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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 October 2017 (26.10.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/184585 A1

(51) International Patent Classification:
A61B 5/055 (2006.01)

(21) International Application Number:
PCT/US2017/028105

(22) International Filing Date:
18 April 2017 (18.04.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2016-085200 21 April 2016 (21.04.2016) JP

(71) Applicant: GENERAL ELECTRIC COMPANY [US/US]; One River Road, Schenectady, New York 12345 (US).

(72) Inventor: GOTO, Takao; GE Healthcare, Hino-shi 4-7-127 Asahigaoka, Hino, Tokyo 191-8503 (JP).

(74) Agent: BAXTER, William et al.; GE Corporate, 9900 W. Innovation Drive, RP2131, Wauwatosa, Wisconsin 53226 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, 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, 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).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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

(54) Title: BLOOD VESSEL DETECTING APPARATUS, MAGNETIC RESONANCE IMAGING APPARATUS, AND PROGRAM

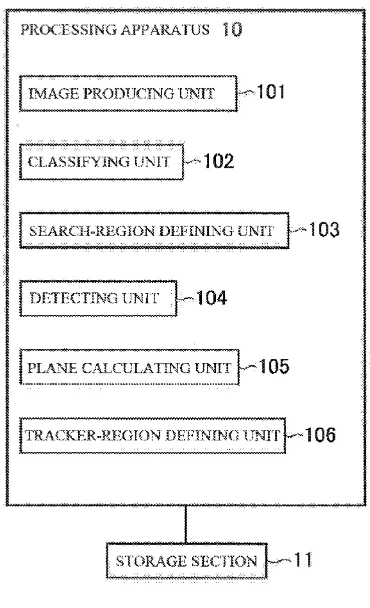


FIG. 2

(57) Abstract: An MRI apparatus (1) comprising an image producing unit (101) for producing a plurality of axial images D_1 to D_{10} in a plurality of slices defined in a body part to be imaged containing a blood vessel; a classifying unit (102) for classifying the plurality of axial images D_1 to D_1 into a plurality of classes I to IV based on which a portion of the imaged body part each of the plurality of axial images D_1 to D_1 represents; and a defining unit (103) for defining a search region for searching for a blood vessel from within an axial image based on within which of the plurality of classes I to IV the axial image falls.

WO 2017/184585 A1

BLOOD VESSEL DETECTING APPARATUS, MAGNETIC RESONANCE IMAGING APPARATUS, AND PROGRAM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to Japanese Patent Application No. 2016-085200, filed on April 21, 2016, the entirety of which is incorporated herein by reference.

BACKGROUND

[0002] The present invention relates to a blood vessel detecting apparatus for detecting a blood vessel, a magnetic resonance imaging apparatus comprising the blood vessel detecting apparatus, and a program applied to the blood vessel detecting apparatus.

[0003] Magnetic resonance imaging apparatuses for imaging a subject using a contrast medium are known.

[0004] An example of the method of imaging a subject using a contrast medium is one in which an operator produces an image in each of a plurality of axial planes intersecting a torso, visually finds a position of an aorta from within/among an image/images, and defines a tracker region for detecting the contrast medium at the position of the aorta.

[0005] An aorta is detected by increasing the area of a $Z_{dephaser}$ in a slice gradient magnetic field to diminish as much as possible signals from blood in the aorta rendered in an axial image. Blood in the aorta, however, sometimes exhibits high signals in cardiac systole because the blood flow velocity in the aorta lowers then. Therefore, in practice, signals from blood in the aorta sometimes cannot be fully diminished due to an effect of the high-signal blood. This poses a problem that a tissue different from the aorta is wrongly detected as an aorta, or the aorta cannot be detected. Accordingly, there has been disclosed a technique capable of detecting a position of the aorta even when signals from blood in the aorta are not fully diminished.

[0006] The above-referenced technique is capable of detecting a position of the aorta even when signals from blood in the aorta are not fully diminished. In some axial images, however, a cross section of a body part, different from the cross section of the aorta of interest to be detected, may exhibit a signal pattern resembling that of the aorta. In this case, the cross section of the body part different from the aorta may be wrongly detected as a cross section of an aorta. When the aorta is wrongly detected, a tracker is defined at a position offset from the aorta, resulting in a problem that accuracy in detecting a contrast medium is deteriorated.

[0007] Accordingly, there is a need for developing a technique for improving the accuracy of detection of a blood vessel in an image.

SUMMARY

[0008] In a first aspect, is a blood vessel detecting apparatus comprising an image producing unit for producing a plurality of images in a plurality of slices defined in a body part to be imaged containing a blood vessel; a classifying unit for classifying said plurality of images into a plurality of classes based on which portion in said imaged body part each of said plurality of images represents; and a defining unit for defining a search region for searching for said blood vessel from within said image based on within which of said plurality of classes said image falls.

[0009] The present invention, in its second aspect, is a magnetic resonance imaging apparatus comprising scanning section for performing a scan on a body part to be imaged containing a blood vessel, said apparatus comprising the blood vessel detecting apparatus in the first aspect.

[0010] The present invention, in its third aspect, is a program for causing a computer to execute image producing processing of producing a plurality of images in a plurality of slices defined in a body part to be imaged containing a blood vessel; classifying processing of classifying said plurality of images into a plurality of classes based on which portion in said imaged body part each of said plurality of images represents; and defining processing of defining a search region for searching for said blood vessel from within said image based on within which of said plurality of classes said image falls.

[0011] A plurality of images are classified into a plurality of classes, and a search region for searching for the blood vessel from within an image is defined according to within which of the plurality of classes the image falls; thus, accuracy of detection of a blood vessel within an image may be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic diagram of a magnetic resonance imaging apparatus in one embodiment of the present invention;

[0013] FIG. 2 is a diagram explaining unit the processing apparatus 10 implements;

[0014] FIG. 3 is a diagram showing scans performed in the present embodiment;

[0015] FIG. 4 is a diagram schematically showing a body part to be imaged;

[0016] FIG. 5 is a diagram showing an exemplary flow in performing a localizer scan LS and a main scan MS;

[0017] FIG. 6 is a diagram explaining the localizer scan LS;

[0018] FIG. 7 is a diagram schematically showing axial images DA_1 to DA_n, DA_{n+1} to DA_{n+a}, ..., DA_{j+1} to DA_k for 'm' subjects SU_1 to SU_m;

[0019] FIG. 8 is a diagram schematically showing images each obtained by cropping an image portion in a rectangular region circumscribing a torso region C1 from an axial image;

[0020] FIG. 9 is a diagram schematically showing images after their resolution is scaled down;

[0021] FIG. 10 is a diagram showing a vector determined for each of the scaled-down images a_1' to a_n';

[0022] FIG. 11 is a diagram showing a vector α_i obtained for each axial image for the subjects SU_1 to SU_m;

[0023] FIG. 12 is a diagram schematically showing an adjacency matrix MA;

[0024] FIG. 13 is a diagram showing a classification map CM;

[0025] FIG. 14 is a diagram showing an exemplary flow of Step ST2;

[0026] FIG. 15 is a diagram schematically showing an axial image D_1 in a slice SL_1;

[0027] FIG. 16 is a diagram schematically showing a binary image DB_1 obtained by binarizing the axial image D_1 in the slice SL_1;

[0028] FIG. 17 is a diagram schematically showing a binary image DC_1 in which arm portions are erased;

[0029] FIG. 18 is a diagram schematically showing an image obtained by cropping an image portion in a rectangular region circumscribing a torso region HB from the axial image D_1;

[0030] FIG. 19 is a diagram schematically showing an image D_1'' after its resolution is scaled down;

[0031] FIG. 20 is a diagram showing a vector β_1 determined for the scaled-down image D_1'';

[0032] FIG. 21 is a diagram showing a point E projected onto the classification map CM;

[0033] FIG. 22 is a diagram explaining a method of identifying N points;

[0034] FIG. 23 is a diagram showing within which class each of the axial images D_1 to D_{10} falls;

[0035] FIG. 24 is a diagram explaining a probability distribution model;

[0036] FIG. 25 is a diagram explaining a method of defining a search region;

[0037] FIG. 26 is a diagram schematically showing multiplied images MD_1' to MD_{10}' and search regions R_1 to R_{10} determined for the axial images D_1 to D_{10};

[0038] FIG. 27 is a diagram showing a position of a detected cerebrospinal fluid CSF;

[0039] FIG. 28 is a diagram showing lines Ls and Le;

[0040] FIG. 29 is a diagram showing a window W;

[0041] FIG. 30 is an explanatory diagram wherein an aorta A is detected using a classifier C;

[0042] FIG. 31 is a diagram schematically showing positions PA1 to PA10 of the aorta located respectively for the axial images D_1 to D_{10} according to Step ST2;

[0043] FIG. 32 is a diagram schematically showing a plane FS;

[0044] FIG. 33 is a diagram explaining an exemplary method of defining a tracker region; and

[0045] FIG. 34 is a diagram schematically showing an example involving cropping an image portion so that a body surface portion of the torso region C1 is not included, and determining vectors α_1 to α_k.

DETAILED DESCRIPTION

[0046] Now embodiments for practicing the invention will be described hereinbelow, although the present invention is not limited thereto.

[0047] FIG. 1 is a schematic diagram of a magnetic resonance imaging apparatus in one embodiment of the present invention. The magnetic resonance imaging apparatus (referred to as

"MRI apparatus" hereinbelow) 1 comprises a magnet 2, a table 3, a receive coil 4, and a contrast injection apparatus 5.

[0048] The magnet 2 has a reception space 21 in which a subject 14 is received. Moreover, the magnet 2 has a superconductive coil 22, a gradient coil 23, and an RF coil 24. The superconductive coil 22 applies a static magnetic field, the gradient coil 23 applies a gradient pulse, and the RF coil 24 applies an RF pulse. A permanent magnet may be employed in place of the superconductive coil 22.

[0049] The table 3 has a cradle 3a for carrying the subject 14. It is by the cradle 3a that the subject 14 is carried into the reception space 21.

[0050] The receive coil 4 is attached to the subject 14. The receive coil 4 receives magnetic resonance signals from the subject 14. The contrast injection apparatus 5 injects a contrast medium into the subject 14.

[0051] The MRI apparatus 1 further comprises a control section 6, a transmitter 7, a gradient power supply 8, a receiver 9, a processing apparatus 10, a storage section 11, an operating section 12, and a display section 13.

[0052] The control section 6 receives from the processing apparatus 10 data containing waveform information, the time for application, etc. of the RF pulse and gradient pulse used in a sequence. The control section 6 then controls the transmitter 7 based on the data for the RF pulse, and controls the gradient power supply 8 based on the data for the gradient pulse. The control section 6 also performs control of the start time for injection of the contrast medium by the contrast injection apparatus 5, control of movement of the cradle 3a, etc. While the control section 6 performs control of the contrast injection apparatus 5, transmitter 7, gradient power supply 8, cradle 3a, etc. in FIG. 1, the control of the contrast injection apparatus 5, transmitter 7, gradient power supply 8, cradle 3a, etc. may be performed by a plurality of control sections. For example, there may be separately provided a control section for controlling the contrast injection apparatus 5, that for controlling the transmitter 7 and gradient power supply 8, and that for controlling the cradle 3a.

[0053] The transmitter 7 supplies electric current to the RF coil 24 based on the data received from the control section 6.The gradient power supply 8 supplies electric current to the gradient coil 23 based on the data received from the control section 6.

[0054] The receiver 9 applies processing, such as demodulation/detection, to magnetic resonance signals received by the receive coil 4, and outputs the resulting signals to the processing apparatus 10. It should be noted that a combination of the magnet 2, receive coil 4, control section 6, transmitter 7, gradient power supply 8, and receiver 9 constitute the scanning section.

[0055] The storage section 11 stores therein programs executed by the processing apparatus 10, and the like. The storage section 11 may be a non-transitory storage medium, such as a hard disk or CD-ROM. The processing apparatus 10 loads a program stored in the storage section 11, and operates as a processor executing processing written in the program. By executing the processing written in the program, the processing apparatus 10 implements several kinds of units. FIG. 2 is a diagram explaining the units the processing apparatus 10 implements.

[0056] Image producing unit 101 produces an image in each of a plurality of slices intersecting a body part to be imaged in the subject 14.

[0057] Classifying unit 102 classifies the plurality of images into a plurality of classes based on which portion in the imaged body part each of the plurality of images obtained by the image producing unit 101 represents. The class will be discussed later.

[0058] Search-region defining unit 103 defines a search region for searching for a blood vessel on an image-by-image basis based on within which of the plurality of classes each of the plurality of images falls.

[0059] Detecting unit 104 detects a position of an aorta from within the search region. Plane calculating unit 105 calculates a plane longitudinally cutting the aorta based on positions PA1 to

PA10 (see FIG. 31) of the aorta A detected by the detecting unit 104.

[0060] Tracker-region defining unit 106 defines a tracker region R_t (see FIG. 33) for detecting a contrast medium.

[0061] The MRI apparatus 1 comprises a computer including the processing apparatus 10. The processing apparatus 10 implements the image producing unit 101 to tracker-region defining unit 106, etc. by loading programs stored in the storage section 11. The processing apparatus 10 may implement the image producing unit 101 to tracker-region defining unit 106 by a single processor, or by two or more processors. The programs executed by the processing apparatus 10 may be stored in a single storage section, or separately in a plurality of storage sections. The processing apparatus 10 constitutes the blood vessel detecting apparatus.

[0062] Referring back to FIG. 1, the description will be continued. The operating section 12 is operated by an operator to input several kinds of information to the computer 8. The display section 13 displays several kinds of information. The MRI apparatus 1 is configured as described above.

[0063] FIG. 3 is a diagram showing scans performed in the present embodiment, and FIG. 4 is a diagram schematically showing a body part to be imaged. In the present embodiment, a localizer scan LS, a main scan MS, etc. are performed. The localizer scan LS is a scan for acquiring an image used in defining slice positions or a tracker region R_t (see FIG. 33). The tracker region R_t is a region defined for detecting a contrast medium flowing through the aorta A. Subsequent to the localizer scan LS, the main scan MS is performed.

[0064] In the main scan MS, a contrast medium is injected into the subject, and a sequence for detecting the contrast medium from the tracker region R_t is repetitively performed. Once a predetermined amount of the contrast medium has been injected into the tracker region, an imaging sequence for acquiring an image of a liver is performed. Now an exemplary flow in performing the localizer scan LS and main scan MS will be described below.

[0065] FIG. 5 is a diagram showing an exemplary flow in performing the localizer scan LS and main scan MS. At Step ST1, the localizer scan LS (see FIG. 2) is performed.

[0066] FIG. 6 is a diagram explaining the localizer scan LS. The localizer scan LS is a scan for acquiring an image of a body part including a liver and organs surrounding the liver in the subject. FIG. 6 shows slices in performing the localizer scan LS. Although the localizer scan LS acquires axial, sagittal, and coronal images, FIG. 6 shows a plurality of slices (ten slices SL_1 to SL_{10} here) for acquiring axial images for convenience of explanation.

[0067] In performing the localizer scan LS, the control section 6 (see FIG. 1) sends data for an RF pulse in a sequence used in the localizer scan LS to the transmitter 7, and data for a gradient pulse in the sequencer used in the localizer scan LS to the gradient power supply 8. The transmitter 7 supplies electric current to the RF coil 24 based on the data received from the control section 6, while the gradient power supply 8 supplies electric current to the gradient coil 23 based on the data received from the control section 6. Thus, the RF coil 24 applies an RF pulse, while the gradient coil 23 applies a gradient pulse. By performing the localizer scan LS, an MR signal is generated from the body part to be imaged. The MR signal is received by the receive coil 4 (see FIG. 1). The receive coil 4 receives the MR signal and outputs an analog signal containing information on the MR signal. The receiver 9 applies signal processing, such as demodulation/detection, to the signal received from the receive coil 4, and outputs data resulting from the signal processing to the processing apparatus 10.

[0068] The image producing unit 101 (see FIG. 2) produces images D_1 to D_{10} in the slices SL_1 to SL_{10} based on the data collected by the localizer scan LS (which images will be referred to as "axial images" hereinbelow). In the drawing, axial images D_1, D_4, D_6, and D_{10} are schematically shown. Since the slices SL_1 to SL_{10} intersect the aorta A, the axial images D_1 to D_{10} render cross sections of the aorta A.

[0069] An axial image includes three regions. The first one is a region (referred to hereinbelow as "torso region") HB representing a cross section of the torso of the subject, the second is a region (referred to hereinbelow as "left-arm region") HL representing a cross section of the left arm of the subject, and the third is a region (referred to hereinbelow as "right-arm region") HR representing a cross section of the right arm of the subject. After producing the axial images D_1 to D_{10}, the flow goes to Step ST2.

[0070] At Step ST2, the classifying unit 102 (see FIG. 2) classifies the axial images D_1 to D_{10} into a plurality of classes. Now a method of classifying the axial images D_1 to D_{10} will be described below. In the following example, a method of classifying the axial images using a Laplacian eigenmaps method will be described.

[0071] In the present embodiment, the axial images D_1 to D_{10} are classified into four classes as defined as follows:

Class I: axial images having a large cross-sectional area of the lungs;

Class II: axial images intersecting the vicinity of a border between the lungs and liver;

Class III: axial images having a large cross-sectional area of the liver; and

Class IV: axial images intersecting the liver and kidneys.

[0072] In the present embodiment, before imaging the subject, a classification map is prepared in advance for classifying each of the axial images D_1 to D_{10} according to within which of the four classes I to IV the axial image falls, and the classification of the axial images is achieved using the classification map. Now an exemplary method of creating the classification map will be described below.

[0073] FIGS. 7 to 13 are diagrams explaining a method of creating a classification map. First, a plurality of axial images of the abdomen for use to create a classification map are prepared. FIG. 7 shows an example in which a plurality of axial images DA_1 to DA_n, DA_{n+1} to DA_{n+a}, ..., DA_{j+1} to DA_k of the abdomen are prepared from 'm' subjects SU_1 to SU_m. Each axial image displays a torso region C1, a left-arm region C2, and a right-arm region C3. The present embodiment shows an example in which the 'k' axial images DA_1 to DA_k are prepared from the 'm' subjects SU_1 to SU_m.

[0074] Next, a map creator who creates a classification map decides within which of Classes

I to IV described above each of the axial images DA_1 to DA_k falls. For example, the axial images DA_1, DA_2, etc. are decided to fall within Class I, while the axial image DA_k, etc. are decided to fall within Class IV.

[0075] Next, an image portion in a rectangular region circumscribing the torso region C1 is clopped from each of the axial images DA_1 to DA_k. FIG. 8 is a diagram schematically showing images each obtained by cropping an image portion in a rectangular region circumscribing the torso region C1 from the axial image. In FIG. 8, only the subject SU_1 is chosen from among the subjects SU_1 to SU_m to show images clopped from the axial images for convenience of explanation.

[0076] Referring to FIG. 8, images clopped from the axial images DA_1 to DA_n are designated by symbols a_1, a_2, ..., a_n. Moreover, the size of the clopped images a_1 to a_n is represented by the number of pixels: v_i by w_i ($i = 1$ to n). Since the rectangular region circumscribes the torso region C1, the left-arm region C2 and right-arm region C3 may be excluded from the clopped images a_1 to a_n.

[0077] After cropping the image portion of the torso from the axial images DA_1 to DA_n, the resolution of the clopped images a_1 to a_n is scaled down. FIG. 9 is a diagram schematically showing images after their resolution is scaled down. The scaled-down images are designated by symbols a_1', a_2', ..., a_n'. The scaled-down images a_1' to a_n' are scaled down to a resolution (v_0 by w_0) of the same size. For example, $v_0=44$ and $w_0=22$. By thus scaling down the images, images a_1' to a_n' of the same resolution may be produced.

[0078] Next, a vector for each of the scaled-down images a_1' to a_n' is determined. FIG. 10 is a diagram showing a vector determined for each of the scaled-down images a_1' to a_n'.

[0079] First, let us consider a vector α_i for an i-th image a_i' of the scaled-down images a_1' to a_n'. The vector α_i is a vector defined so that its elements are pixel values of pixels in the image a_i'. Representing the number of pixels of the image a_i' as t (= v_0 by w_0), the vector α_i may be expressed by the following equation:

$$\alpha_i = (\alpha_{i1}, \alpha_{i2}, \alpha_{i3}, \alpha_{i4}, \alpha_{i5}, ..., \alpha_{it}) \quad ... (1)$$

where α_{i1}, α_{i2}, α_{i3}, α_{i4}, α_{i5}, ..., α_{it} denote pixel values of pixels in the image a_i', so that the vector α_i is expressed by the vector having 't' elements.

[0080] Therefore, a vector when i = 1, for example, that is, a vector α_1 for the image a_1', may be expressed by the following equation:

$$\alpha_1 = (\alpha_{11}, \alpha_{12}, \alpha_{13}, \alpha_{14}, \alpha_{15}, ..., \alpha_{1t}) \quad ... (2)$$

[0081] Referring to FIG. 10, representative vectors α_1, α_2, α_3, α_6, and α_n when i = 1, 2, 3, 6, and n are shown.

[0082] While FIGS. 8 to 10 explain an example in which the vectors α_1 to α_n for the axial images DA_1 to DA_n for the subject SU_1 are determined, the vector α_i may be determined for axial images for the other subjects SU_2 to SU_m as well according to the method described above. FIG. 11 shows vectors α_i obtained for the subjects SU_1 to SU_m on an axial image-by-axial image basis. In the present embodiment, 'k' axial images DA_1 to DA_k are prepared from the subjects SU_1 to SU_m, so that 'k' vectors α_1 to α_k are obtained.

[0083] After determining these vectors α_1 to α_k, an adjacency matrix MA is determined. FIG. 12 schematically shows the adjacency matrix MA. Each element in the adjacency matrix MA represents a distance d_{ij} between two vectors.

[0084] After determining the adjacency matrix MA, it is weighted by a heat kernel according to the distance d_{ij} to thereby obtain a matrix W. Then, a diagonal matrix D whose diagonal elements are respective sums of columns in the matrix W is determined, and a Laplacian matrix is obtained based on the matrices W and D.

[0085] After obtaining the Laplacian matrix, an eigenproblem for the Laplacian matrix is solved to obtain 'k' eigenvectors. After obtaining the 'k' eigenvectors, an eigenvector F1 having a smallest eigenvalue, and an eigenvector F2 having a second smallest eigenvalue are identified from among the 'k' eigenvectors. Thus, the two eigenvectors F1 and F2 may be used to obtain a map representing a relationship among the axial images DA_1 to DA_k (see FIG. 7) for the subjects

SU_1 to SU_m. FIG. 13 schematically shows an example of a resulting map. A horizontal axis of the map CM represents an element of the eigenvector F1, while a vertical axis represents an element of the eigenvector F2. Positions of the axial images DA_1 to DA_k in the map CM may be determined by a coordinate point (f1, f2) (f1: the element of the eigenvector F1, and f2: the element of the eigenvector F2). In FIG. 13, points representing the positions of the axial images DA_1 to DA_k are represented using four marks (a cross, a hollow square, a hollow triangle, and a hollow circle) for convenience of explanation. The cross indicates a point representing the position of an axial image falling within Class I (an axial image having a large cross-sectional area of the lungs). The hollow square indicates a point representing the position of an axial image falling within Class II (an axial image intersecting the vicinity of a border between the lungs and liver). The hollow triangle indicates a point representing the position of an axial image falling within Class III (an axial image having a large cross-sectional area of the liver). The hollow circle indicates a point representing the position of an axial image falling within Class IV (an axial image intersecting the liver and kidneys).

[0086] In the present embodiment, the map CM shown in FIG. 13 is used as a classification map for classifying the axial images D_1 to D_{10} (see FIG. 6) obtained in the localizer scan LS. The classification map CM is stored in the storage section 11 (see FIG. 1).

[0087] At Step ST2, the classifying unit 102 classifies the axial images D_1 to D_{10} obtained in the localizer scan LS into the plurality of classes I to IV based on the classification map CM stored in the storage section 11. Now a procedure of classifying the axial images D_1 to D_{10} into the plurality of classes I to IV based on the classification map CM will be described referring to FIG. 14.

[0088] FIG. 14 is a diagram showing an exemplary flow of Step ST2. Step ST2 has Steps ST21 to ST29. Now Steps ST21 to ST29 will be described one by one.

[0089] At Step ST21, the classifying unit 102 selects one axial image from among the axial images D_1 to D_{10} in the slices SL_1 to SL_{10}. Assume here that the axial image D_1 in the slice SL_1 intersecting the lungs is selected. FIG. 15 schematically shows the selected axial image D_1 in the slice SL_1. In the axial image D_1, a torso region HB in the subject, and in addition, a left-arm region HL and a right-arm region HR are rendered. After selecting the axial image D_1 in the slice SL_1, the flow goes to Step ST22.

[0090] At Step ST22, the classifying unit 102 binarizes the axial image D_1 in the slice SL_1. FIG. 16 schematically shows a binary image DB_1 obtained by binarizing the axial image D_1 in the slice SL_1. The classifying unit 102 executes binarization processing so that the torso region HB, left-arm region HL, and right-arm region HR are rendered with a logical value of one, while regions outside of the body are rendered with a logical value of zero. This provides the binary image DB_1 in which regions inside of the body are rendered with a logical value of one and regions outside of the body are rendered with a logical value of zero. A method of binarization that may be employed is, for example, a region growing method as described in "Med. Imag. Tech., Vol. 31, No. 2, March 2013." After applying binarization, the flow goes to Step ST23.

[0091] At Step ST23, the classifying unit 102 executes processing of erasing arm portions from the binary image DB_1.

[0092] FIG. 17 is a diagram schematically showing a binary image DC_1 in which the arm portions are erased. At Step ST23, image processing for erasing the left-arm and right-arm regions from the binary image DB_1 is executed. This provides the binary image DC_1 in which the arm portions are erased. A method of erasing arm portions that may be employed is, for example, a method executing erosion processing, region growing processing, and dilation processing, as described in "Med. Imag. Tech., Vol. 31, No. 2, March 2013." After obtaining the binary image DC_1 in which the arm portions are erased, the flow goes to Step ST24.

[0093] At Step ST24, the classifying unit 102 clops an image portion in a rectangular region circumscribing the torso region HB from the axial image D_1 based on the binary image DC_1 obtained at Step ST23. FIG. 18 schematically shows an image obtained by cropping the image portion in a rectangular region circumscribing the torso region HB from the axial image D_1. Since in the binary image DC_1, the torso region has a logical value of one and regions outside of the torso are assigned with a logical value of zero, the torso region HB within the axial image D_1

may be identified by using the binary image DC_1. Thus, a rectangular region circumscribing the torso region HB may be clopped from the axial image D_1. In FIG. 18, the image clopped from the axial image D_1 is designated by symbol D_1'. Moreover, the size of the clopped image D_1' is represented by a number of pixels of p_1 by q_1. Since the rectangular region circumscribes the torso region HB, the left-arm region HL and right-arm region HR may be excluded from the rectangular region. After cropping the image portion of the torso region from the axial image D_1, the flow goes to Step ST25.

[0094] At Step ST25, the classifying unit 102 scales down the resolution of the clopped image D_1'. FIG. 19 is a diagram schematically showing an image D_1'' after its resolution is scaled down. The scaled-down image D_1'' has been scaled down to a resolution (v_0 by w_0) of the same size as the images a_1' to a_n' (see FIG. 10) used in creating the classification map CM. After scaling down the resolution, the flow goes to Step ST26.

[0095] At Step ST26, the classifying unit 102 determines a vector for the scaled-down image D_1'' (see FIG. 20).

[0096] FIG. 20 is a diagram showing a vector β_1 determined for the scaled-down image D_1''. The vector β_1 is a vector defined so that its elements are pixel values of pixels in the scaled-down image D_1''. The vector β_1 may be expressed by the following equation:

$$\beta_1 = (\beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{15}, ..., \beta_{1t}) \quad ... (3)$$

where $\beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{15}, ..., \beta_{1t}$ denote pixel values of pixels in the scaled-down image D_1''. After determining the vector β_1, the flow goes to Step ST27.

[0097] At Step ST27, the classifying unit 102 determines a distance between each of the 'k' vectors α_1 to α_k (see FIG. 11) used to create the classification map CM and the vector β_1 for the axial image D_1. The distance is then weighted with a heat kernel according to the distance value to determine a matrix Y. Next, the two eigenvectors F1 and F2 identified in creating the classification map CM are used to project the matrix Y onto the classification map CM (see FIG. 13). FIG. 21 shows a point E representing the matrix Y projected onto the classification map CM. In FIG. 21, the point E lies at coordinates (f11, f21). In this way, the point E corresponding to the axial image D_1 is mapped onto the classification map CM. After the mapping, the flow goes to Step ST28.

[0098] At Step ST28, the classifying unit 102 identifies N points from among a plurality of points defined on the classification map CM in an ascending order of distance to the point E corresponding to the axial image D_1.

[0099] FIG. 22 is a diagram explaining a method of identifying N points. FIG. 22 shows the vicinity of the point E mapped onto the classification map CM in an enlarged view.

[0100] The classifying unit 102 calculates a distance between each of the plurality of points defined on the classification map CM and the point E, and identifies N points in an ascending order of distance. Thus, N points may be identified in an ascending order of distance to the point E. Assume here that N = 7. Therefore, seven points e1, e2, e3, e4, e5, e6, and e7 are identified in an ascending order of distance to the point E. After identifying the seven points e1 to e7, the flow goes to Step ST29.

[0101] At Step ST29, the classifying unit 102 first identifies within which of the four classes I to IV each of the seven points e1 to e7 falls. Here, six points (e1, e2, e4, e5, e6, and e7) of the seven points e1 to e7 are identified as falling within Class I, and one point (e3) as falling within Class II. After identifying within which class each point falls, the classifying unit 102 determines how many of the seven points fall within each class, and identifies a class having a largest number of the points falling there. Since six of the seven points e1 to e7 fall within Class I here, Class I is identified. Therefore, the axial image D_1 is decided to fall within Class I of the four classes I to IV, so that the axial image D_1 is classified into Class I.

[0102] While the preceding description is addressed to classification of the axial image D_1, the other axial images D_2 to D_{10} are also classified according to the flow from Step ST21 to Step ST29. Since information on each of Classes I to IV is reflected in the classification map CM, which portion of the imaged body part each of the axial images D_1 to D_{10} represents may be identified by using the classification map CM. Thus, the axial images D_1 to D_{10} may be classified into four classes.

[0103] FIG. 23 is a diagram showing within which class each of the axial images D_1 to D_{10} falls. FIG. 23 shows within which class four representative axial images D_1, D_4, D_6, and D_{10} of the axial images D_1 to D_{10} fall. The axial image D_1 is classified into Class I, the axial image D_4 into Class II, the axial image D_6 into Class III, and the axial image D_{10} into Class IV. After classifying the axial images D_1 to D_{10}, the flow goes to Step ST3.

[0104] At Step ST3, the search-region defining unit 103 (see FIG. 2) defines an aorta search region for each of the axial images D_1 to D_{10}. Now a method of defining the aorta search region will be described below.

[0105] In the present embodiment, a probability distribution model expressing the probability of presence of the aorta for each of Classes I to IV is stored in the storage section 11.

[0106] FIG. 24 is a diagram explaining the probability distribution model. The storage section 11 stores therein four probability distribution models M1 to M4.

[0107] The probability distribution model M1 represents the probability of presence of the aorta in Class I. The probability of presence of the aorta in Class I may be determined based on the position of the aorta appearing in axial images (for example, axial images DA_1, DA_{n+1}, DA_{j+1}) having a large cross-sectional area of the lungs among the plurality of axial images DA_1 to DA_k (see FIG. 7) used to create the classification map CM. A region RM1 in the probability distribution model M1 represents a region having a high probability of presence of the aorta. Referring to an a-a cross section of the probability distribution model M1, it is shown that the probability of presence of the aorta increases from an outer periphery of the region RM1 toward the inside thereof.

[0108] The probability distribution model M2 represents the probability of presence of the aorta in Class II. The probability of presence of the aorta in Class II may be determined based on the position of the aorta appearing in axial images (for example, axial images DA_3, DA_{n+3},

DA_{j+3}) intersecting the vicinity of a border between the lungs and liver among the plurality of axial images DA_1 to DA_k (see FIG. 7) used to create the classification map CM. A region RM2 in the probability distribution model M2 represents a region having a high probability of presence of the aorta. Referring to an a-a cross section of the probability distribution model M2, it is shown that the probability of presence of the aorta increases from an outer periphery of the region RM2 toward the inside thereof.

[0109] The probability distribution model M3 represents the probability of presence of the aorta in Class III. The probability of presence of the aorta in Class III may be determined based on the position of the aorta appearing in axial images (for example, axial images DA_6, DA_{n+6}, DA_{j+6}) having a large cross-sectional area of the liver among the plurality of axial images DA_1 to DA_k (see FIG. 7) used to create the classification map CM. A region RM3 in the probability distribution model M3 represents a region having a high probability of presence of the aorta. Referring to an a-a cross section of the probability distribution model M3, it is shown that the probability of presence of the aorta increases from an outer periphery of the region RM3 toward the inside thereof.

[0110] The probability distribution model M4 represents the probability of presence of the aorta in Class IV. The probability of presence of the aorta in Class IV may be determined based on the position of the aorta appearing in axial images (for example, axial images DA_n, DA_{n+a}, DA_k) intersecting the liver and kidneys among the plurality of axial images DA_1 to DA_k (see FIG. 7) used to create the classification map CM. A region RM4 in the probability distribution model M4 represents a region having a high probability of presence of the aorta. Referring to an a-a cross section of the probability distribution model M4, it is shown that the probability of presence of the aorta increases from an outer periphery of the region RM4 toward the inside thereof.

[0111] The search-region defining unit 103 defines a search region for searching for the aorta in the axial images D_1 to D_{10} based on the probability distribution models M1 to M4. Now a method of defining a search region in the axial images D_1 to D_{10} will be described below. Since the method of defining a search region in the axial images D_1 to D_{10} is the same for all the axial images, the axial image D_1 is chosen from the axial images D_1 to D_{10} to describe the method of defining a search region in the following description.

[0112] FIG. 25 is a diagram explaining the method of defining a search region. The search-region defining unit 103 selects a probability distribution model used to determine a search region in the axial image D_1 from among the probability distribution models M1 to M4. Since the axial image D_1 is classified into Class I (see FIG. 23), the search-region defining unit 103 selects the probability distribution model M1 corresponding to Class I from among the probability distribution models M1 to M4.

[0113] Next, the search-region defining unit 103 multiplies the clopped image D_1' (see FIG. 18) obtained from the axial image D_1 by the probability distribution model M1 to obtain a multiplied image MD_1'.

[0114] After obtaining the multiplied image MD_1', the search-region defining unit 103 determines a region R1 corresponding to the region RM1 in the probability distribution model M1 from within the multiplied image MD_1' based on the information on the position of the region RM1 in the probability distribution model M1. The thus-determined region R1 is defined as the aorta search region R_1 in the axial image D_1.

[0115] While the method of defining the aorta search region R_1 in the axial image D_1 is explained in FIG. 25, a search region is determined for each of the other axial images D_2 to D_{10} as well by determining a multiplied image according to a similar procedure. FIG. 26 schematically shows multiplied images MD_1' to MD_{10}' and search regions R_1 to R_{10} determined for the axial images D_1 to D_{10}. In FIG. 26, multiplied images MD_1', MD_4', MD_6', and MD_{10}', and search regions R_1, R_4, R_6, and R_{10} determined for the four representative axial images D_1, D_4, D_6, and D_{10} among the axial images D_1 to D_{10} are schematically shown. After determining the search regions R_1 to R_{10}, the flow goes to Step ST4.

[0116] At Step ST4, the detecting unit 104 (see FIG. 2) detects a position of the aorta from within the search region R1. Now a method of detecting a position of the aorta will be described below. Since the method of detecting a position of the aorta in the axial images D_1 to D_{10} is the same for all the axial images, the axial image D_1 is chosen from the axial images D_1 to D_{10} to describe the method of detecting a position of the aorta in the following description.

[0117] At Step ST4, a cerebrospinal fluid CSF is first detected from within the multiplied image MD_1' for the axial image D_1. A method of detecting a cerebrospinal fluid CSF that may be employed is, for example, one described in "Med. Imag. Tech., Vol. 31, No. 2, March 2013." FIG. 27 shows a position of the detected cerebrospinal fluid CSF.

[0118] After detecting the cerebrospinal fluid CSF, the detecting unit 104 defines lines Ls and Le tangent to the search region R1 with respect to the cerebrospinal fluid CSF. FIG. 28 shows the lines Ls and Le.

[0119] After defining the lines Ls and Le, the detecting unit 104 defines a window on the line Ls for use in detecting the aorta A (see FIG. 29).

[0120] FIG. 29 is a diagram showing a window W defined. The size of the window W is represented by a number of pixels of a by b. The detecting unit 104 defines the window W on the line Ls with respect to the cerebrospinal fluid CSF. After defining the window W, the detecting unit 104 changes a rotation angle θ of the window W by rotating the window W around the cerebrospinal fluid CSF within a range delineated by the lines Ls and Le, and moreover changes the size (the numbers a and b of pixels) of the window W. It then detects the aorta A from within the search region R1 using a classifier C (see FIG. 30), which will be discussed below.

[0121] FIG. 30 is an explanatory diagram wherein the aorta A is detected using a classifier C. The detecting unit 104 changes θ between θ1 and θ2, and changes values of a and b for the window W each time θ is changed. Then, each time any one of the three parameters (θ, a, b) for the window W is changed, data for pixels in the window W is extracted. The classifier C is for outputting an output value Out for deciding whether the possibility that the aorta A in the axial image D_1 inscribes a distal portion of the window W is high or low based on the extracted data, and the classifier C is created in advance before imaging the subject. The classifier C may be created by, for example, learning training data containing information on a signal value for the aorta, and training data containing information on a signal value for a tissue different from the aorta. In the present embodiment, the classifier C is configured so that the output value Out is greater for a higher possibility that the aorta A inscribes the distal portion of the window W. Therefore, it may be decided that the possibility that the aorta A in the axial image D_1 inscribes the distal portion of the window W is highest when the output value Out from the classifier C is largest. Assume here that the output value Out from the classifier C is largest when the rotation angle $\theta = \theta_1$, the number a of pixels = a_1, and the number b of pixels = b_1. It is then decided that the aorta A in the axial image D_1 inscribes the distal portion of the window W when the parameters (θ, a, b) for the window W = (θ_1, a_1, b_1), and thus, the aorta A may be detected from within the search region R1.

[0122] While the method of detecting the aorta A in the axial image D_1 is explained in the preceding description, the aorta is detected from within the search region using the classifier C for the other axial images D_2 to D_{10} as well. Thus, the position of the aorta may be located for the axial images. FIG. 31 schematically shows positions PA1 to PA10 of the aorta located according to Step ST2 respectively for the axial images D_1 to D_{10}. The positions PA1 to PA10 of the aorta are not necessarily the center of the aorta, and may lie in the inside of the cross section of the aorta. After locating the position of the aorta in each of the axial images D_1 to D_{10}, the flow goes to Step ST5.

[0123] At Step ST5, the plane calculating unit 105 (see FIG. 2) calculates a plane longitudinally cutting the aorta based on the positions PA1 to PA10 of the detected aorta A. Now a method of calculating the plane will be described below.

[0124] First, based on the positions PA1 to PA10 of the aorta, the plane calculating unit 105 identifies a region of a cross section of the aorta on an axial image-by-axial image basis. A method of identifying a region of the cross section of the aorta that may be employed is, for example, a segmentation technique such as a Level Set method. After identifying the region of the cross section of the aorta, a center of the cross section of the aorta is located. For example, a centroid of the cross section of the aorta A may be located as a center of the aorta A. The center of the aorta A may be located by considering the cross section of the aorta A to have a generally circular shape.

[0125] After locating the center of the aorta A, the plane calculating unit 105 determines a plane FS longitudinally cutting the aorta A generally in parallel with a direction of the course of the aorta A based on the information on the position of the center of the aorta A located for each of the axial images D_1 to D_{10}. FIG. 32 schematically shows the determined plane FS. In the present embodiment, the plane calculating unit 105 calculates a square sum of the distance between the center of the aorta A located for each of the axial images D_1 to D_{10} and the plane, and determines as the plane FS a plane when the square sum is minimized. After determining the plane FS, the flow goes to Step ST4.

[0126] At Step ST4, a tracker region for detecting a contrast medium is defined. Now a method of defining the tracker region will be described below.

[0127] FIG. 33 is a diagram explaining an exemplary method of defining a tracker region. The operator operates the operating section 12 (see FIG. 1) to input a command for displaying the plane FS determined at Step ST3 in the display section 13. Once the command has been input, the plane FS determined at Step ST3 is displayed in the display section 13.

[0128] After the plane FS is displayed, the operator operates the operating section 12 to input information for defining a tracker region referring to a positional relationship among organs and the aorta displayed in the plane FS. Once the information has been input, the tracker-region defining unit 106 (see FIG. 2) defines a tracker region based on the input information. FIG. 32 shows a case in which a tracker region R_t is defined to lie in the inside of the aorta A. It should be noted that the tracker region R_t may be automatically defined based on the position of the aorta A. After defining the tracker region R_t, the flow goes to Step ST5.

[0129] At Step ST5, a main scan MS (see FIG. 3) is performed. In the main scan MS, the subject is injected with a contrast medium, and a sequence for detecting the contrast medium from the tracker region R_t is repetitively performed. Once a predefined amount of the contrast medium has been injected in the tracker region R_t, a scan for acquiring an image of the liver is performed, and the flow is terminated.

[0130] In the present embodiment, within which class an axial image falls is determined, and a probability distribution model corresponding to that class is used to determine an aorta search region. Therefore, detection of an aorta may be achieved while focusing upon a region having a high probability of presence of the aorta, thus improving accuracy of detection of the aorta.

[0131] Moreover, in the present embodiment, an image portion is clopped from each of the axial images D_1 to D_{10} so as to circumscribe the torso region HB, and classification of the axial images D_1 to D_{10} is performed. Therefore, the axial images D_1 to D_{10} may be classified without being affected by the signal value in the left-arm region HL and right-arm region HR, thus fully reducing a risk that the axial images are wrongly classified.

[0132] While the window W is defined with respect to the cerebrospinal fluid CSF in the present embodiment, the window W may be defined with respect to a body part different from the cerebrospinal fluid CSF. Moreover, while the aorta A is detected in the present embodiment, the present invention may be applied to a case in which a blood vessel different from the aorta A is to be detected.

[0133] While the present embodiment detects an aorta based on an axial image, the aorta may be determined based on an image in a plane other than the axial plane (for example, an oblique plane intersecting the axial plane at an angle).

[0134] While in the present embodiment the window W is rectangular, it may have a different shape (an elliptical shape, for example).

[0135] In creating the classification map CM in the present embodiment, an image portion in a rectangular region circumscribing the torso region C1 is clopped from each of the axial images (see FIG. 8) to determine vectors α_1 to α_k (see FIG. 11). However, the vectors α_1 to α_k may be determined by cropping the image portion so that the center portion of the torso region C1 is included and a body surface portion is not included. FIG. 34 is a diagram schematically showing an example involving cropping an image portion so that the body surface portion of the torso region C1 is not included, and determining the vectors α_1 to α_k. According to the method in FIG. 34, since the vectors α_1 to α_k are determined based on the image portion (hatched portion) including the center portion of the torso region C1 and not including the body surface portion, a classification map CM' (not shown) may be created with a reduced effect of fat in the body surface portion. When the classification map CM' is created in place of the classification map CM (see FIG. 13), again, the axial images may be classified by performing Step ST2. When classifying axial images using the classification map CM, an image portion is clopped from the axial image D_1 so as to circumscribe the torso region HB at Step ST24. When classifying axial images using the classification map CM' in place of the classification map CM, however, an image portion may be clopped from the axial image D_1 so as not to include the body surface portion of the torso region HB at Step ST24.

[0136] Furthermore, in the present embodiment, the classification map is created by cropping the image portion so as not to include the left-arm and right-arm regions. However, the classification map may be created by cropping an image portion so as to include the left-arm and right-arm regions insofar as axial images are correctly classified.

[0137] While the method of classifying axial images using the Laplacian eigenmaps method is described in the present embodiment, the classification method in the present embodiment is exemplary, and axial images may be classified using any other technique.

CLAIMS

What is claimed is:

1. A blood vessel detecting apparatus comprising:

an image producing unit for producing a plurality of images in a plurality of slices defined in a body part to be imaged containing a blood vessel;

a classifying unit for classifying said plurality of images into a plurality of classes based on which portion in said imaged body part each of said plurality of images represents; and

a defining unit for defining a search region for searching for said blood vessel from within said image based on within which of said plurality of classes said image falls.

2. The blood vessel detecting apparatus as recited in claim 1, wherein a model representing a probability of presence of said blood vessel is made corresponding to each said class; and said defining unit defines said search region based on said model.

3. The blood vessel detecting apparatus as recited in claim 1, wherein said plurality of classes includes

a first class corresponding to images having a large cross-sectional area of lungs;

a second class corresponding to images intersecting a vicinity of a border between the lungs and a liver;

a third class corresponding to images having a large cross-sectional area of the liver; and

a fourth class corresponding to images intersecting the liver and kidneys.

4. The blood vessel detecting apparatus as recited in claim 1, wherein said classifying unit classifies said plurality of images into a plurality of classes based on a map for identifying which portion of said imaged body part each of said plurality of images represents.

5. The blood vessel detecting apparatus as recited in claim 4, wherein said classifying unit determines a vector whose elements are pixel values of pixels in said image, maps a point corresponding to said image onto said map based on said vector, and determines within which of said plurality of classes said image falls based on a position at which said point is mapped in said

map.

6. The blood vessel detecting apparatus as recited in claim 5, wherein each of said plurality of images includes a first region representing a cross-section of a torso of a subject, a second region representing a cross-section of a left arm of said subject, and a third region representing a cross-section of a right arm of said subject; and said classifying unit clops from said image an image portion that includes said first region and does not include said second region nor said third region, and determines said vector based on an image obtained by cropping said image portion.

7. The blood vessel detecting apparatus as recited in claim 5, wherein each of said plurality of images includes a first region representing a cross-section of a torso of a subject, a second region representing a cross-section of a left arm of said subject, and a third region representing a cross-section of a right arm of said subject; and said classifying unit crops from said image an image portion that includes a central portion of said first region and does not include a body surface portion of said first region, said second region, nor said third region, and determines said vector based on an image obtained by cropping said image portion.

8. The blood vessel detecting apparatus as recited in claim 1, comprising a detecting unit for detecting a position of said blood vessel from said search region.

10. A program for causing a computer to execute:

image producing processing of producing a plurality of images in a plurality of slices defined in a body part to be imaged containing a blood vessel;

classifying processing of classifying said plurality of images into a plurality of classes based on which portion in said imaged body part each of said plurality of images represents; and

defining processing of defining a search region for searching for said blood vessel from within said image based on within which of said plurality of classes said image falls.

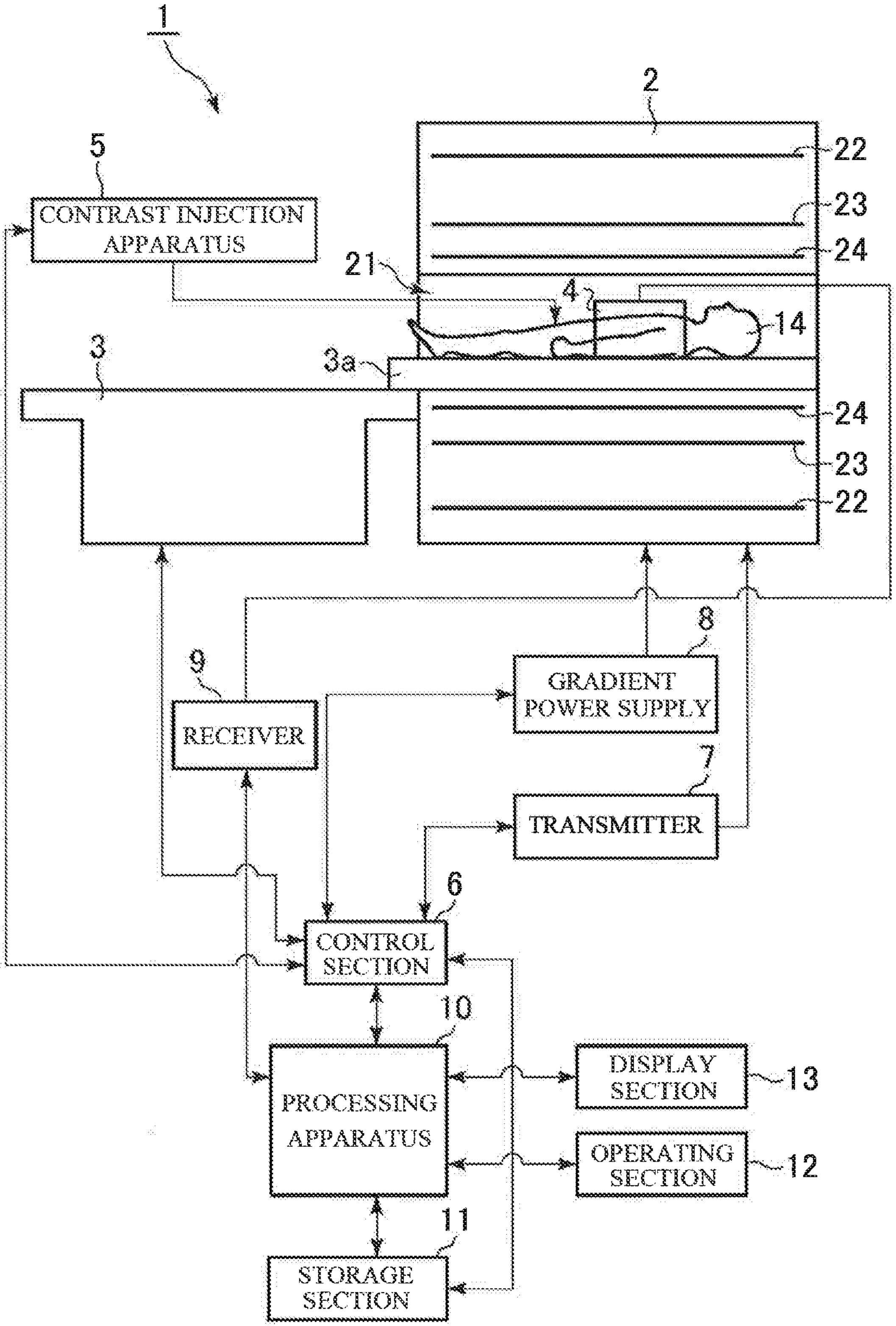

1
2
22
23
24
5
CONTRAST INJECTION APPARATUS
21
4
14
3
3a
24
23
22
8
9
GRADIENT POWER SUPPLY
RECEIVER
7
TRANSMITTER
6
CONTROL SECTION
10
DISPLAY SECTION
13
PROCESSING APPARATUS
OPERATING SECTION
12
11
STORAGE SECTION

FIG. 1

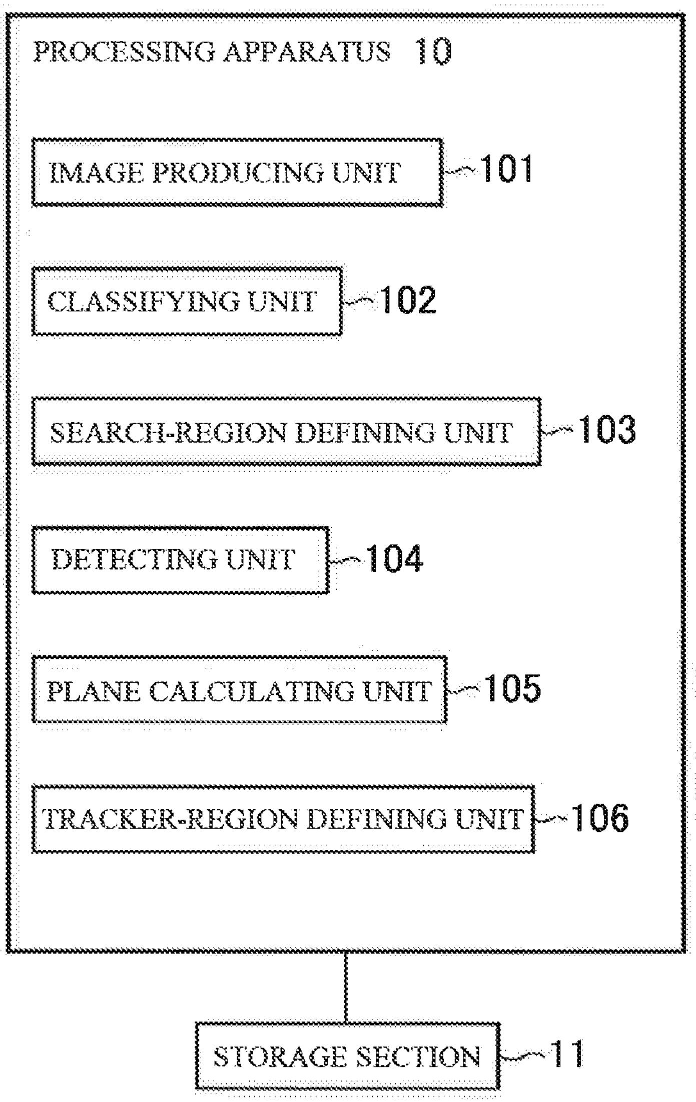

PROCESSING APPARATUS 10
IMAGE PRODUCING UNIT
101
CLASSIFYING UNIT
102
SEARCH-REGION DEFINING UNIT
103
DETECTING UNIT
104
PLANE CALCULATING UNIT
105
TRACKER-REGION DEFINING UNIT
106
STORAGE SECTION
11

FIG. 2

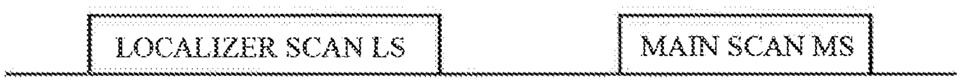


FIG. 3

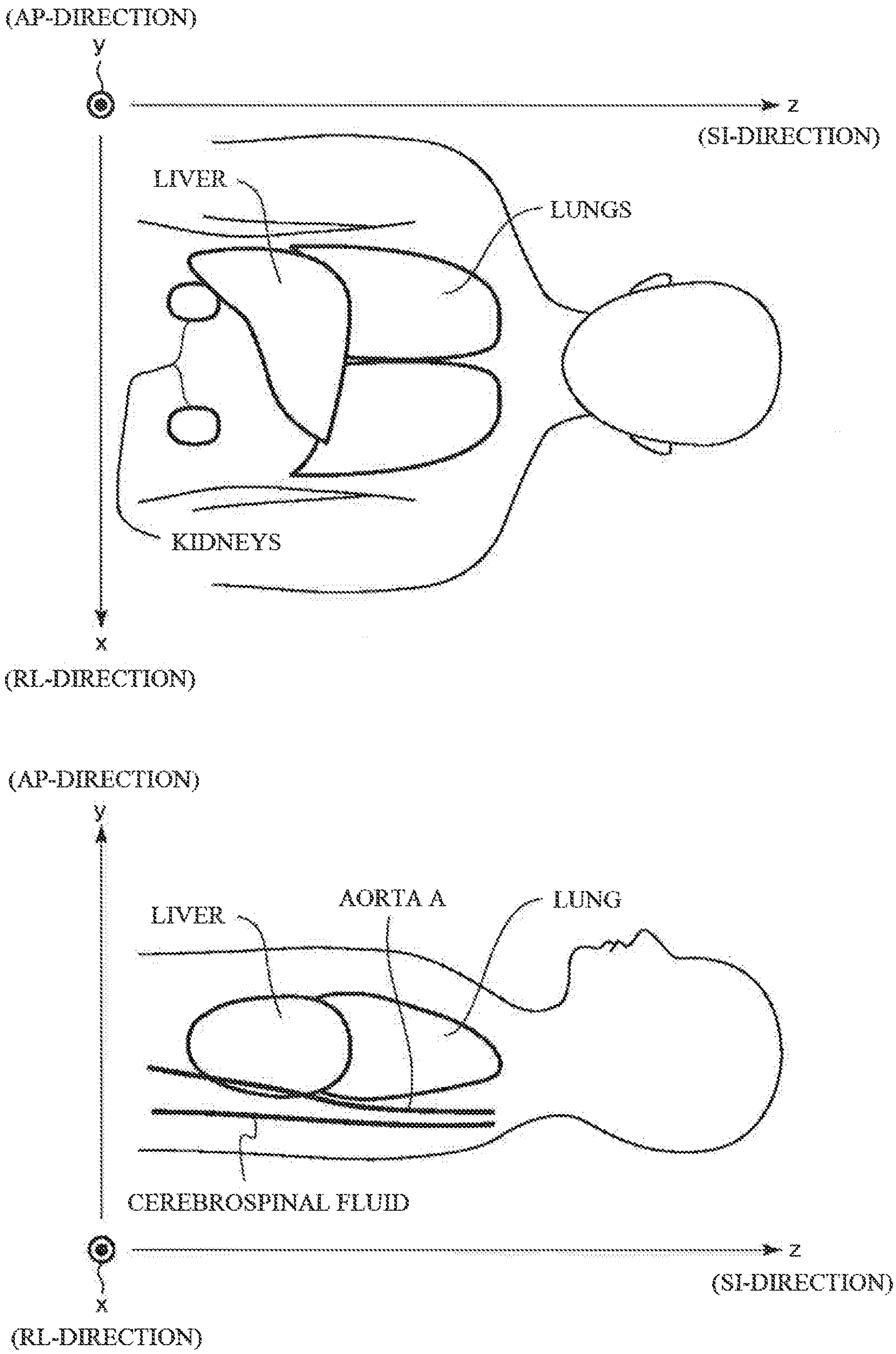

(AP-DIRECTION)
y
z
(SI-DIRECTION)
LIVER
LUNGS
KIDNEYS
x
(RL-DIRECTION)
(AP-DIRECTION)
y
LIVER
AORTA A
LUNG
CEREBROSPINAL FLUID
z
(SI-DIRECTION)
x
(RL-DIRECTION)

FIG. 4

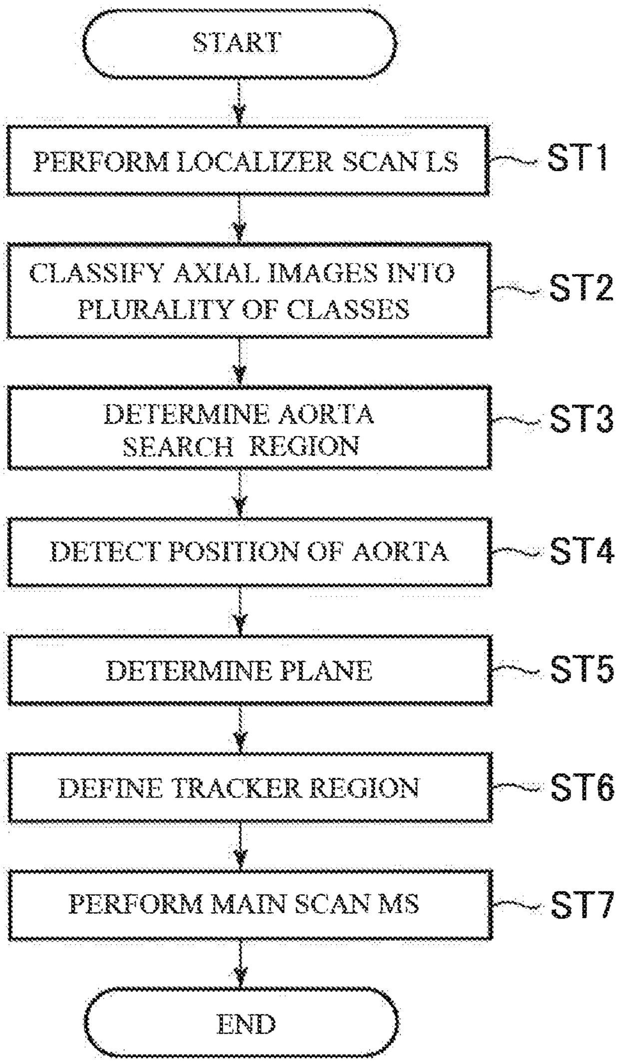
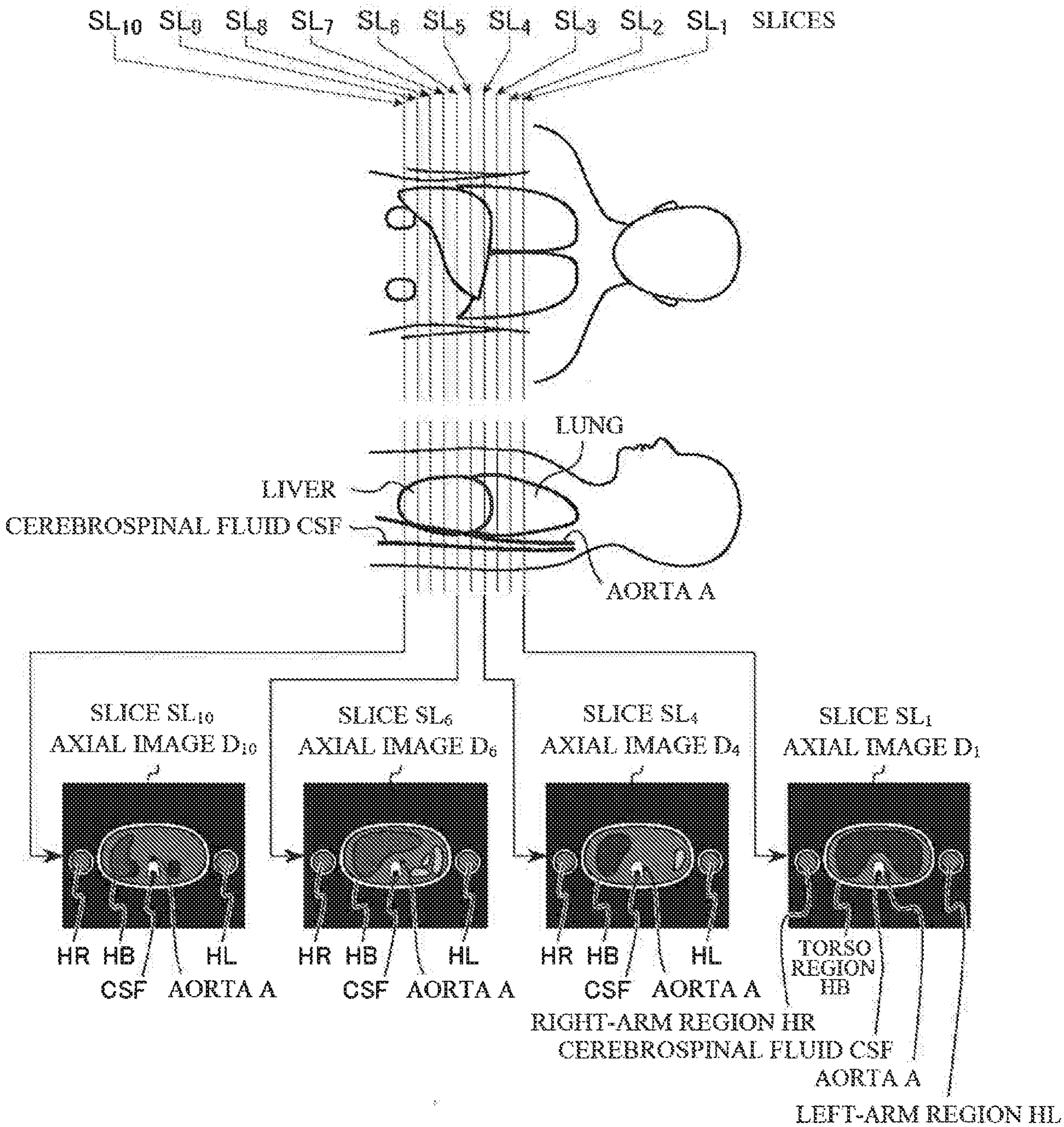

START
PERFORM LOCALIZER SCAN LS
ST1
CLASSIFY AXIAL IMAGES INTO PLURALITY OF CLASSES
ST2
DETERMINE AORTA SEARCH REGION
ST3
DETECT POSITION OF AORTA
ST4
DETERMINE PLANE
ST5
DEFINE TRACKER REGION
ST6
PERFORM MAIN SCAN MS
ST7
END

FIG. 5



SL10 SL9 SL8 SL7 SL6 SL5 SL4 SL3 SL2 SL1 SLICES
LUNG
LIVER
CEREBROSPINAL FLUID CSF
AORTA A
SLICE SL10
AXIAL IMAGE D10
SLICE SL6
AXIAL IMAGE D6
SLICE SL4
AXIAL IMAGE D4
SLICE SL1
AXIAL IMAGE D1
HR HB HL
CSF AORTA A
HR HB HL
CSF AORTA A
HR HB HL
CSF AORTA A
TORSO REGION HB
RIGHT-ARM REGION HR
CEREBROSPINAL FLUID CSF
AORTA A
LEFT-ARM REGION HL

FIG. 6

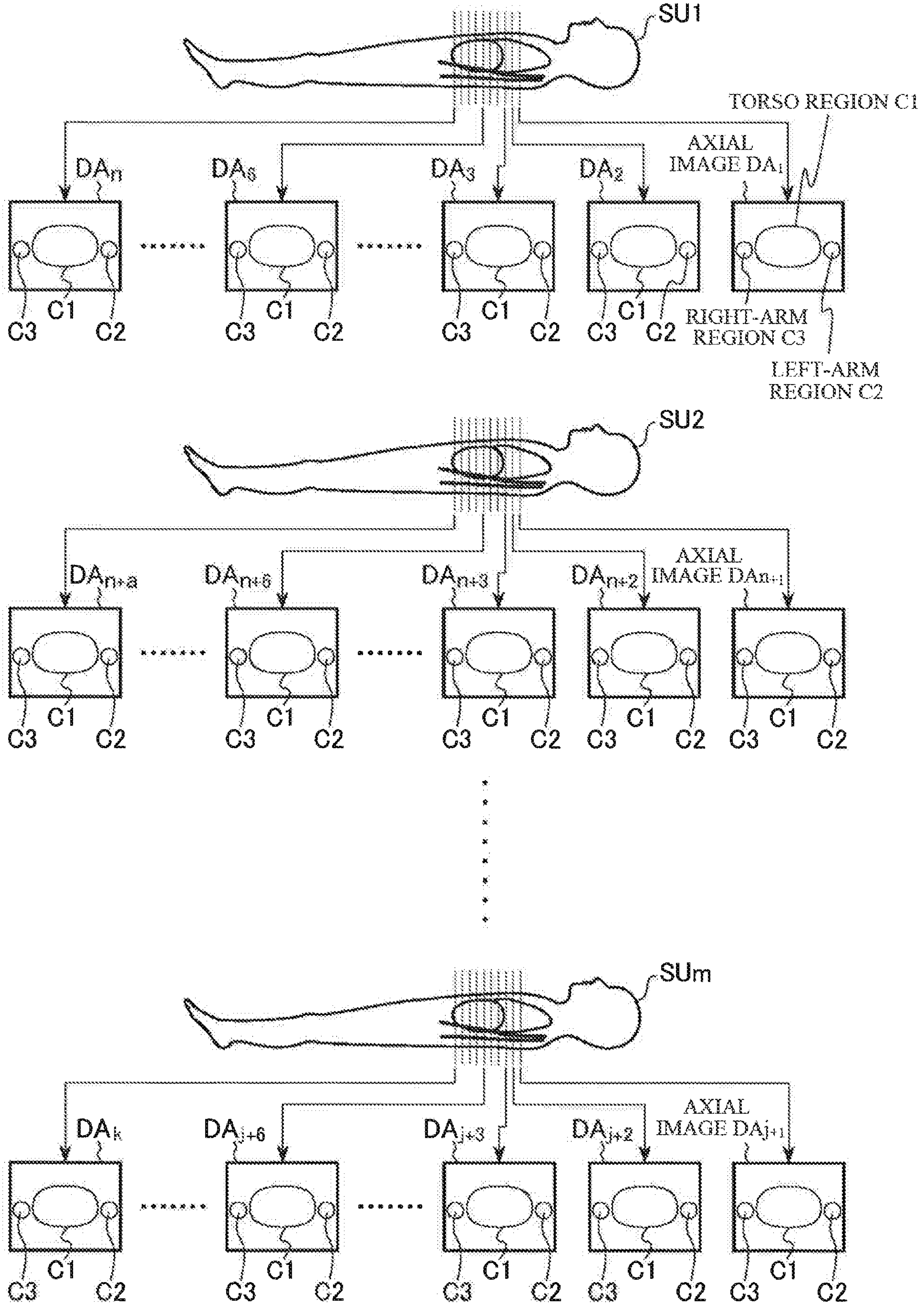

SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA6
DA3
DA2
C1
C3
C2
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
SU2
AXIAL IMAGE DAn+1
DAn+a
DAn+6
DAn+3
DAn+2
SUm
AXIAL IMAGE DAj+1
DAk
DAj+6
DAj+3
DAj+2

FIG. 7

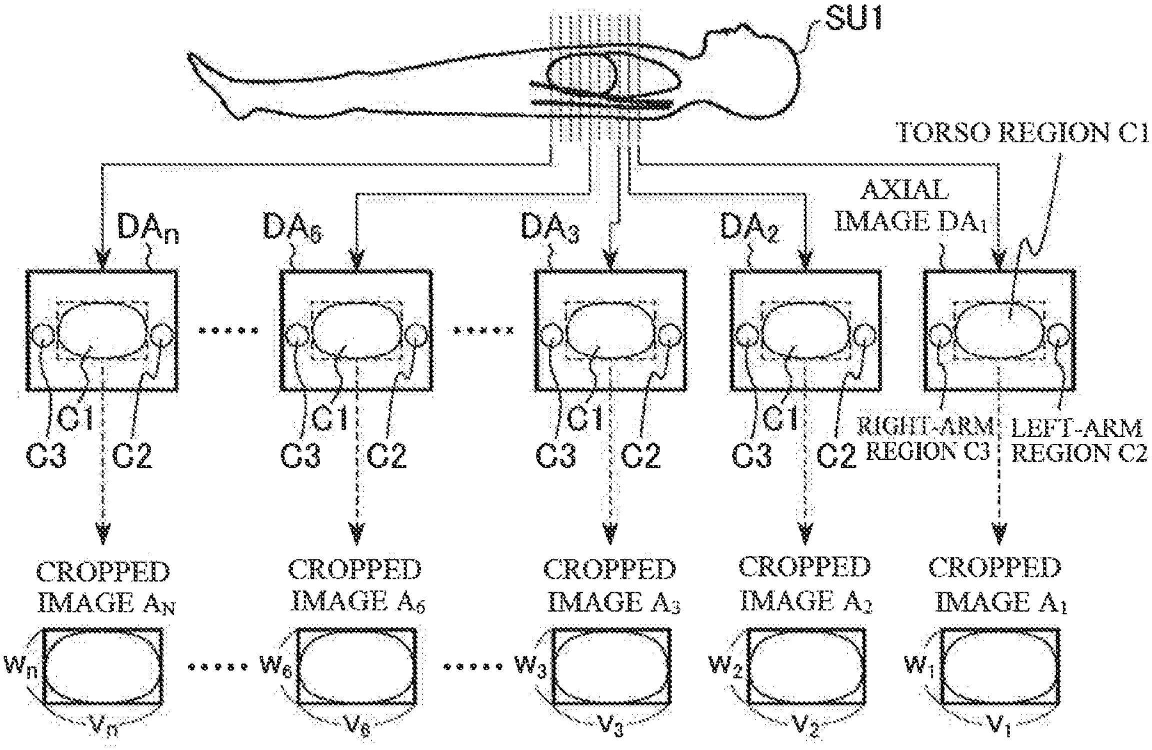

SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA6
DA3
DA2
C1
C2
C3
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
CROPPED IMAGE AN
CROPPED IMAGE A6
CROPPED IMAGE A3
CROPPED IMAGE A2
CROPPED IMAGE A1
Wn
W6
W3
W2
W1
Vn
V6
V3
V2
V1

FIG. 8

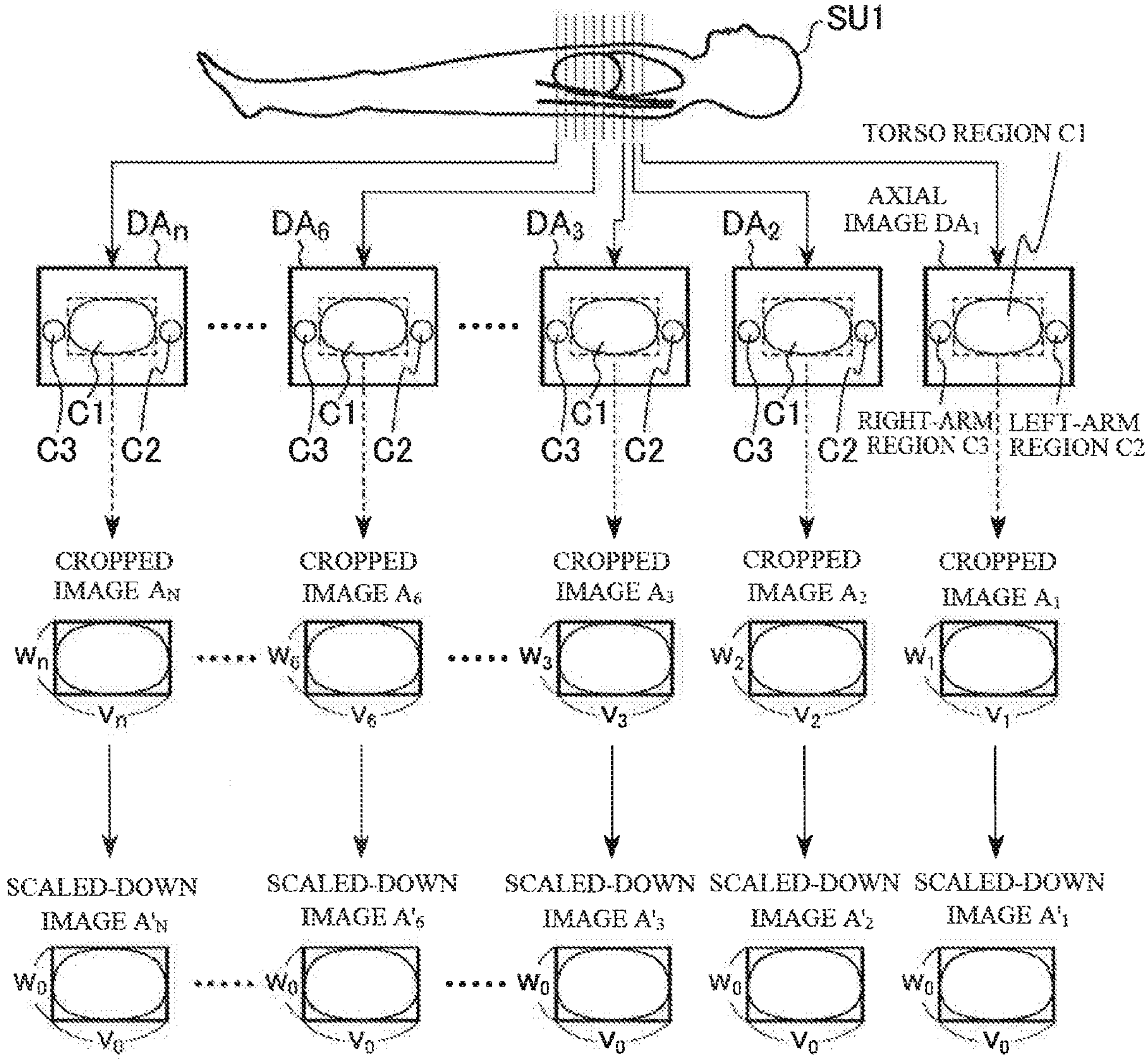
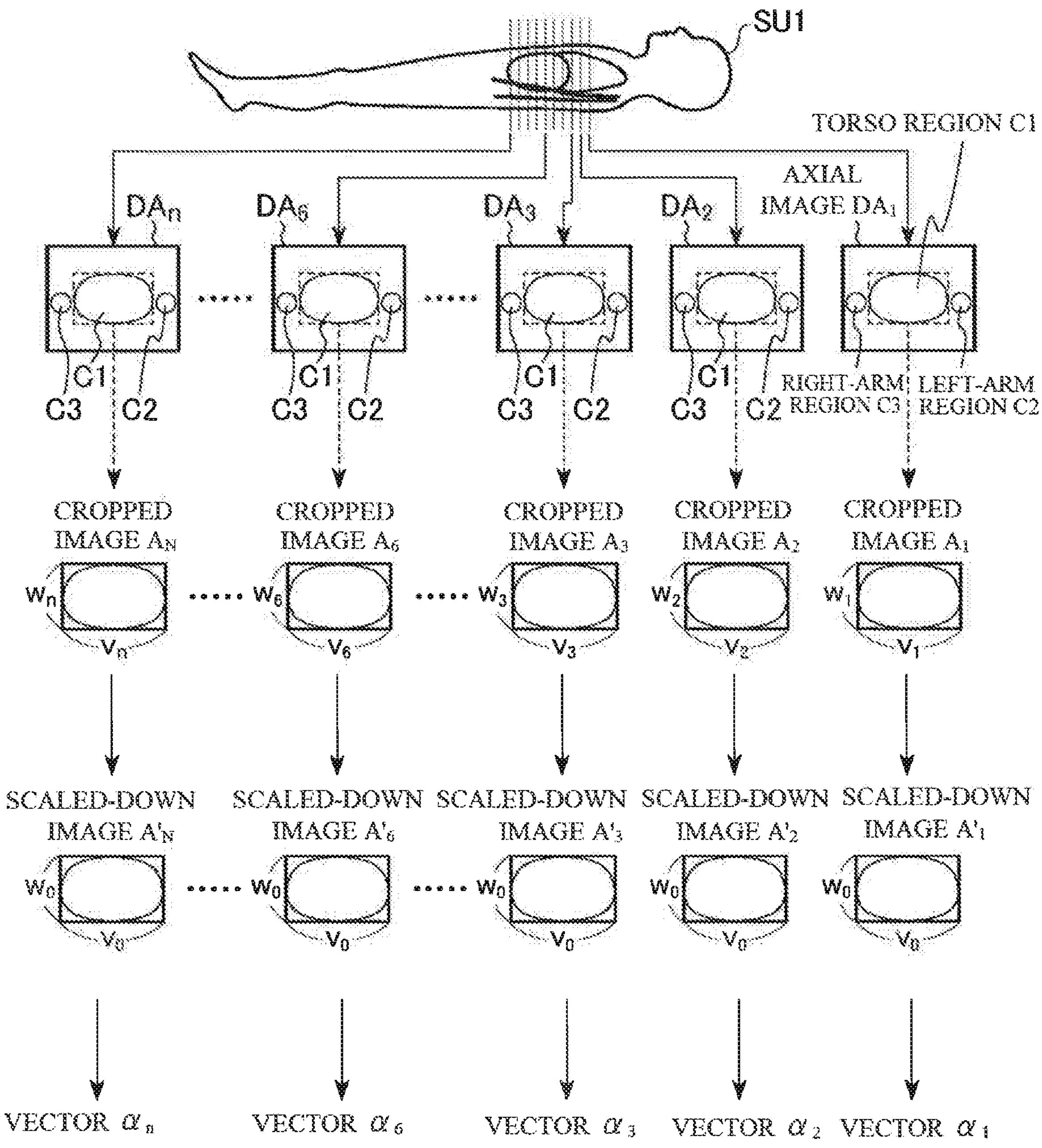

SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA6
DA3
DA2
C1
C2
C3
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
CROPPED IMAGE AN
CROPPED IMAGE A6
CROPPED IMAGE A3
CROPPED IMAGE A2
CROPPED IMAGE A1
Wn
W6
W3
W2
W1
Vn
V6
V3
V2
V1
SCALED-DOWN IMAGE A'N
SCALED-DOWN IMAGE A'6
SCALED-DOWN IMAGE A'3
SCALED-DOWN IMAGE A'2
SCALED-DOWN IMAGE A'1
W0
V0

FIG. 9



SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA6
DA3
DA2
C1
C3
C2
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
CROPPED IMAGE AN
CROPPED IMAGE A6
CROPPED IMAGE A3
CROPPED IMAGE A2
CROPPED IMAGE A1
Wn
W6
W3
W2
W1
Vn
V6
V3
V2
V1
SCALED-DOWN IMAGE A'N
SCALED-DOWN IMAGE A'6
SCALED-DOWN IMAGE A'3
SCALED-DOWN IMAGE A'2
SCALED-DOWN IMAGE A'1
W0
V0
VECTOR αn
VECTOR α6
VECTOR α3
VECTOR α2
VECTOR α1

FIG. 10

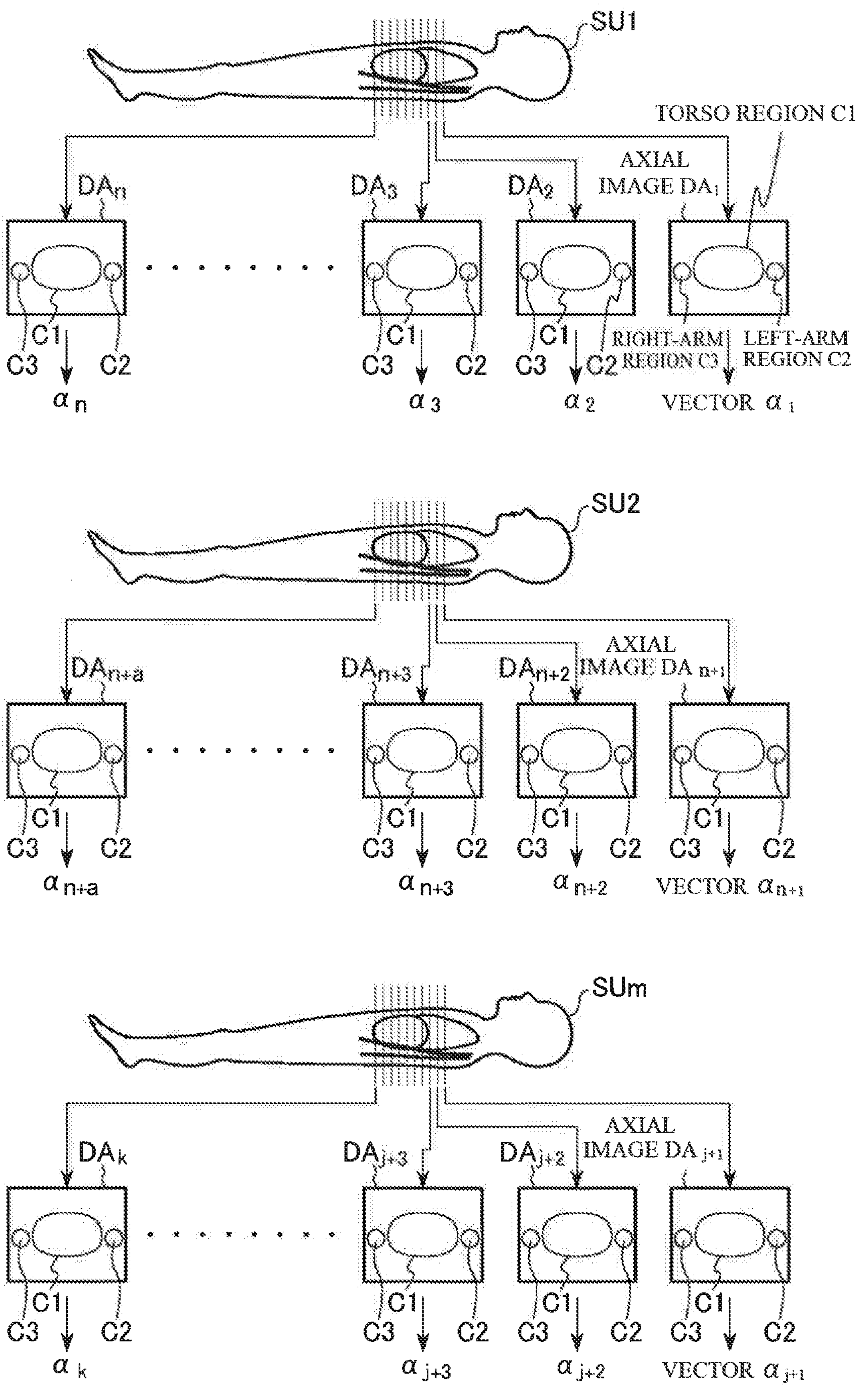

SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA3
DA2
C1
C3
C2
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
αn
α3
α2
VECTOR α1
SU2
AXIAL IMAGE DA n+1
DAn+a
DAn+3
DAn+2
αn+a
αn+3
αn+2
VECTOR αn+1
SUm
AXIAL IMAGE DA j+1
DAk
DAj+3
DAj+2
αk
αj+3
αj+2
VECTOR αj+1

FIG. 11

$$
MA = \begin{array}{cc}
 & \begin{array}{ccccc} \alpha_1 & \alpha_2 & \alpha_3 & \cdots & \alpha_k \end{array} \\
\begin{array}{c} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_k \end{array} &
\begin{pmatrix}
0 & d_{12} & d_{13} & \cdots & d_{1k} \\
d_{21} & 0 & d_{23} & \cdots & d_{2k} \\
d_{31} & d_{32} & 0 & \cdots & d_{3k} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
x_{k1} & x_{k2} & x_{k3} & \cdots & 0
\end{pmatrix}
\end{array}
$$

FIG. 12

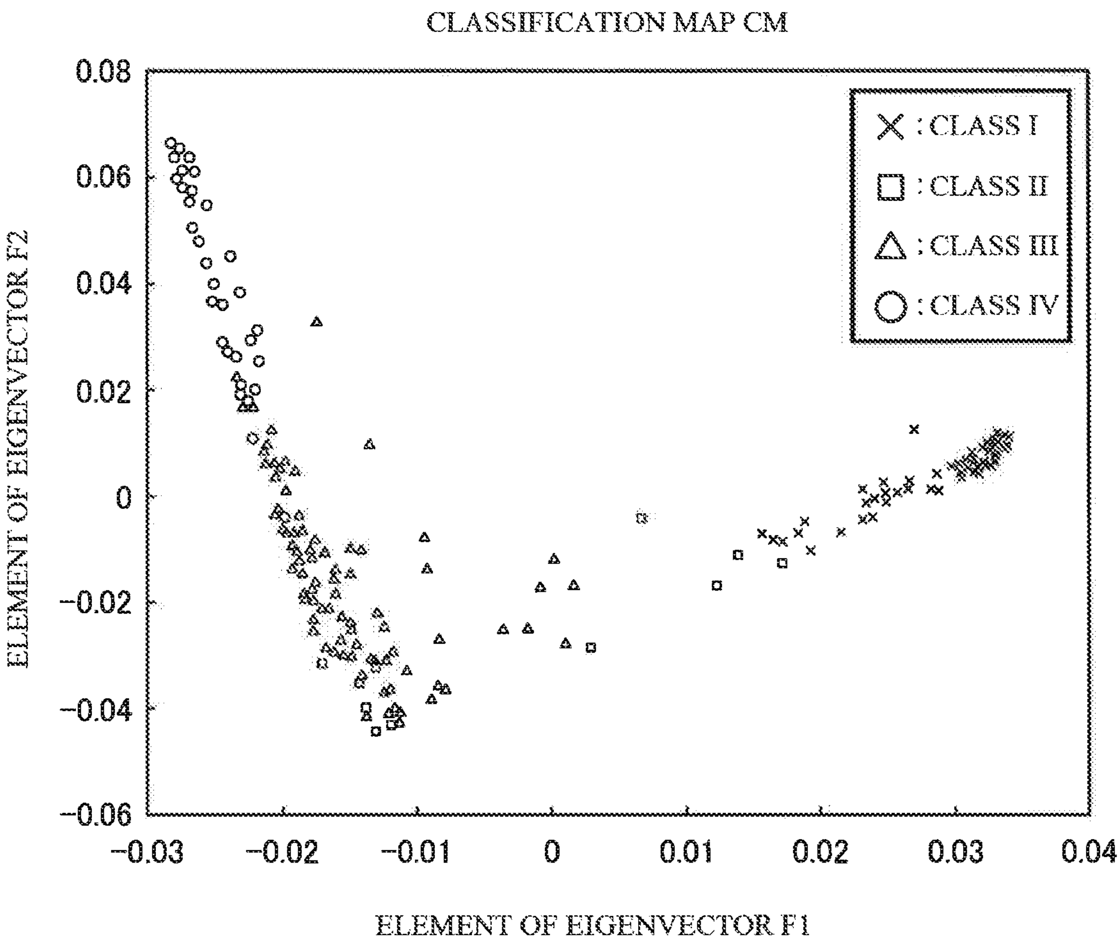

CLASSIFICATION MAP CM
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.03
−0.02
−0.01
0
0.01
0.02
0.03
0.04
ELEMENT OF EIGENVECTOR F2
ELEMENT OF EIGENVECTOR F1
: CLASS I
: CLASS II
: CLASS III
: CLASS IV

FIG. 13

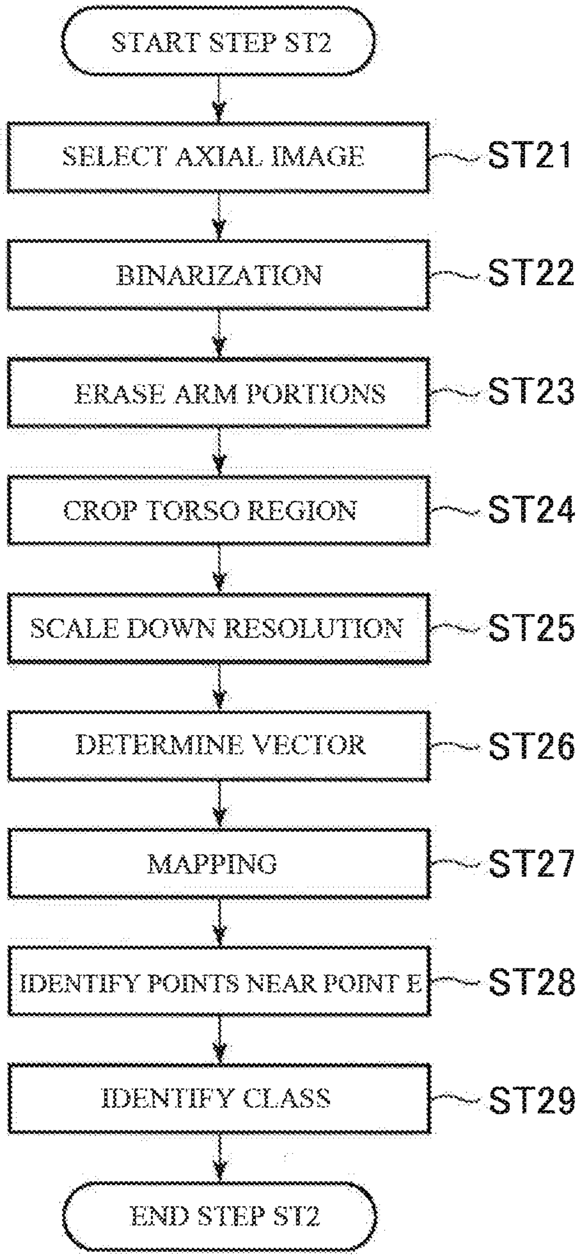

START STEP ST2
SELECT AXIAL IMAGE
ST21
BINARIZATION
ST22
ERASE ARM PORTIONS
ST23
CROP TORSO REGION
ST24
SCALE DOWN RESOLUTION
ST25
DETERMINE VECTOR
ST26
MAPPING
ST27
IDENTIFY POINTS NEAR POINT E
ST28
IDENTIFY CLASS
ST29
END STEP ST2

FIG. 14

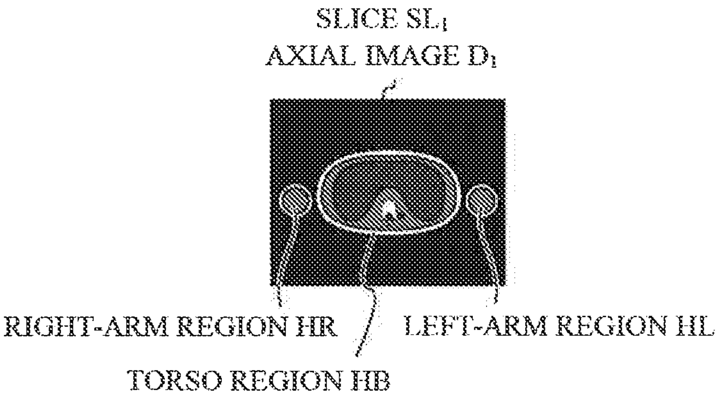

SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
LEFT-ARM REGION HL
TORSO REGION HB

FIG. 15

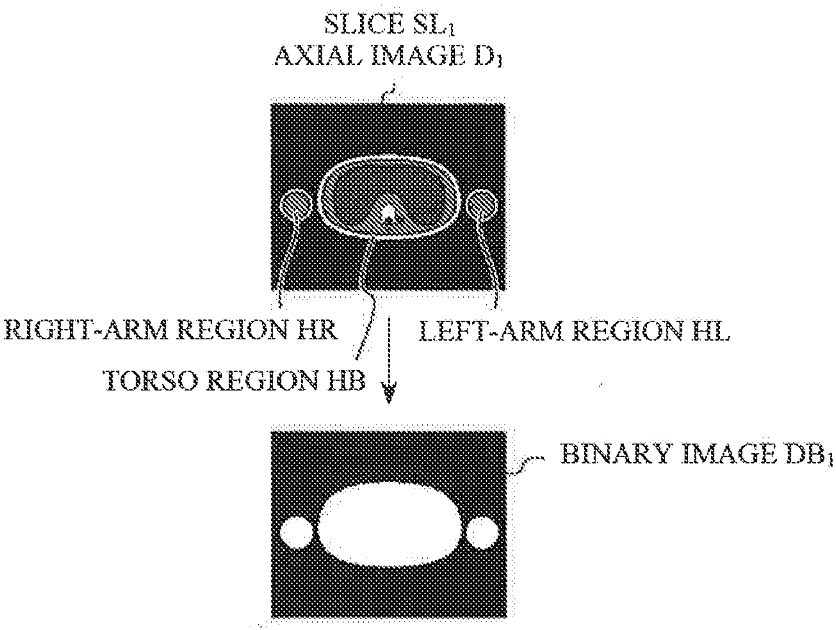
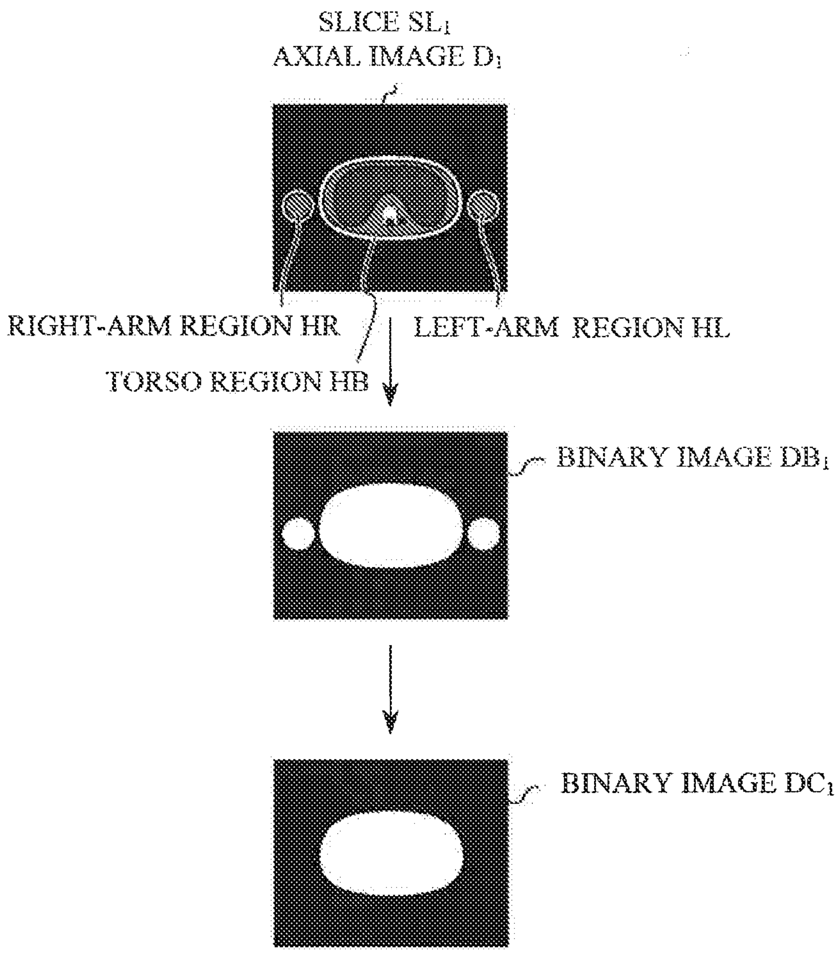

SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
LEFT-ARM REGION HL
TORSO REGION HB
BINARY IMAGE DB_1

FIG. 16



SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
LEFT-ARM REGION HL
TORSO REGION HB
BINARY IMAGE DB_1
BINARY IMAGE DC_1

FIG. 17

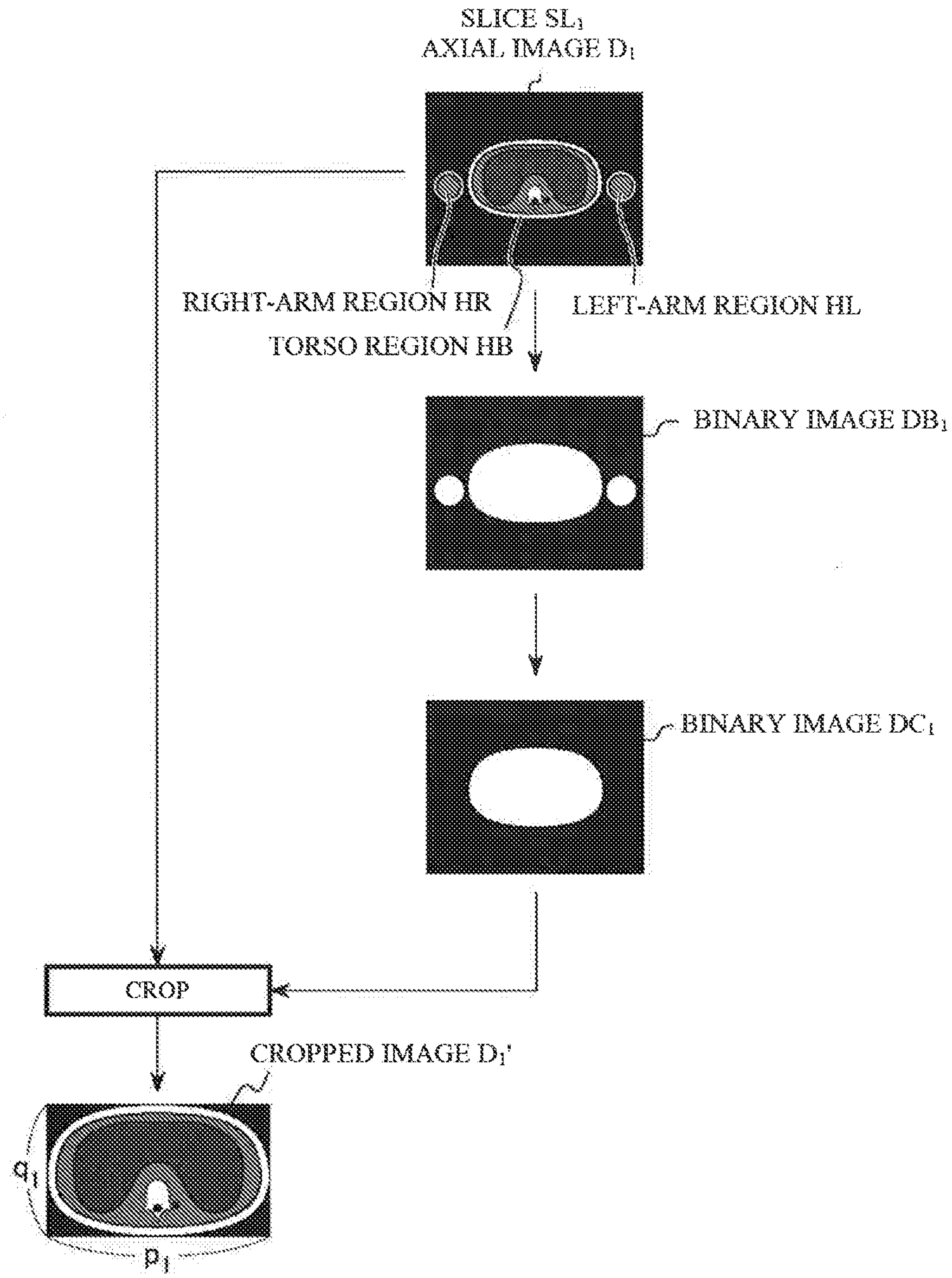
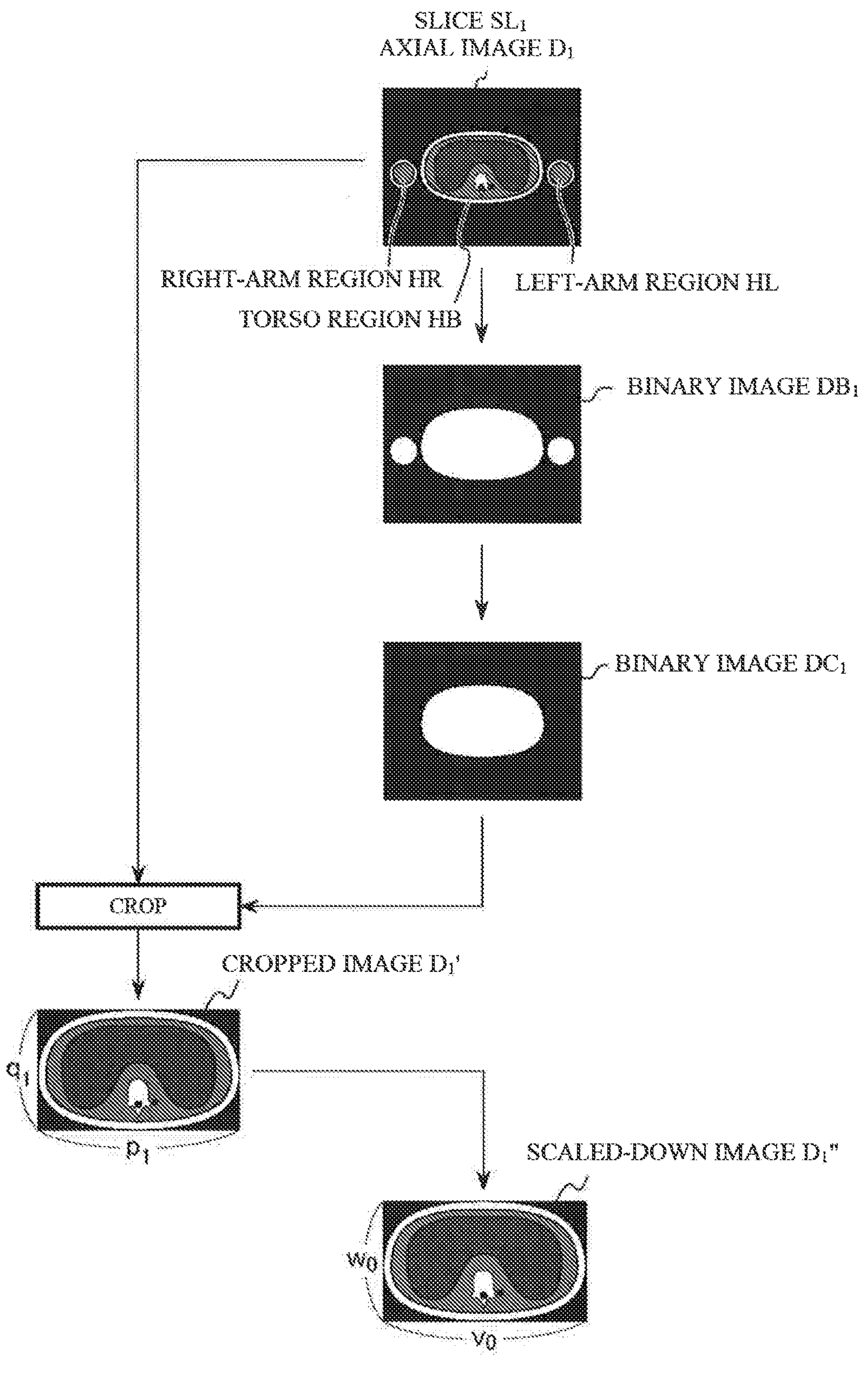

SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
TORSO REGION HB
LEFT-ARM REGION HL
BINARY IMAGE DB_1
BINARY IMAGE DC_1
CROP
CROPPED IMAGE D_1'
q_1
p_1

FIG. 18



SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
TORSO REGION HB
LEFT-ARM REGION HL
BINARY IMAGE DB_1
BINARY IMAGE DC_1
CROP
CROPPED IMAGE D_1'
q_1
p_1
SCALED-DOWN IMAGE D_1''
w_0
v_0

FIG. 19

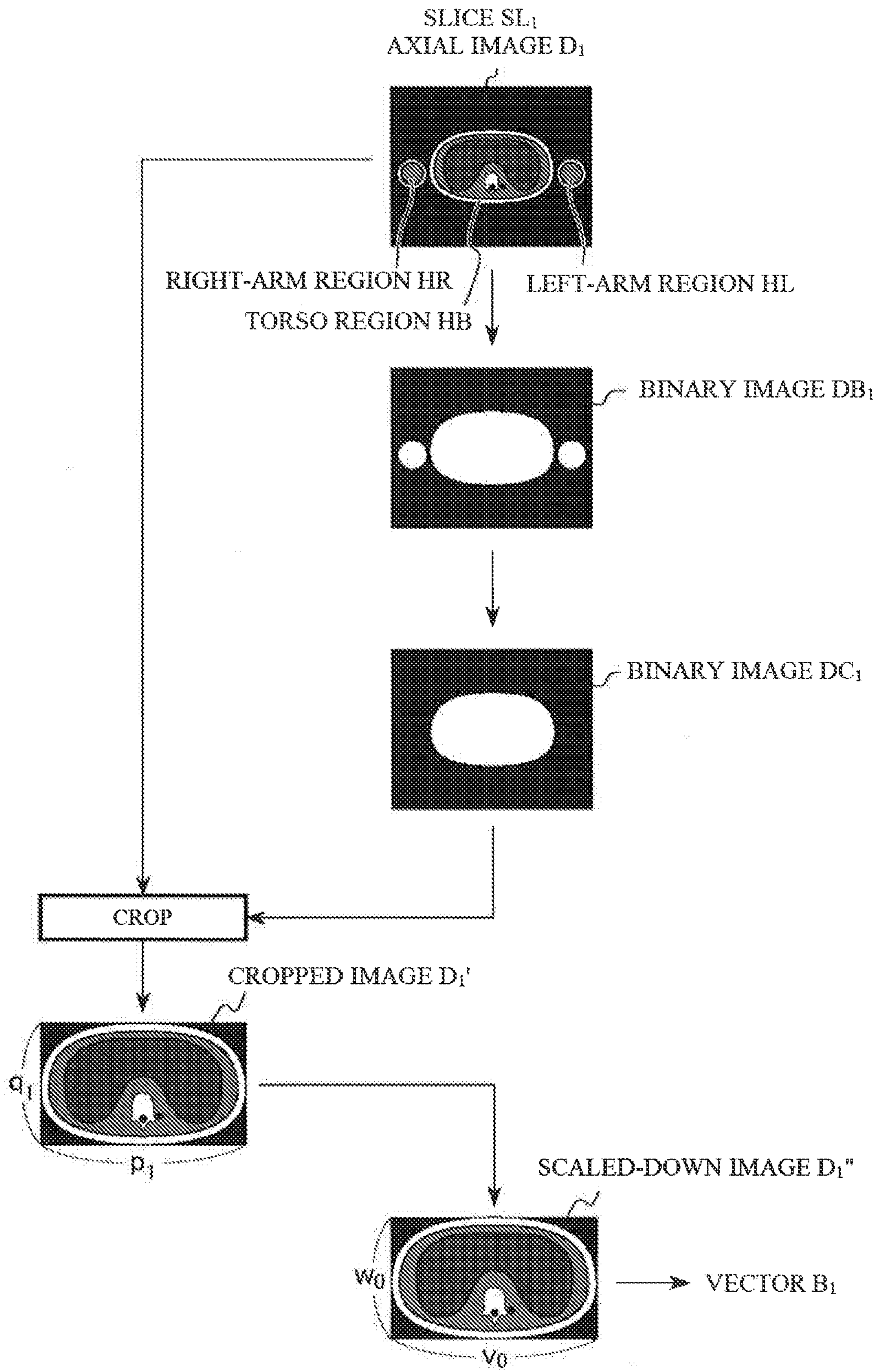

SLICE SL_1
AXIAL IMAGE D_1
RIGHT-ARM REGION HR
TORSO REGION HB
LEFT-ARM REGION HL
BINARY IMAGE DB_1
BINARY IMAGE DC_1
CROP
CROPPED IMAGE D_1'
q_1
p_1
SCALED-DOWN IMAGE D_1''
w_0
v_0
VECTOR B_1

FIG. 20

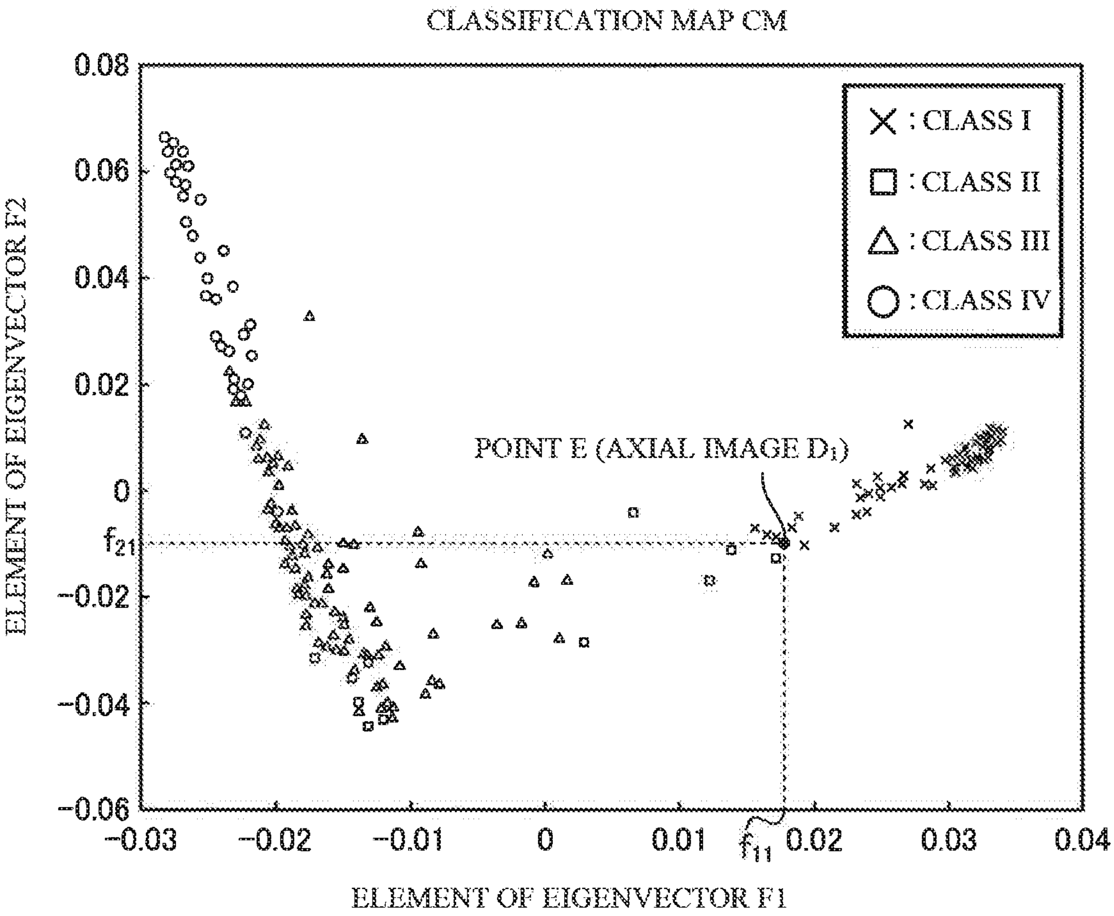

CLASSIFICATION MAP CM
0.08
0.06
0.04
0.02
0
f_{21}
−0.02
−0.04
−0.06
−0.03
−0.02
−0.01
0
0.01
f_{11}
0.02
0.03
0.04
ELEMENT OF EIGENVECTOR F2
ELEMENT OF EIGENVECTOR F1
: CLASS I
: CLASS II
: CLASS III
: CLASS IV
POINT E (AXIAL IMAGE D_1)

FIG. 21

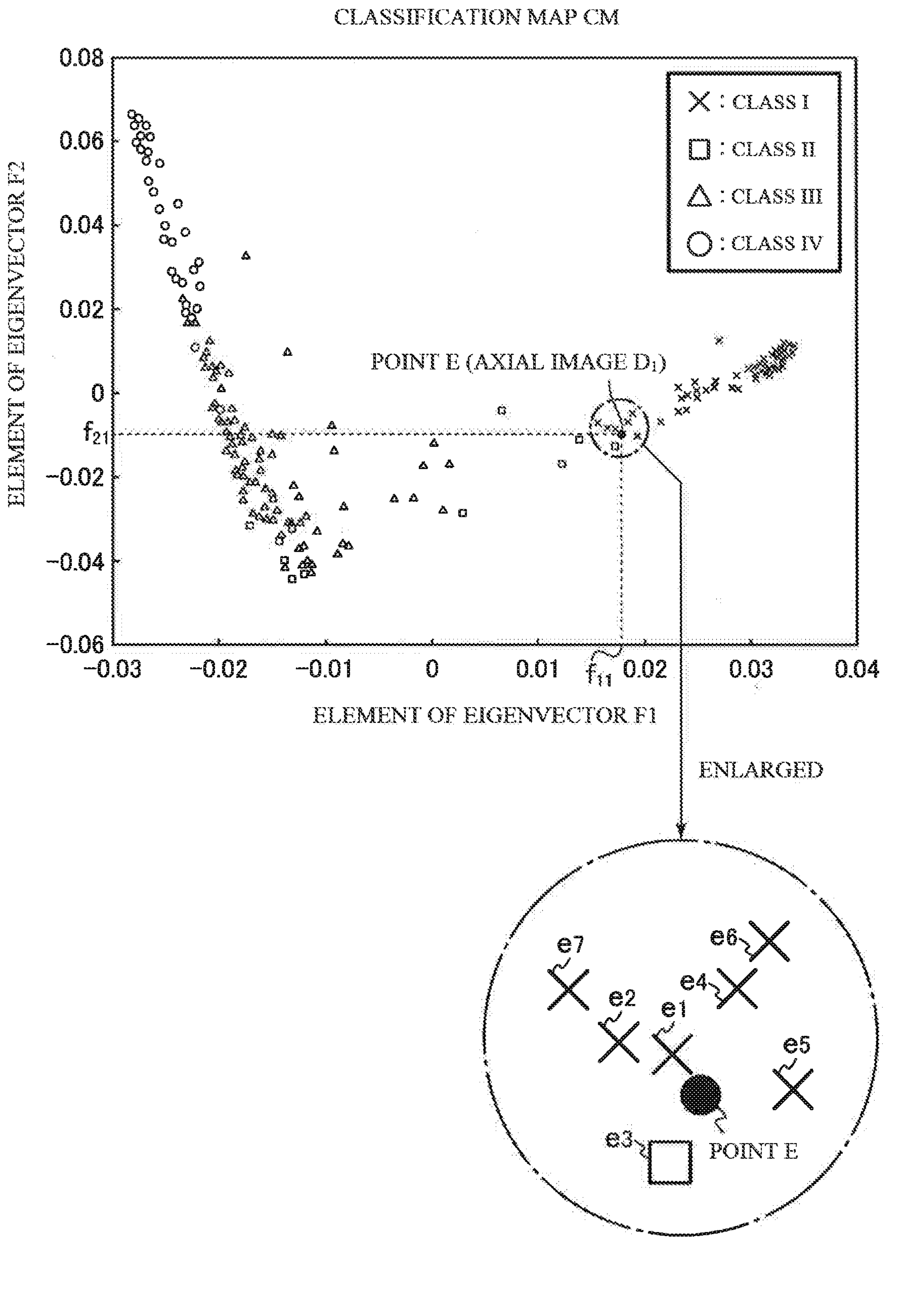

CLASSIFICATION MAP CM
0.08
0.06
0.04
0.02
0
f21
−0.02
−0.04
−0.06
−0.03
−0.02
−0.01
0
0.01
f11
0.02
0.03
0.04
ELEMENT OF EIGENVECTOR F2
ELEMENT OF EIGENVECTOR F1
: CLASS I
: CLASS II
: CLASS III
: CLASS IV
POINT E (AXIAL IMAGE D1)
ENLARGED
e7
e6
e4
e2
e1
e5
e3
POINT E

FIG. 22

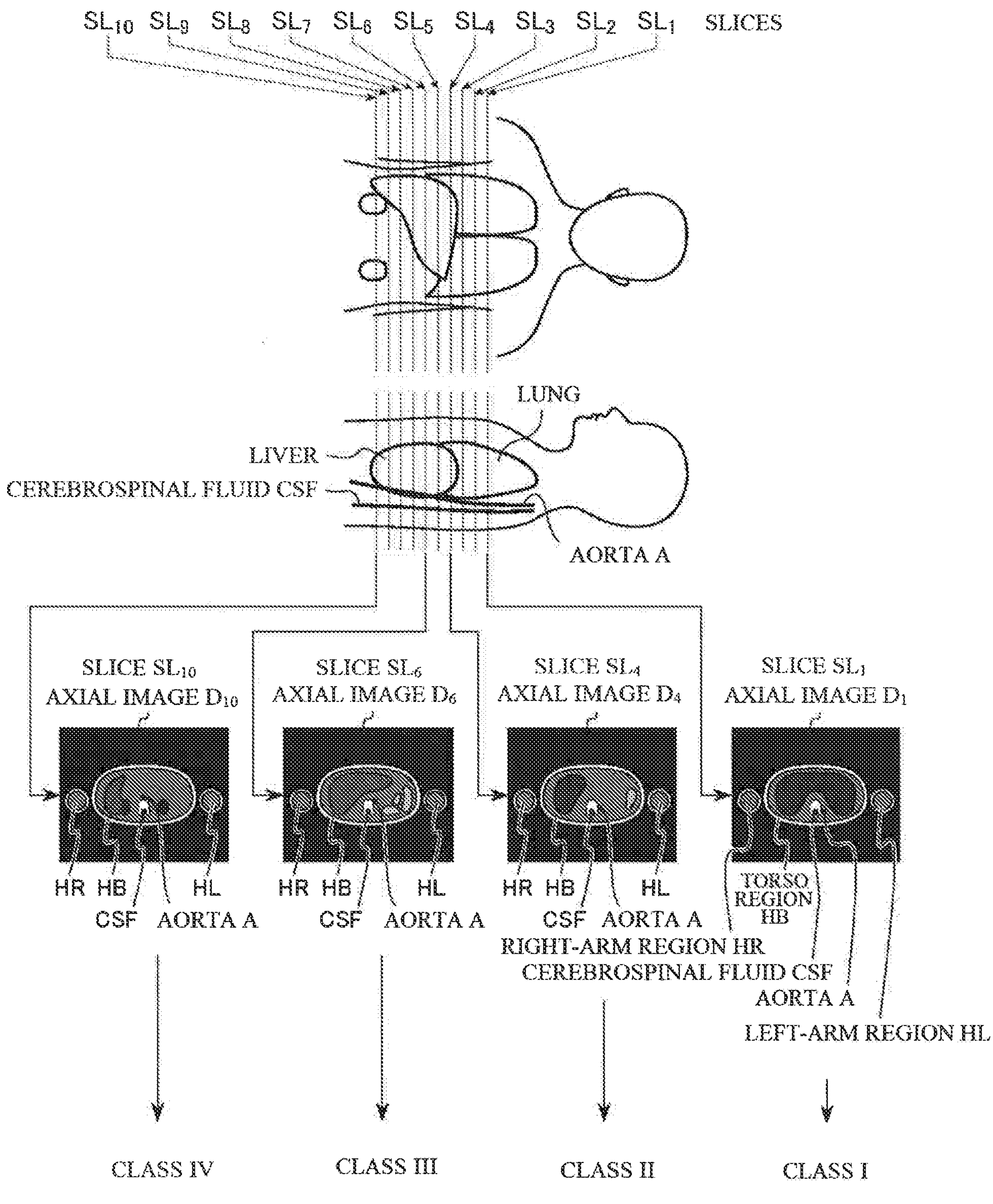

SL10 SL9 SL8 SL7 SL6 SL5 SL4 SL3 SL2 SL1 SLICES
LUNG
LIVER
CEREBROSPINAL FLUID CSF
AORTA A
SLICE SL10
AXIAL IMAGE D10
SLICE SL6
AXIAL IMAGE D6
SLICE SL4
AXIAL IMAGE D4
SLICE SL1
AXIAL IMAGE D1
HR HB HL
CSF AORTA A
HR HB HL
CSF AORTA A
HR HB HL
CSF AORTA A
TORSO REGION HB
RIGHT-ARM REGION HR
CEREBROSPINAL FLUID CSF
AORTA A
LEFT-ARM REGION HL
CLASS IV
CLASS III
CLASS II
CLASS I

FIG. 23

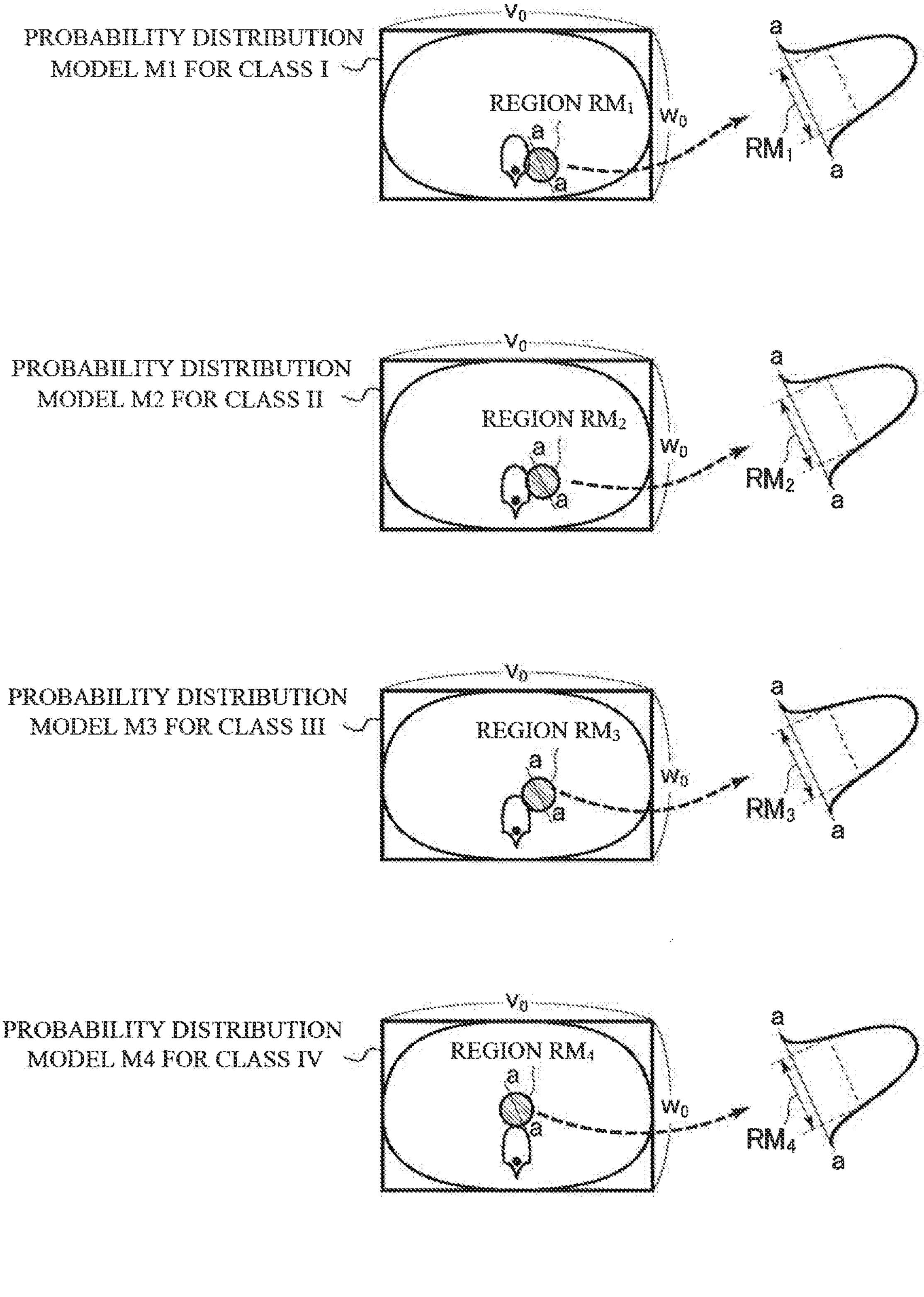
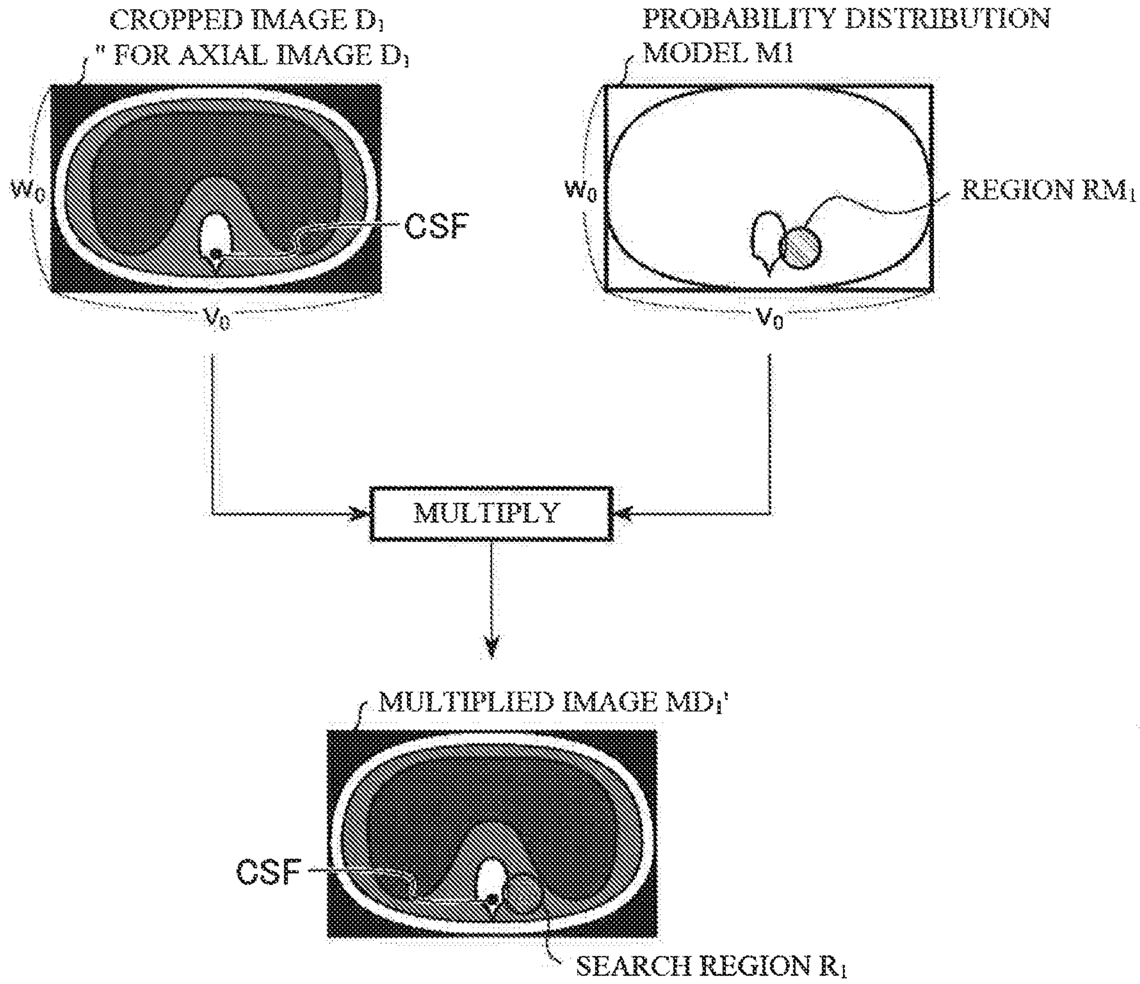
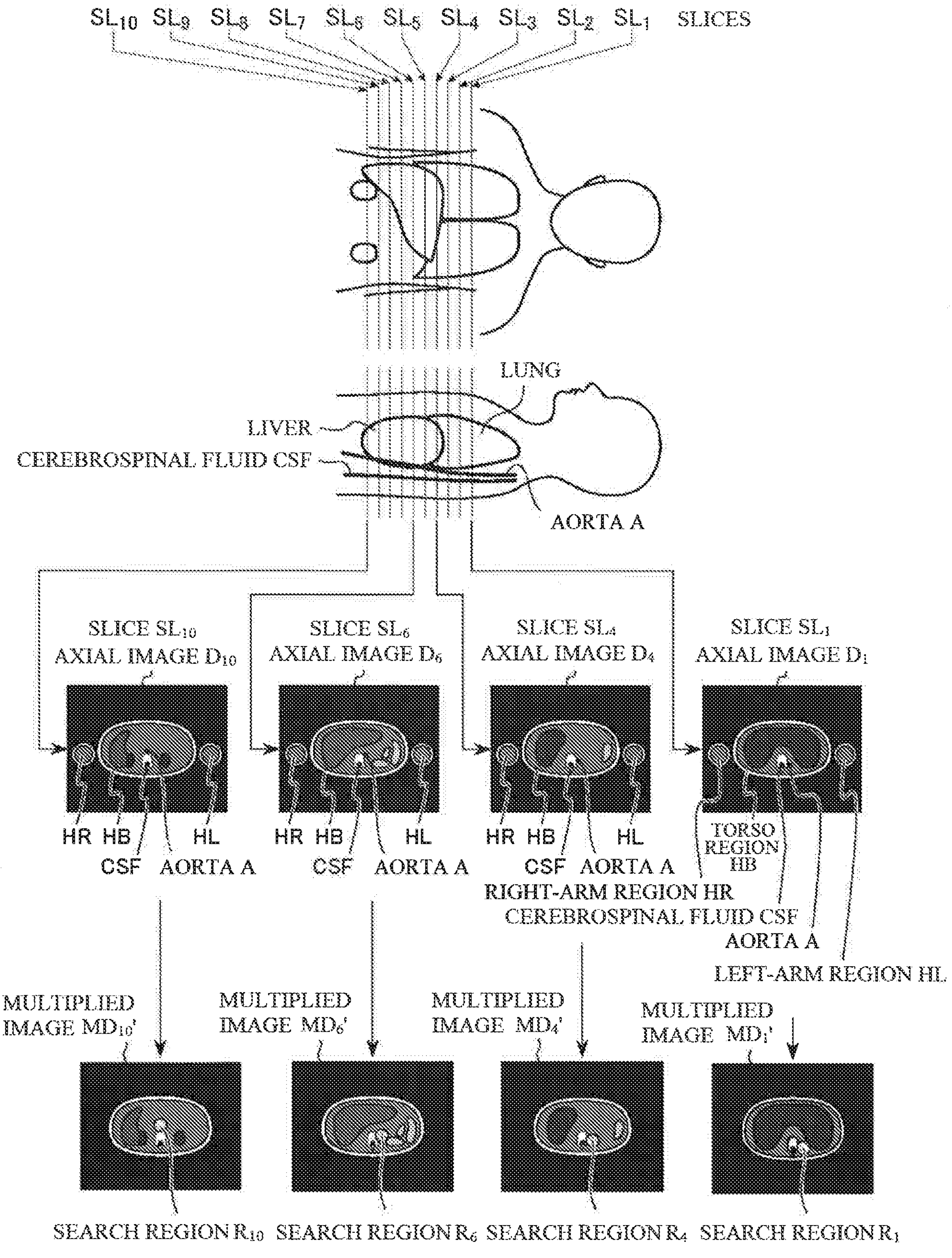

PROBABILITY DISTRIBUTION MODEL M1 FOR CLASS I
v_0
REGION RM_1
w_0
a
a
a
RM_1
a
PROBABILITY DISTRIBUTION MODEL M2 FOR CLASS II
v_0
REGION RM_2
w_0
a
a
a
RM_2
a
PROBABILITY DISTRIBUTION MODEL M3 FOR CLASS III
v_0
REGION RM_3
w_0
a
a
a
RM_3
a
PROBABILITY DISTRIBUTION MODEL M4 FOR CLASS IV
v_0
REGION RM_4
w_0
a
a
a
RM_4
a

FIG. 24



CROPPED IMAGE D1
" FOR AXIAL IMAGE D1
PROBABILITY DISTRIBUTION
MODEL M1
W0
CSF
REGION RM1
V0
MULTIPLY
MULTIPLIED IMAGE MD1'
CSF
SEARCH REGION R1

FIG. 25



SL10 SL9 SL8 SL7 SL6 SL5 SL4 SL3 SL2 SL1 SLICES
LUNG
LIVER
CEREBROSPINAL FLUID CSF
AORTA A
SLICE SL10
AXIAL IMAGE D10
SLICE SL6
AXIAL IMAGE D6
SLICE SL4
AXIAL IMAGE D4
SLICE SL1
AXIAL IMAGE D1
HR HB HL
CSF AORTA A
TORSO REGION HB
RIGHT-ARM REGION HR
CEREBROSPINAL FLUID CSF
AORTA A
LEFT-ARM REGION HL
MULTIPLIED IMAGE MD10'
MULTIPLIED IMAGE MD6'
MULTIPLIED IMAGE MD4'
MULTIPLIED IMAGE MD1'
SEARCH REGION R10
SEARCH REGION R6
SEARCH REGION R4
SEARCH REGION R1

FIG. 26

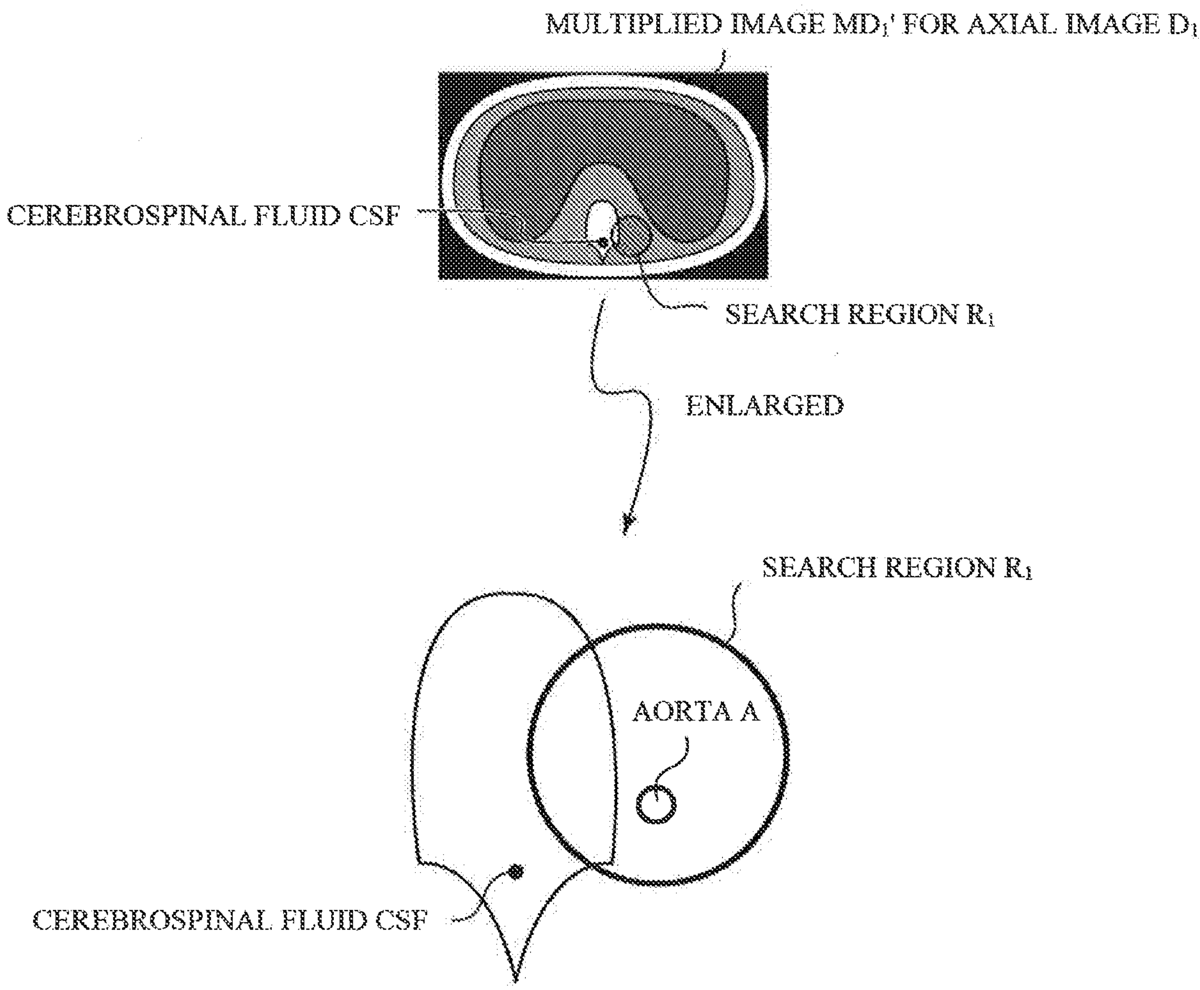

MULTIPLIED IMAGE MD1' FOR AXIAL IMAGE D1
CEREBROSPINAL FLUID CSF
SEARCH REGION R1
ENLARGED
SEARCH REGION R1
AORTA A
CEREBROSPINAL FLUID CSF

FIG. 27

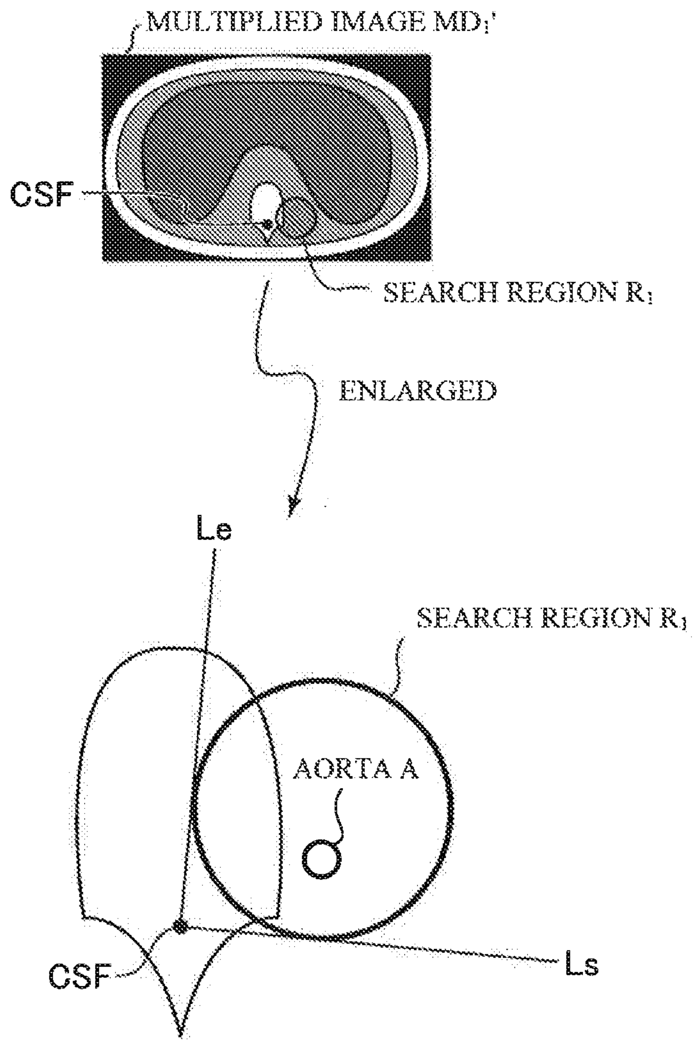

MULTIPLIED IMAGE MD_1'
CSF
SEARCH REGION R_1
ENLARGED
Le
SEARCH REGION R_1
AORTA A
CSF
Ls

FIG. 28

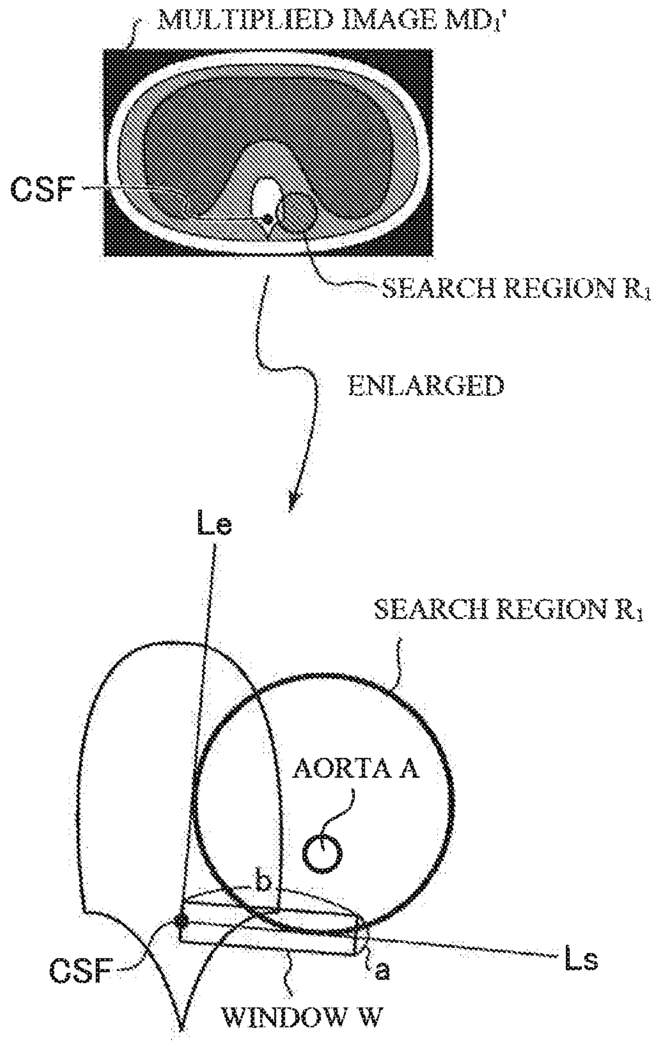

MULTIPLIED IMAGE MD1'
CSF
SEARCH REGION R1
ENLARGED
Le
SEARCH REGION R1
AORTA A
b
CSF
a
Ls
WINDOW W

FIG. 29

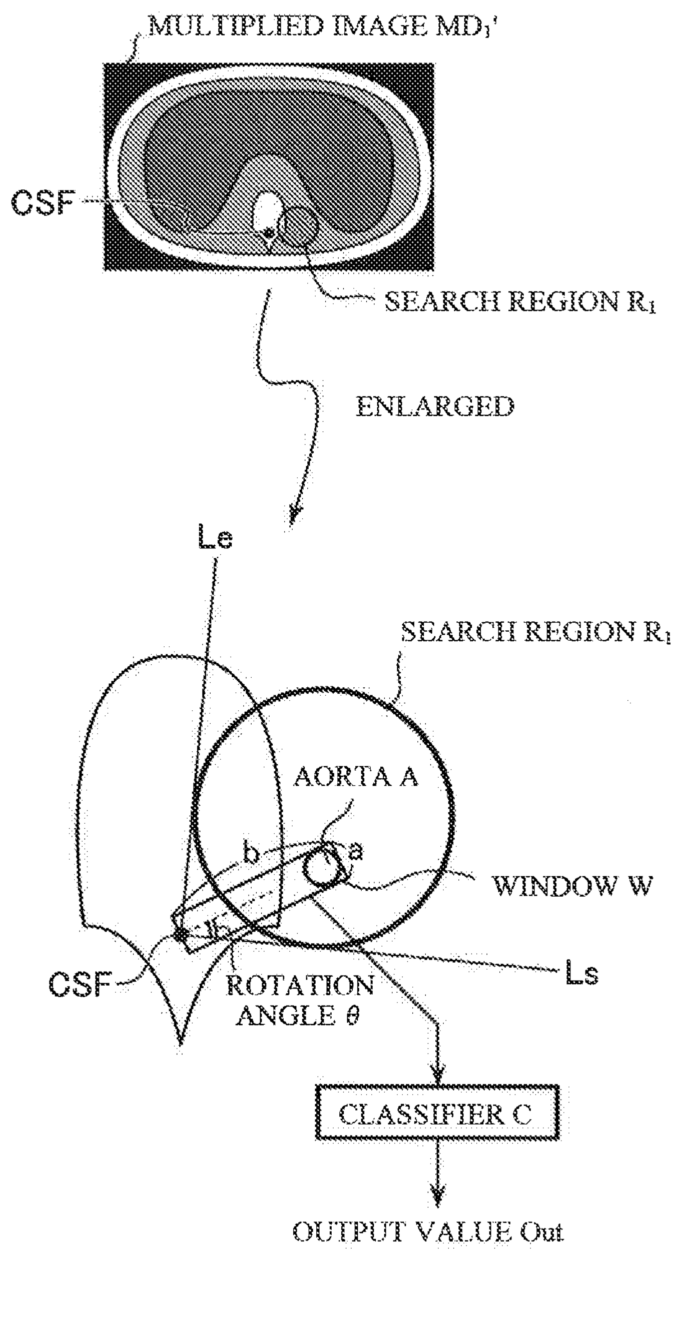
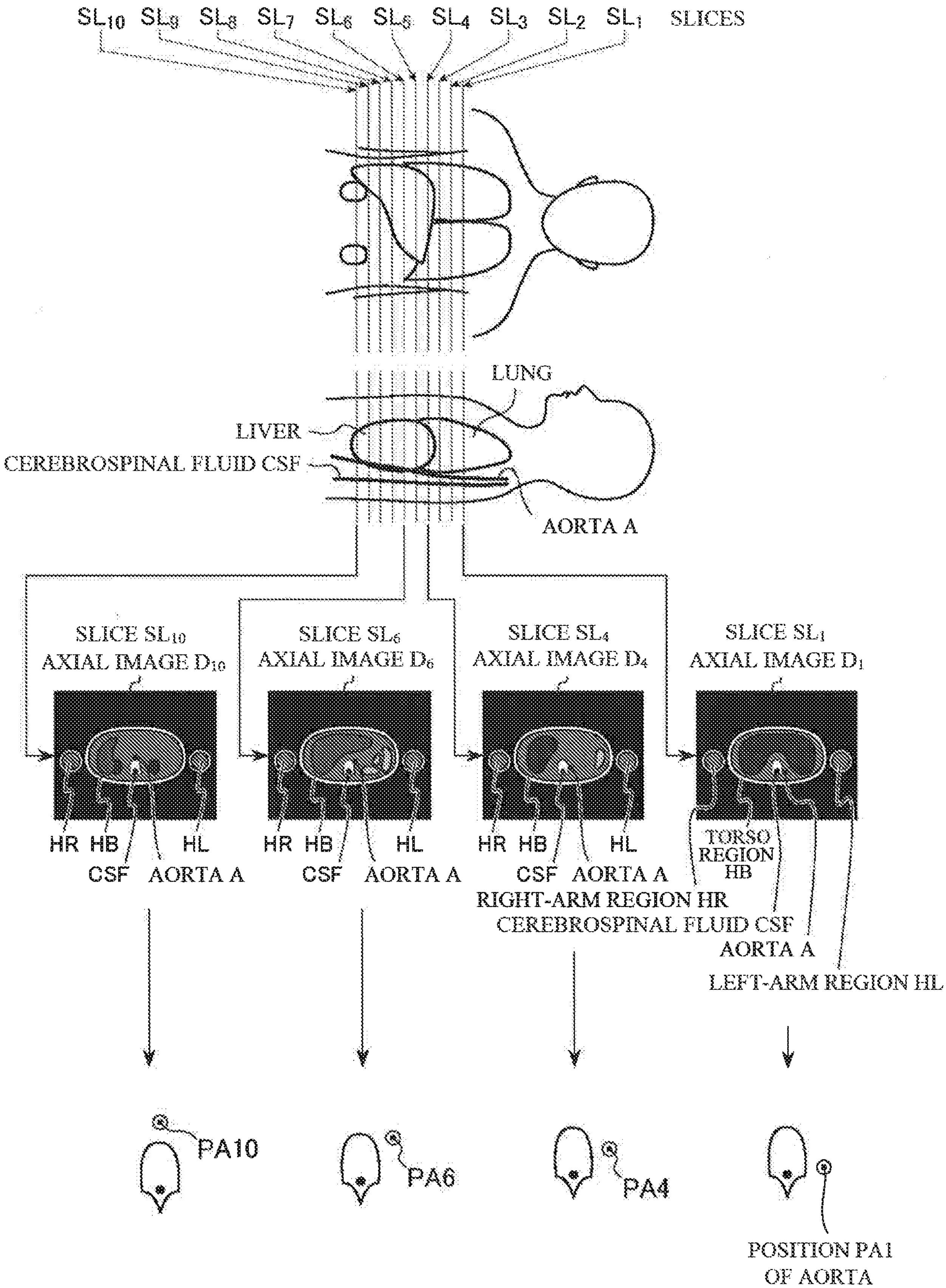

MULTIPLIED IMAGE MD1'
CSF
SEARCH REGION R1
ENLARGED
Le
SEARCH REGION R1
AORTA A
b
a
WINDOW W
h
CSF
ROTATION ANGLE θ
Ls
CLASSIFIER C
OUTPUT VALUE Out

FIG. 30



SL10 SL9 SL8 SL7 SL6 SL5 SL4 SL3 SL2 SL1 SLICES
LUNG
LIVER
CEREBROSPINAL FLUID CSF
AORTA A
SLICE SL10
AXIAL IMAGE D10
SLICE SL6
AXIAL IMAGE D6
SLICE SL4
AXIAL IMAGE D4
SLICE SL1
AXIAL IMAGE D1
HR HB HL
CSF AORTA A
TORSO REGION HB
RIGHT-ARM REGION HR
CEREBROSPINAL FLUID CSF
AORTA A
LEFT-ARM REGION HL
PA10
PA6
PA4
POSITION PA1 OF AORTA

FIG. 31

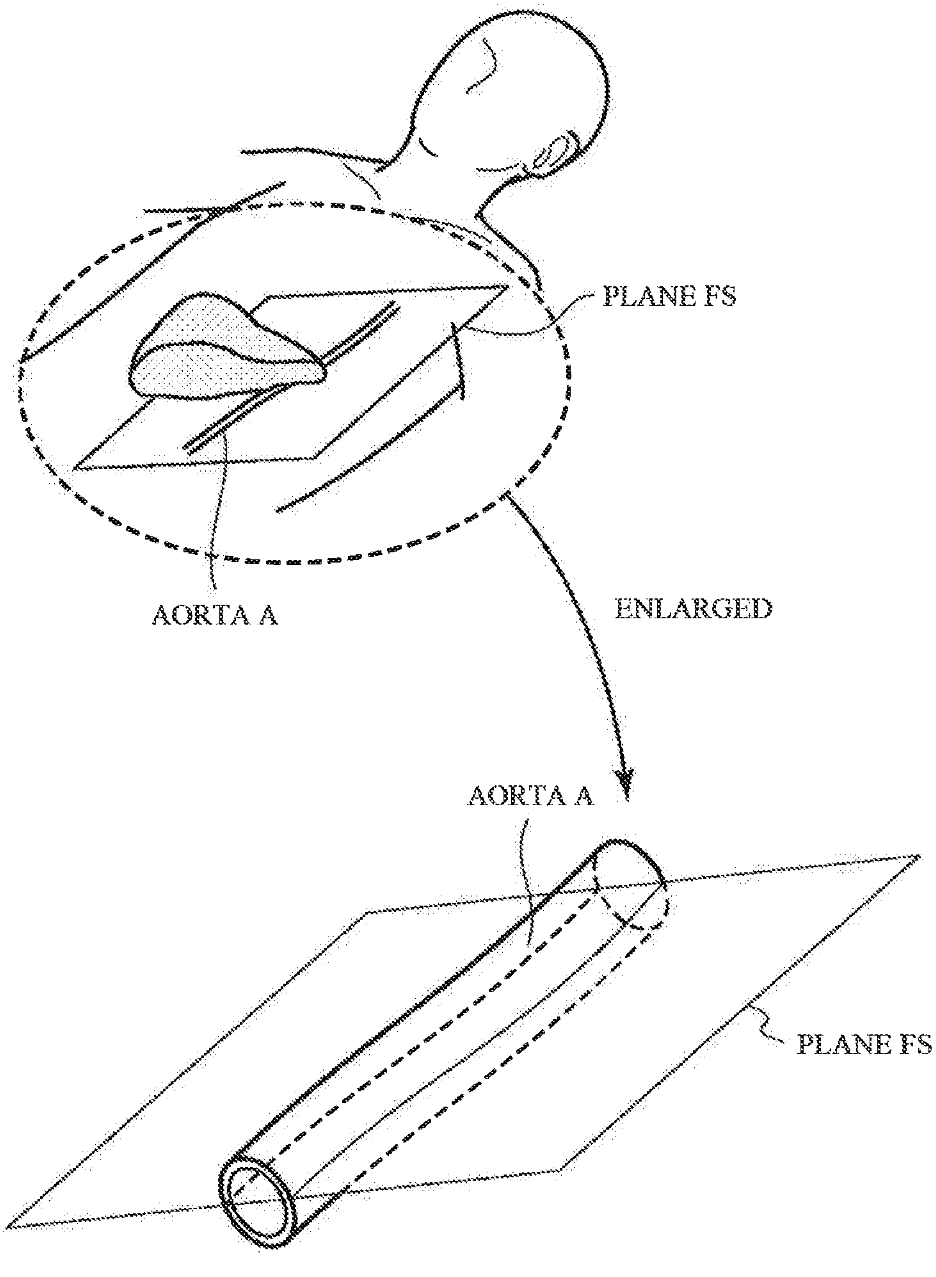


FIG. 32

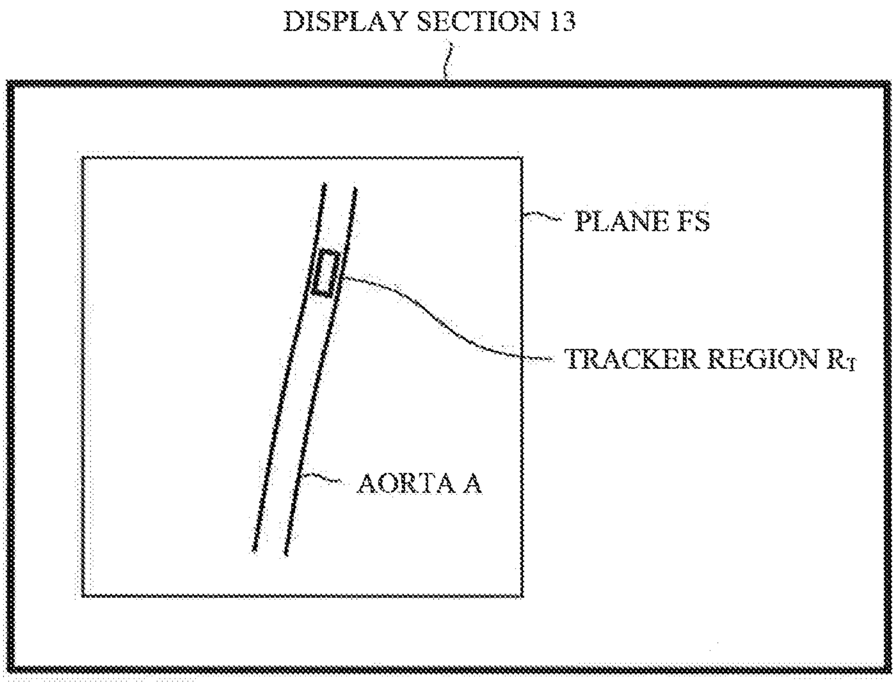


FIG. 33

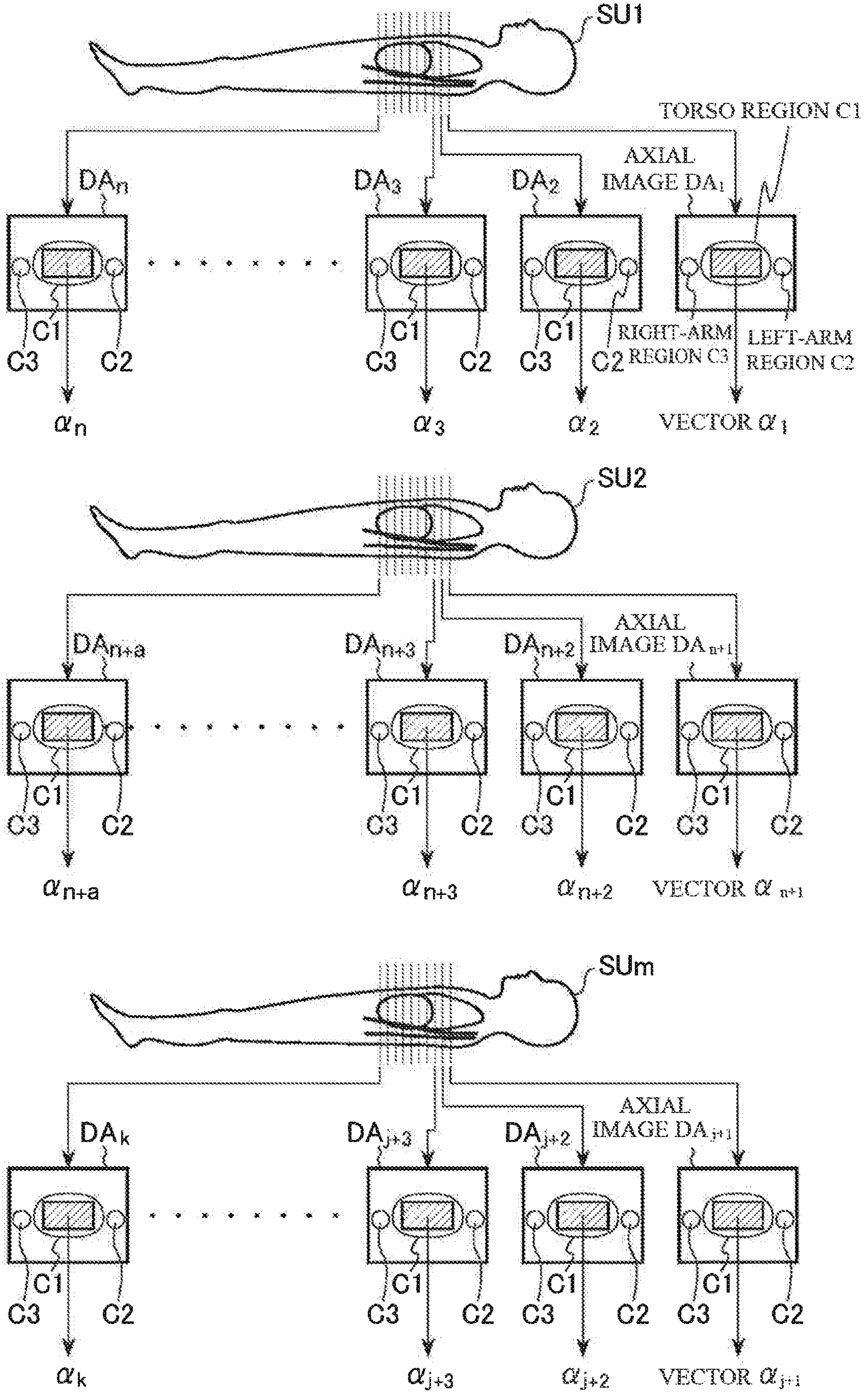

SU1
TORSO REGION C1
AXIAL IMAGE DA1
DAn
DA3
DA2
C1
C2
C3
RIGHT-ARM REGION C3
LEFT-ARM REGION C2
αn
α3
α2
VECTOR α1
SU2
AXIAL IMAGE DA n+1
DAn+a
DAn+3
DAn+2
αn+a
αn+3
αn+2
VECTOR α n+1
SUm
AXIAL IMAGE DA j+1
DAk
DAj+3
DAj+2
αk
αj+3
αj+2
VECTOR αj+1

FIG. 34

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/028105

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/055(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B 5/055; G06K 9/00; G06K 9/62; G06T 7/00

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: MRI, image, slice, image, classify, vessel, detect

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012-0271156 A1 (BI et al.) 25 October 2012 See paragraphs [16]-[20], claim 1 and figures 1-4.	1-8,10
A	US 2013-0202173 A1 (VASCUVIS INC. et al.) 08 August 2013 See claim 1 and figures 1-4.	1-8,10
A	US 2011-0026798 A1 (MADABHUSHI et al.) 03 February 2011 See paragraphs [15]-[20] and figures 1,2.	1-8,10
A	US 2010-0119136 A1 (ITAGAKI et al.) 13 May 2010 See claims 1,2 and figures 1-5.	1-8,10
A	US 2006-0110018 A1 (CHEN et al.) 25 May 2006 See claims 1-5 and figures 1-3. (note: claim 9 is found missing.)	1-8,10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 June 2017 (21.06.2017)	**21 June 2017 (21.06.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
KIM, Yeon Kyung
Telephone No. +82-42-481-3325

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/028105

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012-0271156 A1	25/10/2012	CN 102743171 A	24/10/2012
		CN 102743171 B	24/08/2016
		US 8600476 B2	03/12/2013
US 2013-0202173 A1	08/08/2013	US 2011-0026798 A1	03/02/2011
		US 8774479 B2	08/07/2014
		US 9235887 B2	12/01/2016
		WO 2009-105530 A2	27/08/2009
		WO 2009-105530 A3	07/01/2010
		WO 2014-107402 A1	10/07/2014
US 2011-0026798 A1	03/02/2011	US 2013-0202173 A1	08/08/2013
		US 8774479 B2	08/07/2014
		US 9235887 B2	12/01/2016
		WO 2009-105530 A2	27/08/2009
		WO 2009-105530 A3	07/01/2010
		WO 2014-107402 A1	10/07/2014
US 2010-0119136 A1	13/05/2010	CN 101677782 A	24/03/2010
		CN 101677782 B	15/05/2013
		JP 2014-012206 A	23/01/2014
		JP 5426370 B2	26/02/2014
		JP 5777678 B2	09/09/2015
		WO 2008-146551 A1	04/12/2008
US 2006-0110018 A1	25/05/2006	US 7317821 B2	08/01/2008