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Kato

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(54) **ULTRASOUND DIAGNOSTIC APPARATUS AND CONTROL METHOD OF ULTRASOUND DIAGNOSTIC APPARATUS**

(71) Applicant: **FUJIFILM Corporation**, Tokyo (JP)

(72) Inventor: **Noriji Kato**, Tokyo (JP)

(73) Assignee: **FUJIFILM Corporation**, Tokyo (JP)

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A61B 8/08 (2006.01)

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CPC ***A61B 8/523*** (2013.01); ***A61B 8/085*** (2013.01); ***A61B 8/4254*** (2013.01); ***A61B 8/5223*** (2013.01)

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See application file for complete search history.

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Primary Examiner — Carolyn A Pehlke
(74) *Attorney, Agent, or Firm* — Studebaker Brackett PLLC

(57) **ABSTRACT**

There are provided an ultrasound diagnostic apparatus and a control method of the ultrasound diagnostic apparatus which can obtain a cross-sectional image in which a structure of a lesion part is accurately reproduced. An ultrasound diagnostic apparatus generates a cross-sectional image orthogonal to an observation plane on the basis of a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, and includes a pseudo orthogonal cross section generation unit that sets a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video, and generates a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images; and a pseudo orthogonal cross section deformation unit that non-rigidly deforms the pseudo orthogonal cross-sectional image in a horizontal direction to generate a normalized pseudo orthogonal cross-sectional image.

15 Claims, 11 Drawing Sheets

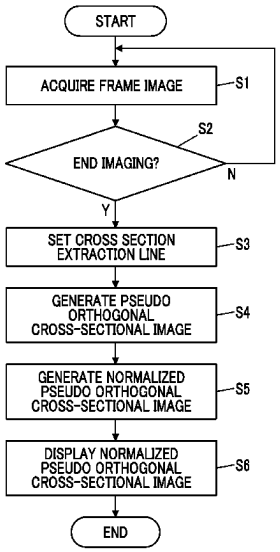

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FIG. 1

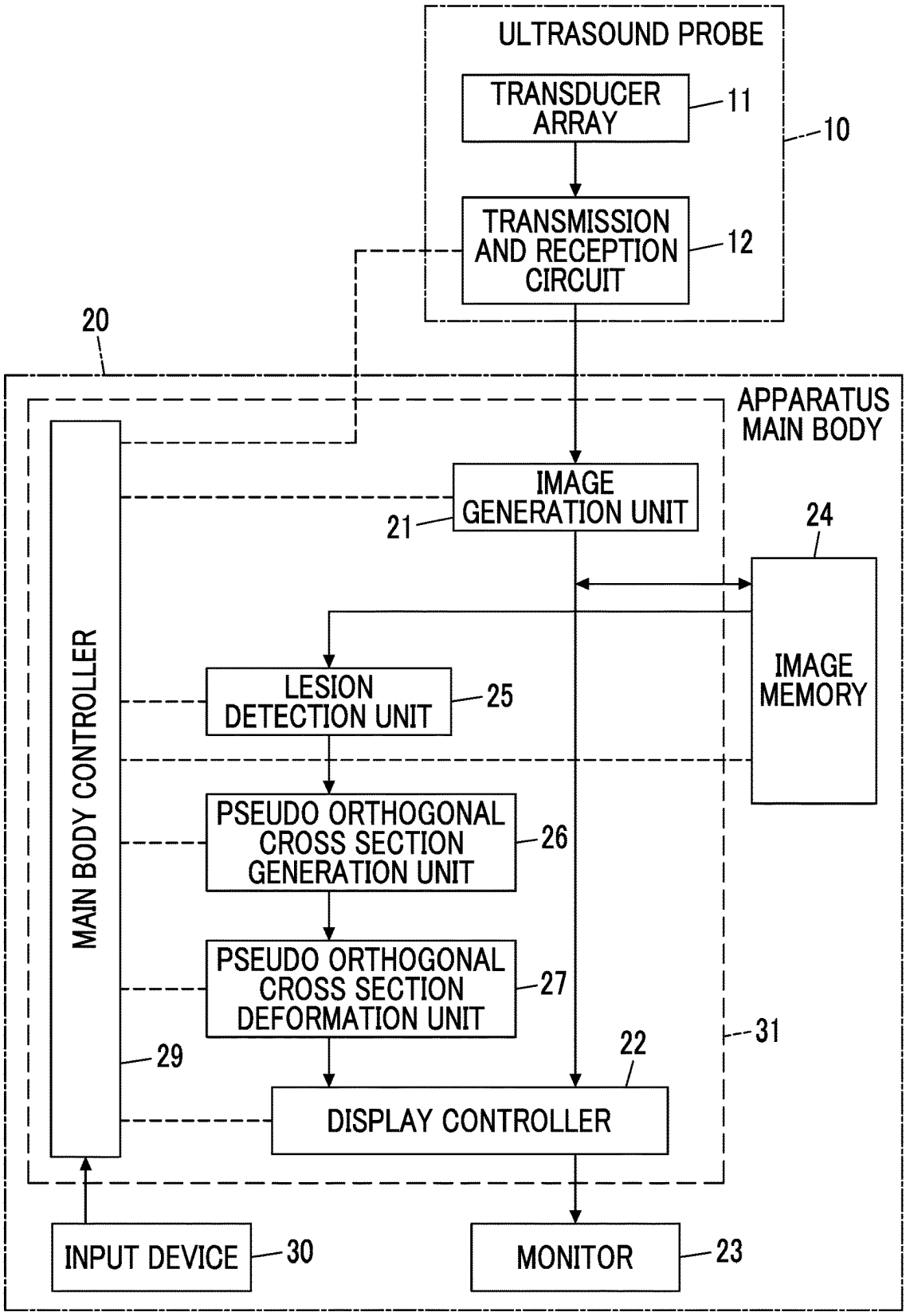

ULTRASOUND PROBE
TRANSDUCER ARRAY
11
10
TRANSMISSION AND RECEPTION CIRCUIT
12
20
APPARATUS MAIN BODY
IMAGE GENERATION UNIT
21
24
IMAGE MEMORY
MAIN BODY CONTROLLER
LESION DETECTION UNIT
25
PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27
31
29
22
DISPLAY CONTROLLER
INPUT DEVICE
30
MONITOR
23

FIG. 2

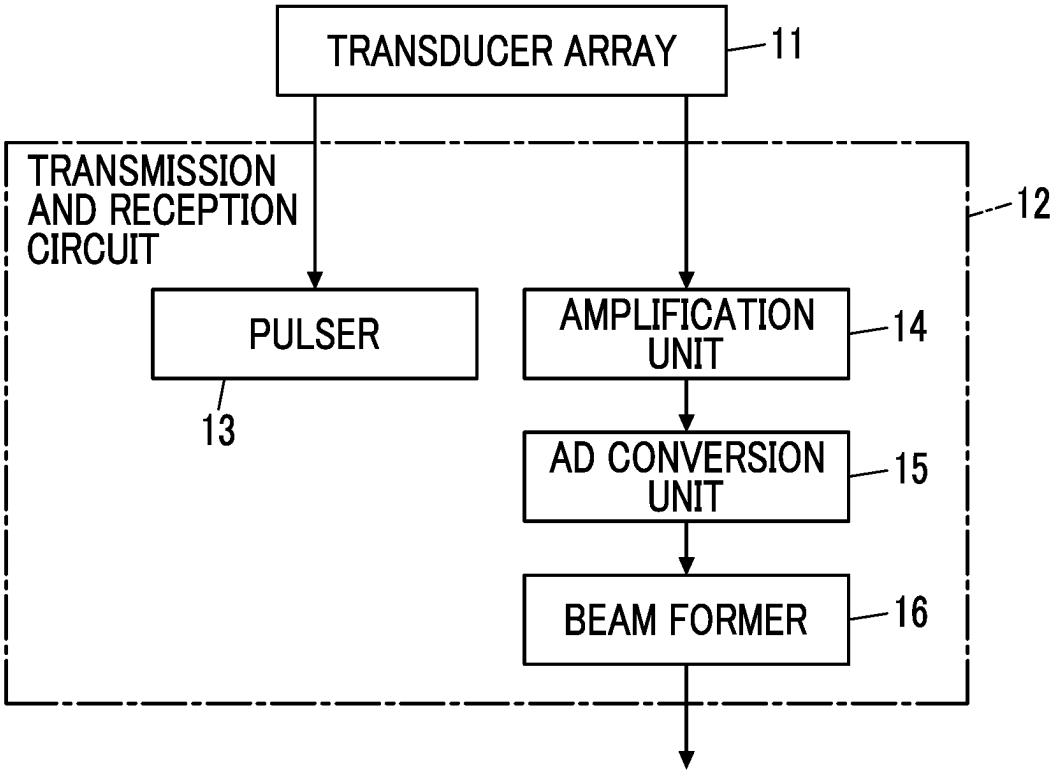

TRANSDUCER ARRAY
11
TRANSMISSION AND RECEPTION CIRCUIT
12
PULSER
13
AMPLIFICATION UNIT
14
AD CONVERSION UNIT
15
BEAM FORMER
16

FIG. 3

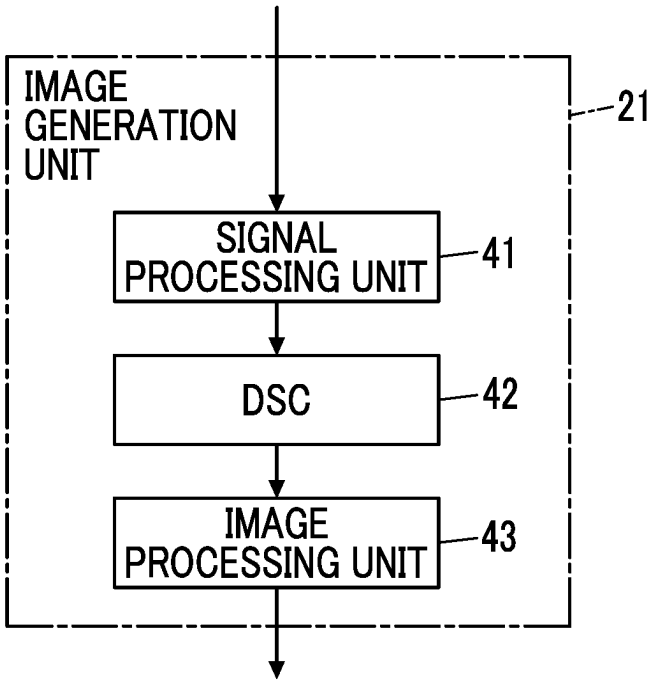


IMAGE GENERATION UNIT
21
SIGNAL PROCESSING UNIT
41
DSC
42
IMAGE PROCESSING UNIT
43

FIG. 4

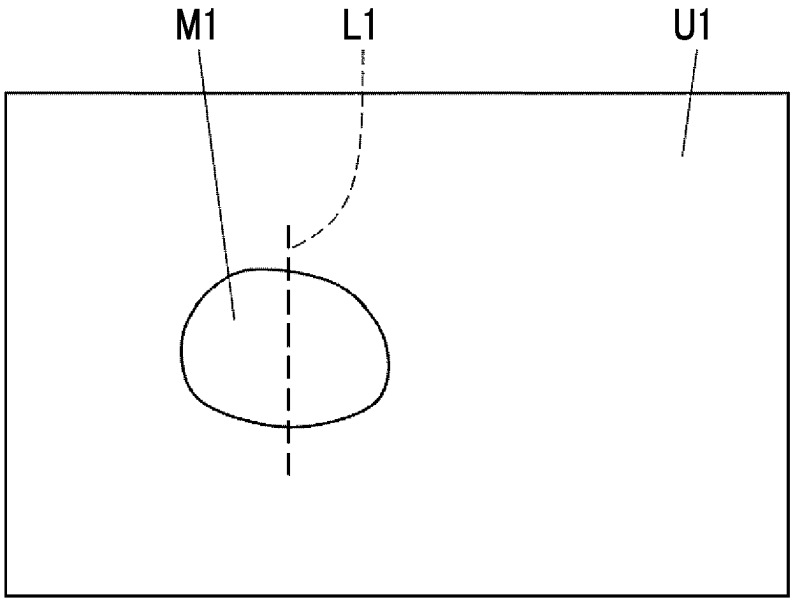


FIG. 5

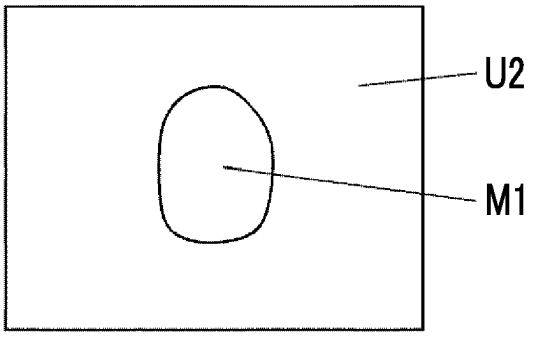


FIG. 6

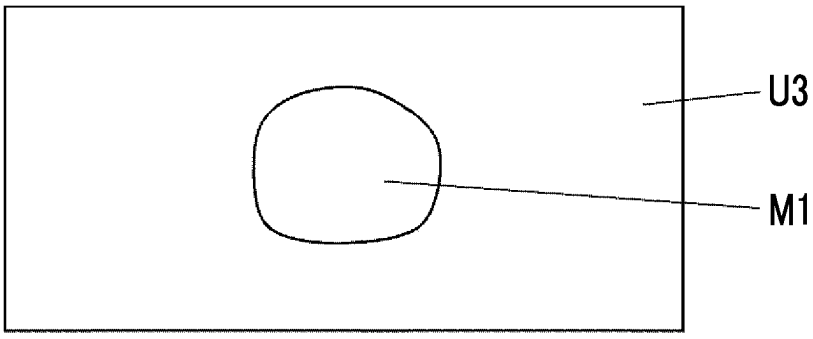


FIG. 7

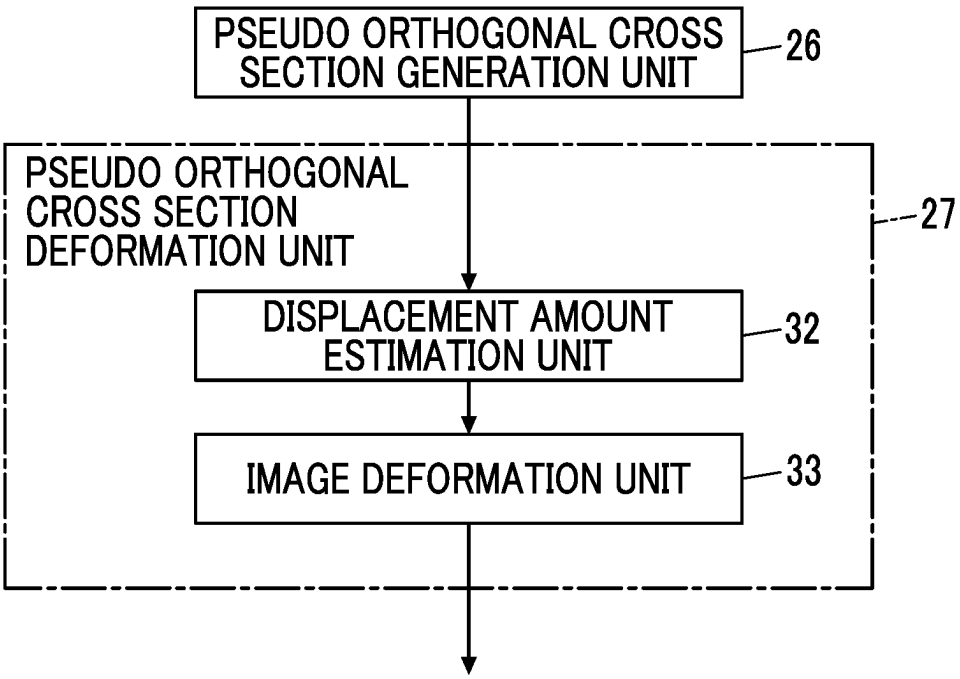

PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27
DISPLACEMENT AMOUNT ESTIMATION UNIT
32
IMAGE DEFORMATION UNIT
33

FIG. 8

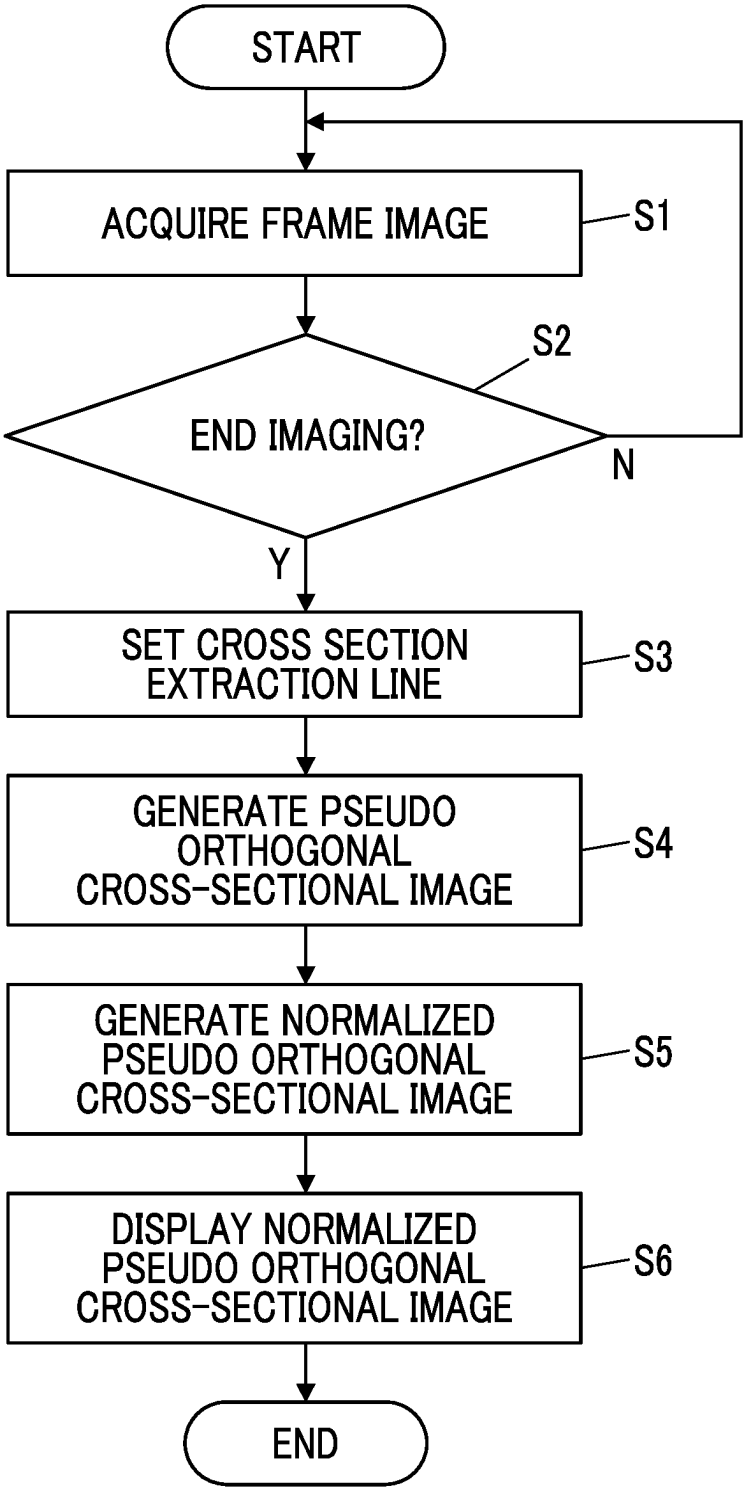

START
ACQUIRE FRAME IMAGE
S1
S2
END IMAGING?
N
Y
SET CROSS SECTION EXTRACTION LINE
S3
GENERATE PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE
S4
GENERATE NORMALIZED PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE
S5
DISPLAY NORMALIZED PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE
S6
END

FIG. 9

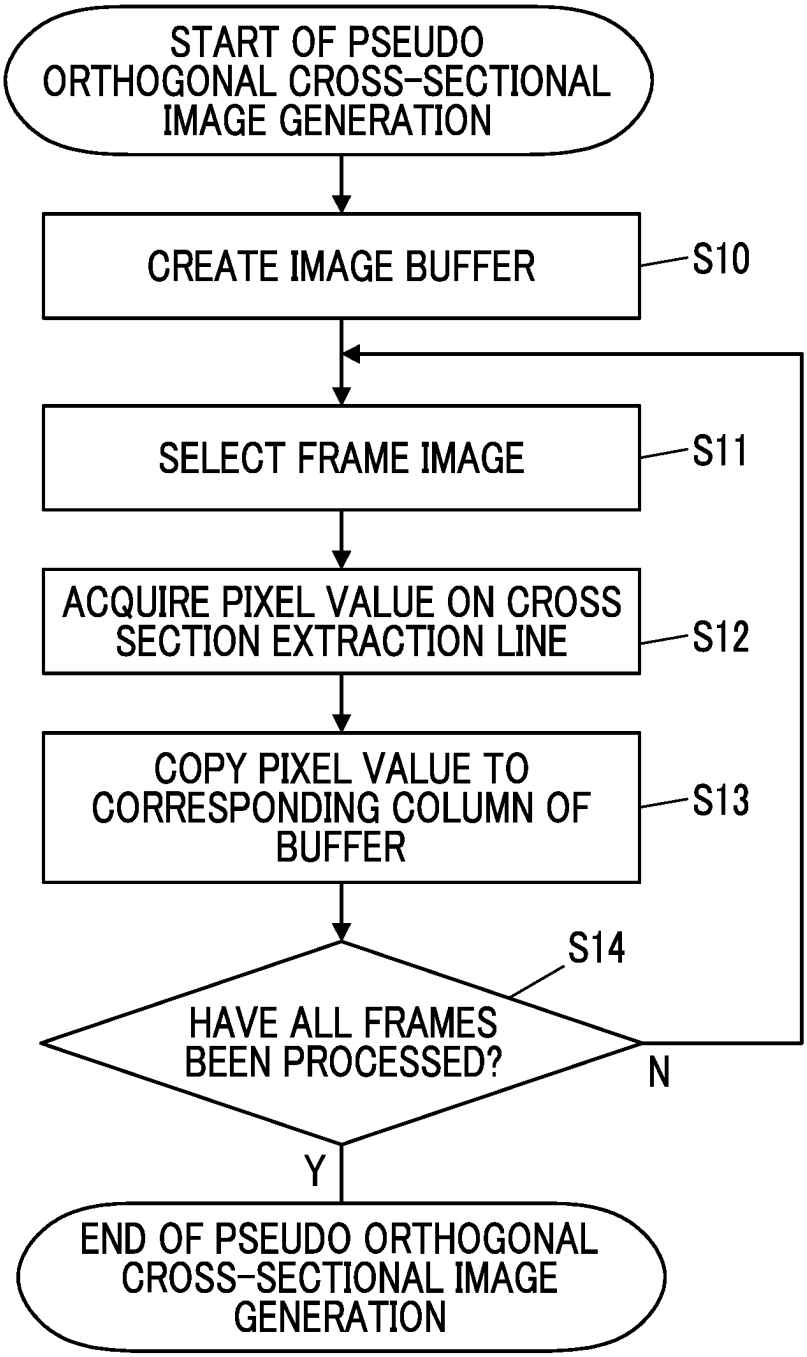

START OF PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE GENERATION
CREATE IMAGE BUFFER
S10
SELECT FRAME IMAGE
S11
ACQUIRE PIXEL VALUE ON CROSS SECTION EXTRACTION LINE
S12
COPY PIXEL VALUE TO CORRESPONDING COLUMN OF BUFFER
S13
S14
HAVE ALL FRAMES BEEN PROCESSED?
N
Y
END OF PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE GENERATION

FIG. 10

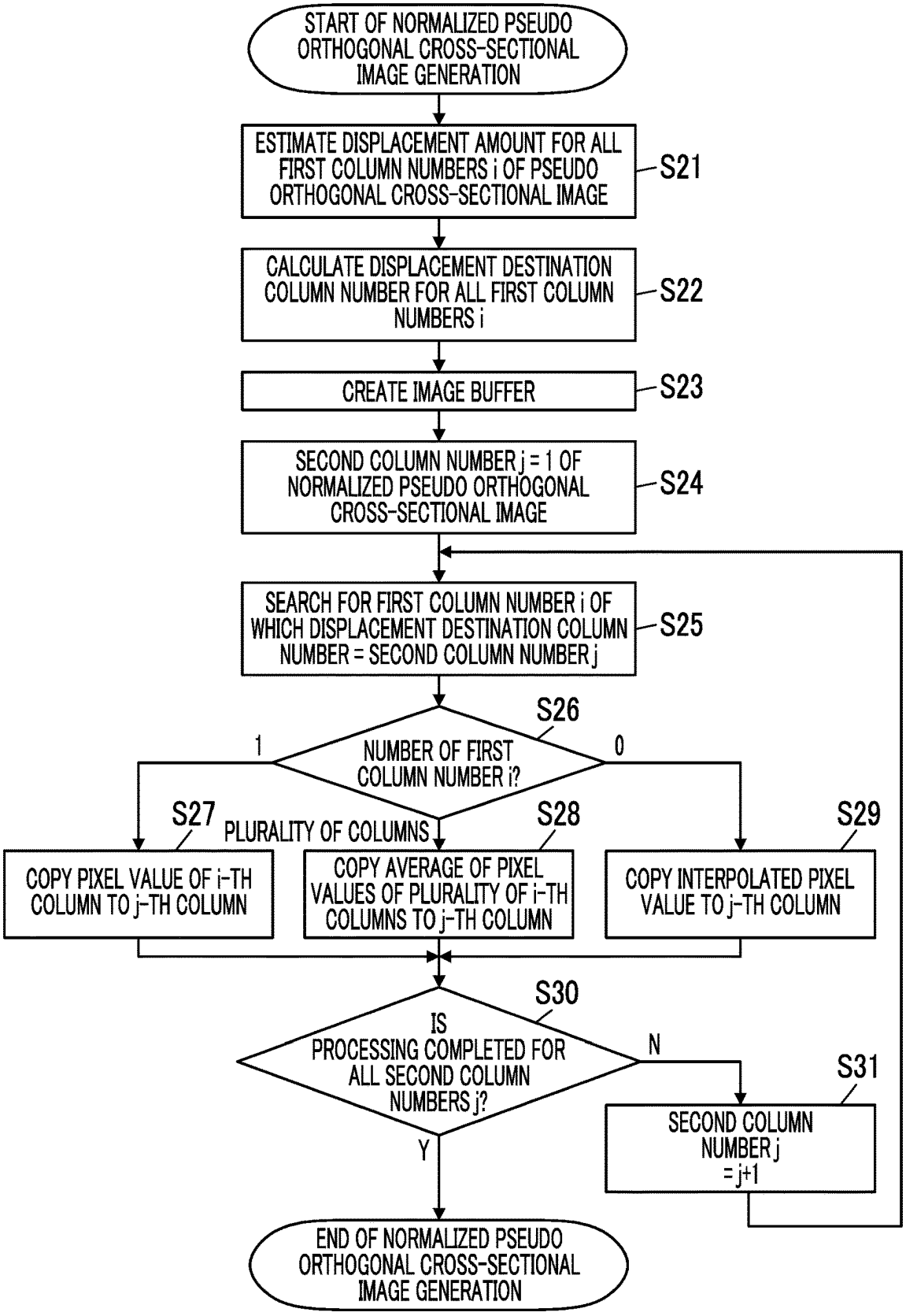

START OF NORMALIZED PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE GENERATION
ESTIMATE DISPLACEMENT AMOUNT FOR ALL FIRST COLUMN NUMBERS i OF PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE
S21
CALCULATE DISPLACEMENT DESTINATION COLUMN NUMBER FOR ALL FIRST COLUMN NUMBERS i
S22
CREATE IMAGE BUFFER
S23
SECOND COLUMN NUMBER j = 1 OF NORMALIZED PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE
S24
SEARCH FOR FIRST COLUMN NUMBER i OF WHICH DISPLACEMENT DESTINATION COLUMN NUMBER = SECOND COLUMN NUMBER j
S25
S26
NUMBER OF FIRST COLUMN NUMBER i?
1
0
PLURALITY OF COLUMNS
S27
COPY PIXEL VALUE OF i-TH COLUMN TO j-TH COLUMN
S28
COPY AVERAGE OF PIXEL VALUES OF PLURALITY OF i-TH COLUMNS TO j-TH COLUMN
S29
COPY INTERPOLATED PIXEL VALUE TO j-TH COLUMN
S30
IS PROCESSING COMPLETED FOR ALL SECOND COLUMN NUMBERS j?
N
Y
S31
SECOND COLUMN NUMBER j = j+1
END OF NORMALIZED PSEUDO ORTHOGONAL CROSS-SECTIONAL IMAGE GENERATION

FIG. 11

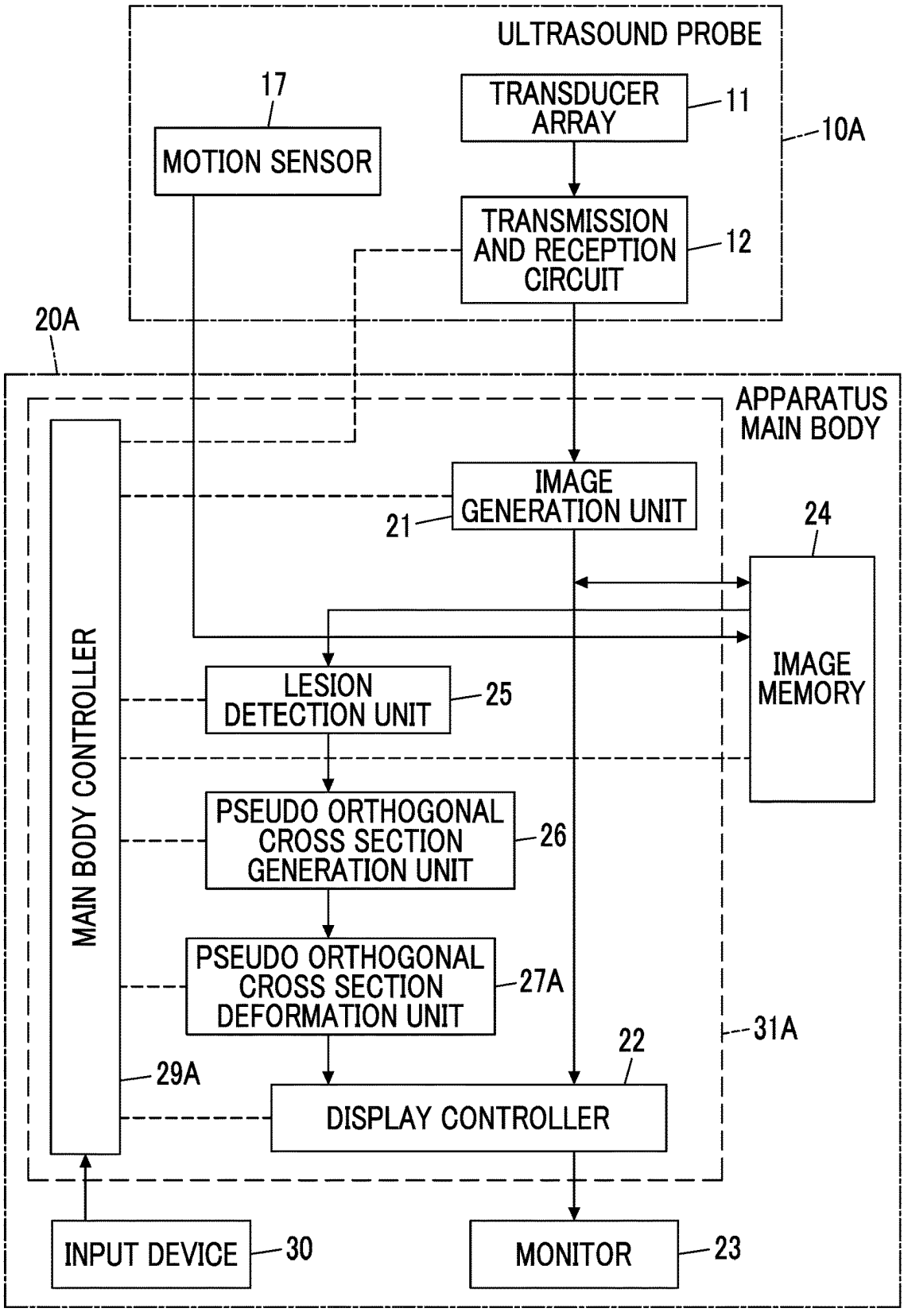

ULTRASOUND PROBE
17
MOTION SENSOR
TRANSDUCER ARRAY
11
10A
TRANSMISSION AND RECEPTION CIRCUIT
12
20A
APPARATUS MAIN BODY
IMAGE GENERATION UNIT
21
24
IMAGE MEMORY
MAIN BODY CONTROLLER
LESION DETECTION UNIT
25
PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27A
31A
22
29A
DISPLAY CONTROLLER
INPUT DEVICE
30
MONITOR
23

FIG. 12

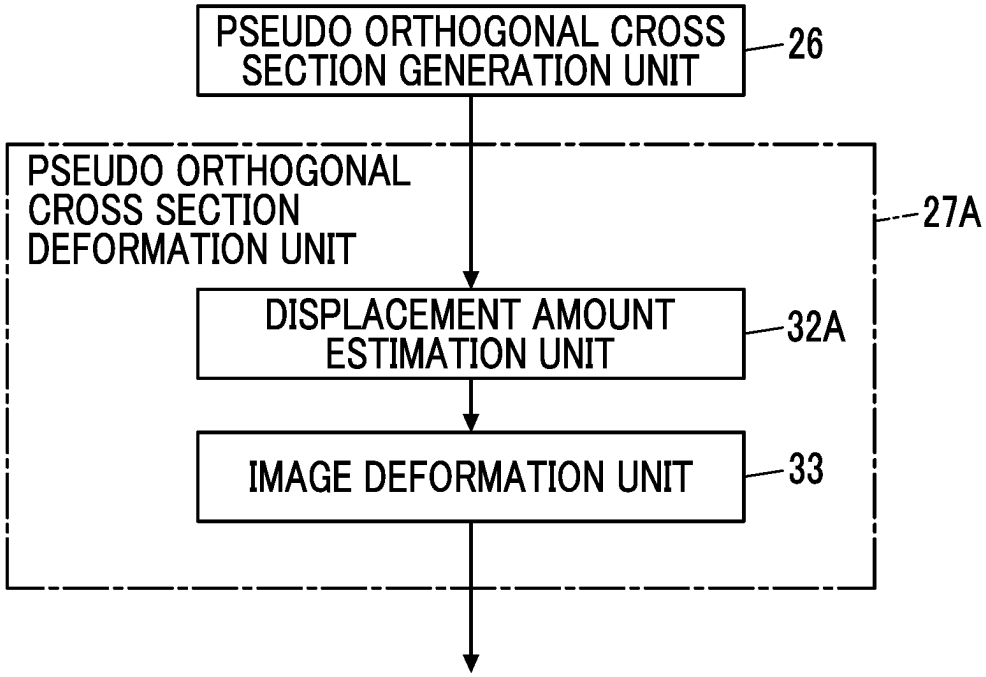

PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27A
DISPLACEMENT AMOUNT ESTIMATION UNIT
32A
IMAGE DEFORMATION UNIT
33

FIG. 13

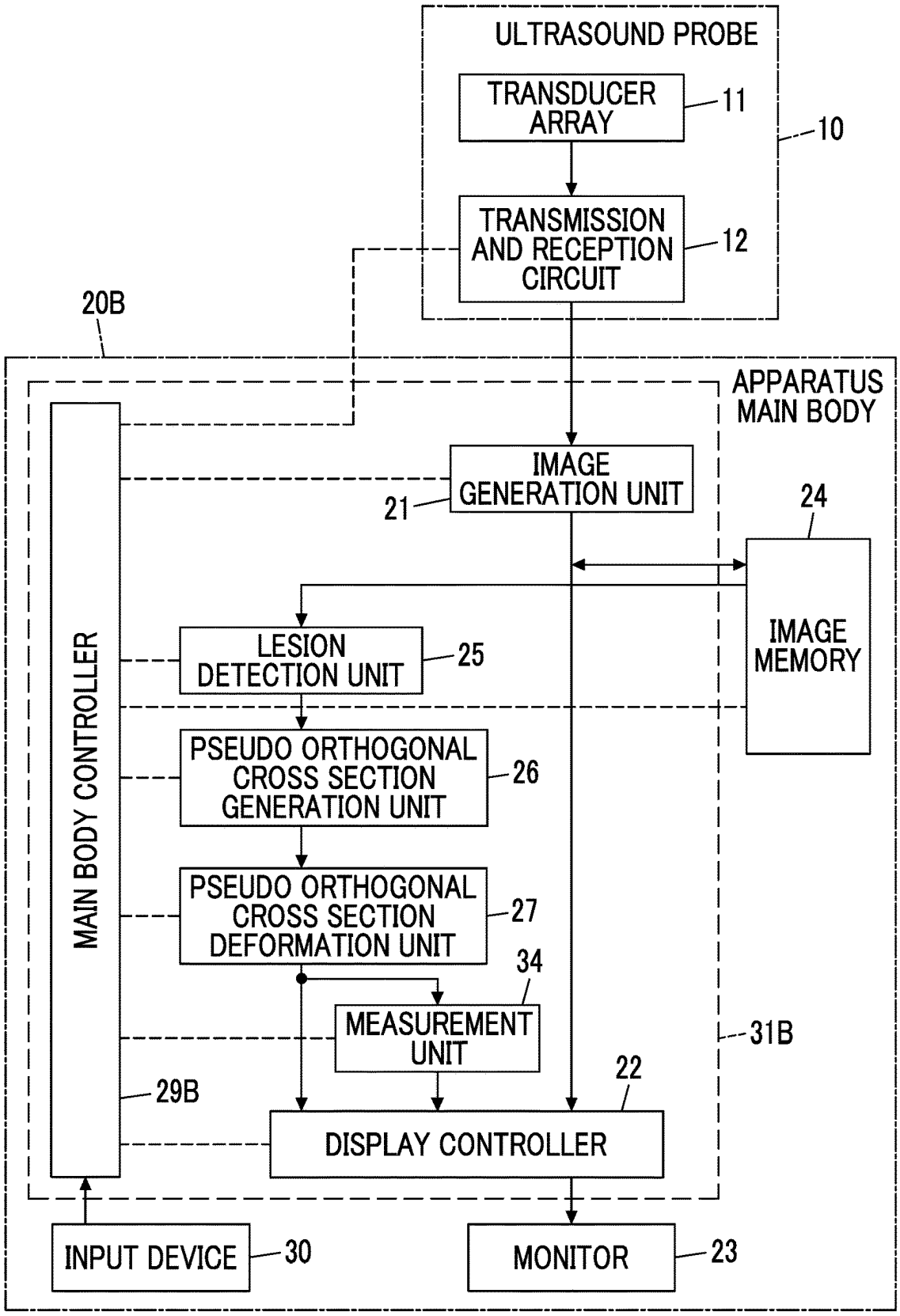
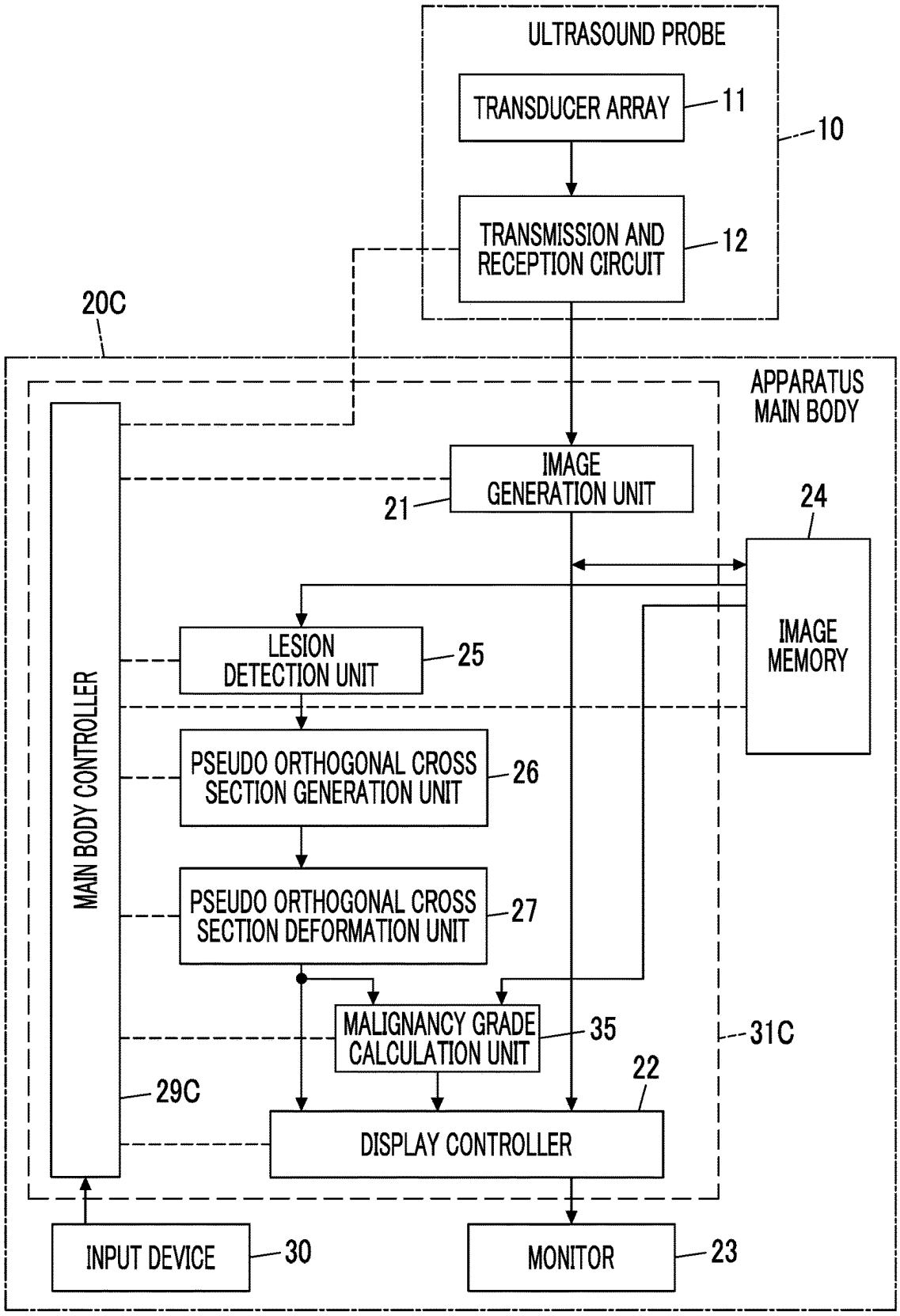

ULTRASOUND PROBE
TRANSDUCER ARRAY
11
10
TRANSMISSION AND RECEPTION CIRCUIT
12
20B
APPARATUS MAIN BODY
IMAGE GENERATION UNIT
21
24
IMAGE MEMORY
MAIN BODY CONTROLLER
LESION DETECTION UNIT
25
PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27
34
MEASUREMENT UNIT
31B
22
29B
DISPLAY CONTROLLER
INPUT DEVICE
30
MONITOR
23

FIG. 14


ULTRASOUND PROBE
TRANSDUCER ARRAY
11
10
TRANSMISSION AND RECEPTION CIRCUIT
12
20C
APPARATUS MAIN BODY
IMAGE GENERATION UNIT
21
24
IMAGE MEMORY
LESION DETECTION UNIT
25
MAIN BODY CONTROLLER
PSEUDO ORTHOGONAL CROSS SECTION GENERATION UNIT
26
PSEUDO ORTHOGONAL CROSS SECTION DEFORMATION UNIT
27
MALIGNANCY GRADE CALCULATION UNIT
35
31C
22
29C
DISPLAY CONTROLLER
INPUT DEVICE
30
MONITOR
23

ULTRASOUND DIAGNOSTIC APPARATUS AND CONTROL METHOD OF ULTRASOUND DIAGNOSTIC APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority under 35 U.S.C. § 119 to Japanese Patent Application No. 2022-107801, filed on Jul. 4, 2022. The above application is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an ultrasound diagnostic apparatus, and a control method of the ultrasound diagnostic apparatus which generate a cross-sectional image orthogonal to an observation plane.

2. Description of the Related Art

In the related art, in the medical field, an ultrasound diagnostic apparatus using an ultrasound image has been put to practical use. In general, an ultrasound diagnostic apparatus includes an ultrasound probe with a built-in transducer array, and an apparatus main body connected to the ultrasound probe, and the ultrasound diagnostic apparatus causes the ultrasound probe to transmit an ultrasound beam toward a subject, receives an ultrasound echo from the subject by the ultrasound probe, and electrically processes a reception signal thereof to generate an ultrasound image.

For example, in a case where an examination for a lesion part positioned at mammary glands or the like of a subject is performed by the ultrasound diagnostic apparatus, two cross sections orthogonal to each other are often imaged. In this way, in a case where two cross sections are imaged, a user such as a doctor usually switches the ultrasound probe to image the same lesion part in order to change the orientation of imaging, but this sometimes hinders the examination from being smoothly performed.

Therefore, for example, as disclosed in JP1996-280678A (JP-H08-280678A) and JP2002-306474A, a technique of generating a cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on a designated line in a plurality of frame images constituting a video has been developed.

SUMMARY OF THE INVENTION

The speed of the ultrasound probe moved by the user in a case of capturing the plurality of frame images constituting the video may fluctuate for some reason. As described above, since temporal intervals between the plurality of frame images are not constant in a case where the scanning speed of the ultrasound probe is not constant, the structure of the lesion part in the cross-sectional image generated by the techniques of JP1996-280678A (JP-H08-280678A) and JP2002-306474A differs from the actual structure, and thus it is difficult for the user such as a doctor to perform an accurate diagnosis in some cases.

The present invention has been made in order to solve such a problem in the related art, and an object of the invention is to provide an ultrasound diagnostic apparatus and a control method of the ultrasound diagnostic apparatus which can obtain a cross-sectional image in which the structure of the lesion part is accurately reproduced.

The above object can be achieved by the following configuration.

[1] An ultrasound diagnostic apparatus that generates a cross-sectional image orthogonal to an observation plane on the basis of a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, the ultrasound diagnostic apparatus including a pseudo orthogonal cross section generation unit that sets a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video, and generates a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images; and a pseudo orthogonal cross section deformation unit that non-rigidly deforms the pseudo orthogonal cross-sectional image in a horizontal direction to generate a normalized pseudo orthogonal cross-sectional image.

[2] The ultrasound diagnostic apparatus described in [1], further including a measurement unit that detects the lesion part from the normalized pseudo orthogonal cross-sectional image, and measures a size of the lesion part.

[3] The ultrasound diagnostic apparatus described in [2],

in which the pseudo orthogonal cross section generation unit sets a plurality of the cross section extraction lines extending in parallel to each other, and generates a plurality of the pseudo orthogonal cross-sectional images,

the pseudo orthogonal cross section deformation unit generates a plurality of the normalized pseudo orthogonal cross-sectional images on the basis of the plurality of pseudo orthogonal cross-sectional images, and

the measurement unit calculates a volume of the lesion part on the basis of the area of the lesion part measured from each of the plurality of normalized pseudo orthogonal cross-sectional images.

[4] The ultrasound diagnostic apparatus described in any one of [1] to [3], further including a malignancy grade calculation unit that calculates a malignancy grade of the lesion part on the basis of an image in which the lesion part is imaged.

[5] The ultrasound diagnostic apparatus described in [4],

in which the malignancy grade calculation unit calculates a total malignancy grade obtained by integrating a first malignancy grade calculated on the basis of one of the plurality of frame images and a second malignancy grade calculated on the basis of the normalized pseudo orthogonal cross-sectional image.

[6] The ultrasound diagnostic apparatus described in any one of [1] to [5], further including:

a lesion detection unit that detects the lesion part for each of the plurality of frame images,

in which the pseudo orthogonal cross section generation unit sets the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

[7] The ultrasound diagnostic apparatus described in any one of [1] to [6],

in which the pseudo orthogonal cross section deformation unit includes

a displacement amount estimation unit that estimates a displacement amount between a position of a pixel in the pseudo orthogonal cross-sectional image in a

case where a scanning speed of the ultrasound probe is made constant and a position of a pixel in the actual pseudo orthogonal cross-sectional image, in each of time points at which the plurality of frame images are captured, and

an image deformation unit that non-rigidly deforms the pseudo orthogonal cross-sectional image on the basis of the displacement amount.

[8] The ultrasound diagnostic apparatus described in [7], in which the ultrasound probe has a motion sensor that detects a moving speed of the ultrasound probe, and

the displacement amount estimation unit estimates the displacement amount on the basis of the moving speed detected by the motion sensor.

[9] A control method of an ultrasound diagnostic apparatus that generates a cross-sectional image orthogonal to an observation plane on the basis of a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, the control method including:

setting a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video;

generating a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images; and

non-rigidly deforming the pseudo orthogonal cross-sectional image in a horizontal direction to generate a normalized pseudo orthogonal cross-sectional image.

According to the present invention, an ultrasound diagnostic apparatus generates a cross-sectional image orthogonal to an observation plane on the basis of a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, and includes a pseudo orthogonal cross section generation unit that sets a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video, and generates a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images; and a pseudo orthogonal cross section deformation unit that non-rigidly deforms the pseudo orthogonal cross-sectional image in a horizontal direction to generate a normalized pseudo orthogonal cross-sectional image. Therefore, it is possible to obtain a cross-sectional image in which the structure of the lesion part is accurately reproduced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating a configuration of an ultrasound diagnostic apparatus according to a first embodiment.

FIG. **2** is a block diagram illustrating an internal configuration of a transmission and reception circuit in the first embodiment.

FIG. **3** is a block diagram illustrating an internal configuration of an image generation unit in the first embodiment.

FIG. **4** is a diagram schematically illustrating a cross section extraction line.

FIG. **5** is a diagram schematically illustrating an example of a pseudo orthogonal cross-sectional image.

FIG. **6** is a diagram schematically illustrating an example of a normalized pseudo orthogonal cross-sectional image.

FIG. **7** is a block diagram illustrating an internal configuration of a pseudo orthogonal cross section deformation unit in the first embodiment.

FIG. **8** is a flowchart illustrating an operation of the ultrasound diagnostic apparatus according to the first embodiment.

FIG. **9** is a flowchart illustrating an operation of generating a pseudo orthogonal cross-sectional image in the first embodiment.

FIG. **10** is a flowchart illustrating an operation of generating a normalized pseudo orthogonal cross-sectional image in the first embodiment.

FIG. **11** is a block diagram illustrating a configuration of an ultrasound diagnostic apparatus according to a second embodiment.

FIG. **12** is a block diagram illustrating an internal configuration of a pseudo orthogonal cross section deformation unit in the second embodiment.

FIG. **13** is a block diagram illustrating a configuration of an ultrasound diagnostic apparatus according to a third embodiment.

FIG. **14** is a block diagram illustrating a configuration of an ultrasound diagnostic apparatus according to a fourth embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the invention will be described with reference to the accompanying drawings.

The description of configuration requirements described below is given on the basis of the representative embodiment of the present invention, but the present invention is not limited to such an embodiment.

In the present specification, a numerical range represented using "to" means a range including the numerical values before and after "to" as a lower limit value and an upper limit value.

In the present specification, the terms "same" and "identical" include an error range generally allowed in the technical field.

First Embodiment

FIG. **1** illustrates a configuration of an ultrasound diagnostic apparatus according to a first embodiment of the present invention. The ultrasound diagnostic apparatus includes an ultrasound probe **10** and an apparatus main body **20**. The ultrasound probe **10** and the apparatus main body **20** are connected to each other in a wired manner via a cable (not illustrated).

The ultrasound probe **10** includes a transducer array **11**, and a transmission and reception circuit **12** is connected to the transducer array **11**.

The apparatus main body **20** has an image generation unit **21** connected to the transmission and reception circuit **12** of the ultrasound probe **10**, a display controller **22** and a monitor **23** are sequentially connected to the image generation unit **21**, and an image memory **24** is connected to the image generation unit **21**. A lesion detection unit **25**, a pseudo orthogonal cross section generation unit **26**, and a pseudo orthogonal cross section deformation unit **27** are sequentially connected to the image memory **24**. The pseudo orthogonal cross section deformation unit **27** is connected to the display controller **22**. Further, a main body controller **29** is connected to the transmission and reception circuit **12**, the image generation unit **21**, the display controller **22**, the

image memory **24**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, and the pseudo orthogonal cross section deformation unit **27**. An input device **30** is connected to the main body controller **29**.

Further, the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**, and the main body controller **29** constitute a processor **31** for the apparatus main body **20**.

The transducer array **11** of the ultrasound probe **10** has a plurality of ultrasonic transducers arranged in a one-dimensional or two-dimensional manner. According to a drive signal supplied from the transmission and reception circuit **12**, each of the transducers transmits an ultrasonic wave and receives a reflected wave from the subject to output an analog reception signal. For example, each transducer is configured by forming electrodes at both ends of a piezoelectric body consisting of piezoelectric ceramic represented by lead zirconate titanate (PZT), a polymer piezoelectric element represented by poly vinylidene di fluoride (PVDF), piezoelectric single crystal represented by lead magnesium niobate-lead titanate (PMN-PT), or the like.

The transmission and reception circuit **12** causes the transducer array **11** to transmit the ultrasonic wave and generates a sound ray signal on the basis of a reception signal acquired by the transducer array **11**, under the control of the main body controller **29**. As illustrated in FIG. **2**, the transmission and reception circuit **12** has a pulser **13** connected to the transducer array **11**, and an amplification unit **14**, an analog digital (AD) conversion unit **15**, and a beam former **16** that are sequentially connected in series to the transducer array **11**.

The pulser **13** includes, for example, a plurality of pulse generators, and the pulser **13** adjusts the amount of delay of each drive signal so that ultrasonic waves transmitted from the plurality of transducers of the transducer array **11** form an ultrasound beam on the basis of a transmission delay pattern selected according to the control signal from the main body controller **29**, and supplies the obtained signals to the plurality of transducers. Thus, in a case where a pulsed or continuous-wave voltage is applied to the electrodes of the transducers of the transducer array **11**, the piezoelectric body expands and contracts to generate pulsed or continuous-wave ultrasonic waves from each transducer. From the combined wave of these ultrasonic waves, an ultrasound beam is formed.

The transmitted ultrasound beam is reflected by a target, for example, a site of the subject, and the ultrasound echo propagates toward the transducer array **11** of the ultrasound probe **10**. The ultrasound echo propagating toward the transducer array **11** in this manner is received by each transducer constituting the transducer array **11**. In this case, each transducer constituting the transducer array **11** expands and contracts by receiving the propagating ultrasound echo to generate a reception signal that is an electric signal, and outputs the reception signal to the amplification unit **14**.

The amplification unit **14** amplifies the signals input from each transducer constituting the transducer array **11**, and transmits the amplified signals to the AD conversion unit **15**. The AD conversion unit **15** converts the signal transmitted from the amplification unit **14** into digital reception data, and transmits the reception data to the beam former **16**. The beam former **16** performs so-called reception focusing processing in which addition is performed by giving delays to respective pieces of the reception data converted by the AD conversion unit **15** according to a sound speed distribution or a sound speed set on the basis of a reception delay pattern selected according to the control signal from the main body controller **29**. Through the reception focusing processing, a sound ray signal in which each piece of the reception data converted by the AD conversion unit **15** is phased and added and the focus of the ultrasound echo is narrowed is acquired.

As illustrated in FIG. **3**, the image generation unit **21** of the apparatus main body **20** has a configuration in which a signal processing unit **41**, a digital scan converter (DSC) **42**, and an image processing unit **43** are sequentially connected in series.

The signal processing unit **41** generates an ultrasound image signal (B-mode image signal), which is tomographic image information regarding tissues inside the subject, by performing, on the sound ray signal sent from the transmission and reception circuit **12** of the ultrasound probe **10**, correction of the attenuation due to the distance according to the depth of the reflection position of the ultrasonic wave and then performing envelope detection processing.

The DSC **42** converts (raster conversion) the ultrasound image signal generated by the signal processing unit **41** into an image signal according to a normal television signal scanning method.

The image processing unit **43** performs various kinds of necessary image processing such as gradation processing on the ultrasound image signal input from the DSC **42**, and then outputs the signal representing the ultrasound image to the display controller **22** and the image memory **24**. Hereinafter, the signal representing the ultrasound image generated by the image generation unit **21** in this manner is referred to as a frame image.

The image memory **24** is a memory that stores the frame image generated by the image generation unit **21** under the control of the main body controller **29**. For example, the image memory **24** can store a plurality of frame images constituting a video, which are generated by consecutively imaging a region including the same lesion part of the subject by the image generation unit **21**.

Here, as the image memory **24**, recording media such as a flash memory, a hard disc drive (HDD), a solid state drive (SSD), a flexible disc (FD), a magneto-optical disc (MO disc), a magnetic tape (MT), a random access memory (RAM), a compact disc (CD), a digital versatile disc (DVD), a secure digital card (SD card), and a universal serial bus memory (USB memory), or the like can be used.

The lesion detection unit **25** performs an image analysis on each of the plurality of frame images stored in the image memory **24** to detect the lesion part in each of the plurality of frame images. For example, the lesion detection unit **25** can detect the lesion part using an object detection algorithm described in "REDMON, Joseph, et al. You only look once: Unified, real-time object detection. In: Proceedings of the IEEE conference on computer vision and pattern recognition. 2016. p. 779-788".

Further, the lesion detection unit **25** can detect the lesion part, for example, by a so-called template matching method of storing a plurality of template images regarding the lesion part, and using these template images. The lesion detection unit **25** can detect the lesion part by using, for example, a machine learning method described in Csurka et al.: Visual Categorization with Bags of Keypoints, Proc. of ECCV Workshop on Statistical Learning in Computer Vision, pp. 59-74 (2004), or a general image recognition method using deep learning described in Krizhevsk et al.: ImageNet Classification with Deep Convolutional Neural Networks, Advances in Neural Information Processing Systems 25, pp. 1106-1114 (2012).

The pseudo orthogonal cross section generation unit **26** generates a pseudo orthogonal cross-sectional image U**2** orthogonal to an observation plane as illustrated in FIG. **5** by setting a cross section extraction line L**1** passing through a lesion part M**1** on one frame image U**1** of a plurality of frame images U**1** constituting a video stored in the image memory **24** as illustrated in FIG. **4** and arranging, in time series, pixel values on the cross section extraction line L**1** in the plurality of frame images U**1** constituting the video, for example, arranging, in time series, pixel values from the frame image U**1** acquired in the past to the latest frame image U**1**.

For example, the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** on the frame image U**1** with the largest lesion part M**1** detected by the lesion detection unit **25**, among the plurality of frame images U**1**.

Further, for example, the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** on one frame image U**1** designated by the user via the input device **30**, among the plurality of frame images U**1**.

The pseudo orthogonal cross section generation unit **26** can track the position of the lesion part M**1** included in each of the plurality of frame images U**1** on the basis of the detection result of the lesion part M**1** by the lesion detection unit **25**, and set the cross section extraction lines L**1** for the lesion parts M**1** of the plurality of frame images U**1** to have the same positional relationship as the positional relationship between the lesion part M**1** and the cross section extraction line L**1** of one frame image U**1**. The pseudo orthogonal cross section generation unit **26** can arrange, in time series, the pixel values on the cross section extraction lines L**1** of the plurality of frame images U**1** set in this manner.

Here, since the pseudo orthogonal cross-sectional image U**2** is generated by simply arranging, in time series, the pixel values on the cross section extraction lines L**1** in the plurality of frame images U**1**, for example, in a case where the speed at which the user moves the ultrasound probe **10** at the time of capturing the plurality of frame images U**1** fluctuates, that is, in a case where the ultrasound probe **10** is not moving at a constant speed, the temporal intervals between pixels in the horizontal direction orthogonal to the depth direction are not constant, and therefore, the structure of the lesion part M**1** may not be correctly reproduced.

Then, in order to improve the accuracy of the cross-sectional image of the lesion part M**1**, the pseudo orthogonal cross section deformation unit **27** non-rigidly deforms the pseudo orthogonal cross-sectional image U**2** in the horizontal direction to generate a normalized pseudo orthogonal cross-sectional image U**3** in a case where the scanning speed of the ultrasound probe **10** is made constant as illustrated in FIG. **6**. The normalized pseudo orthogonal cross-sectional image U**3** includes the lesion part M**1** of which the structure is accurately reproduced. Here, the horizontal direction refers to a direction orthogonal to the depth direction in the pseudo orthogonal cross-sectional image U**2**.

As illustrated in FIG. **7**, the pseudo orthogonal cross section deformation unit **27** includes a displacement amount estimation unit **32** and an image deformation unit **33**.

The displacement amount estimation unit **32** estimates a displacement amount between a position of the pixel in the pseudo orthogonal cross-sectional image U**2** in a case where the scanning speed of the ultrasound probe **10** is made constant and a position of the pixel in the actual pseudo orthogonal cross-sectional image U**2** for each of time points at which the plurality of frame images U**1** are captured, that is, corresponding to each of the plurality of frame images U**1**. For example, the displacement amount estimation unit **32** can include a displacement amount estimation model using a so-called neural network in which H and T are positive integer values, the pseudo orthogonal cross-sectional image U**2** consisting of vertical H pixels and horizontal T pixels is input, and a displacement amount r(i) (i=1, 2, . . . , T) as T integer values is output, and the displacement amount estimation unit **32** can estimate the displacement amount r(i) by the displacement amount estimation model. The column number i of the pseudo orthogonal cross-sectional image U**2** is a frame number of the plurality of frame images U constituting the video, and corresponds to a scanning time point of the pixel of the pseudo orthogonal cross-sectional image U**2**. Further, the displacement amount r(i) indicates a displacement amount between a position of the pixel in the pseudo orthogonal cross-sectional image U**2** corresponding to the frame image U**1** with the i-th frame number in a case where the scanning speed of the ultrasound probe **10** is made constant and an actual position of the pixel in the pseudo orthogonal cross-sectional image U**2** corresponding to the frame image U**1** with the i-th frame number. The displace amount represents how much the actual scanning position is displaced with respect to the column number i of the pseudo orthogonal cross-sectional image U**2**. Hereinafter, the column number i of the pseudo orthogonal cross-sectional image U**2** can be referred to as a first column number i.

For example, the displacement amount estimation model can be trained for a relationship between the pseudo orthogonal cross-sectional image U**2** and the displacement amount r(i) as follows. First, as training videos, videos generated by scanning at an arbitrary speed with the ultrasound probe, and probe position data X recorded by synchronizing the position of the ultrasound probe measured by a position sensor such as an acceleration sensor, a gyro sensor, or a magnetic sensor with the frame rate of the video are prepared. Here, the speed of the ultrasound probe at the time of generating the video may fluctuate. In a case where it is assumed that the number of frames of the video is N, the number of pieces of data of the probe position data X is also N. The pseudo orthogonal cross-sectional image U**2** is generated by the pseudo orthogonal cross section generation unit **26** for the prepared video. Further, the probe position data X is converted into a displacement amount Y(t) (t=1, 2, . . . , M) by following Equation 1.

$$Y(t) = \mathrm{Int}\left[\frac{X(t) - X(1)}{X(M) - X(1)} \times (M-1) + 1\right] - t \tag{1}$$

Here, t is a column number of the pseudo orthogonal cross-sectional image U**2**, that is, a frame number of the plurality of frame images U**1** constituting the video. Further, "Int[ ]" is a function that truncates the decimal part of the numerical value in parentheses and outputs an integer value. The displacement amount Y(t) is a difference between the frame number of the pseudo orthogonal cross-sectional image that should be originally captured in a case where the ultrasound probe is moved at a constant speed, and the frame number of the pseudo orthogonal cross-sectional image U**2** that is actually captured.

A large number of sets of the displacement amount Y(t) and the pseudo orthogonal cross-sectional image U**2** obtained in this manner are prepared as teacher data, and the

teacher data can be learned by the displacement amount estimation model by a learning method such as so-called back propagation method.

The image deformation unit **33** non-rigidly deforms the pseudo orthogonal cross-sectional image U**2** in the horizontal direction to generate the normalized pseudo orthogonal cross-sectional image U**3** such that a plurality of pixels corresponding to a plurality of positions arranged at equal intervals in the actual lesion part M**1** are arranged at equal intervals in the horizontal direction of the image orthogonal to the depth direction, on the basis of the displacement amount r(i) estimated by the displacement amount estimation unit **32**. The non-rigid deformation of the pseudo orthogonal cross-sectional image U**2** performed by the image deformation unit **33** will be described later in detail.

The display controller **22** performs predetermined processing on the frame image U**1** generated by the image generation unit **21**, the normalized pseudo orthogonal cross-sectional image U**3** generated by the pseudo orthogonal cross section deformation unit **27**, and the like, and displays the processed images on the monitor **23**.

The monitor **23** is for displaying the frame image U**1** generated by the image generation unit **21**, the normalized pseudo orthogonal cross-sectional image U**3** generated by the pseudo orthogonal cross section deformation unit **27**, and the like, under the control of the display controller **22**, and includes, for example, a display device such as a liquid crystal display (LCD), or an organic electroluminescence (EL) display.

The main body controller **29** controls each unit of the apparatus main body **20** and the transmission and reception circuit **12** of the ultrasound probe **10** on the basis of a control program and the like stored in advance.

The input device **30** is for a user to perform an input operation, and is configured by, for example, a device such as a keyboard, a mouse, a trackball, a touchpad, and a touch sensor superimposed on the monitor **23**.

The processor **31** having the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**, and the main body controller **29** is configured by a central processing unit (CPU) and a control program for causing the CPU to execute various kinds of processing, but the processor **31** may be configured by using a field programmable gate array (FPGA), a digital signal processor (DSP), an application specific integrated circuit (ASIC), a graphics processing unit (GPU), or other integrated circuits (IC) or may be configured by a combination thereof.

Further, the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**, and the main body controller **29** of the processor **31** can also be configured by being integrated partially or entirely into one CPU or the like.

Next, the operation of the ultrasound diagnostic apparatus according to the first embodiment of the present invention will be described using the flowchart illustrated in FIG. **8**.

First, in Step S**1**, in a state where the ultrasound probe **10** is in contact with the body surface of the subject by the user, the frame image U**1** in which the lesion part M**1** of the subject is imaged is acquired. In a case where the frame image U**1** is acquired, the transmission and reception circuit **12** performs so-called reception focusing processing under the control of the main body controller **29** to generate sound ray signals. The sound ray signals generated by the transmission and reception circuit **12** are sent to the image generation unit **21**. The image generation unit **21** generates the frame image U**1** using the sound ray signals sent from the transmission and reception circuit **12**. The frame image U**1** acquired in this manner is sent to the image memory **24**, and is stored in the image memory **24**.

Next, in Step S**2**, the main body controller **29** determines whether to end the capturing of the frame image U**1**. For example, the main body controller **29** determines to end the capturing of the frame image U**1** in a case where an instruction to end the capturing of the frame image U**1** is input by the user via the input device **30**. In this case, for example, the main body controller **29** controls each unit of the ultrasound diagnostic apparatus such as the transmission and reception circuit **12** to end the capturing of the frame image U**1**. For example, the main body controller **29** determines to continue the capturing of the frame image U**1** in a case where an instruction to end the capturing of the frame image U**1** is not input by the user via the input device **30**, and causes each unit of the ultrasound diagnostic apparatus to continue the imaging.

In a case where it is determined not to end the capturing of the frame image U**1** in Step S**2**, the processing returns to Step S**1**, and a new frame image U**1** is acquired. In this manner, as long as it is determined not to end the capturing of the frame image U**1** in Step S**2**, the processing of Step S**1** and Step S**2** is repeated, and the plurality of frame images U**1** constituting the video are stored in the image memory **24**. Further, in a case where it is determined to end the capturing of the frame image U**1** in Step S**2**, the processing proceeds to Step S**3**.

In Step S**3**, the pseudo orthogonal cross section generation unit **26** sets the cross section extraction line L**1** passing through, for example, the lesion part M**1** as illustrated in FIG. **4** on one frame image U**1** among the plurality of frame images U**1** constituting the video, which are obtained by repeating Step S**1** and Step S**2**.

For example, the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** passing through the lesion part M**1** on the frame image U**1** designated by the user via the input device **30**. In Step S**3**, the lesion detection unit **25** can detect the lesion parts M**1** in the plurality of frame images U**1**, and the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** on the frame image U**1** including the largest lesion part M**1** among the plurality of lesion parts M**1** detected by the lesion detection unit **25**.

For example, the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** for the lesion parts M**1** in the plurality of frame images U**1** such that the positional relationship between the set cross section extraction line L**1** and the lesion part M**1** is maintained.

In subsequent Step S**4**, the pseudo orthogonal cross section generation unit **26** generates the pseudo orthogonal cross-sectional image U**2** orthogonal to the observation plane as illustrated in FIG. **5** by arranging, in time series, the pixel values on the same position as the position on the cross section extraction line L**1** set in Step S**3**, in the plurality of frame images U**1** constituting the video. The processing of Step S**4** includes processing of Step S**10** to Step S**14** illustrated in the flowchart of FIG. **9**.

First, in Step S**10**, the pseudo orthogonal cross section generation unit **26** creates an image buffer corresponding to the pseudo orthogonal cross-sectional image U**2**. The image buffer has a size of vertical H pixels and horizontal T**1** pixels. Here, T**1** is the number of frames of the plurality of frame images U**1** constituting the video acquired by repeat-

ing Step S1 and Step S2, and is the number of pixels of the pseudo orthogonal cross-sectional image U2 in the horizontal direction.

In Step S11, the pseudo orthogonal cross section generation unit **26** selects the frame image U1, which is one of the plurality of frame images U1 constituting the video, for example, which is the oldest frame image U1, that is, of which the frame number is "1".

In Step S12, the pseudo orthogonal cross section generation unit **26** acquires the pixel value on the same position as the position on the cross section extraction line L1 set in Step S3, in the frame image U1 selected in Step S11.

In Step S13, the pseudo orthogonal cross section generation unit **26** copies the pixel value acquired in Step S12 to a column of the image buffer created in Step S10 corresponding to the frame image U1 selected in Step S11, for example, a column of the image buffer corresponding to the frame number "1".

In Step S14, the pseudo orthogonal cross section generation unit **26** determines whether or not the processing of Step S11 to Step S13 has been performed on all the plurality of frame images U1 constituting the video. At the current time point, since only the processing of Step S12 and Step S13 has been performed on one frame image U1, the pseudo orthogonal cross section generation unit **26** determines that the processing of Step S12 and Step S13 has not been performed on all the plurality of frame images U1 constituting the video. In this case, the processing returns to Step S11. In Step S11, the pseudo orthogonal cross section generation unit **26** selects the frame image U1 which has not been selected yet among the plurality of frame images U1 constituting the video, for example, the frame image U1 that is secondly acquired in the past.

In this manner, in Step S14, until it is determined that the processing of Step S12 and Step S13 has been performed on all the frame images U1 constituting the video, the processing of Step S11 to Step S14 is repeated. As a result, the pixel value is sequentially copied to the column of the image buffer created in Step S10.

In a case where it is determined in Step S14 that the processing of Step S12 and Step S13 has been performed on all the frame images U1 constituting the video, the processing of Step S4 is completed. As a result, the pixel values on the cross section extraction line L1 in the corresponding frame image U1 are copied to all columns of the image buffer created in Step S10, and the pseudo orthogonal cross-sectional image U2 is generated.

In a case where Step S4 is completed in this manner, the processing proceeds to Step S5. In Step S5, the pseudo orthogonal cross section deformation unit **27** non-rigidly deforms the pseudo orthogonal cross-sectional image U2 generated in Step S4 in the horizontal direction to generate the normalized pseudo orthogonal cross-sectional image U3 in a case where the scanning speed of the ultrasound probe **10** is made constant. The processing of Step S5 includes processing of Step S21 to Step S31 illustrated in the flowchart of FIG. **10**.

In Step S21, the pseudo orthogonal cross section deformation unit **27** estimates the displacement amount r(i) for all the first column numbers i of the pseudo orthogonal cross-sectional image U2 generated in Step S4. In this case, the pseudo orthogonal cross section deformation unit **27** can estimate the displacement amount r(i) by using the displacement amount estimation model trained for the relationship between the pseudo orthogonal cross-sectional image U2 and the displacement amount r(i), for example. For example, the displacement amount estimation model can be trained using a plurality of sets of the pseudo orthogonal cross-sectional image U2 and the displacement amount Y(t) represented by Equation (1) as teacher data.

In Step S22, the pseudo orthogonal cross section deformation unit **27** calculates a displacement destination column number for all the first column numbers i of the pseudo orthogonal cross-sectional image U2. Here, the displacement destination column number is calculated by adding or subtracting a constant to the sum i+r(i) of the first column number i and the displacement amount r(i) estimated in Step S21 such that l+r(l) is 1. Table 1 below illustrates examples of the first column number i, the displacement amount r(i), the sum i+r(i), and the displacement destination column number of the pseudo orthogonal cross-sectional image U2. In the example of Table 1, sine l+r(l)=−4, the displacement destination column number is calculated by adding a constant **5** to the sum i+r(i).

TABLE 1

FIRST COLUMN NUMBER i	DISPLACEMENT AMOUNT r(i)	SUM i + r(i)	DISPLACEMENT DESTINATION COLUMN NUMBER
1	−5	−4	1
2	−4	−2	3
3	−2	1	6
4	0	4	9
5	1	6	11
6	0	6	11
7	3	10	15
...	...	...	...
T1	10	T1 + 10	T1 + 15

In Step S23, the pseudo orthogonal cross section deformation unit **27** creates an image buffer corresponding to the normalized pseudo orthogonal cross-sectional image U3. The image buffer has a size of vertical H pixels and horizontal T2 pixels. Here, T2 is a number obtained by adding 1 to the difference between the maximum value and the minimum value of the displacement destination column number. In the example of Table 1, T2=T1+15.

In Step S24, the pseudo orthogonal cross section deformation unit **27** selects the column number j=1 of the normalized pseudo orthogonal cross-sectional image U3. Hereinafter, the column number j of the normalized pseudo orthogonal cross-sectional image U3 is referred to as a second column number j.

In Step S25, the pseudo orthogonal cross section deformation unit **27** searches for the first column number i of which the displacement destination column number calculated in Step S22 is equal to the second column number j selected in Step S24. In the example of Table 1, the pseudo orthogonal cross section deformation unit **27** can search for the first column number i=1 of which the displacement destination column number is the second column number j=1.

In Step S26, the pseudo orthogonal cross section deformation unit **27** determines the number of first column numbers i searched in Step S25. The processing proceeds to Step S27 in a case where the number of searched first column numbers i is one, the processing proceeds to Step S28 in a case where the number of searched first column numbers i is plural, and the processing proceeds to Step S29 in a case where the number of searched first column numbers i is zero.

In the example of Table 1, since the number of first column numbers i searched in Step S25 is one of "1" in the

case of the second column number j=1, the processing proceeds to Step S27. In Step S27, the pseudo orthogonal cross section deformation unit **27** copies the pixel value of the first column number i=1 of the pseudo orthogonal cross-sectional image U2 to the column of the image buffer created in Step S23 of which the second column number j is 1.

In Step S30 subsequent to Step S27, the pseudo orthogonal cross section deformation unit **27** determines whether or not the processing of Step S26 to Step S29 has been completed for all the second column numbers j. In a case where it is determined that the processing has not been completed for all the second column numbers j, the processing proceeds to Step S31.

In Step S31, the pseudo orthogonal cross section deformation unit **27** selects a number obtained by adding 1 to the second column number j=1 that is currently selected, that is, the second column number j=2. In a case where Step S31 is completed, the processing returns to Step S25.

In Step S25, the pseudo orthogonal cross section deformation unit **27** searches for the first column number i of which the displacement destination column number=the second column number j=2. In the example of Table 1, since there is no "2" in the displacement destination column number, in this case, the first column number i cannot be searched in Step S25. In a case where the scanning speed of the ultrasound probe **10** is suddenly increased while the plurality of frame images U1 are captured, the displacement amount r(i) is increased, and the first column number i of which the displacement destination column number=the second column number j is not searched in some cases.

In Step S26, in a case where it is determined that the number of first column numbers i searched in Step S25 is zero, the processing proceeds to Step S29. In Step S29, the pseudo orthogonal cross section deformation unit **27** interpolates the pixel value, and copies the interpolated pixel value to the column of the image buffer created in Step S23 of which the second column number j is 2. In this case, for example, the pseudo orthogonal cross section deformation unit **27** can interpolate pixel values between the pixel value of the first column number i=1 and the pixel value of the first column number i=3 corresponding to two displacement destination column numbers closest to the displacement destination column number that has not been searched, for example, two displacement destination column numbers "1" and "3" closest to the displacement destination column number=the second column number j=2, and copy the pixel value obtained by the interpolation to the column of the image buffer of which the second column number j is 2. The interpolation method is not particularly limited, and for example, a known method such as so-called linear interpolation or quadratic interpolation can be used.

In Step S30 subsequent to Step S28, the pseudo orthogonal cross section deformation unit **27** determines whether or not the processing of Step S25 to Step S29 has been completed for all the second column numbers j, and the processing proceeds to Step S31 in a case where it is determined that the processing has not been completed for all the second column numbers j.

In Step S31, 1 is added to the second column number j. Thereafter, the processing returns to Step S25.

Step S25 to Step S31 are repeated in this manner, and in a case where the second column number j=11 is selected in Step S31, the first column number i of which the displacement destination column number=the second column number j=11 is searched in subsequent Step S25. In the example of Table 1, there are two first column numbers i "5" and "6" of which the displacement destination column number=the second column number j=11, and the first column numbers i=5 and 6 are searched. While the plurality of frame images U1 are captured, for example, in a case where the ultrasound probe **10** is paused or the like, the plurality of first column numbers i are searched.

In subsequent Step S25, it is determined that the number of searched first column numbers i is two (plural) of "5" and "6", and the processing proceeds to Step S28.

In Step S28, the pseudo orthogonal cross section deformation unit **27** copies the average value of the pixel values of the plurality of searched first column numbers i to the column of the image buffer corresponding to the second column number j. In the example of Table 1, the pseudo orthogonal cross section deformation unit **27** copies the average value of the pixel values of the searched first column numbers i=5 and 6 to the column of the image buffer of which the second column number j is 11, for example.

In this manner, by repeating the processing of Step S25 to Step S31, the pixel values are sequentially copied to the columns of the image buffer created in Step S23.

In Step S30, in a case where it is determined that the processing of Step S25 to Step S29 has been completed for all the second column numbers j, the processing of Step S5 is completed. As a result, the pixel values are copied to all columns of the image buffer created in Step S23, and the normalized pseudo orthogonal cross-sectional image U3 is generated. The normalized pseudo orthogonal cross-sectional image U3 represents a cross-sectional image of the lesion part M1 in a case where the scanning speed of the ultrasound probe **10** is made constant. With the processing of Step S5, a cross-sectional image with high accuracy is obtained.

Finally, in Step S6, the normalized pseudo orthogonal cross-sectional image U3 generated in Step S5 is displayed on the monitor **23**. In this case, for example, the frame image U1 can be displayed on the monitor **23** together with the normalized pseudo orthogonal cross-sectional image U3 by the user's input operation via the input device **30**. The user can accurately diagnose the lesion part M1 of the subject by checking the normalized pseudo orthogonal cross-sectional image U3 displayed on the monitor **23**.

As described above, with the ultrasound diagnostic apparatus of the first embodiment, the pseudo orthogonal cross section generation unit **26** generates the pseudo orthogonal cross-sectional image U2 orthogonal to the observation plane by arranging, in time series, the pixel values on the cross section extraction line L1 in the plurality of frame images U1 constituting the video, and the pseudo orthogonal cross section deformation unit **27** non-rigidly deforms the pseudo orthogonal cross-sectional image U2 in the horizontal direction to generate the normalized pseudo orthogonal cross-sectional image U3 in a case where the scanning speed of the ultrasound probe **10** is made constant. Therefore, it is possible to obtain the cross-sectional image in which the structure of the lesion part M1 is accurately reproduced.

It has been described that the ultrasound probe **10** and the apparatus main body **20** are connected to each other in a wired manner, but the ultrasound probe **10** and the apparatus main body **20** can be connected to each other in a wireless manner.

The apparatus main body **20** may be a so-called stationary type, a portable type, or a handheld type configured by a so-called smartphone or tablet computer. As described above, the type of equipment constituting the apparatus main body **20** is not particularly limited.

Further, the transmission and reception circuit **12** is included in the ultrasound probe **10**, but the transmission and reception circuit **12** may be included in the apparatus main body **20** instead of being included in the ultrasound probe **10**.

Further, the image generation unit **21** is included in the apparatus main body **20**, but the image generation unit **21** may be included in the ultrasound probe **10** instead of being included in the apparatus main body **20**.

In a case of setting the cross section extraction line L**1** passing through the lesion part M**1**, the pseudo orthogonal cross section generation unit **26** can set the cross section extraction line L**1** at a position determined for the lesion part M**1**, such as the center of the lesion part M**1** or a position where the width of the lesion part M**1** is internally divided at a constant ratio. In this manner, the position of the lesion part M**1** through which the cross section extraction line L**1** is set to pass can be decided by the user's input operation via the input device **30** or can be unchangeably decided for each apparatus.

It has been described that the pseudo orthogonal cross section deformation unit **27** non-rigidly deforms the pseudo orthogonal cross-sectional image U**2** in the horizontal direction to generate the normalized pseudo orthogonal cross-sectional image U**3**, but in this case, the pseudo orthogonal cross section deformation unit **27** can non-rigidly deform the pseudo orthogonal cross-sectional image U**2** in the depth direction as necessary.

Second Embodiment

In the first embodiment, the pseudo orthogonal cross section deformation unit **27** estimates the displacement amount r(i) using the displacement amount estimation model, but can estimate the displacement amount r(i) on the basis of the signal from the motion sensor attached to the ultrasound probe **10**.

FIG. **11** illustrates a configuration of an ultrasound diagnostic apparatus of a second embodiment. The ultrasound diagnostic apparatus of the second embodiment is obtained by including an ultrasound probe **10**A instead of the ultrasound probe **10** and including an apparatus main body **20**A instead of the apparatus main body **20** in the ultrasound diagnostic apparatus of the first embodiment illustrated in FIG. **1**.

The ultrasound probe **10**A is obtained by adding a motion sensor **17** to the ultrasound probe **10** in the first embodiment. The motion sensor **17** is connected to the image memory **24**.

The apparatus main body **20**A is obtained by including a pseudo orthogonal cross section deformation unit **27**A instead of the pseudo orthogonal cross section deformation unit **27** and including a main body controller **29**A instead of the main body controller **29** in the apparatus main body **20** in the first embodiment. As illustrated in FIG. **12**, the pseudo orthogonal cross section deformation unit **27**A includes a displacement amount estimation unit **32**A instead of the displacement amount estimation unit **32** in the pseudo orthogonal cross section deformation unit **27** in the first embodiment.

Further, the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**A, and the main body controller **29**A constitute a processor **31**A for the apparatus main body **20**A.

The motion sensor **17** is a sensor device that is attached to the ultrasound probe **10**A, and detects a moving speed of the ultrasound probe **10**A. The motion sensor **17** sends the moving speed of the ultrasound probe **10**A to the image memory **24** in synchronization with the generation frame rate of the frame image U**1** generated by the image generation unit **21**. The moving speed of the ultrasound probe **10**A sent to the image memory **24** in this manner is stored as a moving speed V(i) (i=1, 2, . . . , T) in the image memory **24** by being associated with each of the plurality of corresponding frame images U**1**.

For example, the motion sensor **17** can include a known sensor device such as an acceleration sensor, an angular velocity sensor, or a magnetic sensor.

The displacement amount estimation unit **32**A of the pseudo orthogonal cross section deformation unit **27**A estimates the displacement amount r(i) on the basis of the moving speed V(i) of the ultrasound probe **10**A detected by the motion sensor **17**. Specifically, the pseudo orthogonal cross section deformation unit **27**A can estimate the displacement amount r(i) corresponding to the first column number i of the pseudo orthogonal cross-sectional image U**2** by using Equation (2) and Equation (3) described below.

$$r(i) = \mathrm{Int}\left[\frac{\sum_{j=1}^{i} V(j) - \overline{V} \times i}{\overline{V}}\right] \times T \tag{2}$$

$$\overline{V} = \frac{\sum_{j=1}^{T} V(j)}{T} \tag{3}$$

The image deformation unit **33** non-rigidly deforms the pseudo orthogonal cross-sectional image U**2** in the horizontal direction on the basis of the displacement amount r(i) estimated by the displacement amount estimation unit **32**A in this manner to generate the normalized pseudo orthogonal cross-sectional image U**3** in a case where the scanning speed of the ultrasound probe **10**A is made constant.

As described above, with the ultrasound diagnostic apparatus of the second embodiment, even in a case where the displacement amount estimation unit **32**A estimates the displacement amount r(i) by using Equation (2) and Equation (3) using the moving speed V(i) of the ultrasound probe **10**A measured by the motion sensor **17**, the normalized pseudo orthogonal cross-sectional image U**3** in which the structure of the lesion part M**1** is accurately reproduced is obtained.

Third Embodiment

In the embodiment of the present invention, since the normalized pseudo orthogonal cross-sectional image U**3** in which the structure of the lesion part M**1** is accurately reproduced is obtained, the size and the like of the lesion part M**1** can be accurately measured by using the normalized pseudo orthogonal cross-sectional image U**3**.

FIG. **13** illustrates a configuration of an ultrasound diagnostic apparatus of a third embodiment. The ultrasound diagnostic apparatus of the third embodiment is obtained by including an apparatus main body **20**B instead of the apparatus main body **20** in the ultrasound diagnostic apparatus of the first embodiment illustrated in FIG. **1**.

The apparatus main body **20**B is obtained by adding a measurement unit **34** and including a main body controller **29**B instead of the main body controller **29** in the apparatus main body **20** in the first embodiment. The measurement

unit **34** is connected to the display controller **22**, the pseudo orthogonal cross section deformation unit **27**, and the main body controller **29**B.

Further, the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**, the main body controller **29**B, and the measurement unit **34** constitute a processor **31**B for the apparatus main body **20**B.

The measurement unit **34** detects the lesion part M**1** from the normalized pseudo orthogonal cross-sectional image U**3** generated by the pseudo orthogonal cross section deformation unit **27**, and measures the size of the lesion part M**1**. For example, the measurement unit **34** can detect the lesion part M**1** using a lesion detection algorithm described in "REDMON, Joseph, et al. You only look once: Unified, real-time object detection. In: Proceedings of the IEEE conference on computer vision and pattern recognition. 2016. p. 779-788".

Further, for example, the measurement unit **34** can detect the lesion part M**1** by a so-called template matching method of storing a plurality of template images regarding the lesion part M**1**, and using these template images. For example, the measurement unit **34** can detect the lesion part M**1** by using a machine learning method described in Csurka et al.: Visual Categorization with Bags of Keypoints, Proc. of ECCV Workshop on Statistical Learning in Computer Vision, pp. 59-74 (2004), or a general image recognition method using deep learning described in Krizhevsk et al.: ImageNet Classification with Deep Convolutional Neural Networks, Advances in Neural Information Processing Systems 25, pp. 1106-1114 (2012).

The measurement unit **34** can particularly measure the size of the lesion part M**1** in the horizontal direction orthogonal to the depth direction in a case of measuring the size of the lesion part M**1** included in the normalized pseudo orthogonal cross-sectional image U**3**. As a result, it is possible to accurately obtain the size of the lesion part M**1** in the scanning direction, that is, in the movement direction of the ultrasound probe **10**.

As described above, with the ultrasound diagnostic apparatus of the third embodiment, since the size of the lesion part M**1** in the scanning direction can be accurately measured from the normalized pseudo orthogonal cross-sectional image U**3**, the user such as a doctor can smoothly and precisely perform an examination for the lesion part M**1** without requiring to newly capture the frame image U**1** by changing the orientation of the ultrasound probe **10** in order to measure the size of the lesion part M**1** in the scanning direction.

The measurement of the size of the lesion part M**1** has been described, but the measurement unit **34** can measure the volume of the lesion part M**1**.

In this case, first, the pseudo orthogonal cross section generation unit **26** sets a plurality of cross section extraction lines L**1** extending in parallel to each other and passing through the lesion part M**1** in one frame image U**1**, and generates a plurality of pseudo orthogonal cross-sectional images U**2**. Next, the pseudo orthogonal cross section deformation unit **27** generates a plurality of normalized pseudo orthogonal cross-sectional images U**3** on the basis of the plurality of pseudo orthogonal cross-sectional images U**2** generated by the pseudo orthogonal cross section generation unit **26**. The measurement unit **34** can measure the number of pixels, that is, the area of the lesion part M**1** from each of the plurality of normalized pseudo orthogonal cross-sectional images U**3** generated by the pseudo orthogonal cross section deformation unit **27**, and calculate the volume of the lesion part M**1** by adding the obtained values of the plurality of areas.

Fourth Embodiment

In some cases, the user such as a doctor determines the malignancy grade of the lesion part M**1** by checking the image in which the lesion part M**1** is imaged. The ultrasound diagnostic apparatus of the embodiment of the present invention can calculate the malignancy grade of the lesion part M**1** by analyzing the image in which the lesion part M**1** is imaged.

FIG. **14** illustrates a configuration of an ultrasound diagnostic apparatus of a fourth embodiment. The ultrasound diagnostic apparatus of the fourth embodiment is obtained by including an apparatus main body **20**C instead of the apparatus main body **20** in the ultrasound diagnostic apparatus of the first embodiment illustrated in FIG. **1**.

The apparatus main body **20**C is obtained by adding a malignancy grade calculation unit **35** and including a main body controller **29**C instead of the main body controller **29** in the apparatus main body **20** in the first embodiment. The malignancy grade calculation unit **35** is connected to the display controller **22**, the image memory **24**, the pseudo orthogonal cross section deformation unit **27**, and the main body controller **29**C. Further, the image generation unit **21**, the display controller **22**, the lesion detection unit **25**, the pseudo orthogonal cross section generation unit **26**, the pseudo orthogonal cross section deformation unit **27**, the main body controller **29**C, and the malignancy grade calculation unit **35** constitute a processor **31**C for the apparatus main body **20**C.

The malignancy grade calculation unit **35** calculates the malignancy grade of the lesion part M**1** on the basis of the image in which the lesion part M**1** is imaged. For example, the malignancy grade calculation unit **35** can have a malignancy grade calculation model that is trained in advance for a large number of sets consisting of images in each of which the lesion part M**1** is imaged and the malignancy grades of the lesion parts M**1** shown in the images, as teacher data. In this case, the malignancy grade calculation unit **35** can calculate the malignancy grade of the lesion part M**1** by inputting the image in which the lesion part M**1** is imaged, to the malignancy grade calculation model.

The malignancy grade of the lesion part M**1** calculated by the malignancy grade calculation unit **35** is displayed on the monitor **23** via the display controller **22**. The user such as a doctor can precisely and easily diagnose the lesion part M**1** by checking the value of the malignancy grade displayed on the monitor **23**.

Further, the malignancy grade calculation unit **35** can calculate a first malignancy grade of the lesion part M**1** on the basis of one of the plurality of frame images U**1** constituting the video, calculate a second malignancy grade of the lesion part M**1** on the basis of the normalized pseudo orthogonal cross-sectional image U**3** generated by the pseudo orthogonal cross section deformation unit **27**, and calculate a total malignancy grade obtained by integrating the first malignancy grade and the second malignancy grade. Here, the frame image U**1** used for calculating the first malignancy grade can be read from the image memory **24** by the user's instruction via the input device **30**, for example.

In the normalized pseudo orthogonal cross-sectional image U**3**, the structure of the lesion part M**1** is accurately reproduced, and therefore, the second malignancy grade can be accurately calculated. The total malignancy grade is

calculated on the basis of two cross sections of the lesion part M1, which are orthogonal to each other, and therefore, a more accurate value than the first malignancy grade and the second malignancy grade is obtained. Therefore, the user such as a doctor can precisely and easily diagnose the lesion part M1 by checking the total malignancy grade displayed on the monitor **23**.

EXPLANATION OF REFERENCES

10, **10**A: ultrasound probe
11: transducer array
12: transmission and reception circuit
13: pulser
14: amplification unit
15: AD conversion unit
16: beam former
17: motion sensor
20, **20**A, **20**B, **20**C: apparatus main body
21: image generation unit
22: display controller
23: monitor
24: image memory
25: lesion detection unit
26: pseudo orthogonal cross section generation unit
27, **27**A: pseudo orthogonal cross section deformation unit
29, **29**A, **29**B, **29**C: main body controller
30: input device
31, **31**A, **31**B, **31**C: processor
32: displacement amount estimation unit
33: image deformation unit
34: measurement unit
35: malignancy grade calculation unit
41: signal processing unit
42: DSC
43: image processing unit
L1: cross section extraction line
M1: lesion part
U1: frame image
U2: pseudo orthogonal cross-sectional image
U3: normalized pseudo orthogonal cross-sectional image

What is claimed is:

1. An ultrasound diagnostic apparatus that generates a cross-sectional image orthogonal to an observation plane based on a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, the ultrasound diagnostic apparatus comprising:

a processor configured to

set a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video,

generate a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images, and

generate a normalized pseudo orthogonal cross-sectional image by non-rigidly deforming the pseudo orthogonal cross-sectional image in a horizontal direction,

wherein the processor is further configured to

estimate a displacement amount between a position of a pixel in the pseudo orthogonal cross-sectional image in a case where a scanning speed of the ultrasound probe is made constant and a position of a pixel in the actual pseudo orthogonal cross-sectional image, in each of time points at which the plurality of frame images are captured, and

non-rigidly deform the pseudo orthogonal cross-sectional image based on the displacement amount.

2. The ultrasound diagnostic apparatus according to claim **1**,

wherein the processor is further configured to

detect the lesion part from the normalized pseudo orthogonal cross-sectional image, and

measure a size of the lesion part.

3. The ultrasound diagnostic apparatus according to claim **2**,

wherein the processor is further configured to

set a plurality of the cross section extraction lines extending in parallel to each other,

generate a plurality of the pseudo orthogonal cross-sectional images,

generate a plurality of the normalized pseudo orthogonal cross-sectional images based on the plurality of pseudo orthogonal cross-sectional images, and

calculate a volume of the lesion part based on an area of the lesion part measured from each of the plurality of normalized pseudo orthogonal cross-sectional images.

4. The ultrasound diagnostic apparatus according to claim **1**,

the processor is further configured to calculate a malignancy grade of the lesion part based on an image in which the lesion part is imaged.

5. The ultrasound diagnostic apparatus according to claim **2**,

the processor is further configured to calculate a malignancy grade of the lesion part based on an image in which the lesion part is imaged.

6. The ultrasound diagnostic apparatus according to claim **3**,

the processor is further configured to calculate a malignancy grade of the lesion part based on an image in which the lesion part is imaged.

7. The ultrasound diagnostic apparatus according to claim **4**,

wherein the processor is further configured to calculate a total malignancy grade obtained by integrating a first malignancy grade calculated based on one of the plurality of frame images and a second malignancy grade calculated based on the normalized pseudo orthogonal cross-sectional image.

8. The ultrasound diagnostic apparatus according to claim **1**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

9. The ultrasound diagnostic apparatus according to claim **2**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

10. The ultrasound diagnostic apparatus according to claim **3**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

11. The ultrasound diagnostic apparatus according to claim **4**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

12. The ultrasound diagnostic apparatus according to claim **7**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

13. The ultrasound diagnostic apparatus according to claim **8**,

wherein the processor is further configured to

detect the lesion part for each of the plurality of frame images, and

set the cross section extraction line on the frame image with the largest lesion part, among the plurality of frame images.

14. The ultrasound diagnostic apparatus according to claim **1**,

wherein the ultrasound probe has a motion sensing device configured to detect that detects a moving speed of the ultrasound probe, and

the processor is further configured to estimate the displacement amount based on the moving speed detected by the motion sensor.

15. A control method of an ultrasound diagnostic apparatus that generates a cross-sectional image orthogonal to an observation plane based on a video which is acquired during scanning by an ultrasound probe and in which a lesion part is imaged, the control method comprising:

setting a cross section extraction line passing through the lesion part on one frame image among a plurality of frame images constituting the video;

generating a pseudo orthogonal cross-sectional image orthogonal to the observation plane by arranging, in time series, pixel values on the cross section extraction line in the plurality of frame images; and

non-rigidly deforming the pseudo orthogonal cross-sectional image in a horizontal direction to generate a normalized pseudo orthogonal cross-sectional image,

wherein the control method further comprises:

estimating a displacement amount between a position of a pixel in the pseudo orthogonal cross-sectional image in a case where a scanning speed of the ultrasound probe is made constant and a position of a pixel in the actual pseudo orthogonal cross-sectional image, in each of time points at which the plurality of frame images are captured, and

non-rigidly deforming the pseudo orthogonal cross-sectional image based on the displacement amount.

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