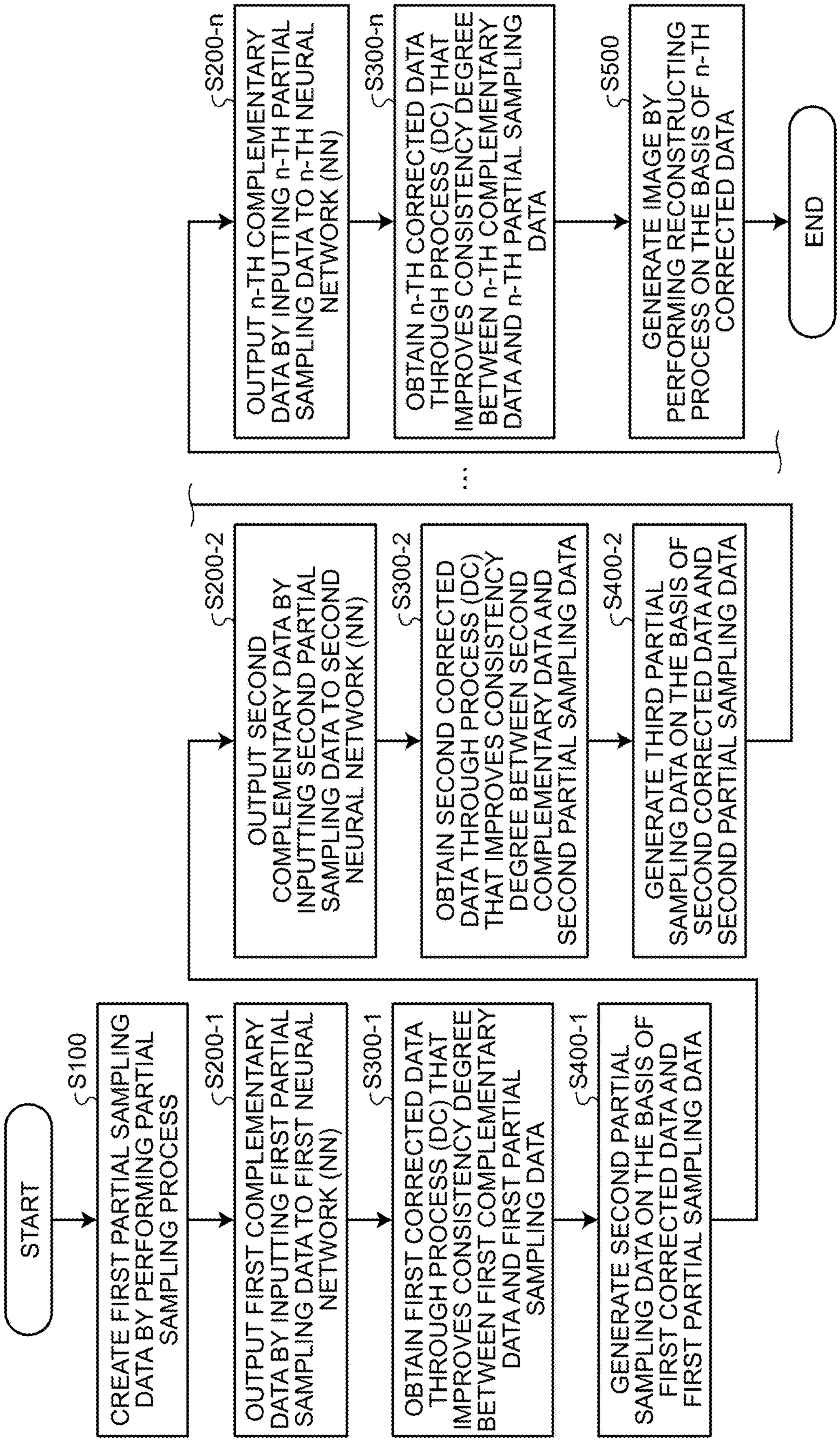

START
S100
CREATE FIRST PARTIAL SAMPLING DATA BY PERFORMING PARTIAL SAMPLING PROCESS
S200-1
OUTPUT FIRST COMPLEMENTARY DATA BY INPUTTING FIRST PARTIAL SAMPLING DATA TO FIRST NEURAL NETWORK (NN)
S300-1
OBTAIN FIRST CORRECTED DATA THROUGH PROCESS (DC) THAT IMPROVES CONSISTENCY DEGREE BETWEEN FIRST COMPLEMENTARY DATA AND FIRST PARTIAL SAMPLING DATA
S400-1
GENERATE SECOND PARTIAL SAMPLING DATA ON THE BASIS OF FIRST CORRECTED DATA AND FIRST PARTIAL SAMPLING DATA
S200-2
OUTPUT SECOND COMPLEMENTARY DATA BY INPUTTING SECOND PARTIAL SAMPLING DATA TO SECOND NEURAL NETWORK (NN)
S300-2
OBTAIN SECOND CORRECTED DATA THROUGH PROCESS (DC) THAT IMPROVES CONSISTENCY DEGREE BETWEEN SECOND COMPLEMENTARY DATA AND SECOND PARTIAL SAMPLING DATA
S400-2
GENERATE THIRD PARTIAL SAMPLING DATA ON THE BASIS OF SECOND CORRECTED DATA AND SECOND PARTIAL SAMPLING DATA
...
S200-n
OUTPUT n-TH COMPLEMENTARY DATA BY INPUTTING n-TH PARTIAL SAMPLING DATA TO n-TH NEURAL NETWORK (NN)
S300-n
OBTAIN n-TH CORRECTED DATA THROUGH PROCESS (DC) THAT IMPROVES CONSISTENCY DEGREE BETWEEN n-TH COMPLEMENTARY DATA AND n-TH PARTIAL SAMPLING DATA
S500
GENERATE IMAGE BY PERFORMING RECONSTRUCTING PROCESS ON THE BASIS OF n-TH CORRECTED DATA
END

FIG.8

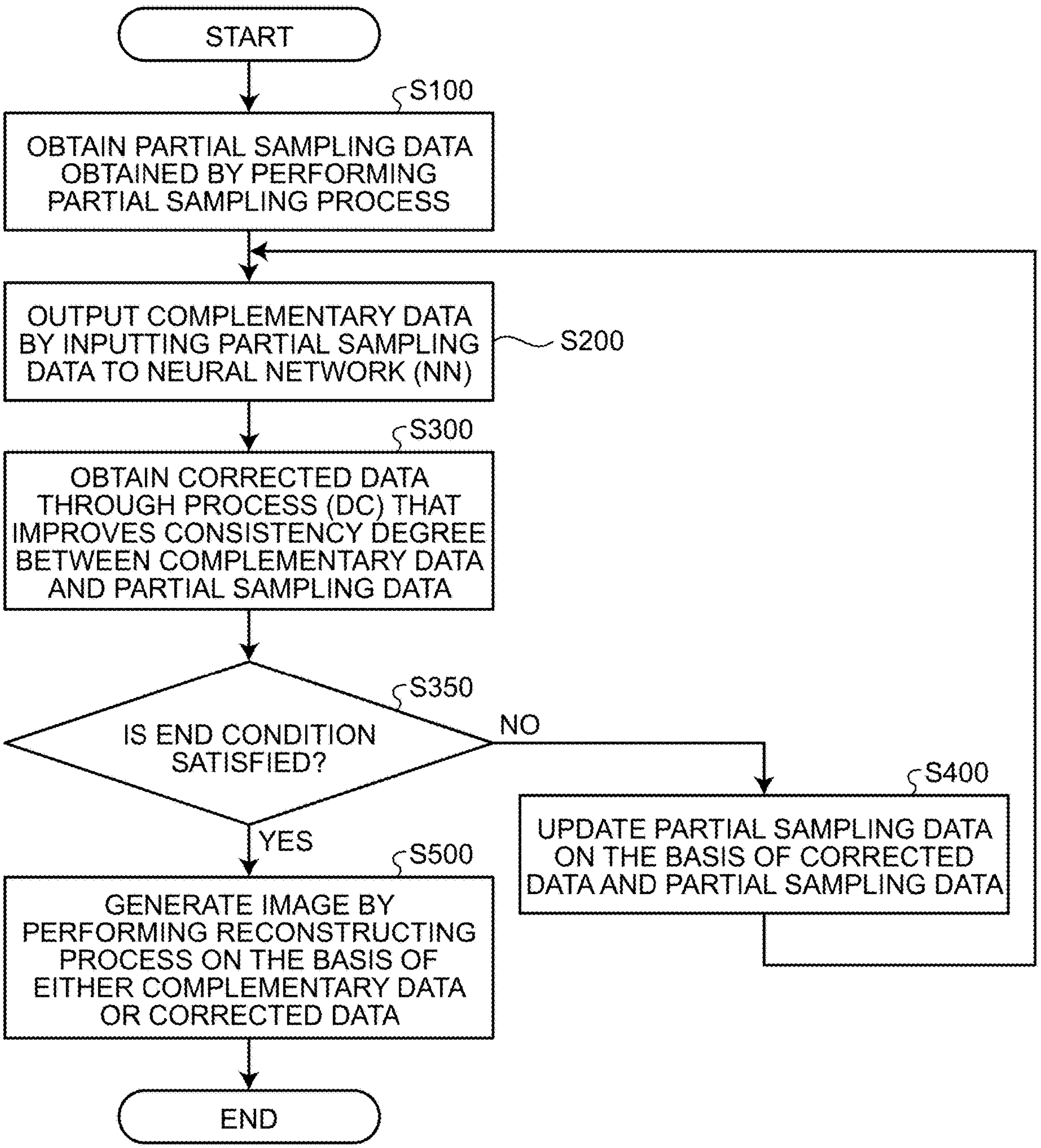

START
S100
OBTAIN PARTIAL SAMPLING DATA OBTAINED BY PERFORMING PARTIAL SAMPLING PROCESS
OUTPUT COMPLEMENTARY DATA BY INPUTTING PARTIAL SAMPLING DATA TO NEURAL NETWORK (NN)
S200
S300
OBTAIN CORRECTED DATA THROUGH PROCESS (DC) THAT IMPROVES CONSISTENCY DEGREE BETWEEN COMPLEMENTARY DATA AND PARTIAL SAMPLING DATA
S350
IS END CONDITION SATISFIED?
NO
S400
UPDATE PARTIAL SAMPLING DATA ON THE BASIS OF CORRECTED DATA AND PARTIAL SAMPLING DATA
YES
S500
GENERATE IMAGE BY PERFORMING RECONSTRUCTING PROCESS ON THE BASIS OF EITHER COMPLEMENTARY DATA OR CORRECTED DATA
END

FIG.9

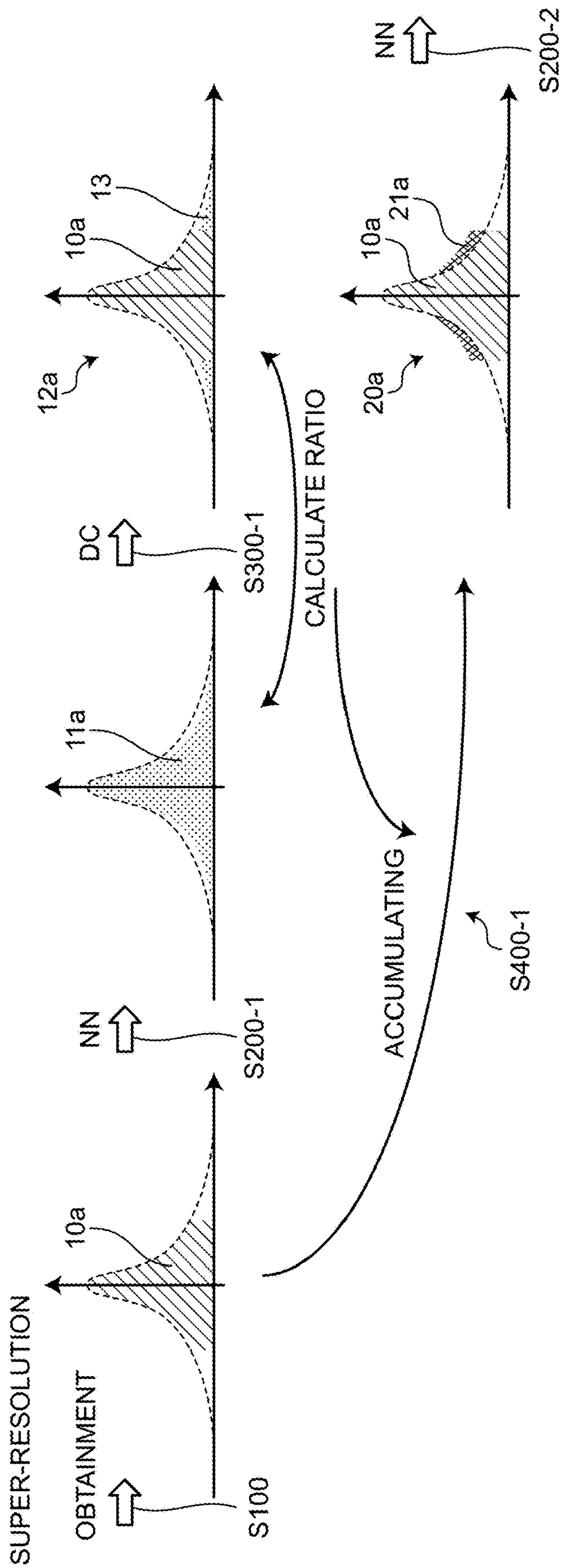

SUPER-RESOLUTION
OBTAINMENT
S100
10a
NN
S200-1
11a
DC
S300-1
12a
10a
13
CALCULATE RATIO
ACCUMULATING
S400-1
20a
10a
21a
NN
S200-2

FIG.10

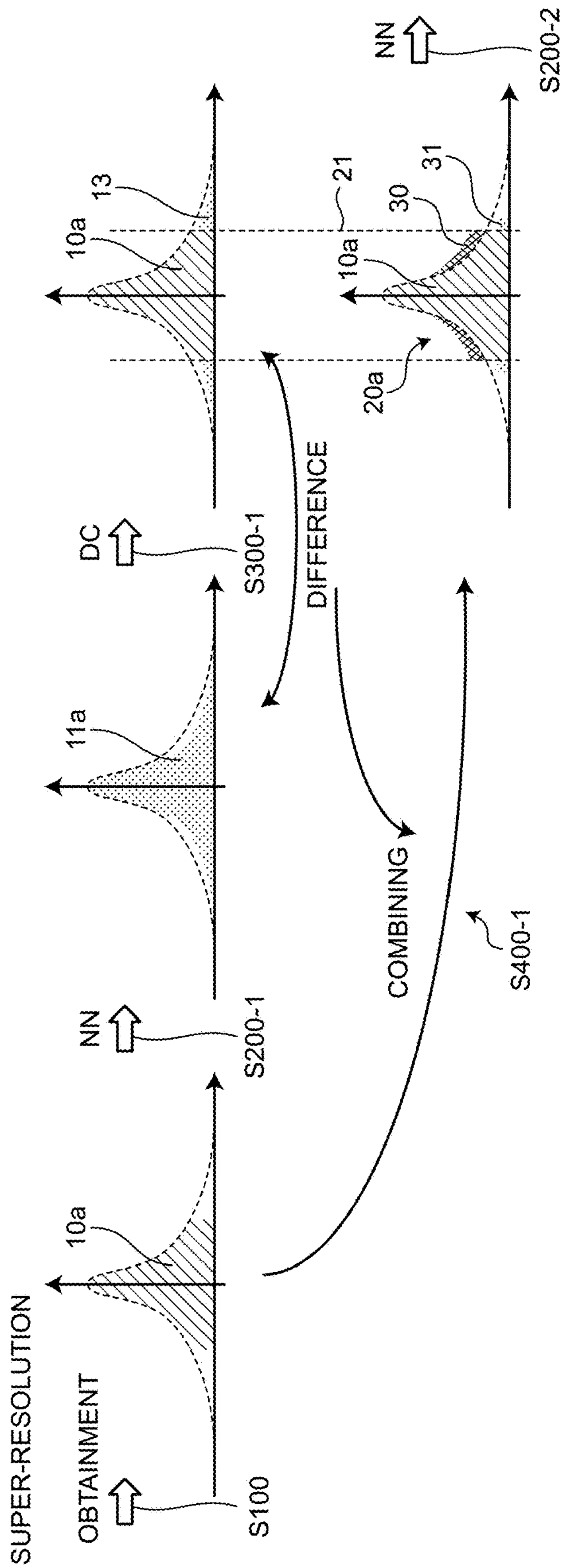

SUPER-RESOLUTION
OBTAINMENT
S100
10a
NN
S200-1
11a
DC
S300-1
10a
13
DIFFERENCE
COMBINING
S400-1
20a
10a
21
30
31
NN
S200-2

FIG.11

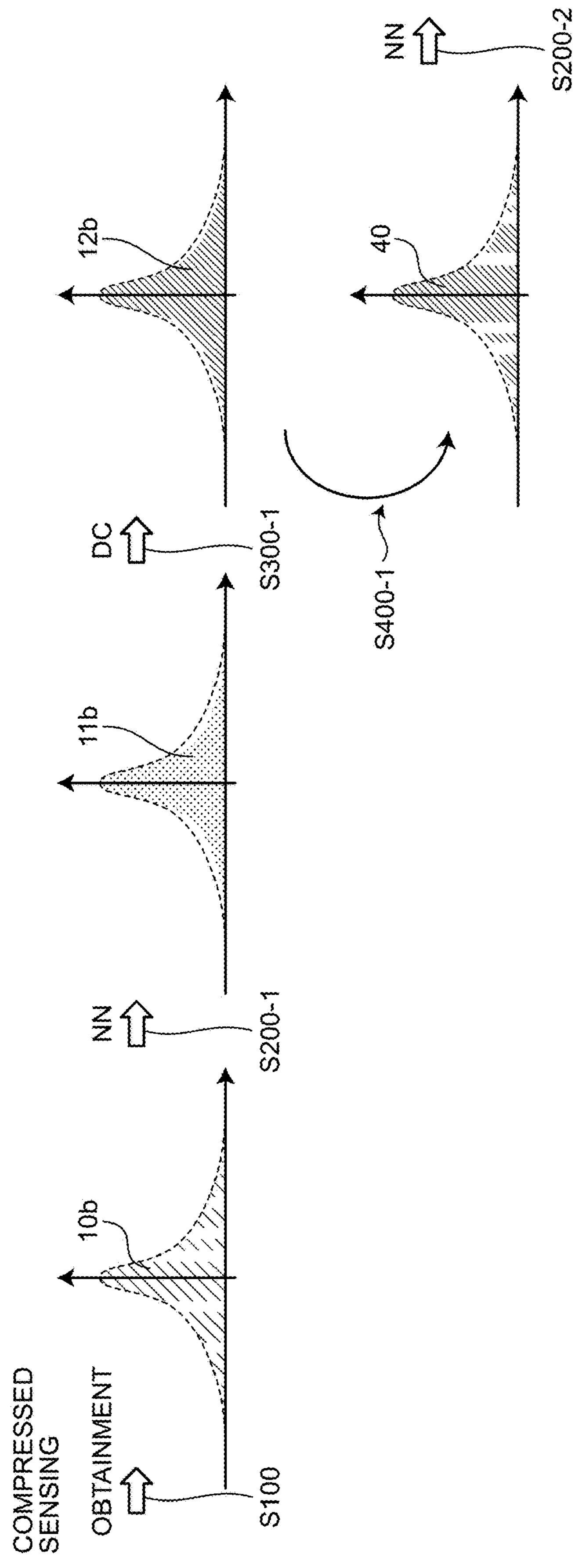

COMPRESSED SENSING
OBTAINMENT
S100
10b
NN
S200-1
11b
DC
S300-1
12b
S400-1
40
NN
S200-2

FIG.12

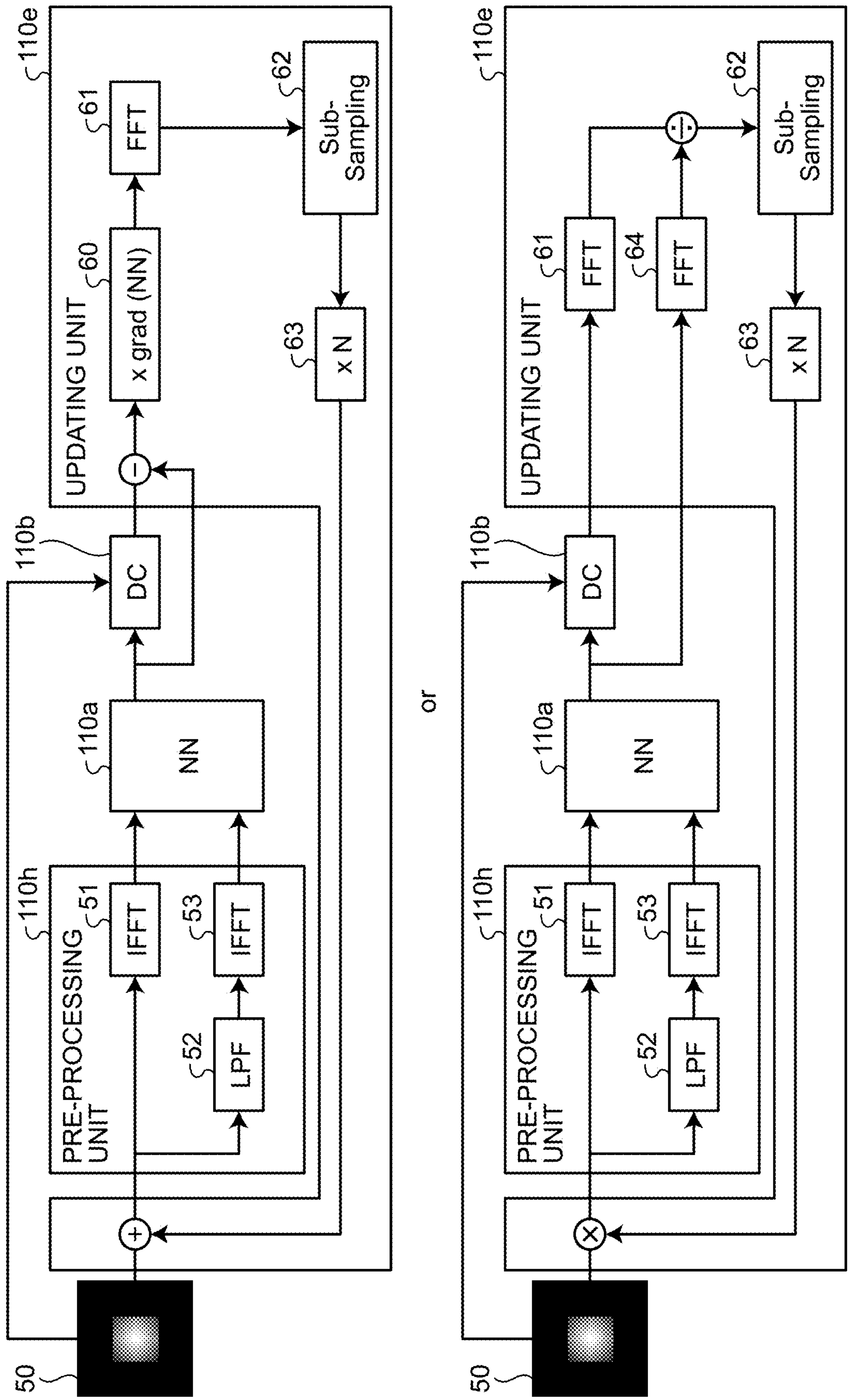
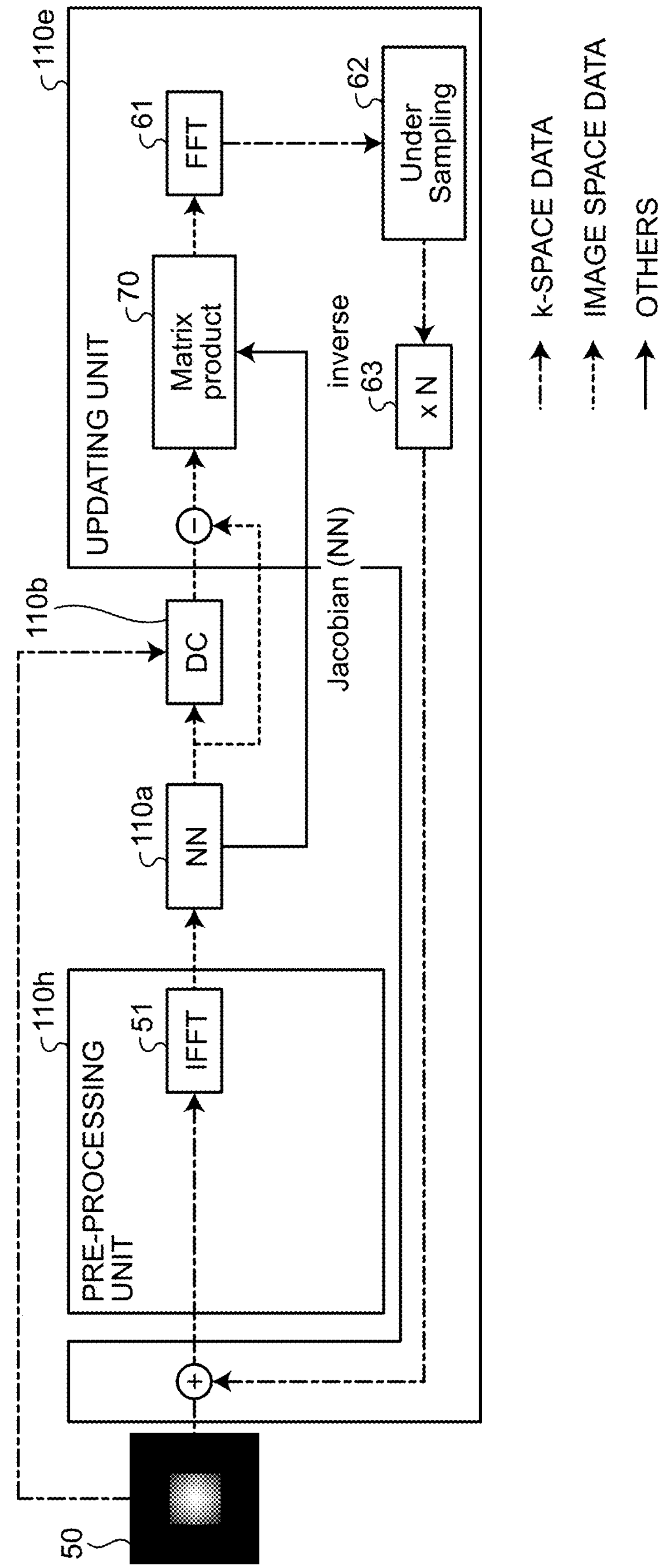

110e
UPDATING UNIT
61
FFT
62
Sub-
Sampling
60
x grad (NN)
63
x N
110b
DC
110a
NN
110h
PRE-PROCESSING
UNIT
51
IFFT
53
IFFT
52
LPF
50
or
110e
UPDATING UNIT
61
FFT
64
FFT
62
Sub-
Sampling
63
x N
110b
DC
110a
NN
110h
PRE-PROCESSING
UNIT
51
IFFT
53
IFFT
52
LPF
50

FIG.13


110e
UPDATING UNIT
61
FFT
62
Under Sampling
70
Matrix product
63
x N
inverse
Jacobian (NN)
110b
DC
110a
NN
110h
PRE-PROCESSING UNIT
51
IFFT
50
k-SPACE DATA
IMAGE SPACE DATA
OTHERS

DATA PROCESSING APPARATUS, MAGNETIC RESONANCE IMAGING APPARATUS, AND DATA PROCESSING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-019587, filed on Feb. 13, 2024; the entire contents of which are incorporated herein by reference.

FIELD

[0002] Embodiments described herein relate generally to a data processing apparatus, a magnetic resonance imaging apparatus, and a data processing method.

BACKGROUND

[0003] A method is known by which image reconstruction is carried out by combining machine learning with a Data Consistency (DC) process. According to this method, a full sampling magnetic resonance image is reconstructed from multi-channel data resulting from a partial sampling process, by carrying out an iterative process multiple times while each repetitive session includes a neural network and the DC process. In this situation, mutually the same value shared among the neural networks is used as a weight coefficient by a plurality of neural networks.

[0004] However, according to this method, it may not be possible to obtain a proper output result, in some situations. One possible solution to this problem may be to carry out training in an end-to-end manner while including the DC process, so that each of the neural networks independently determines a weight coefficient. However, this solution has low learning efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** is a diagram illustrating an exemplary configuration of a data processing apparatus according to an embodiment;

[0006] FIG. **2** is a diagram illustrating an exemplary configuration of a magnetic resonance imaging apparatus according to the embodiment;

[0007] FIG. **3** is a flowchart for explaining a flow of processes performed by a data processing apparatus according to a first embodiment;

[0008] FIG. **4** is a drawing for explaining processes performed by the data processing apparatus according to the first embodiment;

[0009] FIG. **5** is a drawing for explaining processes performed by the data processing apparatus according to the first embodiment, in an example of super-resolution processing;

[0010] FIG. **6** is a drawing for explaining processes performed by the data processing apparatus according to the first embodiment, in an example of compressed sensing;

[0011] FIG. **7** is a flowchart for explaining a flow of processes performed by the data processing apparatus according to the first embodiment;

[0012] FIG. **8** is a flowchart for explaining another flow of processes performed by the data processing apparatus according to the first embodiment;

[0013] FIG. **9** is a drawing for explaining processes performed by a data processing apparatus according to a second embodiment;

[0014] FIG. **10** is a drawing for explaining processes performed by a data processing apparatus according to a third embodiment;

[0015] FIG. **11** is another drawing for explaining processes performed by the data processing apparatus according to the third embodiment;

[0016] FIG. **12** is a drawing for explaining processes performed by a data processing apparatus according to a fourth embodiment; and

[0017] FIG. **13** is a drawing for explaining processes performed by a data processing apparatus according to a fifth embodiment.

DETAILED DESCRIPTION

[0018] A data processing apparatus provided in at least one aspect of the present disclosure includes processing circuitry. The processing circuitry is configured to output first complementary data by inputting, to a first neural network, first partial sampling data resulting from performing a partial sampling process; to obtain first corrected data, by performing a process to improve a consistency degree between the first complementary data and the first partial sampling data; to generate second partial sampling data, on the basis of the first corrected data and the first partial sampling data; and to output second complementary data, by inputting the second partial sampling data to a second neural network.

First Embodiment

[0019] Exemplary embodiments of a data processing apparatus, a magnetic resonance imaging apparatus, and a data processing method will be explained in detail below, with reference to the accompanying drawings.

[0020] To begin with, a configuration of a data processing apparatus **100** according to an embodiment will be explained, with reference to FIG. **1**.

[0021] The data processing apparatus **100** is an apparatus configured to generate data and to carry out image reconstruction by using a neural network. In an example, the data processing apparatus **100** is connected to various medical image diagnosis apparatuses such as a magnetic resonance imaging apparatus **200** illustrated in FIG. **2**, for instance, and is configured to process a signal received from any of the medical image diagnosis apparatuses, to generate/execute a trained model, and to carry out image reconstructing processes, and the like. In this situation, examples of the medical image diagnosis apparatuses to which the data processing apparatus **100** is connected may include apparatuses other than the magnetic resonance imaging apparatus, such as an ultrasound diagnosis apparatus, a general X-ray imaging apparatus, an X-ray Computed Tomography (CT) apparatus, a Positron Emission Tomography (PET) apparatus, and a Single Photon Emission Computed Tomography (SPECT) apparatus, for instance.

[0022] Typically, the data processing apparatus **100** is a medical data processing apparatus configured to process medical data. However, possible embodiments are not limited to the situation where the data processing apparatus **100** is a medical data processing apparatus. In another example, the data processing apparatus **100** may be an apparatus configured to process magnetic resonance data that is not medical data.

[0023] The data processing apparatus **100** includes processing circuitry **110**, a memory **132**, an input apparatus **134**, and a display **135**. The processing circuitry **110** includes a complementing function **110***a*, a correcting function **110***b*, an interface function **110***c*, a controlling function **110***d*, a generating function **110***e*, an obtaining function **110***f*, a reconstructing function **110***g*, a pre-processing function **110***h*, a training data creating function **110***i*, and a training function **110***j*.

[0024] In an embodiment, processing functions performed by the complementing function **110***a*, the correcting function **110***b*, the interface function **110***c*, the controlling function **110***d*, the generating function **110***e*, the obtaining function **110***f*, the reconstructing function **110***g*, the pre-processing function **110***h*, the training data creating function **110***i*, and the training function **110***j*, as well as the trained model (e.g., a neural network) are stored in the memory **132** in the form of computer-executable programs. The processing circuitry **110** is a processor configured to realize the functions corresponding to the programs, by reading and executing the programs from the memory **132**. In other words, the processing circuitry **110** that has read the programs has the functions illustrated within the processing circuitry **110** in FIG. **1**. Further, when having read the program corresponding to the trained model (a neural network), the processing circuitry **110** is capable of performing processes in accordance with the trained model. Further, although an example is explained with reference to FIG. **1** in which the functions of the processing circuitry **110** are realized by a single piece of processing circuitry, it is also acceptable to structure the processing circuitry **110** by combining together a plurality of independent processors, so that the functions are realized as a result of the processors executing the programs. In other words, each of the abovementioned functions may be structured as a program, so that a single piece of processing circuitry executes the programs. Further, a single piece of processing circuitry may realize two or more of the functions included in the processing circuitry **110**. In another example, specific one or more of the functions may be installed in dedicated and independent program execution circuitry.

[0025] Further, in FIG. **1**, the processing circuitry **110**, the complementing function **110***a*, the correcting function **110***b*, the interface function **110***c*, the controlling function **110***d*, the generating function **110***e*, the obtaining function **110***f*, the reconstructing function **110***g*, the pre-processing function **110***h*, the training data creating function **110***i*, and the training function **110***j* are examples of a complementing unit, a correcting unit, an interface unit, a controlling unit, a generating unit, an obtaining unit, a reconstructing unit, a pre-processing unit, a creating unit, and a training unit, respectively.

[0026] The term "processor" used in the above explanations may denote, for example, a Central Processing Unit (CPU), a Graphical Processing Unit (GPU), or circuitry such as an Application Specific Integrated Circuit (ASIC) or a programmable logic device (e.g., a Simple Programmable Logic Device (SPLD), a Complex Programmable Logic Device (CPLD), or a Field Programmable Gate Array (FPGA)). The one or more processors are configured to realize the functions by reading and executing the programs saved in the memory **132**.

[0027] Further, instead of having the programs saved in the memory **132**, another configuration is also acceptable in which the programs are directly incorporated in the circuitry of one or more processors. In that situation, the one or more processors are configured to realize the functions by reading and executing the programs incorporated in the circuitry thereof. Accordingly, for example, instead of having the trained model saved in the memory **132**, it is also acceptable to directly incorporate a program related to the trained model into the circuitry of the one or more processors.

[0028] Further, when being incorporated in various types of medical image diagnosis apparatuses or being configured to perform processes in collaboration with various types of medical image diagnosis apparatuses, the processing circuitry **110** may have a function of executing processes relevant thereto in a combined manner.

[0029] By employing the interface function **110***c*, the processing circuitry **110** is configured to obtain, from the memory **132**, data, image, and/or the like used for an image generating process realized by the reconstructing function **110***g*.

[0030] By employing the controlling function **110***d*, the processing circuitry **110** is configured to control overall processes performed by the data processing apparatus **100**. More specifically, by employing the controlling function **110***d*, the processing circuitry **110** is configured to control processes performed by the processing circuitry **110**, on the basis of various types of setting requests input by an operator via the input apparatus **134** or any of various types of control programs and various types of data read from the memory **132**.

[0031] By employing the training data creating function **110***i*, the processing circuitry **110** is configured to generate training data for carrying out training, on the basis of the data and/or the image obtained by the interface function **110***c*. By employing the training function **110***j*, the processing circuitry **110** is configured to generate the trained model by carrying out the training with the use of the training data generated by the training data creating function **110***i*. Further, by employing the reconstructing function **110***g*, the processing circuitry **110** is configured to generate an image on the basis of a result of processes performed by employing the training data creating function **110***i* and the training function **110***j*.

[0032] Further, by employing the reconstructing function **110***g*, the processing circuitry **110** is configured to apply the trained model generated by the training function **110***j* to an input image and is configured to generate an image on the basis of a result of applying the trained model.

[0033] Further, details of the complementing function **110***a*, the correcting function **110***b*, the generating function **110***e*, the obtaining function **110***f*, and the pre-processing function **110***h* will be explained later.

[0034] The memory **132** is configured by using a semiconductor memory element such as a Random Access memory (RAM) or a flash memory, or a hard disk, an optical disc, or the like. The memory **132** is a memory configured to store data therein, such as display-purpose image data and training-purpose image data generated by the processing circuitry **110**.

[0035] The memory **132** is configured to store therein, as necessary, various types of data such as a control program for performing an image processing process and a display process.

[0036] The input apparatus **134** is configured to receive various types of instructions and inputs of information from the operator. For example, the input apparatus **134** may be a pointing mechanism such as a mouse or a trackball, a selecting mechanism such as a mode changing switch, and/or an input mechanism such as a keyboard.

[0037] The display **135** is configured, under control of the controlling function **110***d* or the like, to display a Graphical User Interface (GUI) for receiving an input of an image taking condition and an image generated by the controlling function **110***d* or the like. For example, the display **135** may be a display mechanism such as a liquid crystal display monitor. The display **135** is an example of a display unit. The display **135** has a mouse, a keyboard, a button, a panel switch, a touch command screen, a foot switch, a trackball, a joystick, and/or the like.

[0038] FIG. **2** illustrates an example of the magnetic resonance imaging apparatus **200** in which the data processing apparatus **100** according to the embodiment is incorporated.

[0039] As illustrated in FIG. **2**, the magnetic resonance imaging apparatus **200** includes a static magnetic field magnet **201**, a static magnetic field power source (not illustrated), a gradient coil **203**, a gradient power supply **204**, a couch **205**, couch controlling circuitry **206**, a transmitter coil **207**, transmitter circuitry **208**, a receiver coil **209**, receiver circuitry **210**, sequence controlling circuitry **220** (a sequence controlling unit), and the data processing apparatus **100** explained with reference to FIG. **1**. In this situation, an examined subject (hereinafter, "patient") P (e.g., a human body) is not included in the magnetic resonance imaging apparatus **200**. Further, the configuration illustrated in FIG. **2** is merely an example.

[0040] The static magnetic field magnet **201** is a magnet formed to have a hollow and substantially circular cylindrical shape and is configured to generate a static magnetic field in a space on the inside thereof. For example, the static magnetic field magnet **201** may be a superconductive magnet or the like and is configured to be excited magnetically by receiving a supply of an electric current from the static magnetic field power source. The static magnetic field power source is configured to supply the electric current to the static magnetic field magnet **201**. In another example, the static magnetic field magnet **201** may be a permanent magnet. In that situation, the magnetic resonance imaging apparatus **200** does not necessarily need to include the static magnetic field power supply. Alternatively, the static magnetic field power supply may be provided separately from the magnetic resonance imaging apparatus **200**.

[0041] The gradient coil **203** is a coil formed to have a hollow and substantially circular cylindrical shape and is provided on the inside of the static magnetic field magnet **201**. The gradient coil **203** is formed by combining together three coils corresponding to an X-axis, a Y-axis, and a Z-axis that are orthogonal to one another. The three coils are configured to generate gradient magnetic fields of which magnetic field intensities change along the X-, Y-, and Z-axes by individually receiving a supply of an electric current from the gradient power supply **204**. The gradient magnetic fields generated along the X-, Y-, and Z-axes by the gradient coil **203** may be referred to, for example, as a slice gradient magnetic field Gs, a phase encoding gradient magnetic field Ge, and a read-out gradient magnetic field Gr. The gradient power supply **204** is configured to supply the electric currents to the gradient coil **203**.

[0042] The couch **205** includes a couchtop **205***a* on which the patient P is placed. Under control of the couch controlling circuitry **206**, the couchtop **205***a* is inserted into the hollow space (an image taking opening) of the gradient coil **203**, while the patient P is placed thereon. Normally, the couch **205** is installed in such a manner that the longitudinal direction thereof extends parallel to the central axis of the static magnetic field magnet **201**. Under control of the data processing apparatus **100**, the couch controlling circuitry **206** is configured to move the couchtop **205***a* in longitudinal directions and up-and-down directions by driving the couch **205**.

[0043] The transmitter coil **207** is provided on the inside of the gradient magnetic coil **203** and is configured to generate a radio frequency magnetic field by receiving a supply of a Radio Frequency (RF) pulse from the transmitter circuitry **208**. The transmitter circuitry **208** is configured to supply the RF pulse corresponding to a Larmor frequency defined by the type of targeted atoms and the magnetic field intensities, to the transmitter coil **207**.

[0044] The receiver coil **209** is provided on the inside of the gradient coil **203** and is configured to receive a magnetic resonance signal (hereinafter, "MR signal", as necessary) emitted from the patient P due to an influence of the radio frequency magnetic field. Upon receipt of the magnetic resonance signal, the receiver coil **209** is configured to output the received magnetic resonance signal to the receiver circuitry **210**.

[0045] In this situation, the transmitter coil **207** and the receiver coil **209** described above are merely examples. The configuration may use a selected one, or two or more in combination, from among the following: a coil provided only with a transmitting function; a coil provided only with a receiving function; and a coil provided with a transmitting/receiving function.

[0046] The receiver circuitry **210** is configured to detect the magnetic resonance signal output from the receiver coil **209** and to generate magnetic resonance data on the basis of the detected magnetic resonance signal. More specifically, the receiver circuitry **210** is configured to generate the magnetic resonance data by performing a digital conversion on the magnetic resonance signal output from the receiver coil **209**. Further, the receiver circuitry **210** is configured to transmit the generated magnetic resonance data to the sequence controlling circuitry **220**. In an example, the receiver circuitry **210** may be provided as a part of a gantry apparatus in which the static magnetic field magnet **201**, the gradient coil **203**, and the like are provided.

[0047] The sequence controlling circuitry **220** is configured to perform an imaging process on the patient P, by driving the gradient power supply **204**, the transmitter circuitry **208**, and the receiver circuitry **210**, on the basis of sequence information. In this situation, the sequence information is information defining a procedure for performing the imaging process. The sequence information defines: an intensity of the electric current and timing with which the electric current is to be supplied by the gradient power supply **204** to the gradient coil **203** and the intensity of the electric current to be supplied; an intensity of the RF pulse and timing with which the RF pulse is to be supplied by the transmitter circuitry **208** to the transmitter coil **207**; and timing with which the magnetic resonance signal is detected by the receiver circuitry **210**; and the like. For example, the sequence controlling circuitry **220** may be integrated circuitry such as an Application Specific Integrated Circuit (ASIC) or a Field Programmable Gate Array (FPGA) or may be electronic circuitry such as a Central Processing Unit (CPU) or a Micro Processing Unit (MPU). The sequence controlling circuitry **220** is an example of a scan unit.

[0048] Further, when having received the magnetic resonance data from the receiver circuitry **210**, as a result of imaging the patient P by driving the gradient power supply **204**, the transmitter circuitry **208**, and the receiver circuitry **210**, the sequence controlling circuitry **220** is configured to transfer the received magnetic resonance data to the data processing apparatus **100**. In addition to the processes explained with reference to FIG. **1**, the data processing apparatus **100** is configured to control the entirety of the magnetic resonance imaging apparatus **200**.

[0049] With reference back to FIG. **1**, processes performed by the data processing apparatus **100** that are other than those explained with reference to FIG. **1** will be explained. By employing the interface function **110***c*, the processing circuitry **110** is configured to transmit the sequence information to the sequence controlling circuitry **220** and configured to receive the magnetic resonance data from the sequence controlling circuitry **220**. Also, upon receipt of the magnetic resonance data, the processing circuitry **110** including the interface function **110***c* is configured to store the received magnetic resonance data into the memory **132**.

[0050] The magnetic resonance data stored in the memory **132** is arranged in a k-space by the controlling function **110***d*. As a result, the memory **132** has k-space data stored therein.

[0051] The memory **132** is configured to store therein the magnetic resonance data received by the processing circuitry **110** including the interface function **110***c*, the k-space data arranged in the k-space by the processing circuitry **110** including the controlling function **110***d*, image data generated by the processing circuitry **110** including the reconstructing function **110***g*, and the like.

[0052] By employing the controlling function **110***d*, the processing circuitry **110** is configured to control imaging processes, image generating processes, image displaying processes, and the like, by controlling the entirety of the magnetic resonance imaging apparatus **200**. For example, the processing circuitry **110** including the controlling function **110***d* is configured to receive, via the GUI, the input of the image taking condition (e.g., an imaging parameter) and to generate the sequence information according to the received image taking condition. Further, the processing circuitry **110** including the controlling function **110***d* is configured to transmit the generated sequence information to the sequence controlling circuitry **220**.

[0053] By employing the reconstructing function **110***g*, the processing circuitry **110** is configured to generate a magnetic resonance image by reading the k-space data from the memory **132** and performing a reconstructing process such as a Fourier transform on the read k-space data.

[0054] Next, processes performed by the data processing apparatus **100** according to an embodiment will be explained. FIG. **3** is a flowchart for explaining a flow of the processes performed by the data processing apparatus **100** according to the embodiment.

[0055] To begin with, at step S**100**, for example, a medical image diagnosis apparatus connected to the data processing apparatus **100** creates first partial sampling data by performing an imaging/imaging taking process while carrying out a partial sampling process by which an acquisition is performed with a data volume smaller than that in a full sampling process. In an example, when the medical image diagnosis apparatus connected to the data processing apparatus **100** is the magnetic resonance imaging apparatus **200**, the sequence controlling circuitry **220** included in the magnetic resonance imaging apparatus **200** generates the first partial sampling data being magnetic resonance imaging data, by carrying out a magnetic resonance imaging process by executing a pulse sequence, while performing the partial sampling process by which the acquisition is performed with a data volume smaller than that in a full sampling process. As compared to k-space data from a full sampling process, the first partial sampling data may be, for example, k-space data obtained by thinning out the k-space data. By employing the obtaining function **110***f*, the processing circuitry **110** is configured to obtain the first partial sampling data.

[0056] In an example where super-resolution processing is to be carried out, which is processing involving a process to estimate full k-space data from k-space data of only the vicinity of the center of the k-space, for example, the processing circuitry **110** is configured to obtain first partial sampling data **10***a* by employing the obtaining function **110***f*, as illustrated in the top section of FIG. **4**. The first partial sampling data **10***a* is data resulting from performing a partial sampling process (a subsampling process) and missing a part of the k-space data, as compared to k-space data **14** resulting from a full sampling process. In the example of the super-resolution processing, the first partial sampling data **10***a* is data obtained by extracting the data in the vicinity of the center of the k-space, as compared to full-size k-space data. Each of the graphs in FIG. **4** indicates, in a schematic chart, an outline of the k-space data, while the horizontal axis expresses positions in the k-space, whereas the vertical axis expresses signal values. The graphs in FIG. **4** are merely schematic charts. Generally speaking, the first partial sampling data **10***a* in actuality is not one-dimensional k-space data, but is multi-dimensional k-space data.

[0057] Further, the bottom section of FIG. **4** illustrates an example in which compressed sensing is carried out. When the compressed sensing is to be carried out, as indicated in the bottom section of FIG. **4**, the processing circuitry **110** is configured to obtain first partial sampling data **10***b* by employing the obtaining function **110***f*. The first partial sampling data **10***b* is data resulting from a partial sampling process (a subsampling process) and missing a part of the k-space data, as compared to the k-space data **14** resulting from the full sampling process. In the example of the compressed sensing, the first partial sampling data **10***b* is data obtained by thinning out the full-size k-space data **14**. Unlike the first partial sampling data **10***a* being data of regions coupled by a k-space, the first partial sampling data **10***b* in the example of the compressed sensing is non-coupled k-space data.

[0058] After that, at step S**200-1**, by employing the complementing function **110***a*, the processing circuitry **110** outputs first complementary data by inputting the first partial sampling data resulting from the partial sampling process, to a first neural network. In other words, the first neural network is configured to receive the input of the data missing a part of the k-space and to estimate and output full-size k-space data. In the example of the super-resolution processing, as illustrated in the top section of FIG. **4**, by employing the complementing function **110***a*, the processing circuitry **110** outputs first complementary data **11***a* by inputting the first partial sampling data **10***a* to the first neural network. The first complementary data **11***a* is data spreading over the entire k-space, as compared to the first partial sampling data **10***a*. In contrast, in the example of the compressed sensing, by employing the complementing function **110***a*, the processing circuitry **110** outputs first complementary data **11***b* by inputting the first partial sampling data **10***b* to the first neural network. The first complementary data **11***b* is data spreading over the entire k-space, as compared to the first partial sampling data **10***b* being the data thinned out within the k-space.

[0059] Subsequently, at step S**300-1**, by employing the correcting function **110***b*, the processing circuitry **110** obtains first corrected data by performing a Data Consistency (DC) process, which is a process to improve a consistency degree between the first complementary data and the first partial sampling data.

[0060] In the example of the super-resolution processing, as a result of performing the DC process, which is a process to improve a consistency degree between the first complementary data **11***a* and the first partial sampling data **10***a*, the processing circuitry **110** obtains first corrected data **12***a* by employing the correcting function **110***b*. For example, the first corrected data **12***a* is data being the first partial sampling data **10***a* within the k-space in which the first partial sampling data is present but, in other k-spaces, is data being data **13**, which is the same data as the first complementary data **11***a*.

[0061] In contrast, in the example of the compressed sensing, as a result of performing the DC process, which is a process to improve a consistency degree between the first complementary data **11***b* and the first partial sampling data **10***b*, the processing circuitry **110** obtains first corrected data **12***b* by employing the correcting function **110***b*. Subsequently, at step S**400-1**, by employing the generating function **110***e*, the processing circuitry **110** generates second partial sampling data obtained by updating the first partial sampling data, on the basis of the first corrected data and the first partial sampling data.

[0062] Next, a background of performing the process at step S**400-1** in the embodiment will briefly be explained.

[0063] When image reconstruction is carried out by complementing k-space data through machine learning, for example, it is possible to reconstruct an image corresponding to full sampling of a k-space, on the basis of partial sampling data of the k-space, by calculating, through a learning process, a weight coefficient for a neural network configured, for example, to receive an input of partial sampling data of a k-space and to output a reconstructed image. Examples of this type of method include a method using super-resolution processing as a base and a method using compressed sensing as a base. According to the method using super-resolution processing as a base, the data in the vicinity of the center of the k-space serves as the partial sampling data to be input to the neural network. In contrast, according to the method using compressed sensing as a base, k-space data obtained by thinning out data in the k-space serves as the partial sampling data to be input to the neural network.

[0064] Further, another method is also known by which image reconstruction is carried out by combining machine learning such as Model-based Deep Learning (MoDL) with a Data Consistency (DC) process. According to this method, by carrying out an iterative process multiple times while each repetitive session includes a neural network and the DC process, a full sampling image is reconstructed from multi-channel data resulting from a partial sampling process. In this situation, used as a weight coefficient by a plurality of networks is mutually the same value shared among the neural networks.

[0065] In this situation, when the process at step S**400-1** is skipped so as to proceed to the process at step S**200-2** and to input the first corrected data **12***a* to a second neural network, characteristics of the first corrected data **12***a* input to the second neural network are different from characteristics of the first partial sampling data **10***a* input to the first neural network. For example, the first corrected data **12***a* includes the k-space data **13** which is not included in the first partial sampling data **10***a*. For this reason, for example, if the value of the weight coefficient learned in the first neural network is re-used as the value of the weight coefficient for the second neural network, there is a possibility that a proper output result may not be obtained.

[0066] One possible solution to this problem may be, instead of having the weight coefficient learned by the one neural network and re-using the weight coefficient in another neural network, to carry out training in an end-to-end manner while including the DC process, so that each of the neural networks independently determines a weight coefficient. However, this solution has low learning efficiency.

[0067] To cope with the situation, in the embodiment, by employing the generating function **110***e*, the processing circuitry **110** is configured to determine a correction amount for the first partial sampling data **10***a* being input data, on the basis of the first complementary data **11***a* being pre-DC process data and the first corrected data **12***a* being post-DC process data and configured to use the first partial sampling data **10***a* that has been corrected as second partial sampling data to be input to the next neural network. On such occasion, a correcting process is performed so that the second partial sampling data, which is the first partial sampling data **10***a* that has been corrected, becomes partial sampling data having the same characteristics as those of the first partial sampling data **10***a*. As a result, it is possible to re-use a weight coefficient learned in one neural network in another neural network and to thus eliminate the need to carry out the end-to-end training process including the DC process. With this configuration, the learning efficiency is expected to be enhanced.

[0068] FIG. **5** illustrates a process at step S**400-1** in the example of the super-resolution processing. Because the processes at steps S**100**, S**200-1**, and S**300-1** are the same as those in FIG. **4**, duplicate explanations thereof will be omitted. At step S**400-1**, by employing the generating function **110***e*, the processing circuitry **110** generates second partial sampling data **20***a* obtained by updating the first partial sampling data **10***a*, on the basis of the first corrected data **12***a* and the first partial sampling data **10***a*. In an example, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***a*, on the basis of a difference between the first corrected data **12***a* and the first complementary data **11***a*. More specifically, by employing the generating function **110***e*, the processing circuitry **110** calculates the difference between the first corrected data **12***a* and the first complementary data **11***a*. Subsequently, the processing circuitry **110** generates the second partial sampling data **20***a*, by adding an output of a mathematical function that uses the difference as an input, to the first partial sampling data **10***a*. In an example, the processing circuitry **110** generates the second partial sampling data **20***a*, by adding the difference to the first partial sampling data **10***a*. The second partial sampling data **20***a* is a result of adding data **21***a* to the first partial sampling data **10***a*. The second partial sampling data **20***a* is data obtained by sampling data points in the same positions as those used for the first partial sampling data **10***a*. As a result, this configuration makes it possible to re-use a weight coefficient from the first neural network also in the second neural network, and the learning efficiency is thus enhanced.

[0069] FIG. **6** illustrates a process at step S**400-1** in the example of the compressed sensing. Because the processes at steps S**100**, S**200-1**, and S**300-1** are the same as those in FIG. **4**, duplicate explanations thereof will be omitted. At step S**400-1**, by employing the generating function **110***e*, the processing circuitry **110** generates second partial sampling data **20***b* obtained by updating the first partial sampling data **10***b*, on the basis of the first corrected data **12***b* and the first partial sampling data **10***b*. In an example, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***b*, on the basis of a difference between the first corrected data **12***b* and the first complementary data **11***b*. More specifically, by employing the generating function **110***e*, the processing circuitry **110** calculates the difference between the first corrected data **12***b* and the first complementary data **11***b*. Subsequently, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***b*, by adding an output of a mathematical function that uses the difference as an input, to the first partial sampling data **10***b*, and further including a process of carrying out a partial sampling process. In other words, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***b*, by adding the output of the mathematical function that uses the difference as an input, to the first partial sampling data **10***b*, and further performing the process of carrying out the partial sampling process thereon, for example, in the same positions as those used for the first partial sampling process. The second partial sampling data **20***b* is a result of adding data **21***b* to the first partial sampling data **10***b*. The second partial sampling data **20***b* is data obtained by sampling data points in the same positions as those used for the first partial sampling data **10***b*. As a result, this configuration makes it possible to re-use a weight coefficient from the first neural network also in the second neural network, and the learning efficiency is thus enhanced.

[0070] Returning to the description of FIG. **3**, after that, at step S**200-2**, the processing circuitry **110** controls the complementing function **110***a*, the correcting function **110***b*, and the generating function **110***e*, by employing the controlling function **110***d*. Under control of the controlling function **110***d*, by employing the complementing function **110***a*, the processing circuitry **110** outputs second complementary data by inputting the second partial sampling data to the second neural network.

[0071] For instance, in the example of the super-resolution processing, by employing the controlling function **110***d*, the processing circuitry **110** controls the complementing function **110***a*, the correcting function **110***b*, and the generating function **110***e*. As illustrated in FIG. **5**, under the control of the controlling function **110***d*, by employing the complementing function **110***a*, the processing circuitry **110** outputs second complementary data by inputting the second partial sampling data **20***a* to the second neural network.

[0072] In contrast, in the example of the compressed sensing, by employing the controlling function **110***d*, the processing circuitry **110** controls the complementing function **110***a*, the correcting function **110***b*, and the generating function **110***e*. As illustrated in FIG. **6**, under the control of the controlling function **110***d*, by employing the complementing function **110***a*, the processing circuitry **110** outputs second complementary data, by inputting the second partial sampling data **20***b* to the second neural network.

[0073] Subsequently, at step S**500**, by employing the reconstructing function **110***g*, the processing circuitry **110** generates an image by performing a reconstructing process on the basis of the second complementary data.

[0074] Although the example was explained above in which the processing circuitry **110** is configured to generate the image by performing the reconstructing process on the basis of the second complementary data, possible embodiments are not limited to the above example. In another example, after step S**200-2**, under the control of the controlling function **110***d*, by employing the correcting function **110***b*, the processing circuitry **110** may obtain new first corrected data by using the second complementary data as new first complementary data and using the second partial sampling data as new first partial sampling data. By employing the reconstructing function **110***g*, the processing circuitry **110** may generate an image by performing a reconstructing process on the basis of the new first corrected data.

[0075] Further, although the example was explained above in which the processing circuitry **110** generates the image by performing the reconstructing process with the data correction, by employing the two neural networks, namely, the first neural network and the second neural network; however, possible embodiments are not limited to this example. The processing circuitry **110** may generate an image by performing a reconstructing process with a data correction that employs neural networks of which the quantity is expressed as n.

[0076] FIG. **7** illustrates an example with the above configuration. At step S**200**-*m* where m is a natural number, by employing the complementing function **110***a*, the processing circuitry **110** outputs m-th complementary data, by inputting m-th partial sampling data resulting from a partial sampling process to an m-th neural network. At step S**300**-*m*, by employing the correcting function **110***b*, the processing circuitry **110** obtains m-th corrected data, by performing the Data Consistency (DC) process, which is a process to improve a consistency degree between the m-th complementary data and the m-th partial sampling data. At step S**400**-*m*, by employing the generating function **110***e*, the processing circuitry **110** generates (m+1)-th partial sampling data obtained by updating the m-th partial sampling data on the basis of the m-th corrected data and the m-th partial sampling data. The processing circuitry **110** repeatedly performs the processes at steps S**200**-*m* and S**300**-*m* from "m=1" to "m=n−1" and the process at step S**400**-*m* from "m=1" to "m=n". At step S**500**, by employing the reconstructing function **110***g*, the processing circuitry **110** generates an image by performing a reconstructing process on the basis of n-th corrected data.

[0077] Further, in FIG. **3**, the second neural network may be the same neural network as the first neural network. Also, in FIG. **7**, the second to the n-th neural networks may be the same as the first neural network. By allowing the second to the n-th neural networks to be the same as the first neural network, it is possible to re-use a weight coefficient from the first neural network in the other neural networks, and the learning efficiency is thus enhanced.

[0078] FIG. **8** illustrates a flowchart of processes to be performed when the second to the n-th neural networks are the same neural network as the first neural network.

[0079] At step S**100**, by employing the obtaining function **110***f*, the processing circuitry **110** obtains partial sampling data resulting from performing a partial sampling process. At step S**200**, by employing the complementing function **110***a*, the processing circuitry **110** outputs complementary data, by inputting the partial sampling data obtained at step S**100** to a neural network. At step S**300**, by employing the correcting function **110***b*, the processing circuitry **110** obtains corrected data by performing the Data Consistency (DC) process, which is a process to improve a consistency degree between the complementary data and the partial sampling data. When an end condition is not satisfied (step S**350**: No), the process proceeds to step S**400**. At step S**400**, by employing the generating function **110***e*, the processing circuitry **110** updates the partial sampling data on the basis of the corrected data and the partial sampling data, and the process proceeds to step S**200**. On the contrary, when the end condition is satisfied (step S**350**: Yes), by employing the reconstructing function **110***g*, the processing circuitry **110** generates an image by performing a reconstructing process on the basis of either the complementary data or the corrected data.

[0080] As explained above, in the first embodiment, by employing the generating function **110***e*, the processing circuitry **110** is configured to generate the second partial sampling data obtained by updating the first partial sampling data, on the basis of the first corrected data and the first partial sampling data. As a result, this configuration makes it possible to re-use a weight coefficient from one neural network also in another neural network, and the learning efficiency is thus enhanced.

Second Embodiment

[0081] In the first embodiment, the example among others was explained in which, in the process at step S**300**, the processing circuitry **110** is configured, by employing the generating function **110***e*, to calculate the difference between the first corrected data **12***a* and the first complementary data **11***a* and to further generate the second partial sampling data **20***a*, by adding the output of the mathematical function that uses the difference as an input, to the first partial sampling data **10***a*; however, possible embodiments are not limited to the example in which the second partial sampling data is generated on the basis of the difference between the corrected data and the complementary data. For instance, it is also acceptable to generate second partial sampling data, on the basis of a ratio between the corrected data and the complementary data.

[0082] FIG. **9** illustrates an example with the above configuration. Because the processes at steps S**100**, S**200**-**1**, and S**300**-**1** are the same as those in FIG. **5**, duplicate explanations thereof will be omitted. At step S**400**-**1**, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***a* obtained by updating the first partial sampling data **10***a*, on the basis of the first corrected data **12***a* and the first partial sampling data **10***a*. In an example, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***a*, on the basis of a ratio between the first corrected data **12***a* and the first complementary data **11***a*. More specifically, by employing the generating function **110***e*, the processing circuitry **110** calculates the ratio between the first corrected data **12***a* and the first complementary data **11***a*. Subsequently, the processing circuitry **110** generates the second partial sampling data **20***a*, by multiplying the first partial sampling data **10***a* by an output of a mathematical function that uses the ratio as an input. In an example, the processing circuitry **110** generates the second partial sampling data **20***a*, by multiplying the first partial sampling data **10***a* by the ratio. The second partial sampling data **20***a* is a result of adding the data **21***a* to the first partial sampling data **10***a*. The second partial sampling data **20***a* is data obtained by sampling data points in the same positions as those used for the first partial sampling data **10***a*. As a result, this configuration makes it possible to re-use a weight coefficient from the first neural network also in the second neural network, and the learning efficiency is thus enhanced.

[0083] As explained above, in the second embodiment, by employing the generating function **110***e*, the processing circuitry **110** is configured to generate the second partial sampling data obtained by updating the first partial sampling data, on the basis of the ratio between the first corrected data **12***a* and the first complementary data **11***a*. Consequently, similarly to the first embodiment, it is possible to re-use a weight coefficient from one neural network also in another neural network, and the learning efficiency is thus enhanced.

Third Embodiment

[0084] In a third embodiment, an example will be explained in which, at step S**400**-**1**, by employing the generating function **110***e*, the processing circuitry **110** is configured to generate second partial sampling data while including a process of carrying out a partial sampling process. In this situation, in the third embodiment, the partial sampling process at the time of generating the second partial sampling data is caused to be slightly different from that of the first partial sampling data. This configuration makes it possible to perform a more flexible process.

[0085] FIG. **10** illustrates a process at step S**400**-**1** in the example of the super-resolution processing. Because the processes at steps S**100**, S**200**-**1**, and S**300**-**1** are the same as those in FIG. **5**, duplicate explanations thereof will be omitted. At step S**400**-**1**, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***a* obtained by updating the first partial sampling data **10***a*, on the basis of the first corrected data **12***a* and the first partial sampling data **10***a*. In an example, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **20***a*, on the basis of the difference between the first corrected data **12***a* and the first complementary data **11***a*. More specifically, by employing the generating function **110***e*, the processing circuitry **110** calculates the difference between the first corrected data **12***a* and the first complementary data **11***a*. Subsequently, the processing circuitry **110** generates the second partial sampling data **20***a*, by adding an output of a mathematical function that uses the difference as an input, to the first partial sampling data **10***a*, and further including a process of carrying out a partial sampling process. In this situation, the partial sampling process performed at the time of generating the second partial sampling data **20***a* uses a sampling percentage different from a sampling percentage used in the partial sampling process performed at the time of generating the first partial sampling data **10***a*. In an example, for the partial sampling process at the time of generating the second partial sampling data, the processing circuitry **110** performs the partial sampling process by making the sampling percentage slightly higher than that used at the time of generating the first partial sampling data, i.e., by making a thin-out percentage smaller. The second partial sampling data **20***a* obtained as a result includes, in addition to the first partial sampling data **10***a* and data **30**, k-space data **31** in a small volume which was not included in the original first partial sampling data **10***a*. However, as a whole, the second partial sampling data **20***a* is data obtained by sampling data points in substantially the same positions as those used for the first partial sampling data **10***a*. As a result, this configuration makes it possible to substantially re-use a weight coefficient from the first network also in the second neural network.

[0086] FIG. **11** illustrates another example of the process at step **S400-1** in the example of the compressed sensing. Because the processes at steps **S100**, **S200-1**, and **S300-1** are the same as those in FIG. **5**, duplicate explanations thereof will be omitted. At step **S400-1**, by employing the generating function **110***e*, the processing circuitry **110** generates second partial sampling data **40** obtained by updating the first partial sampling data **10***b*, on the basis of the first corrected data **12***b* and the first partial sampling data **10***b*. In the example of the compressed sensing, difference data between the first corrected data **12***b* after the DC process and the first complementary data **11***b* before the DC process may not match the shape of the first partial sampling data **10***b*, in some situations. In those situations, by employing the generating function **110***e*, the processing circuitry **110** generates the second partial sampling data **40**, by directly performing a partial sampling process on the first corrected data **12***b*. On such occasion, by employing the generating function **110***e*, the processing circuitry **110** carries out a process of generating the second partial sampling data **40**, while ensuring that sampling positions in the partial sampling process performed at the time of generating second partial sampling data are different from sampling positions in the partial sampling process performed at the time of generating first partial sampling data. As a result, although the second partial sampling data **40** is data having the slightly different sampling positions from those of the first partial sampling data **10***b*, the difference is to such an extent that it is still possible to substantially re-use a weight coefficient from the first neural network also in the second neural network.

[0087] As explained above, in the third embodiment, by employing the generating function **110***e*, the processing circuitry **110** is configured to carry out the second partial sampling data, while including the process of carrying out the partial sampling process. Similarly to the first embodiment, in the third embodiment, it is possible to substantially re-use a weight coefficient from one neural network also in another neural network, and the learning efficiency is thus enhanced.

Fourth Embodiment

[0088] In a fourth embodiment, an example among others will be explained in which the processing circuitry **110** includes a pre-processing unit configured to generate either first partial sampling data or second partial sampling data, by performing a pre-processing process on data resulting from a partial sampling process.

[0089] FIG. **12** illustrates an example with the above configuration. FIG. **12** illustrates an example of a super-resolution method using deep learning. According to this method, by employing the generating function **110***e*, a truncation artifact elimination process is repeatedly performed. Because the examples in both the top and the bottom sections of FIG. **12** can be regarded as corresponding to the example in the flowchart of FIG. **8**, the following explanation will refer to the flowchart in FIG. **8**.

[0090] At step **S100**, by employing the obtaining function **110***f*, the processing circuitry **110** obtains partial sampling data **50** resulting from performing a partial sampling process. At step **S150**, which is not illustrated in FIG. **8**, by employing a pre-processing function **110***h*, the processing circuitry **110** generates data to be input to a neural work serving as the complementing function **110***a*, on the basis of the partial sampling data **50**.

[0091] More specifically, by employing the pre-processing function **110***h*, the processing circuitry **110** carries out an Inverse Fast Fourier Transform (IFFT) **51** on the partial sampling data **50** and inputs the data to the neural work serving as the complementing function **110***a*. Also, by employing the pre-processing function **110***h*, the processing circuitry **110** applies a Low-Pass Filter (LPF) **52** to the partial sampling data **50**, subsequently carries out an inverse fast Fourier transform **53** thereon, and inputs the data to the neural network serving as the complementing function **110***a*.

[0092] At step **S200**, by employing the complementing function **110***a*, the processing circuitry **110** outputs complementary data by inputting the data generated at step **S150** to the neural network.

[0093] At step **S300**, by employing the correcting function **110***b*, the processing circuitry **110** obtains and outputs corrected data by performing a DC process, which is a process to improve a consistency degree between the complementary data and the partial sampling data **50**.

[0094] When the end condition is not satisfied (step **S350**: No), the process proceeds to step **S400**. At step **S400**, by employing the generating function **110***e*, the processing circuitry **110** updates the partial sampling data on the basis of the corrected data and the partial sampling data **50**, and the process proceeds to step **S200**.

[0095] More specifically, by employing the generating function **110***e*, the processing circuitry **110** calculates the difference between the complementary data output at step **S200** and the corrected data output at step **S300**. After that, by employing the generating function **110***e*, the processing circuitry **110** subsequently generates second partial sampling data by using a gradient **60** of the first neural network.

[0096] More specifically, by employing the generating function **110**_e_, the processing circuitry **110** calculates the gradient **60** of the first neural network through an error backpropagation or the like and further multiplies the calculated difference between the complementary data and the corrected data by the calculated gradient **60**. After that, by employing the generating function **110**_e_, the processing circuitry **110** carries out a Fast Fourier Transform (FFT) **61**, subsequently performs a partial sampling process **62** thereon, carries out multiplication **63** by a scalar value N, and adds the result to the partial sampling data **50**, so as to use the generated value as second partial sampling data serving as new partial sampling data.

[0097] On the contrary, when the end condition is satisfied (step S**350**: Yes), by employing the reconstructing function **110**_g_, the processing circuitry **110** generates an image by performing a reconstructing process on the basis of either the complementary data or the corrected data.

[0098] In this situation, possible embodiments are not limited to the above example, and the processing circuitry **110** may perform the processes illustrated in the bottom section of FIG. **12**. In the example in the bottom section of FIG. **12**, the processes performed by the pre-processing unit are the same as those in the example in the top section of FIG. **12**, but the processes performed by the generating unit are different. More specifically, in the configuration in the bottom section of FIG. **12**, at step S**400**, by employing the generating function **110**_e_, the processing circuitry **110** divides the data resulting from performing the fast Fourier transform **61** on the corrected data output at step S**300**, by the data resulting from a fast Fourier transform **64** performed on the complementary data output at step S**200**, further performs the partial sampling process **62** on the quotient, subsequently carries out the multiplication **63** by the scalar value N, and multiplies the result by the partial sampling data **50**, so as to use the generated value as second partial sampling data serving as new partial sampling data.

Fifth Embodiment

[0099] In a fifth embodiment, an example will be explained in which, by employing the generating function **110**_e_, the processing circuitry **110** is configured to generate second partial sampling data by using a process including a matrix product calculation. FIG. **13** illustrates an example with the above configuration. In the example in FIG. **13**, processes performed by the pre-processing unit and the generating unit are different from those in the example in the top section of FIG. **12**.

[0100] In the fifth embodiment, by employing the pre-processing function **110**_h_, the processing circuitry **110** is configured to carry out the inverse fast Fourier transform **51** on the partial sampling data **50** and to input the data to a neural network serving as the complementing function **110**_a_. Unlike the example in the top section of FIG. **12**, the low-pass filter (LPF) **52** is not used.

[0101] At step S**400**, by employing the generating function **110**_e_, the processing circuitry **110** generates second partial sampling data by using a process including a matrix product calculation **70**. In this situation, it is possible to express an output vector I_i^{out} of a neural network NN realized by the complementing function **110**_a_, by using Expression (1) presented below where I_j^{in} denotes an input vector.

$$I_i^{out} = NN\left(I_j^{in}\right) \tag{1}$$

[0102] It is possible to express a Jacobian value of the neural network NN by using Expression (2) presented below.

$$\text{Jacobian}(NN) = \frac{\partial I_i^{out}}{\partial I_j^{in}} \tag{2}$$

[0103] Furthermore, it is possible to express an output vector I_i^{update} resulting from the process with the matrix product calculation **70**, by using Expression (3) presented below,

$$I_i^{update} = \sum_j \left(\frac{\partial I_i^{out}}{\partial I_j^{in}}\right)^{-1} \left(I^{DC_{out}-DC_{in}}\right)_j \tag{3}$$

[0104] In Expression (3), I^{DC_out} denotes an output after the DC process performed by the correcting function **110**_b_, whereas I^{DC_in} denotes an input before the DC process performed by the correcting function **110**_b_.

[0105] In other words, by employing the generating function **110**_e_, the processing circuitry **110** is configured to output, as a processing result of the matrix product calculation **70**, a matrix product of: the difference between the corrected data being the output after the DC process performed by the correcting function **110**_b_ and the complementary data being the input before the DC process; and an inverse matrix of the Jacobian value of the neural network related to the complementing function **110**_a_. By employing the generating function **110**_e_, the processing circuitry **110** is configured to carry out the fast Fourier transform **61** on the processing result of the matrix product calculation **70**, to subsequently perform the partial sampling process **62**, to carry out the multiplication **63** by the scalar value N, and to add the result to the partial sampling data **50**, so as to use the generated value as second partial sampling data serving as new partial sampling data.

[0106] According to at least one aspect of the embodiments described above, it is possible to enhance the learning efficiency.

[0107] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A data processing apparatus comprising processing circuitry configured:

to output first complementary data by inputting, to a first neural network, first partial sampling data resulting from performing a partial sampling process;

to obtain first corrected data, by performing a process to improve a consistency degree between the first complementary data and the first partial sampling data;
to generate second partial sampling data, on a basis of the first corrected data and the first partial sampling data; and
to output second complementary data, by inputting the second partial sampling data to a second neural network.

2. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate an image by performing a reconstructing process on a basis of the second complementary data.

3. The data processing apparatus according to claim **1**, wherein the second neural network is a same neural network as the first neural network.

4. The data processing apparatus according to claim **1**, wherein the second partial sampling data is data obtained by sampling data points in same positions as those used for the first partial sampling data.

5. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate one of the first partial sampling data and the second partial sampling data, by performing a pre-processing process on data resulting from a partial sampling process.

6. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate the second partial sampling data, on a basis of a difference between the first corrected data and the first complementary data.

7. The data processing apparatus according to claim **6**, wherein the processing circuitry is configured to generate the second partial sampling data, by adding an output of a mathematical function that uses the difference as an input, to the first partial sampling data.

8. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate the second partial sampling data, on a basis of a ratio between the first corrected data and the first complementary data.

9. The data processing apparatus according to claim **8**, wherein the processing circuitry is configured to generate the second partial sampling data, by multiplying the first partial sampling data by a mathematical function that uses the ratio as an input.

10. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate the second partial sampling data, while including a process of carrying out a partial sampling process.

11. The data processing apparatus according to claim **10**, wherein a sampling percentage of a partial sampling process performed at a time of generating the second partial sampling data is different from a sampling percentage of a partial sampling process performed at a time of generating the first partial sampling data.

12. The data processing apparatus according to claim **10**, wherein the processing circuitry is configured to ensure that sampling positions of the partial sampling process performed at the time of generating the second partial sampling data are different from sampling positions of the partial sampling process performed at the time of generating the first partial sampling data.

13. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate the second partial sampling data, by using a process including a matrix product calculation.

14. The data processing apparatus according to claim **1**, wherein the processing circuitry is configured to generate the second partial sampling data, by using a gradient of the first neural network.

15. A magnetic resonance imaging apparatus comprising:
sequence controlling circuitry configured to acquire the first partial sampling data by executing a pulse sequence; and
the data processing apparatus according to claim **1**.

16. A data processing method comprising:
outputting first complementary data by inputting, to a first neural network, first partial sampling data resulting from performing a partial sampling process;
obtaining first corrected data, by performing a process to improve a consistency degree between the first complementary data and the first partial sampling data;
generating second partial sampling data, on a basis of the first corrected data and the first partial sampling data; and
outputting second complementary data, by inputting the second partial sampling data to a second neural network.

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