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(19) **United States**(12) **Patent Application Publication**  
**MIYACHI et al.**(10) **Pub. No.: US 2012/0310090 A1**(43) **Pub. Date: Dec. 6, 2012**(54) **ULTRASOUND DIAGNOSTIC APPARATUS**(52) **U.S. Cl. .... 600/440**(75) **Inventors:** **Yukiya MIYACHI**,  
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**Noguchi**, Ashigara-kami-gun (JP)(57) **ABSTRACT**(73) **Assignee:** **FUJIFILM Corporation**, Tokyo  
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An ultrasound diagnostic apparatus comprising: an ultrasound probe which has ultrasound transducers capable of outputting reception signals from fundamental waves and harmonics; an image producer which produces a B-mode image and an M-mode image from the reception signal output from the ultrasound transducers with reception of the fundamental waves, and produces a B-mode image from the reception signal output from the ultrasound transducers with reception of the harmonics; and an actuation controller for the ultrasound probe which switches the ultrasound transducers at a predetermined timing between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.

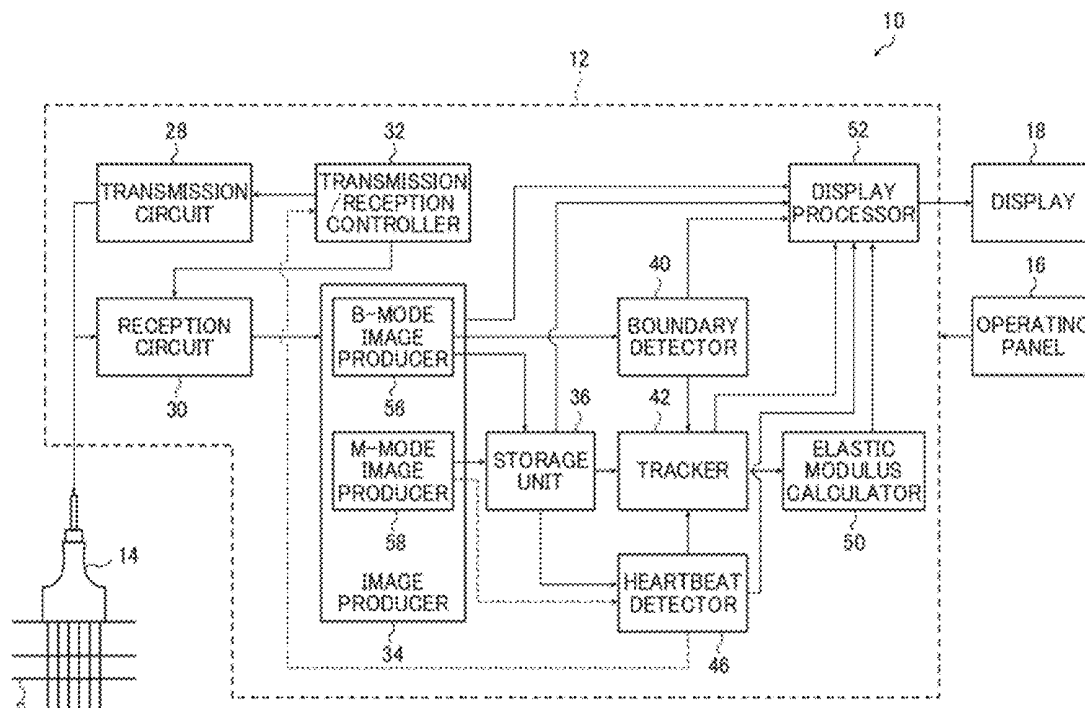


FIG. 1

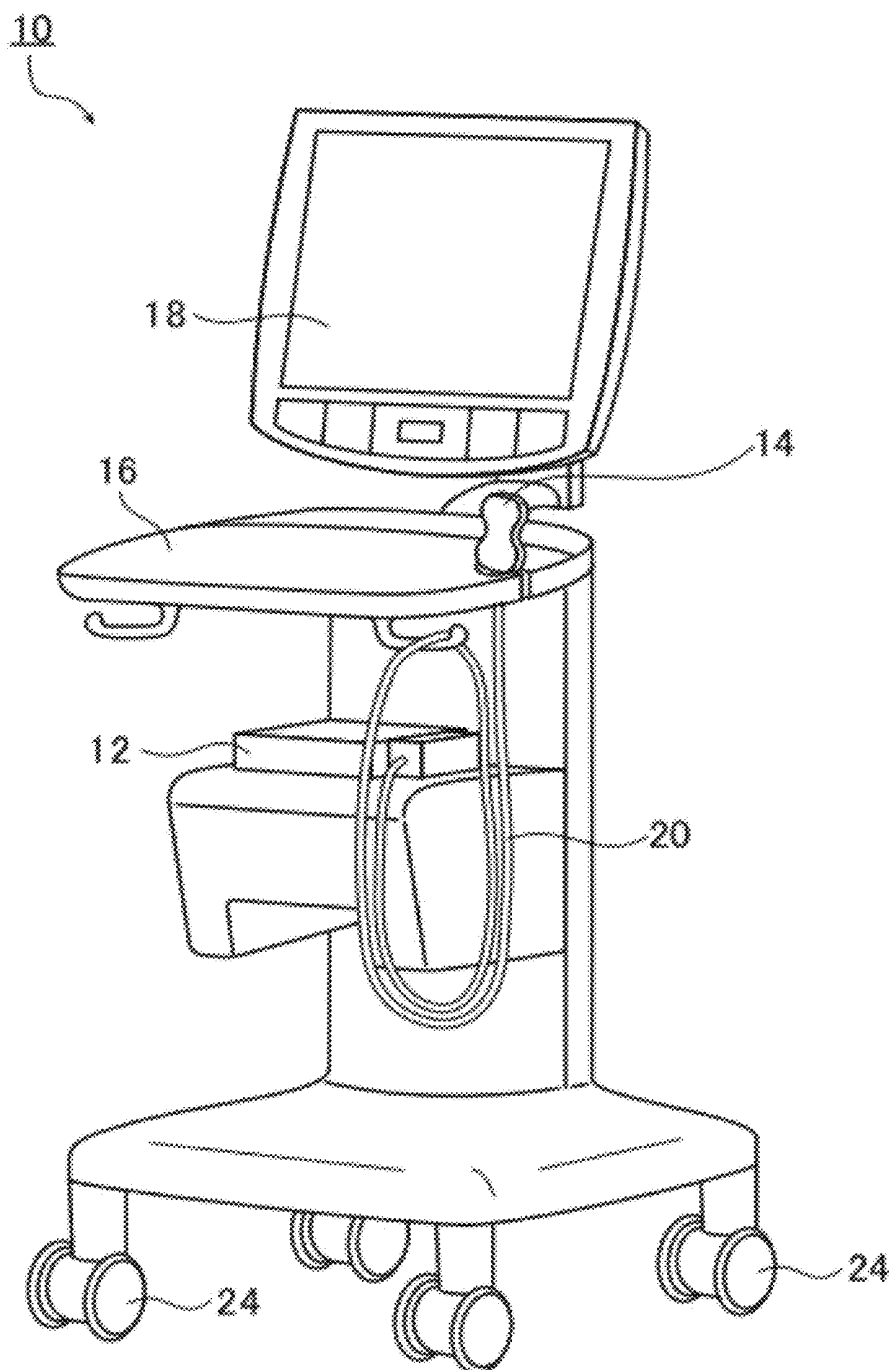


FIG. 2

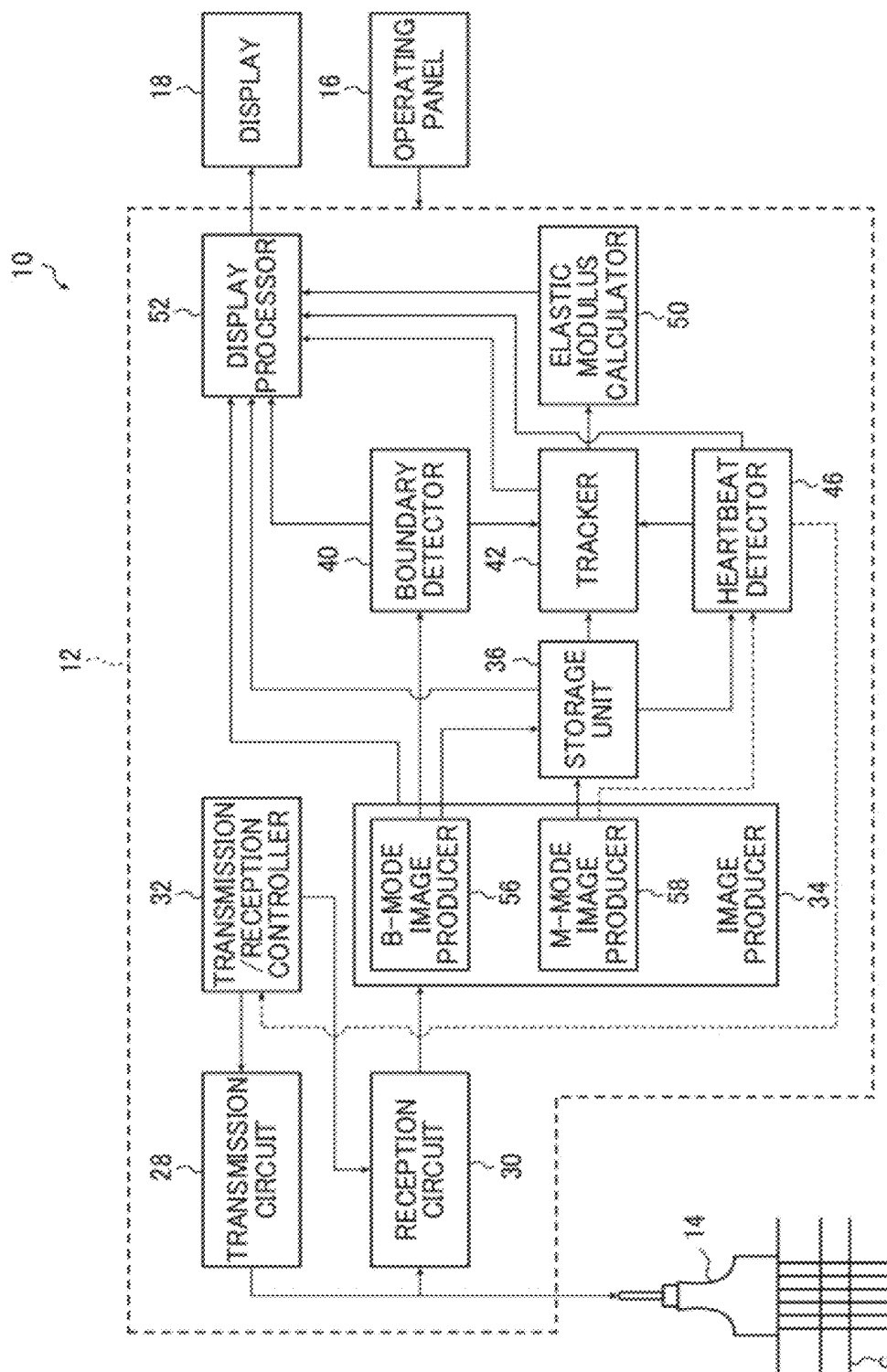


FIG.3

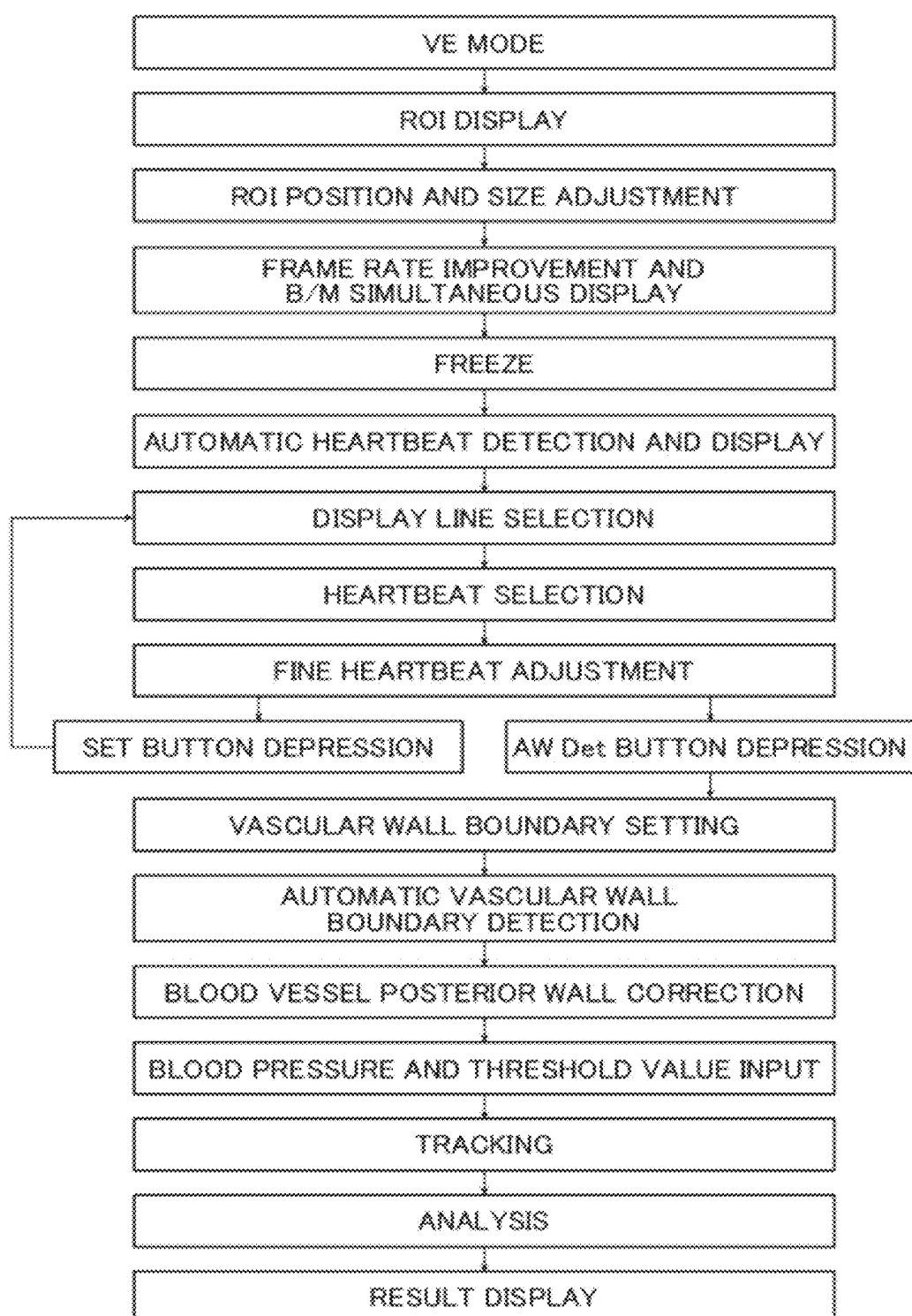


FIG.4

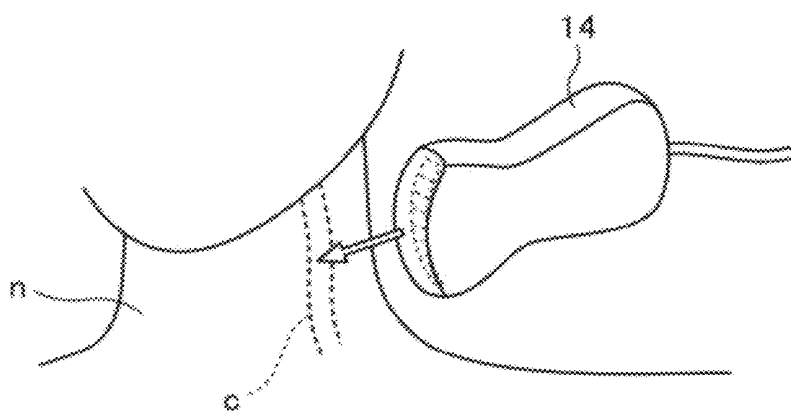


FIG.5A

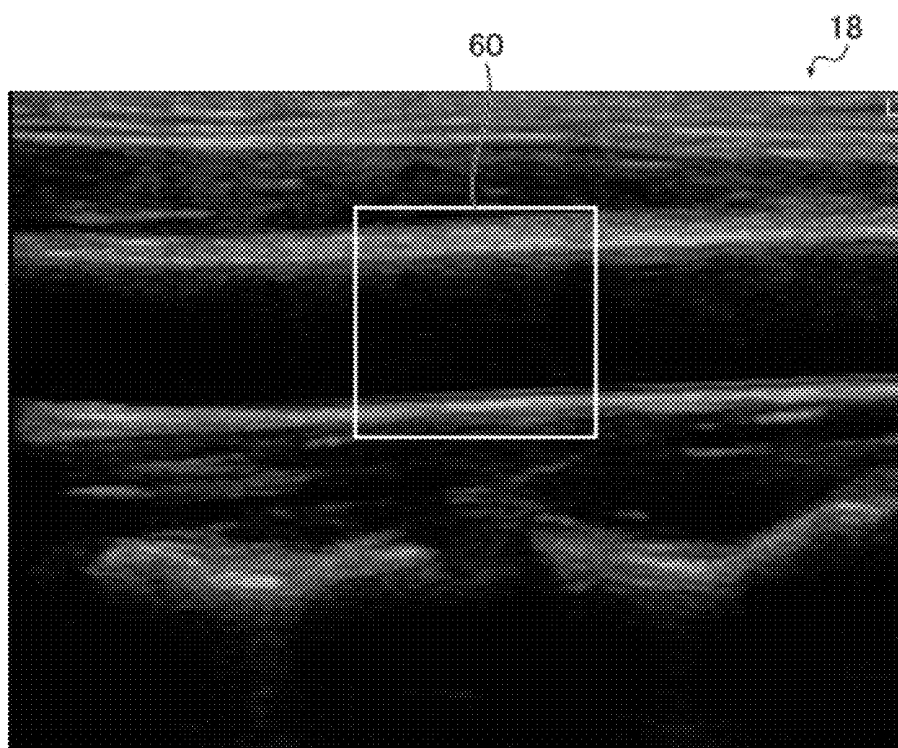


FIG.5B

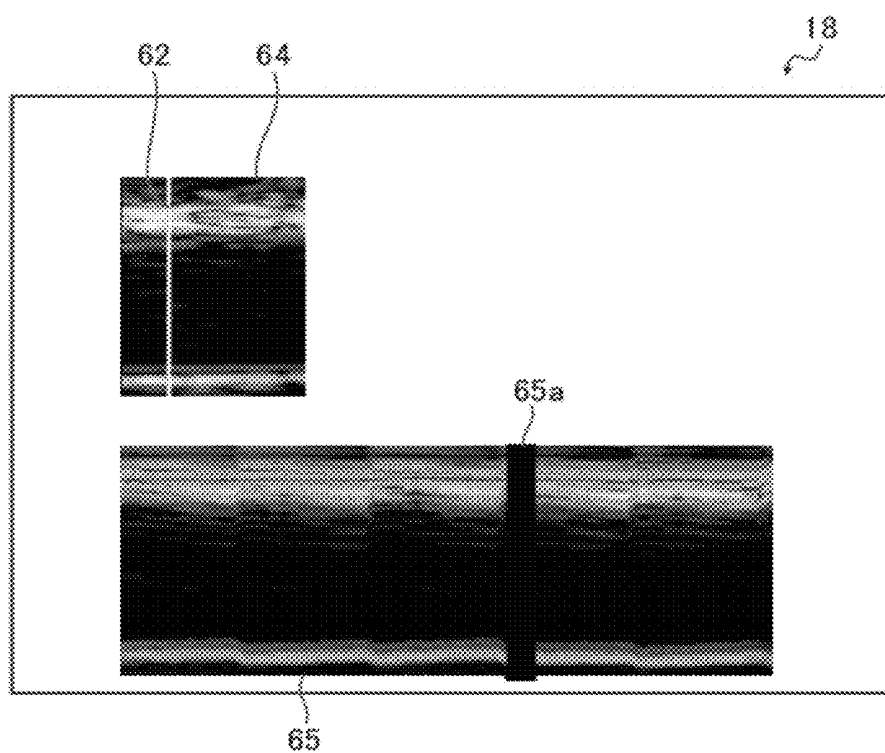


FIG.6A

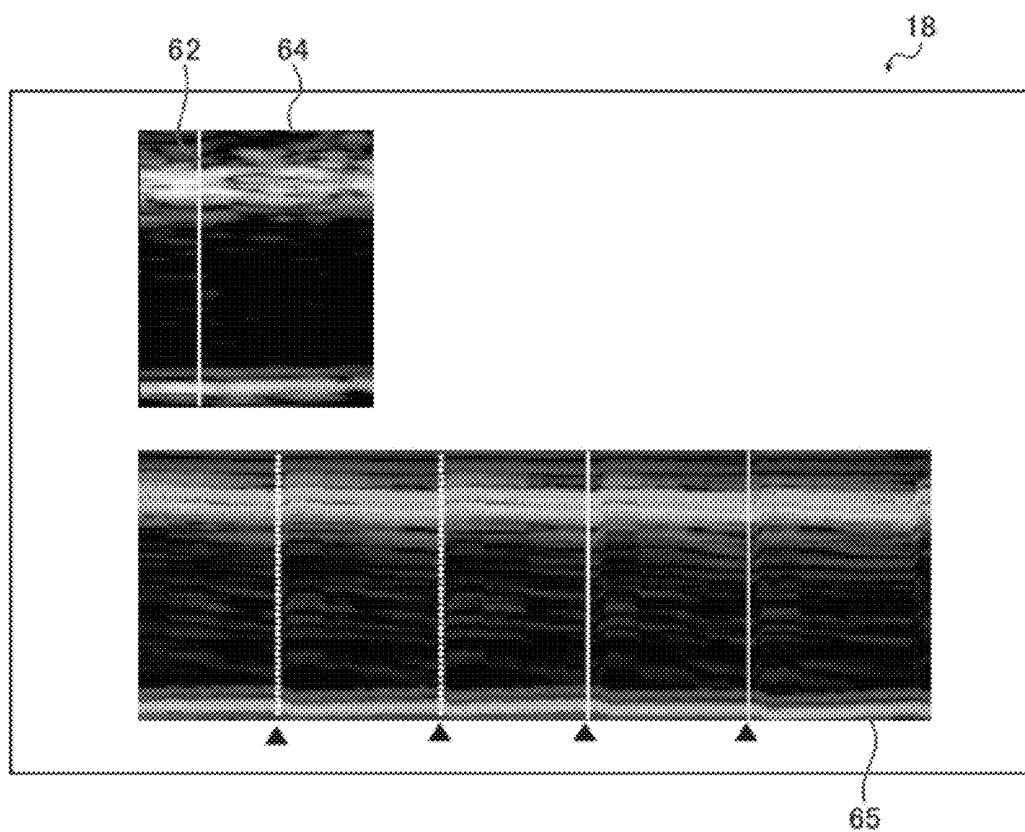


FIG.6B

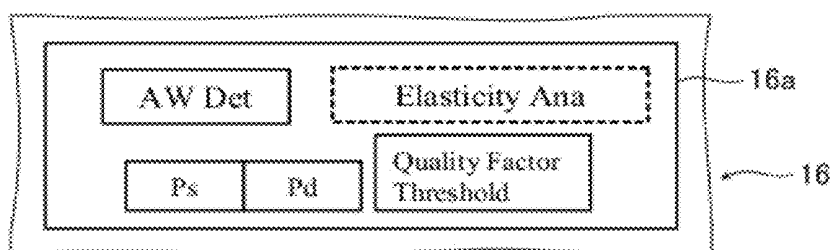


FIG. 7A

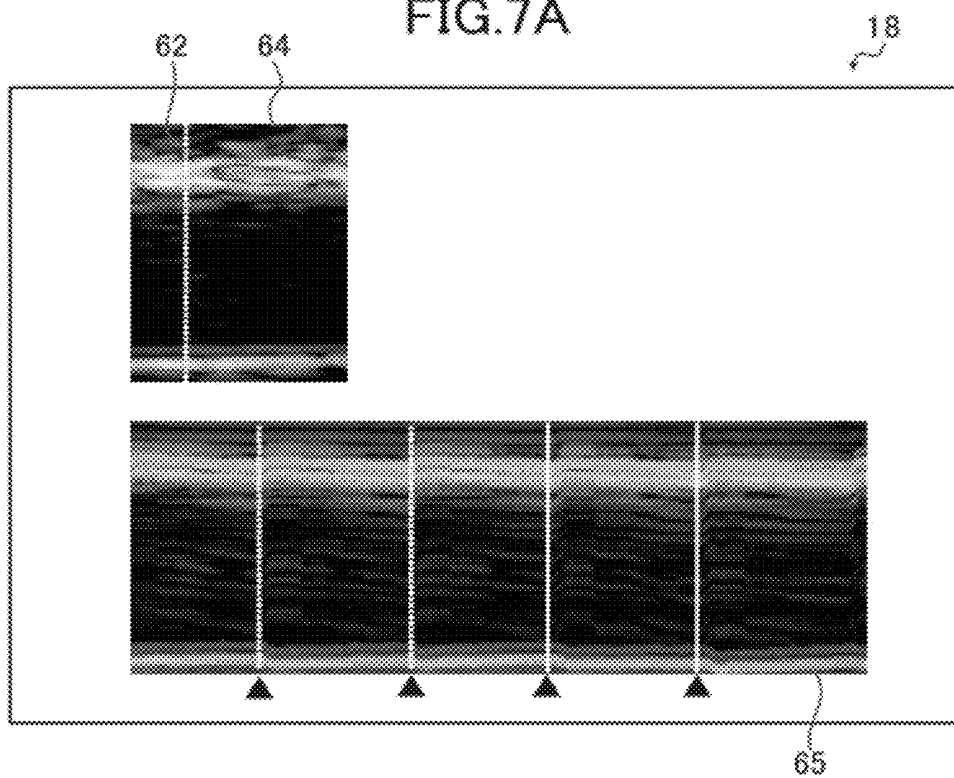


FIG. 7B

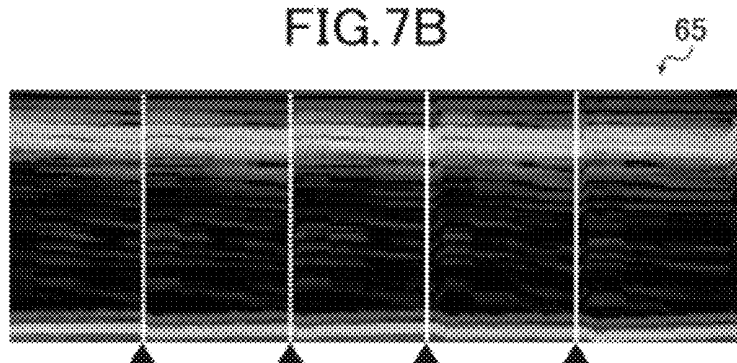


FIG. 7C

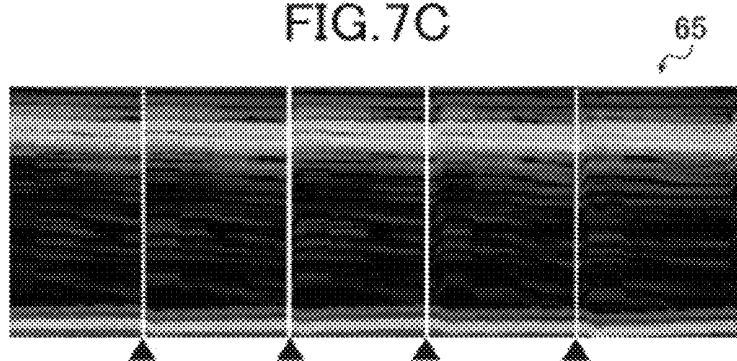


FIG.8A

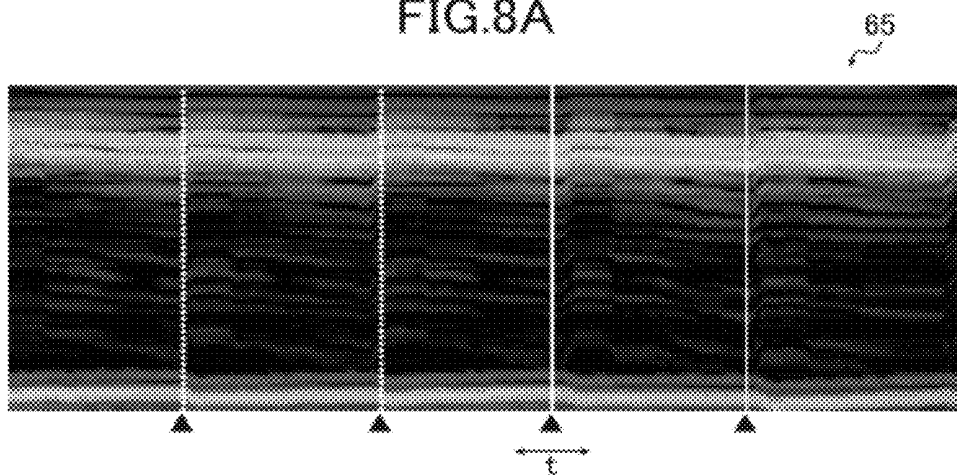


FIG.8B

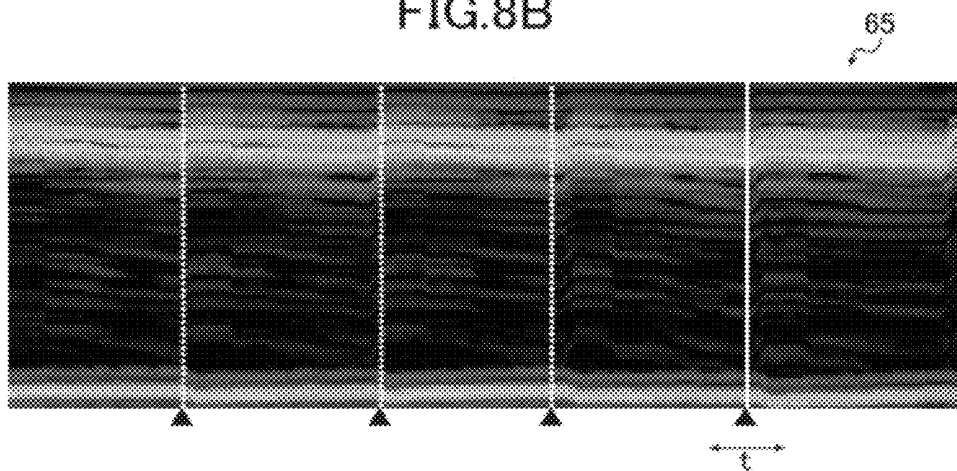


FIG.9A

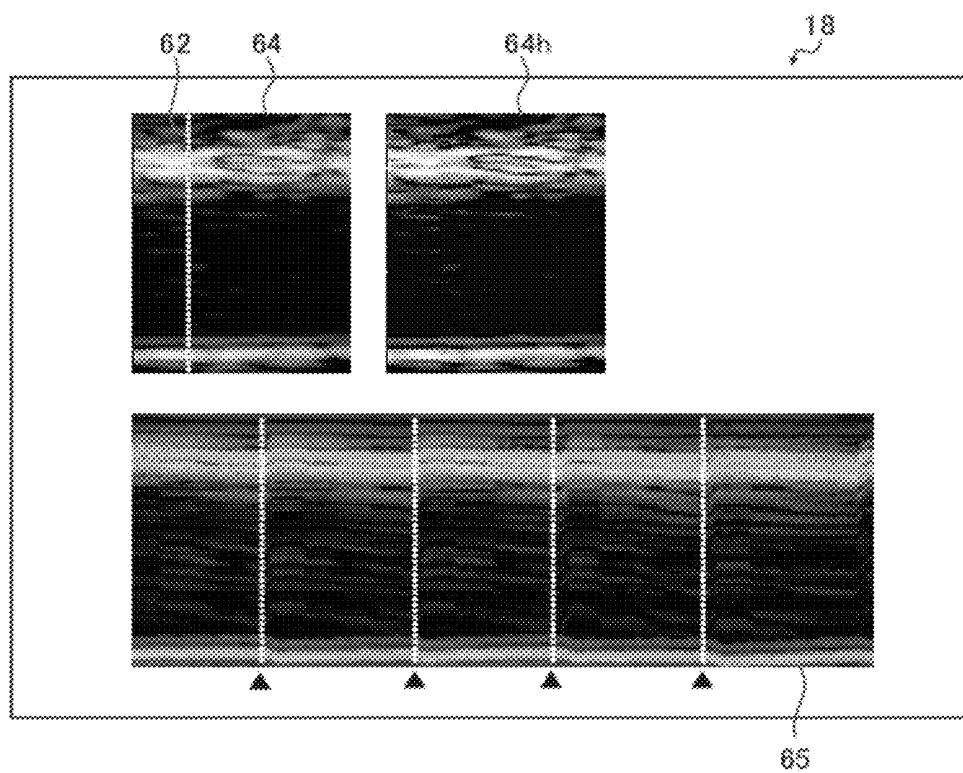
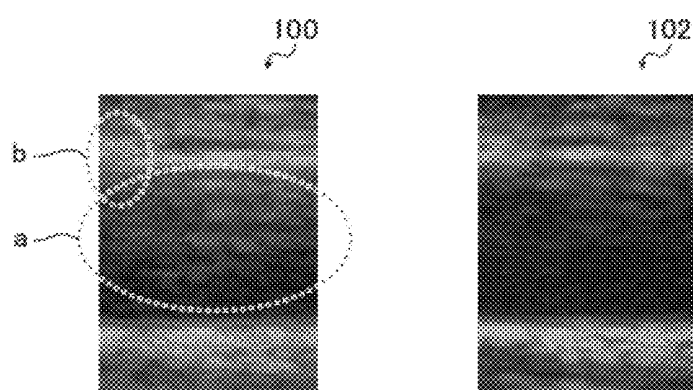


FIG.9B



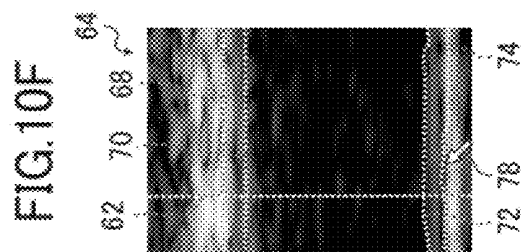
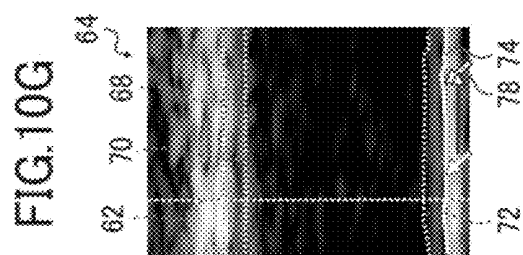
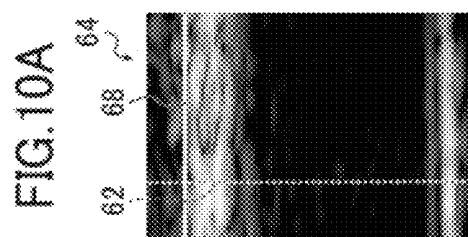
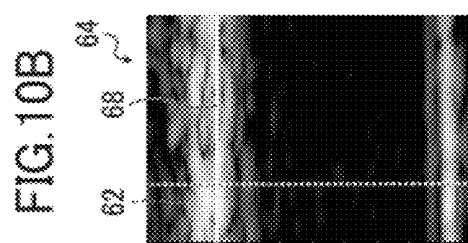
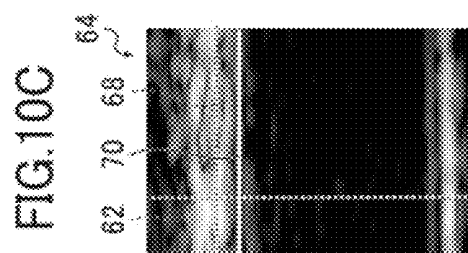
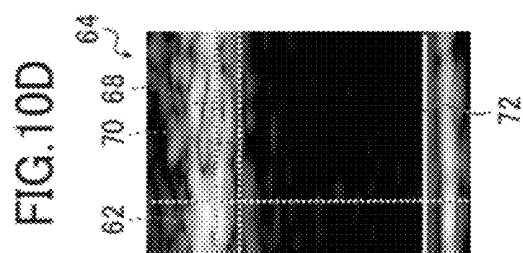
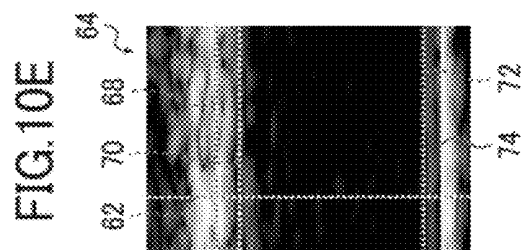


FIG.11A

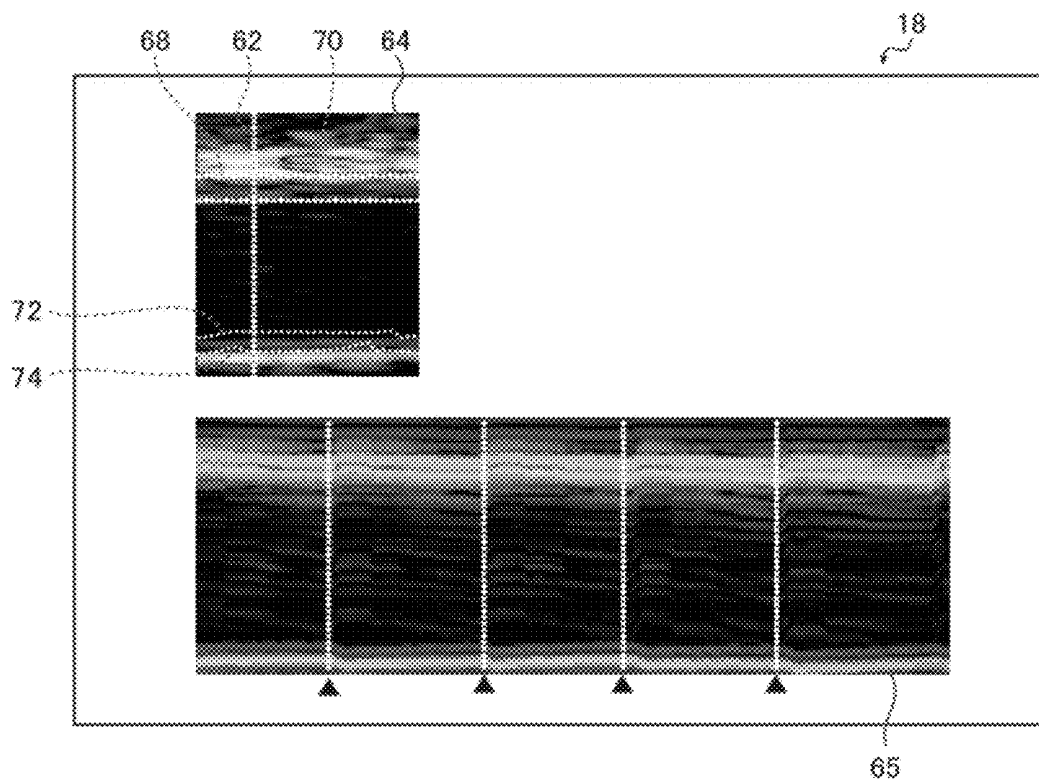
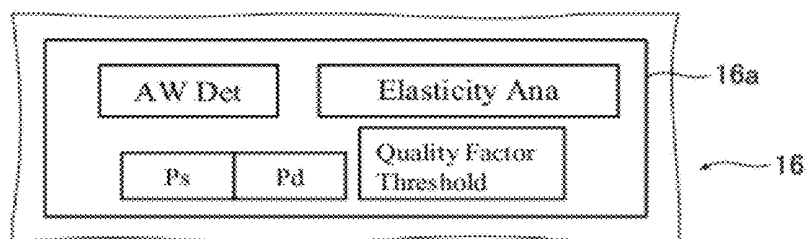
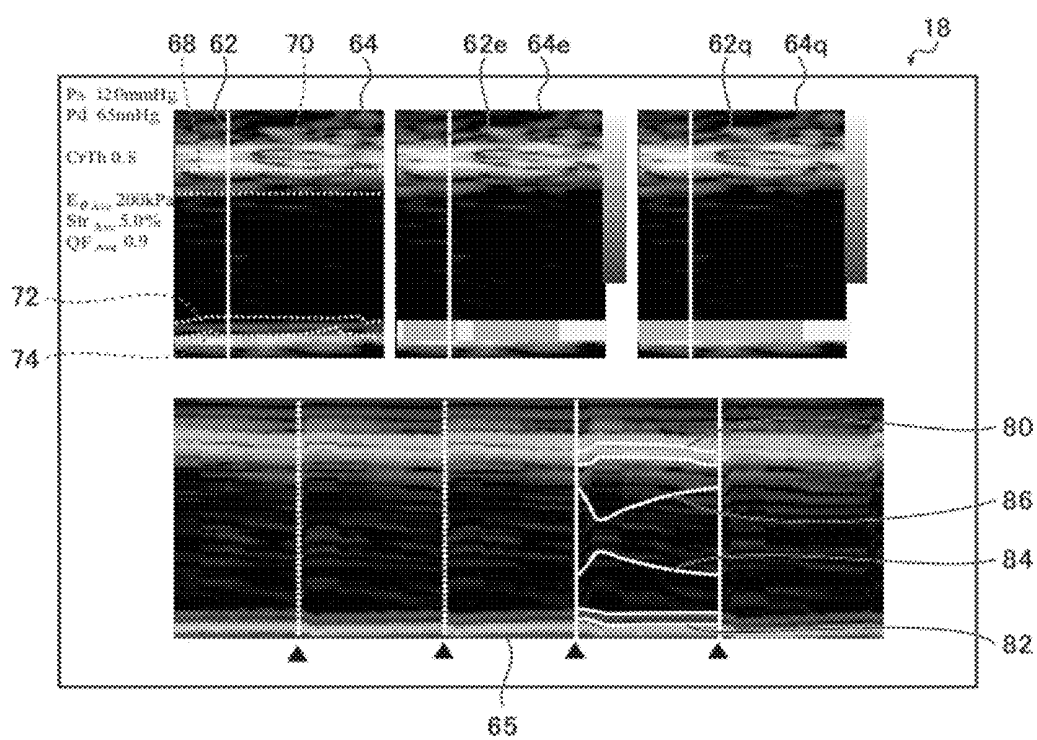


FIG.11B





## ULTRASOUND DIAGNOSTIC APPARATUS

### BACKGROUND OF THE INVENTION

[0001] The present invention relates to an ultrasound diagnostic apparatus which is suitable for measuring an elastic modulus of a vascular wall, and in particular, to an ultrasound diagnostic apparatus which facilitates detection of a blood vessel anterior wall boundary from a B-mode image.

[0002] An ultrasound diagnostic apparatus using an ultrasound image has hitherto been put into practical use in the field of medicine.

[0003] In general, this type of ultrasound diagnostic apparatus has an ultrasound probe (hereinafter, referred to as a probe) and a diagnostic apparatus body. Ultrasonic waves are transmitted from the probe toward a subject, an ultrasonic echo from the subject is received by the probe, and a reception signal is electrically processed by the diagnostic apparatus body to produce an ultrasound image.

[0004] Ultrasonic waves are transmitted toward a blood vessel, a cardiac wall, or the like, an ultrasonic echo therefrom is received, and a reception signal is analyzed to obtain the displacement of a vascular wall or the like. The elastic modulus of the vascular wall, the cardiac wall (heart muscle), or the like is measured from the displacement.

[0005] For example, JP 10-5226 A describes a technique in which ultrasonic waves are transmitted and received with respect to an object moving in synchronization with the heartbeats (cardiac pulsation) to obtain a reception signal of an ultrasonic echo, the instantaneous position of the object is determined using the amplitude and phase of the reception signal, and the large-amplitude displacement motion of the vascular wall based on the heartbeats is tracked, thereby obtaining the elastic modulus of the blood vessel.

[0006] Specifically, the motion velocity waveform of minute vibration of the vascular wall is obtained on the basis of the sequential position of the vascular wall, the tracking trajectory of each of the sections at a predetermined interval in the depth direction in the vascular wall is obtained, and a temporal change in thickness of each section is calculated to obtain the elastic modulus of the blood vessel.

[0007] Similarly, JP 2010-233956 A describes an ultrasound diagnostic apparatus which obtains the displacement of a blood vessel or the like from a reception signal of an ultrasonic echo obtained when ultrasonic waves are transmitted and received with respect to an object moving in synchronization with the heartbeats, and obtains an elastic modulus from the displacement.

[0008] In this ultrasound diagnostic apparatus, a B-mode image and an M-mode image are produced using a reception signal obtained from an object, such as a blood vessel. Blurring due to hand or body movement is detected from the reception signal of the M-mode image, and the positional variation of the probe and the subject is detected using the reception signal of the M-mode image where the blurring is detected. The accuracy of the reception signal is determined from the detection result, and the displacement of the object is obtained using the reception signal of the M-mode image whose accuracy is determined to be high, and the elastic modulus of the vascular wall or the like is measured from the displacement.

[0009] Such measurement of the blood vessel elastic modulus or the like in an ultrasound diagnostic apparatus is normally performed by selecting the position in the azimuth direction on the B-mode image, at which the M-mode image

is displayed, using a display line (line of interest) or the like, displaying and analyzing the M-mode image of the selected display line, and detecting the shift or moving velocity of the vascular wall.

[0010] As described in JP 2010-233956 A, in the ultrasound diagnostic apparatus, the anterior wall of the blood vessel is detected with difficulty compared to the posterior wall (deep side) of the blood vessel. For this reason, in many cases, the analysis of the blood vessel for measuring the blood vessel elastic modulus or the like is performed using the blood vessel posterior wall.

### SUMMARY OF THE INVENTION

[0011] Considering that the blood vessel has a tubular shape, in order to perform more accurate analysis, in some cases it is necessary to recognize the diameter of the blood vessel. For this reason, it is necessary to appropriately detect the position of the blood vessel anterior wall boundary in the B-mode image which is the tomographic image of the blood vessel.

[0012] However, in the existing ultrasound diagnostic apparatus, there are many cases where it is difficult to detect the blood vessel anterior wall boundary from the B-mode image.

[0013] An object of the invention is to solve the problems with the prior art, and to provide an ultrasound diagnostic apparatus which performs measurement of the blood vessel elastic modulus or the like having advantages of suitably detecting the blood vessel anterior wall boundary from the B-mode image, thereby at the time of the measurement of the blood vessel elastic modulus or the like, detecting the blood vessel diameter with high precision and improving operability.

[0014] In order to achieve the above object, the present invention provides an ultrasound diagnostic apparatus comprising: an ultrasound probe which has ultrasound transducers transmitting ultrasonic waves, receiving an ultrasonic echo reflected by a subject, and outputting a reception signal according to the received ultrasonic echo, the ultrasound transducers being capable of outputting reception signals from fundamental waves and harmonics; an image producer which produces a B-mode image and an M-mode image from the reception signal output from the ultrasound transducers with reception of the fundamental waves, and produces a B-mode image from the reception signal output from the ultrasound transducers with reception of the harmonics; and an actuation controller for the ultrasound probe which switches the ultrasound transducers at a predetermined timing between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.

[0015] It is preferable that the ultrasound diagnostic apparatus as above further comprises a prediction unit which predicts constriction and dilatation of a blood vessel diameter, and the actuation controller controls the ultrasound transducers such that the ultrasound transducers perform the output of the reception signal from the harmonics between a time phase in which the blood vessel diameter is maximal and a time phase as a later stage of vascular constriction, the time phases being predicted by the prediction unit. The prediction unit is preferably an electrocardiograph. Alternatively, it is preferable that the ultrasound diagnostic apparatus as above further comprises a moving velocity detector which detects a moving velocity of a vascular wall, and the prediction unit predicts the

constriction and dilatation of the blood vessel diameter using a detection result of the moving velocity of the vascular wall detected by the moving velocity detector.

[0016] It is preferable that the actuation controller switches the ultrasound transducers at a predetermined sound ray interval between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics. Alternatively, it is preferable that the actuation controller switches the ultrasound transducers at a predetermined time interval between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.

[0017] Preferably, the ultrasound diagnostic apparatus of the invention further comprises a blood vessel diameter detector which detects the blood vessel diameter using the B-mode image produced by the image producer from the reception signal of the harmonics, or using the B-mode image produced by the image producer from the reception signal of the harmonics and the B-mode image produced by the image producer from the reception signal of the fundamental waves.

[0018] It is more preferable that the ultrasound diagnostic apparatus of the invention further comprises a display unit, and the B-mode image produced by the image producer from the reception signal of the harmonics and the B-mode image produced by the image producer from the reception signal of the fundamental waves are displayed on the display unit in parallel.

[0019] The ultrasound diagnostic apparatus of the invention configured as above performs at a predetermined timing so-called harmonic imaging in which second and higher harmonics are received to produce an ultrasound image, in addition to normal transmission/reception of ultrasonic waves using fundamental waves, thereby producing B-mode images by both fundamental waves and harmonic imaging.

[0020] With harmonic imaging, it is possible to produce a B-mode image which has little so-called fogging or noise and in which the boundary of the blood vessel anterior wall is satisfactorily reproduced.

[0021] For this reason, according to the ultrasound diagnostic apparatus of the invention, it is possible to appropriately detect the anterior wall boundary and the posterior wall boundary of the blood vessel from the B-mode image by harmonic imaging and even from the B-mode image by normal transmission/reception of fundamental waves, thereby detecting the diameter of the blood vessel or the like.

[0022] Therefore, according to the ultrasound diagnostic apparatus of the invention, it is possible to appropriately recognize the diameter of the blood vessel or the like at the time of the measurement of the blood vessel elastic modulus, thereby performing more accurate measurement with satisfactory operability.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a diagram conceptually illustrating an example of an ultrasound diagnostic apparatus of the invention.

[0024] FIG. 2 is a block diagram conceptually illustrating the configuration of the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0025] FIG. 3 is a flowchart for explaining an example of elasticity measurement of a vascular wall in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0026] FIG. 4 is a conceptual diagram for explaining an ultrasound diagnosis for elasticity measurement of a vascular wall.

[0027] FIGS. 5A and 5B are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0028] FIGS. 6A and 6B are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0029] FIGS. 7A to 7C are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0030] FIGS. 8A and 8B are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0031] FIG. 9A is a conceptual diagram illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1, and FIG. 9B illustrates an example of B-mode images by fundamental waves and by harmonic imaging.

[0032] FIGS. 10A to 10G are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0033] FIGS. 11A and 11B are conceptual diagrams illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

[0034] FIG. 12 is a conceptual diagram illustrating an example of image display in the ultrasound diagnostic apparatus illustrated in FIG. 1.

#### DETAILED DESCRIPTION OF THE INVENTION

[0035] Hereinafter, an ultrasound diagnostic apparatus of the invention will be described in detail on the basis of a preferred example illustrated in the accompanying drawings.

[0036] FIG. 1 conceptually illustrates the appearance of an example of the ultrasound diagnostic apparatus of the invention.

[0037] As illustrated in FIG. 1, an ultrasound diagnostic apparatus 10 basically has a diagnostic apparatus body 12, an ultrasound probe 14, an operating panel 16, and a display 18. Casters 24 are arranged at the lower end of the ultrasound diagnostic apparatus 10, such that the apparatus can be easily moved by human power.

[0038] The ultrasound probe 14 (hereinafter, referred to as a probe 14) performs transmission/reception of ultrasonic waves, and supplies a reception signal according to a received ultrasonic echo to the diagnostic apparatus body 12.

[0039] The probe 14 is a known ultrasound probe which is used in various ultrasound diagnostic apparatuses. The probe 14 has so-called ultrasound transducers (ultrasonic piezoelectric transducers) arranged in a one-dimensional or two-dimensional array which transmit ultrasonic waves toward a subject, receive an ultrasonic echo reflected by the subject, and output an electrical signal (reception signal) according to the received ultrasonic echo.

[0040] In the ultrasound diagnostic apparatus 10 of the invention, the ultrasound transducers of the probe 14 can produce not only an ultrasound image by transmission/reception of ultrasonic waves using fundamental waves (ultrasonic waves having the center frequency) but also an ultrasound image by so-called harmonic imaging in which second and higher harmonics of transmitted ultrasonic waves are received and reception signals are output.

[0041] The transmission/reception of ultrasonic waves in the probe 14 when harmonic imaging is performed may be performed by a known method, for example, a method in which ultrasonic waves having a frequency half of fundamental waves are transmitted and harmonics having the same frequency as the fundamental waves are received, or the like.

[0042] In the invention, as the probe 14, various known ultrasound probes may be used insofar as the production of ultrasound images by fundamental waves and harmonic imaging is possible. Accordingly, the type of the probe 14 is not particularly limited, and various types, such as a convex type, a linear type, and a sector type, may be used. An external probe or a probe for an ultrasound endoscope, such as a radial scan type, may be used.

[0043] In the illustrated example, the probe 14 and the diagnostic apparatus body 12 are connected together by a cable 20. However, the invention is not limited thereto, a transmission circuit 28, a reception circuit 30, a transmission/reception controller 32, and the like described below may be arranged in the probe 14, and the probe 14 and the diagnostic apparatus body 12 may be connected together by wireless communication.

[0044] The display 18 is a known display (display device).

[0045] In the ultrasound diagnostic apparatus 10, as in various ultrasound diagnostic apparatuses, the display 18 displays an ultrasound image according to a reception signal output from the probe 14, information of the subject, selection means or instruction means for operation by a GUI (Graphical User Interface), a region of interest (hereinafter, referred to as ROI), an elasticity measurement result of a vascular wall described below, and the like.

[0046] The operating panel 16 is provided to operate the ultrasound diagnostic apparatus 10.

[0047] Though not illustrated, in the ultrasound diagnostic apparatus 10, the operating panel 16 has arranged therein selection means for selecting various modes, such as a B mode and an M mode, a trackball (track pad/touch pad) for moving a cursor, a line, or the like displayed on the display 18, a set button for determining (confirming) selection or operation, a freeze button for switching between motion image display and still image display, changing means for changing the visual field depth of an ultrasound image, gain adjusting means, a zoom button for enlarging an ultrasound image, and the like.

[0048] As the modes of the ultrasound diagnostic apparatus 10, in addition to the modes of the normal ultrasound diagnostic apparatus, such as a B mode and an M mode, a VE mode (Vascular Elasticity Mode) for measuring the elastic modulus of the vascular wall is set.

[0049] Though not illustrated, the operating panel 16 also has arranged therein a touch panel 16a (see FIG. 6B) which is a display device for operation by GUI.

[0050] The diagnostic apparatus body 12 controls the overall operation of the ultrasound diagnostic apparatus 10, and also performs various processes for producing an ultrasound image according to the reception signal output from the probe 14, displaying the ultrasound image on the display 18, and measuring a blood vessel elastic modulus.

[0051] The diagnostic apparatus body 12 is constituted using, for example, a computer.

[0052] FIG. 2 is a block diagram conceptually illustrating the configuration of the ultrasound diagnostic apparatus 10.

[0053] As illustrated in FIG. 2, the diagnostic apparatus body 12 has the transmission circuit 28, the reception circuit

30, the transmission/reception controller 32, an image producer 34, a storage unit 36, a boundary detector 40, a tracker 42, a heartbeat detector 46, an elastic modulus calculator 50, and a display processor 52.

[0054] The image producer 34 has a B-mode image producer 56 and an M-mode image producer 58.

[0055] The above-mentioned probe 14 is connected to the transmission circuit 28 and the reception circuit 30. The transmission/reception controller 32 is connected to the transmission circuit 28 and the reception circuit 30. If necessary, the heartbeat detector 46 is connected to the transmission/reception controller 32. The reception circuit 30 is connected to the image producer 34.

[0056] The image producer 34 is connected to the display processor 52. The B-mode image producer 56 and the M-mode image producer 58 of the image producer 34 are connected to the storage unit 36. The B-mode image producer 58 is also connected to the boundary detector 40. If necessary, the heartbeat detector 46 is connected to the M-mode image producer 58.

[0057] The storage unit 36 is connected to the tracker 42, the heartbeat detector 46, and the display processor 52. The heartbeat detector 46 and the boundary detector 40 are connected to the tracker 42 and the display processor 52 together. The tracker 42 is connected to the display processor 52 and the elastic modulus calculator 50, and the elastic modulus calculator 50 is connected to the display processor 52.

[0058] The transmission/reception controller 32 sequentially sets the transmission direction of an ultrasonic beam and the reception direction of an ultrasonic echo of the probe 14 through the transmission circuit 28 and the reception circuit 30.

[0059] The transmission/reception controller 32 also has a transmission control function of selecting a transmission delay pattern in accordance with the set transmission direction and a reception control function of selecting a reception delay pattern in accordance with the set reception direction.

[0060] The transmission delay pattern is the pattern of a delay time which is given to an actuation signal of each ultrasound transducer so as to produce an ultrasonic beam to a desired direction by ultrasonic waves transmitted from a plurality of ultrasound transducers of the probe 14. The reception delay pattern is the pattern of a delay time which is given to a reception signal so as to extract an ultrasonic echo from a desired direction by ultrasonic waves received by a plurality of ultrasound transducers.

[0061] A plurality of transmission delay patterns and a plurality of reception delay patterns are stored in an internal memory (not illustrated), and are appropriately selected and used depending on the situation.

[0062] In the ultrasound diagnostic apparatus 10 of the invention, the transmission/reception controller 32 controls the actuation of the transmission circuit 28 and the reception circuit 30 such that the probe 14 is actuated with switching between ultrasonic wave transmission/reception using fundamental waves and ultrasonic wave transmission/reception for harmonic imaging at a predetermined timing. In other words, the transmission/reception controller 32 controls the actuation of the transmission circuit 28 and the reception circuit 30 such that the ultrasonic wave transmission/reception for harmonic imaging is incorporated into the ultrasonic wave transmission/reception using fundamental waves at a predetermined timing.

[0063] This will be described below in detail.

[0064] In the ultrasound diagnostic apparatus 10 of the invention, the ultrasonic wave transmission/reception and the production of the ultrasound image (B-mode image) by harmonic imaging may be performed by known methods.

[0065] The transmission circuit 28 includes a plurality of channels, and produces a plurality of actuation signals which are respectively applied to a plurality of ultrasound transducers of the probe 14. At this time, it is possible to give the delay time to each of a plurality of actuation signals on the basis of the transmission delay pattern selected by the transmission/reception controller 32.

[0066] The transmission circuit 28 may adjust the delay amount of each of a plurality of actuation signals such that ultrasonic waves transmitted from a plurality of ultrasound transducers of the probe 14 produce an ultrasonic beam, and may respectively supply the adjusted actuation signals to the ultrasound transducers. Alternatively, the transmission circuit 28 may supply to the probe 14 a plurality of actuation signals made up such that ultrasonic waves transmitted from a plurality of ultrasound transducers at a time cover the entire imaging region of the subject.

[0067] Similarly to the transmission circuit 28, the reception circuit 30 includes a plurality of channels. The reception circuit 30 amplifies a plurality of analog signals received through a plurality of ultrasound transducers and converts the amplified analog signals to digital reception signals.

[0068] A reception focusing process is performed by giving the delay time to each of a plurality of reception signals on the basis of the reception delay pattern selected by the transmission/reception controller 32 and adding the reception signals. With this reception focusing process, the focus of the ultrasonic echo is narrowed to produce a sound ray signal (sound ray data).

[0069] The produced sound ray data is supplied to the image producer 34.

[0070] The image producer 34 performs a preprocess, such as Log (logarithmic) compression or gain adjustment, on the supplied sound ray data to produce image data of the ultrasound image, converts (raster-converts) the image data to image data based on a normal television signal scan system, performs a necessary image process, such as a gradation process, on the image data and outputs the image data to the display processor 52.

[0071] The image producer 34 has a B-mode image producer 56 which produces a B-mode image, and an M-mode image producer 58 which produces an M-mode image. The B-mode image and the M-mode image may be produced by a known method.

[0072] The display processor 52 produces display data for display on the display 18 in accordance with image data of the ultrasound image supplied from the image producer 34, image data of the ultrasound image read from the storage unit 36, operation (input instruction) on the operating panel 16, the measurement result (analysis result) of a vascular wall elastic modulus described below, and the like, and displays the display data on the display 18.

[0073] In the ultrasound diagnostic apparatus 10 of the illustrated example, the storage unit 36, the boundary detector 40, the tracker 42, the heartbeat detector 46, and the elastic modulus calculator 50 of the diagnostic apparatus body 12 are primarily used in the VE mode in which the elastic modulus of the vascular wall is measured.

[0074] Hereinafter, the respective units, such as the storage unit 36 and the boundary detector 40, and the ultrasound

diagnostic apparatus 10 of the invention will be described in detail by describing the action of the ultrasound diagnostic apparatus 10 in the VE mode with reference to a flowchart of FIG. 3 and FIGS. 5 to 12.

[0075] In the following description, with regard to the display of the display 18, the display processor 52 performs necessary process, such as line production, even though not particularly described.

[0076] If an ultrasound diagnosis by the ultrasound diagnostic apparatus 10 starts, under the control of the transmission/reception controller 32, the transmission circuit 28 causes the ultrasound transducer of the probe 14 to transmit ultrasonic waves, and the reception circuit 30 processes the reception signal output from the probe 14 to produce a sound ray signal and outputs the sound ray signal to the image producer 34.

[0077] As an example, the B mode is selected, as conceptually illustrated in FIG. 4, a carotid artery c of the subject is used as a measurement target, and the probe 14 is brought into contact with a neck n. In this case, a B-mode image produced by the image producer 34 (B-mode image producer 56) is processed by the display processor 52 and displayed on the display 18.

[0078] If the intended carotid artery c can be appropriately observed, and the VE mode is selected by mode selection means of the operating panel 16 (in the following description, "of the operating panel 16" is omitted), as conceptually illustrated in FIG. 5A, the display processor 52 displays the ROI 60 representing the region of interest in the B-mode image.

[0079] In this state, the position of the ROI 60 in the B-mode image can be moved by operation of the trackball. If the set button is depressed, the position of the ROI 60 is fixed, and the size of the ROI 60 can be changed by operation of the trackball.

[0080] Each time the set button is depressed, the position change of the ROI 60 and the size adjustment of the ROI 60 can be alternately carried out.

[0081] If the zoom button is depressed in this state, the adjustment of the position or the size of the ROI 60 ends, and the ROI 60 is set. In response to this situation, the transmission/reception controller 32 increases the frame rate to be higher than before the instruction to set the ROI 60 (for example, to be equal to or higher than 200 Hz, or at least five times higher than before the ROI setting instruction). In addition, the M-mode image producer 58 starts to produce an M-mode image of the ROI 60, and as illustrated in FIG. 5B, a B-mode image 64 where the portion of the ROI 60 is enlarged and an M-mode image 65 of the ROI 60 (at the position of a selection line 62) are displayed simultaneously.

[0082] The simultaneous display (dual mode display) of the B-mode image 64 and the M-mode image 65 may be performed in the same manner as so-called B/M-mode display in the known ultrasound diagnostic apparatus.

[0083] If the zoom button is depressed, the transmission/reception controller 32 controls the actuation of the transmission circuit 28 and the reception circuit 30 such that the probe 14 switches between the ultrasonic wave transmission/reception using fundamental waves and the ultrasonic wave transmission/reception for harmonic imaging at a predetermined timing.

[0084] Accordingly, the B-mode image producer 56 produces a B-mode image by fundamental waves and a B-mode image by harmonic imaging.

[0085] In the illustrated example, the B-mode image 64 to be displayed is the B-mode image by fundamental waves. That is, in the invention, it is not necessary that the B-mode image by harmonic imaging is displayed on the display 18.

[0086] The switching timing between the ultrasonic wave transmission/reception using fundamental waves and the ultrasonic wave transmission/reception for harmonic imaging (the timing at which the ultrasonic wave transmission/reception for harmonic imaging is incorporated into the ultrasonic wave transmission/reception using fundamental waves) is not particularly limited.

[0087] As an example, there is a method in which the ultrasonic wave transmission/reception using fundamental waves and the ultrasonic wave transmission/reception for harmonic imaging are alternately performed for each sound ray (for each line). Alternatively, the ultrasonic wave transmission/reception for harmonic imaging may be incorporated into the ultrasonic wave transmission/reception using fundamental waves at an interval appropriately set such that, for instance, fundamental wave transmission/reception for two or three sound rays is followed by harmonic imaging for one sound ray.

[0088] It is also possible to set an appropriate time interval of 0.1 second, for instance, instead of an interval based on sound rays in one frame, and incorporate a frame obtained by harmonic imaging between frames obtained using fundamental waves at the time interval as set. In that case, for example, it is preferable that the heartbeat detector 46 analyzes the M-mode image to produce the moving velocity waveform of the vascular wall or the change waveform of the blood vessel diameter, thereby finding the timing at which the diameter of the blood vessel starts to rapidly increase, the incorporation of the frame obtained by harmonic imaging is performed before the timing, and the B-mode image by harmonic imaging is used for blood vessel analysis or image display described below.

[0089] Particularly when it is not necessary to display the B-mode image of harmonic imaging, a method in which the ultrasonic wave transmission/reception using fundamental waves is performed, and with regard to only the last sound ray of one frame, the ultrasonic wave transmission/reception for harmonic imaging is performed may be used. Alternatively, with regard to only a plurality of last sound rays of one frame appropriately set, the ultrasonic wave transmission/reception for harmonic imaging may be performed.

[0090] Alternatively, the dilatation and constriction of the blood vessel diameter may be predicted by a prediction means, and with regard to one sound ray or a plurality of sound rays appropriately set, the ultrasonic wave transmission/reception for harmonic imaging may be performed between the time phase in which the blood vessel diameter is maximal and the time phase as a later stage of vascular constriction. If this timing is set, the B-mode image by harmonic imaging is obtained in a state where the movement of the vascular wall is small, thereby detecting the blood vessel anterior wall through image analysis or image observation with higher precision.

[0091] The prediction means is not particularly limited, and various methods may be used. For example, an electrocardiograph may be used as the prediction means, the measurement result of the electrocardiograph may be supplied to, for example, the heartbeat detector 46, and the heartbeat detector 46 may predict the constriction and dilatation of the blood vessel diameter from the obtained electrocardiogram to find

the interval between the time phase in which the blood vessel diameter is maximal and the time phase as a later stage of vascular constriction. Alternatively, for example, the heartbeat detector 46 may analyze the M-mode image to detect the moving velocity of the vascular wall or the heartbeats from the moving velocity (the time at which the velocity starts to increase) in the depth direction of a white line (bright line) extending in the horizontal direction, and the constriction and dilatation of the blood vessel diameter may be predicted from the moving velocity of the vascular wall or the heartbeats to find the interval between the time phase in which the blood vessel diameter is maximal and the time phase as a later stage of vascular constriction.

[0092] In FIG. 5B, the upper side is the B-mode image 64, and the lower side is the M-mode image 65.

[0093] In the B-mode image 64, the horizontal direction of the drawing is the azimuth direction (the arrangement direction of the ultrasound transducers (in the two-dimensional arrangement, the longitudinal direction)), and the vertical direction is the depth direction (the transmission/reception direction of ultrasonic waves). The upper side in the depth direction is the side on which the depth is shallow (the probe 14 side).

[0094] A selection line 62 which extends in the depth direction to select the display position of the M-mode image (the display line of the M-mode image) in the azimuth direction in the B-mode image is displayed in the B-mode image. The selection line 62 is movable in the azimuth direction (left-right direction) by the trackball.

[0095] In the M-mode image 65, the horizontal direction is the direction of the time axis. The time flows from left to right, and the left side of a gap 65a becomes a current frame (that is, the right side of the gap 65a is a previous frame). Similarly to the B-mode image 64, the vertical direction is the depth direction. The upper side in the depth direction is the side on which the depth is shallow.

[0096] In FIG. 5B, the M-mode image 65 displayed on the display 18 is the M-mode image 65 at the position of the selection line 62 set in advance.

[0097] The M-mode image producer 58 produces an M-mode image at a predetermined position (a predetermined position set in advance or a selected position) in the azimuth direction or a selected position in the azimuth direction as well as over the entire region of the B-mode image 64 in the azimuth direction.

[0098] The B-mode image (B-mode image data) of the ROI 60 produced by the B-mode image producer 56 and the M-mode image (M-mode image data) produced by the M-mode image producer 58 are stored in the storage unit 36 together.

[0099] The temporal amount of an image which is stored in the storage unit 36 is not particularly limited, while a duration including two or more common heartbeats is preferred. Accordingly, it is preferable that the storage unit 36 stores the latest B-mode image and M-mode image which are each three seconds or longer in duration.

[0100] As described above, when the ultrasonic wave transmission/reception for harmonic imaging is performed between the time phase in which the blood vessel diameter is maximal and the time phase as a later stage of vascular constriction, the M-mode image produced by the M-mode image producer 58 is also supplied to the heartbeat detector 46.

[0101] At this time, the heartbeat detector 46 predicts the cardiac constriction and dilatation in the above-described

manner, and supplies the prediction result to the transmission/reception controller 32. In response to this situation, the transmission/reception controller 32 performs the ultrasonic wave transmission/reception for harmonic imaging between the time phase in which the blood vessel diameter is maximal and the time phase as a later stage of vascular constriction in accordance with the supplied prediction result of the cardiac constriction and dilatation.

[0102] As described above, the selection line 62 can be moved in the azimuth direction by the trackball.

[0103] The position of the selection line 62 and the M-mode image are moved together. That is, if the selection line 62 is moved in the left-right direction by the trackball, the display processor 52 displays the M-mode image of the position of the selection line 62 on the display 18.

[0104] The operator depresses the freeze button if it is determined that an appropriate image is obtained.

[0105] If the freeze button is depressed, the display processor 52 reads necessary image data from the storage unit 36, and as illustrated in FIG. 6A, the display processor 52 rearranges the M-mode image 65 of the position of the selection line 62 such that the time at which the freeze button is depressed is on the rightmost side (latest position) and displays the M-mode image 65 with the still image of the B-mode image 64 on the display 18. Simultaneously, the selection line 62 becomes a broken line and is not movable (inactive state).

[0106] As illustrated in FIG. 6B, an “AW Det” button for instructing to set the boundary of the vascular wall described below, an “Elasticity Ana” button for instructing to start the analysis of the vascular wall elastic modulus, a “Ps” button and a “Pd” button for inputting the blood pressure of the subject, and a “Quality Factor Threshold” button for inputting a reliability threshold value are displayed on the touch panel 16a of the operating panel 16. At this time, the “Elasticity Ana” button is not selectable.

[0107] If the freeze button is depressed, the heartbeat detector 46 detects the heartbeats (automatically detects the heartbeats) for all the M-mode images stored in the storage unit 36. The detection result of the heartbeats is sent to the storage unit 36, and added to the corresponding M-mode image as information.

[0108] The detection result of the heartbeats is also sent to the display processor 52, and the detection result of the heartbeats is displayed in the M-mode image 65 which is currently displayed.

[0109] The method of detecting the heartbeats is not particularly limited. As an example, an M-mode image may be analyzed, and the heartbeats may be detected using the moving velocity (the time at which the velocity starts to increase) in the depth direction of a white line (bright line) extending in the horizontal direction, the pulsation of the motion in the depth direction of the white line, or the like. Alternatively, an electrocardiograph (electrocardiogram) may be used to detect the heartbeats.

[0110] As illustrated in FIG. 6A, the display processor 52 displays the detection result of the heartbeats in the M-mode image 65 by a triangular mark and a line. In the illustrated example, the time at which the latest heartbeat starts is indicated by a solid line, the time at which the same heartbeat ends is indicated by a thin line, and the position related to other heartbeats is indicated by a broken line. The lines may be distinguished by changing the line color instead of or in addition to the line type.

[0111] When there is the heartbeat which is not detected, the heartbeat is displayed at an appropriate position in accordance with the interval of heartbeats prior to and subsequent to the heartbeat in question, or the like.

[0112] The B-mode image 64 when the freeze button is depressed is a B-mode image at the time when the latest heartbeat starts, with the time being indicated in the M-mode image 65 by a solid line.

[0113] If the lines of the heartbeats are displayed in the M-mode image 65, the selection line 62 in the B-mode image becomes a solid line and is movable in the left-right direction by the trackball. That is, the selection line 62 is in the active state. Whether or not the line is active may be distinguished by changing the line color instead of or in addition to the line type in a similar manner to the above.

[0114] In this state, if the selection line 62 is moved in the left-right direction by the trackball, the display processor 52 reads an M-mode image corresponding to the position of the selection line 62 from the storage unit 36, and displays the image on the display 18 along with the detection result of the heartbeats. That is, the selection line 62 is moved by the trackball even after freeze, thereby selecting the display position (display line) of the M-mode image 65 in the B-mode image 64 over the entire region in the azimuth direction in the B-mode image 64.

[0115] Therefore, according to this example, the M-mode image 65 of an arbitrary position in the azimuth direction of the set ROI 60 is displayed, such that the M-mode image 65 and an image corresponding to each heartbeat in the M-mode image can be observed and confirmed.

[0116] If the set button is depressed in a state where the selection line 62 of the B-mode image 64 is movable, it is determined that the display position (display line) of the M-mode image is selected. As illustrated in FIG. 7A, the selection line 62 of the B-mode image 64 becomes a broken line, such that the movement by the trackball is impossible. Simultaneously, lines indicating the latest heartbeat become a solid line in the M-mode image 65.

[0117] If the lines indicating the latest heartbeat become a solid line in the M-mode image 65, the heartbeat is selectable by the trackball.

[0118] As an example, when the set button is depressed, as illustrated in FIGS. 7A and 7B, the lines indicating the latest heartbeat become a solid line, and the heartbeat is selected. In this state, for example, if the trackball rotates left, as illustrated in FIG. 7C, a line corresponding to the end of the latest heartbeat becomes a broken line, lines corresponding to the second latest heartbeat become a solid line, and the heartbeat is selected. If the trackball further rotates left, lines corresponding to the second latest heartbeat become a broken line, lines corresponding to the third latest heartbeat become a solid line, and the heartbeat is selected.

[0119] If the trackball rotates right, similarly, lines corresponding to later heartbeats are sequentially selected.

[0120] In response to the selection of the heartbeat, the display processor 52 reads from the storage unit 36, the B-mode image at the start position of the selected heartbeat, that is, the B-mode image which is captured at the time (time phase) corresponding to the start position of the selected heartbeat, and changes the B-mode image 64 displayed on the display 18 to this image.

[0121] If the set button is depressed in a state where the heartbeats are selectable, it is determined that the selection of

the heartbeats ends, the selected heartbeat is confirmed, and fine adjustment of the selected heartbeat can be performed.

[0122] If a heartbeat in the M-mode image 65 displayed on the display 18 is selected and confirmed, the same heartbeat is selected in all the M-mode images (that is, the M-mode images over the entire region in the azimuth direction of the B-mode image 64) stored in the storage unit 36.

[0123] As an example, if it is determined that the latest heartbeat is selected and the set button is depressed, as illustrated in FIG. 8A, first, a line corresponding to the end of the selected heartbeat becomes a thin line, and the position (time) of a line corresponding to the start of the selected heartbeat is movable in the left-right direction (time direction) by the trackball as indicated by an arrow t, such that fine adjustment of the start position of the heartbeat can be performed.

[0124] If the set button is depressed after the start position of the heartbeat is adjusted by the trackball as required, as illustrated in FIG. 8B, a line corresponding to the end of the selected heartbeat becomes a normal solid line, and a line corresponding to the start of the selected heartbeat becomes a thin line. Accordingly, the position of the line corresponding to the end of the selected heartbeat is movable in the left-right direction by the trackball as indicated by the arrow t, such that fine adjustment of the end position of the heartbeat can be performed.

[0125] Although the result of fine adjustment of the heartbeat may be reflected only in the M-mode image 65 subjected to fine adjustment, it is preferable that the result is also reflected in all the M-mode images stored in the storage unit 36.

[0126] When the start position of the heartbeat is adjusted, the display processor 52 reads the B-mode image at the adjusted heartbeat start position from the storage unit 36, and the B-mode image 64 displayed on the display 18 is changed to this image.

[0127] The results of heartbeat selection and possible fine adjustment are also supplied to the tracker 42.

[0128] If the set button is depressed in a state where the position corresponding to the end of the selected heartbeat is adjustable, the state where the selection line 62 of the B-mode image 64 illustrated in FIG. 6A is movable, that is, the state where the display line of the M-mode image 65 is selectable in the B-mode image 64 is returned.

[0129] That is, in the ultrasound diagnostic apparatus 10 of the illustrated example, the processes “display line selection”→“heartbeat selection”→“heartbeat fine adjustment” can be repeatedly performed. In other words, the processes “display line selection”→“heartbeat selection”→“heartbeat fine adjustment” may be performed in a looped manner.

[0130] Accordingly, it becomes possible to more suitably select the heartbeat most appropriate for analysis to measure the vascular wall elasticity described below from all the stored M-mode images.

[0131] If the “AW Det” button of the touch panel, not the set button, is depressed in a state where the position corresponding to the end of the selected heartbeat is adjustable, as illustrated in FIG. 9A, the selection line 62 of the B-mode image 64 and the lines representing the heartbeats in the M-mode image 65 all become a broken line and are inoperable, and a vascular wall detection mode is reached.

[0132] When the B-mode image by harmonic imaging can be produced, such as the case where sound rays of fundamental waves and sound rays of harmonic imaging are alternately

produced, as illustrated in FIG. 9A, a B-mode image 64h by harmonic imaging is displayed parallel with the B-mode image 64 by fundamental waves.

[0133] FIG. 9B illustrates an example of a B-mode image by fundamental waves and an example of a B-mode image by harmonic imaging at the same measurement point.

[0134] As illustrated in FIG. 9B, in a B-mode image 100 by fundamental waves (on the left side of the drawing), as indicated by a dotted line a, there is noise, which is liable to result in erroneous recognition or erroneous detection of the vascular wall, in the vascular lumen. In the B-mode image 100 by fundamental waves, as indicated by a dotted line b, there is a high-luminance linear portion which is liable to be erroneously recognized as a vascular wall. In particular, when automatic detection or the like of the vascular wall using maximum luminance detection or the like is performed, a wrong location is liable to be detected.

[0135] In contrast, in a B-mode image 102 by harmonic imaging (on the right side of the drawing), there is little noise or high-luminance portion which results in erroneous recognition or erroneous detection.

[0136] That is, according to harmonic imaging, it is possible to obtain an ultrasound image with little fogging or noise of the blood vessel anterior wall compared to the B-mode image by fundamental waves.

[0137] Accordingly, the B-mode image 64h by harmonic imaging is displayed parallel with the B-mode image 64 by fundamental waves, such that, when subsequently setting the boundary of the blood vessel anterior wall (setting lines 68 and 70), it is possible to perform the setting with reference to the B-mode image 64h by harmonic imaging. For this reason, with this configuration, a tester can set a line of blood vessel anterior wall boundary with ease and high precision with more satisfactory operability.

[0138] If the vascular wall detection mode is reached, first, as illustrated in FIG. 10A, a line 68 corresponding to the adventitia-media boundary of the blood vessel anterior wall is displayed in the B-mode image 64.

[0139] The line 68 is parallel-movable in the up-down direction (depth direction) by the trackball. As illustrated in FIG. 10B, after the line 68 is moved to the position of the adventitia-media boundary of the blood vessel anterior wall by the trackball, the set button is depressed. As illustrated in FIG. 9A, when the B-mode image 64h by harmonic imaging is displayed in addition to the B-mode image 64 by fundamental waves, it is possible to set the line 68 at the adventitia-media boundary of the blood vessel anterior wall in the B-mode image 64 with reference to the B-mode image 64h by harmonic imaging.

[0140] If the set button is depressed, as illustrated in FIG. 10C, the line 68 corresponding to the adventitia-media boundary of the blood vessel anterior wall becomes a broken line and is confirmed in the B-mode image 64, and a line 70 corresponding to the intima-lumen boundary of the blood vessel anterior wall is displayed.

[0141] Similarly, the line 70 is movable in the up-down direction by the trackball, and after the line 70 is moved to the position of the intima-lumen boundary of the blood vessel anterior wall, the set button is depressed. Similarly, when the B-mode image 64h by harmonic imaging is displayed, it is possible to set the line 70 at the intima-lumen boundary of the blood vessel anterior wall in the B-mode image 64 with reference to the B-mode image 64h by harmonic imaging.

[0142] If the set button is depressed in a state where the line 70 is movable, as illustrated in FIG. 10D, the line 70 corresponding to the intima-lumen boundary of the blood vessel anterior wall becomes a broken line and is confirmed in the B-mode image 64, and a line 72 corresponding to the intima-lumen boundary of the blood vessel posterior wall is displayed. Similarly, after the line 72 is moved to the position of the intima-lumen boundary of the blood vessel posterior wall by the trackball, the set button is depressed.

[0143] If the set button is depressed in a state where the line 72 is movable, as illustrated in FIG. 10E, the line 72 corresponding to the intima-lumen boundary of the blood vessel posterior wall becomes a broken line and is confirmed in the B-mode image 64, and a line 74 corresponding to the adventitia-media boundary of the blood vessel posterior wall is displayed. Similarly, after the line 74 is moved to the position of the adventitia-media boundary of the blood vessel posterior wall by the trackball, the set button is depressed.

[0144] The information of each boundary of the vascular wall is supplied to the boundary detector 40.

[0145] If the set button is depressed in a state where the line 74 is movable, the setting of the lines corresponding to all the boundaries ends, and the boundary detector 40 automatically detects the intima-lumen boundary and the adventitia-media boundary of the posterior wall using the set line 72 of the intima-lumen boundary and the set line 74 of the adventitia-media boundary. The result of the automatic detection of both boundaries is sent to the display processor 52 and the tracker 42, and as illustrated in FIG. 10F, the detection result is displayed.

[0146] The method of automatically detecting these boundaries is not particularly limited, and various methods may be used. As an example, a method is used in which a B-mode image is analyzed, continuous high-luminance portions at the positions of the line 72 and the line 74 are tracked to detect the intima-lumen boundary and the adventitia-media boundary.

[0147] If the automatic detection of the intima-lumen boundary and the adventitia-media boundary of the blood vessel posterior wall by the boundary detector 40 ends, as illustrated in FIG. 10F, a cursor 78 is displayed in the B-mode image 64 (the cursor 78 is not displayed until the automatic detection of the blood vessel posterior wall ends).

[0148] The cursor 78 is movable by the trackball. If the cursor 78 is moved to the line representing the automatically detected intima-lumen boundary or adventitia-media boundary, and the set button is depressed, the line closer to the cursor 78 becomes a solid line. The line which has become a solid line is correctable.

[0149] For example, as illustrated in FIG. 10G, it is assumed that the line 74 representing the adventitia-media boundary is selected and becomes a solid line. If the cursor 78 is moved along the line 74 by the trackball, and the set button is depressed again, the line 74 of the region tracked by the cursor is detected again by the boundary detector 40 and rewritten, and the result is sent to the tracker 42.

[0150] If the automatic detection of the intima-lumen boundary and the adventitia-media boundary of the posterior wall ends, and if necessary, the blood vessel posterior wall is corrected, as illustrated in FIG. 11A, all lines become a broken line, and as illustrated in FIG. 11B, the "Elasticity Ana" button of the touch panel 16a is selectable.

[0151] After the "Elasticity Ana" button is selectable, the blood pressure in the heart systole of the subject is input by the "Ps" button, the blood pressure in the heart end diastole of

the subject is input using the "Pd" button, and the reliability threshold value is input using the "Quality Factor Threshold" button. These numerical values may be input by a known method.

[0152] The input of the blood pressure of the subject and the reliability threshold value is not limited to the input after the detection of the vascular wall boundaries has ended. The input may be performed at any timing before analysis described below starts (before the "Elasticity Ana" button described below is depressed).

[0153] In the ultrasound diagnostic apparatus 10, it is usual that before a diagnosis is performed, the subject information is acquired or input. Accordingly, when the subject information includes the information of the blood pressure, the information of the blood pressure may be used.

[0154] If the blood pressure of the subject and the reliability threshold value are input, and the "Elasticity Ana" button is depressed, image analysis starts, and the elastic modulus of the vascular wall is calculated.

[0155] If the "Elasticity Ana" button is depressed, first, the tracker 42 tracks the motions of the blood vessel anterior wall (adventitia-media boundary and intima-lumen boundary) and the blood vessel posterior wall (intima-lumen boundary and adventitia-media boundary) in the selected heartbeat in the M-mode image 65. That is, the blood vessel anterior wall and posterior wall are tracked.

[0156] The tracking of the vascular wall in the M-mode image 65 is performed with the adventitia-media boundary of the blood vessel anterior wall, the intima-lumen boundary of the blood vessel anterior wall, the intima-lumen boundary of the blood vessel posterior wall, and the adventitia-media boundary of the blood vessel posterior wall previously detected (with the lines set) in the B-mode image 64 as a positional starting point (a starting point in the depth direction).

[0157] In regard to the tracking of the vascular wall in the M-mode image 65, a temporal starting point (a starting point on the time axis of the M-mode image) is the time phase of the B-mode image 64, that is, the time at which the B-mode image 64 is captured. That is, in the illustrated example, the start position of the heartbeat which is selected and, if necessary, adjusted in position becomes the temporal starting point for the tracking of the vascular wall.

[0158] In the ultrasound diagnostic apparatus 10, as a preferred form, not only the detected (set) boundaries of the vascular wall but also one or more measurement points in the depth direction may be set in the blood vessel posterior wall. In this way, when one or more measurement points are set in the blood vessel posterior wall, the tracking of the vascular wall is performed at each measurement point.

[0159] The measurement point in the vascular wall may be set in advance, may be automatically set on the basis of a specific algorithm, or may be set by the operator of the ultrasound diagnostic apparatus 10 while viewing the image. These may be used in combination.

[0160] The method of tracking the vascular wall in the M-mode image 65 is not particularly limited, and there are a method which uses continuity of images (luminance) from the starting point of the tracking, a pattern matching method, a zero crossing method, a tissue Doppler method, phase difference tracking, and the like. Of these, any method may be used.

[0161] The tracking result of the vascular wall in the M-mode image by the tracker 42 is supplied to the elastic modulus calculator 50 and the display processor 52.

[0162] The elastic modulus calculator 50 first produces the change waveform of the thickness of the vascular wall (intima-media) and the change waveform of the blood vessel diameter (inner diameter) from the tracking result of the vascular wall. As described above, when one or more measurement points are set in the vascular wall, the change waveform of the vascular wall is produced between the measurement points.

[0163] The change waveform of the thickness of the vascular wall and the change waveform of the blood vessel diameter are sent to the display processor 52.

[0164] The elastic modulus calculator 50 calculates strain in the radial direction of the blood vessel using Equation (1).

$$\epsilon_r = \Delta h_i / h_{di} \quad (1)$$

[0165] In Equation (1),  $\epsilon_r$  denotes strain in the radial direction of the blood vessel between the measurement points,  $\Delta h_i$  denotes the maximum value of a change in thickness of the vascular wall between the measurement points in the heart systole in which the vascular wall is smallest in thickness in one heartbeat, and  $h_{di}$  denotes the thickness between the measurement points in the heart end diastole in which the vascular wall is largest in thickness.

[0166] The elastic modulus calculator 50 calculates an elastic modulus  $E_{\theta i}$  in the circumferential direction of the vascular wall by Equation (2) using the maximum value and the minimum value of the blood pressure input in advance.

$$E_{\theta i} = [1/2] * [1 + (r_d / h_{di})] * [\Delta p / (\Delta h_i / h_{di})] \quad (2)$$

[0167] An elastic modulus  $E_{ri}$  in the radial direction of the vascular wall may be calculated by Equation (3).

$$E_{ri} = \Delta p / (\Delta h_i / h_{di}) \quad (3)$$

[0168] In Equations (2) and (3),  $\Delta h_i$  and  $h_{di}$  are the same as described above,  $\Delta p$  denotes a blood pressure difference between the heart systole and the heart end diastole,  $r_d$  denotes the radius of the vascular lumen in the heart end diastole, and  $h_{di}$  denotes the thickness of the vascular wall in the heart end diastole.

[0169] After the elastic modulus is calculated, the elastic modulus calculator 50 calculates reliability of the elastic modulus.

[0170] The method of calculating reliability of the elastic modulus is not particularly limited, and various known methods may be used. As an example, there is a method in which the waveforms of changes in the blood vessel diameter by the heartbeats of many people, such as 1000 persons are prepared, the model waveform of the change in the blood vessel diameter is created from many waveforms, and reliability of the calculated elastic modulus is calculated using the amount of a shift from the model waveform.

[0171] As described above, if a heartbeat is selected and confirmed in the M-mode image displayed on the display 18, the same heartbeat is selected in all the M-mode images stored in the storage unit 36.

[0172] Accordingly, the processes, such as the tracking of the vascular wall, the production of the change waveforms of the thickness of the vascular wall and the blood vessel diameter, the calculation of strain of the vascular wall, and the calculation of the elastic modulus of the vascular wall and reliability of the elastic modulus, are performed in the selected heartbeat for not only the M-mode image 65 dis-

played on the display 18 but also all the M-mode images stored in the storage unit 36. That is, the processes, such as calculation of the elastic modulus of the vascular wall, in the selected heartbeat are performed over the entire region in the azimuth direction of the B-mode image 64 displayed on the display 18 using the corresponding M-mode images.

[0173] These results are added to the M-mode images stored in the storage unit 36 as information.

[0174] After the calculation over the entire region in the azimuth direction ends, the elastic modulus calculator 50 calculates the average value ( $E_{ave}$ ) of the elastic modulus of the vascular wall, the average value ( $Str_{ave}$ ) of strain of the vascular wall, and the average value ( $QF_{ave}$ ) of reliability of the elastic modulus.

[0175] If the calculation ends, the result is displayed on the display 18.

[0176] FIG. 12 illustrates an example. In the illustrated example, on the right side of the displayed B-mode image 64, the elastic modulus of the blood vessel posterior wall represented in the B-mode image 64 is displayed by a B-mode image 64e. On the right side of the B-mode image 64e which displays the elastic modulus of the blood vessel posterior wall, reliability of the elastic modulus of the vascular wall is displayed by a B-mode image 64q in a similar manner.

[0177] On the left side of the B-mode image 64, the average value ( $E_{ave}$ ) of the elastic modulus of the vascular wall, the average value ( $Str_{ave}$ ) of strain of the vascular wall, and the average value ( $QF_{ave}$ ) of reliability of the elastic modulus are respectively displayed.

[0178] The elastic modulus of the vascular wall is displayed in a strip shape in the B-mode image 64e to overlap the blood vessel posterior wall automatically detected (and corrected as necessary) in the B-mode image 64. On an upper right side of the B-mode image 64e, the index of the elastic modulus is displayed. In the illustrated example, the higher the image density, the higher the elastic modulus.

[0179] That is, in the B-mode image 64e, the density of the strip overlapping the blood vessel posterior wall represents the elastic modulus of the vascular wall at the corresponding position of the blood vessel.

[0180] Similarly, reliability of the elastic modulus is displayed in a strip shape in the B-mode image 64q to overlap the blood vessel posterior wall automatically detected in the B-mode image 64. On an upper right side of the B-mode image 64q, the index of reliability of the elastic modulus is displayed. In the illustrated example, the higher the image density, the higher the reliability of the elastic modulus.

[0181] That is, in the B-mode image 64q, the density of the strip overlapping the blood vessel posterior wall represents reliability of the vascular wall elastic modulus at the corresponding position of the blood vessel.

[0182] The magnitude of the elastic modulus or reliability of the elastic modulus may be realized by changing the image color instead of or in addition to the image density.

[0183] In the display of the result illustrated in FIG. 12, the result is automatically omitted at the position in the azimuth direction where reliability of the result is lower than a threshold value input in advance.

[0184] With regard to the position where the result is omitted, as represented in a right corner portion of the result display of the elastic modulus in the B-mode image 64e or a right corner portion of the result display of reliability in the B-mode image 64q, the display of the strip is thinned.

[0185] In the lower M-mode image 65, a tracking result 80 of the blood vessel anterior wall, a tracking result 82 of the blood vessel posterior wall, a change waveform 84 of the blood vessel diameter, and a change waveform 86 of the thickness of the vascular wall in the M-mode image are displayed in the selected heartbeat.

[0186] As described above, when one or more measurement points are set in the vascular wall in the depth direction, the change waveform of the blood vessel thickness may be output between the measurement points.

[0187] If the measurement result of the elastic modulus of the vascular wall or the like is displayed on the display 18, the selection line 62 becomes a solid line in the B-mode image 64, and is movable in the azimuth direction by the trackball.

[0188] If the selection line 62 is moved in the B-mode image 64, the display processor 52 reads the M-mode image corresponding to the position of the selection line 62 from the storage unit 36 and displays the M-mode image on the display 18. That is, if the selection line 62 is moved by the trackball, the M-mode image 65 is changed to the M-mode image at the position of the selection line 62, and the tracking results 80 and 82 of the blood vessel anterior wall and the blood vessel posterior wall, the change waveform 84 of the blood vessel diameter and the change waveform 86 of the thickness of the vascular wall in the M-mode image are changed to data at the position of the selection line 62 of the B-mode image 64.

[0189] Accordingly, it is possible to select the display line for displaying the M-mode image 65 and the analysis result over the entire region in the azimuth direction of the B-mode image.

[0190] After the set button is depressed, in the B-mode image 64e and the B-mode image 64g, if a selection line 62e and a selection line 62g are moved by the trackball to select an arbitrary region in the azimuth direction, and thereafter, the set button is depressed again, the selected region is handled in a similar manner to the above-mentioned region where reliability is lower than the threshold value, and data is deleted.

[0191] That is, a tester views the result, and when there is a location where the waveform or the like seems to be extraordinary, data can be deleted, thereby making it possible to perform more accurate analysis.

[0192] The state after the deletion of data may be returned in a previous state by depressing a Delete button or the like.

[0193] As described above, considering that the blood vessel has a tubular shape, in order to perform more accurate analysis at the time of the measurement of the blood vessel elastic modulus or the like, it is necessary to recognize the diameter of the blood vessel. To this end, it is necessary to appropriately detect the position of the blood vessel anterior wall boundary in the B-mode image which is the tomographic image of the blood vessel.

[0194] However, as described in JP 2010-233956 A, there are many cases where the blood vessel anterior wall in the ultrasound image is not clear compared to the posterior wall, and it is difficult to detect the blood vessel anterior wall boundary from the B-mode image.

[0195] In contrast, in the ultrasound diagnostic apparatus 10 of the invention, the ultrasonic wave transmission/reception for harmonic imaging is incorporated into the ultrasonic wave transmission/reception using fundamental waves at a predetermined timing, and the B-mode image by fundamental waves and the B-mode image by harmonic imaging are produced.

[0196] In the case of the B-mode image by harmonic imaging, it is possible to obtain an ultrasound image with little fogging or noise of the blood vessel anterior wall compared to the B-mode image by fundamental waves. Therefore, it is possible to more appropriately detect the blood vessel anterior wall boundary through image analysis or image observation.

[0197] In harmonic imaging, it is necessary to lengthen the wave train length of pulse waves so as to suppress the spread of the frequency. For this reason, the positional precision of the blood vessel posterior wall subjected to tracking is lowered. In contrast, according to the invention, harmonic imaging is incorporated into the ultrasonic wave transmission/reception using fundamental waves in which the blood vessel posterior wall is obtained clearly, thereby detecting the blood vessel posterior wall from the B-mode image by fundamental waves with high precision.

[0198] Therefore, according to the invention, it is possible to appropriately detect the boundaries of the blood vessel anterior wall and the blood vessel posterior wall from the B-mode image. As a result, it becomes possible to detect the blood vessel diameter or the like with high precision to perform measurement with higher precision at the time of the measurement of the blood vessel elastic modulus or the like.

[0199] On the other hand, as will be apparent from the operations illustrated in FIGS. 10A to 10G, with regard to the boundary of the blood vessel anterior wall, a rough position may be detected.

[0200] As seen from Equation (2), the boundary of the blood vessel anterior wall is used to detect the radius of the vascular lumen when calculating the blood vessel elasticity.

[0201] For this reason, in the ultrasound diagnostic apparatus of the invention, instead of causing the operator to set the position of the blood vessel anterior wall boundary using the trackball or the like as illustrated in FIGS. 10A to 10G, for example, the elastic modulus calculator 50 may analyze the B-mode image by harmonic imaging to automatically detect the rough position of the blood vessel anterior wall boundary.

[0202] That is, the elastic modulus calculator 50 may perform the detection of the diameter of the vascular lumen or the tracking of the blood vessel anterior wall boundary in the M-mode image 65 using the detection result of the blood vessel anterior wall boundary automatically detected from the B-mode image by harmonic imaging. Also at this time, the tracking of the blood vessel posterior wall is performed using the B-mode image 64 by fundamental waves.

[0203] At this time, like the blood vessel posterior wall illustrated in FIG. 10F, the anterior wall boundary may be automatically detected by tracing the boundary, or as the setting of the blood vessel anterior wall illustrated in FIGS. 10A to 10C, the blood vessel anterior wall may be automatically detected in a linear shape.

[0204] The method which detects the blood vessel anterior wall boundary from the B-mode image of harmonic imaging is not particularly limited, and various methods may be used.

[0205] For example, there is a method in which the gradient of luminance in the depth direction is obtained in a region where it is considered that there is the blood vessel anterior wall, and a position having the maximum luminance in the vicinity of a portion above the maximum gradient point (for example, within 3 mm from the maximum gradient point) is regarded as the blood vessel anterior wall boundary. Since there is no tissue in the lumen of the blood vessel basically, if necessary, an image may be binarized on the basis of density

(luminance), a temporary vascular lumen may be set, and the above-described process may be performed using the temporary vascular lumen.

**[0206]** The blood vessel diameter may be detected from only the B-mode image by harmonic imaging, or the blood vessel anterior wall may be detected from the B-mode image by harmonic imaging, and the blood vessel posterior wall may be detected from the B-mode image by fundamental waves, thereby detecting the blood vessel diameter.

**[0207]** Although the ultrasound diagnostic apparatus of the invention has been described in detail, the invention is not limited to the foregoing examples, and various modifications or improvements may be of course made without departing from the scope of the invention.

**[0208]** The ultrasound diagnostic apparatus of the invention can be suitably used in medical practice for the diagnosis of arteriosclerosis which causes myocardial infarction, angina pectoris, brain diseases, or the like.

What is claimed is:

1. An ultrasound diagnostic apparatus comprising:
  - an ultrasound probe which has ultrasound transducers transmitting ultrasonic waves, receiving an ultrasonic echo reflected by a subject, and outputting a reception signal according to the received ultrasonic echo, the ultrasound transducers being capable of outputting reception signals from fundamental waves and harmonics;
  - an image producer which produces a B-mode image and an M-mode image from the reception signal output from the ultrasound transducers with reception of the fundamental waves, and produces a B-mode image from the reception signal output from the ultrasound transducers with reception of the harmonics; and
  - an actuation controller for the ultrasound probe which switches the ultrasound transducers at a predetermined timing between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.
2. The ultrasound diagnostic apparatus according to claim 1, further comprising:
  - a prediction unit which predicts constriction and dilatation of a blood vessel diameter,
 wherein the actuation controller controls the ultrasound transducers such that the ultrasound transducers perform the output of the reception signal from the harmonics between a time phase in which the blood vessel diameter

is maximal and a time phase as a later stage of vascular constriction, the time phases being predicted by the prediction unit.

3. The ultrasound diagnostic apparatus according to claim 2,
  - wherein the prediction unit is an electrocardiograph.
4. The ultrasound diagnostic apparatus according to claim 2, further comprising:
  - a moving velocity detector which detects a moving velocity of a vascular wall,
 wherein the prediction unit predicts the constriction and dilatation of the blood vessel diameter using a detection result of the moving velocity of the vascular wall detected by the moving velocity detector.
5. The ultrasound diagnostic apparatus according to claim 1,
  - wherein the actuation controller switches the ultrasound transducers at a predetermined sound ray interval between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.
6. The ultrasound diagnostic apparatus according to claim 1,
  - wherein the actuation controller switches the ultrasound transducers at a predetermined time interval between the output of the reception signal from the fundamental waves and the output of the reception signal from the harmonics.
7. The ultrasound diagnostic apparatus according to claim 1, further comprising:
  - a blood vessel diameter detector which detects the blood vessel diameter using the B-mode image produced by the image producer from the reception signal of the harmonics, or using the B-mode image produced by the image producer from the reception signal of the harmonics and the B-mode image produced by the image producer from the reception signal of the fundamental waves.
8. The ultrasound diagnostic apparatus according to claim 1, further comprising:
  - a display unit,
 wherein the B-mode image produced by the image producer from the reception signal of the harmonics and the B-mode image produced by the image producer from the reception signal of the fundamental waves are displayed on the display unit in parallel.

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#### 摘要(译)

一种超声诊断设备，包括：超声探头，其具有能够从基波和谐波输出接收信号的超声换能器；图像产生器，其从接收基波的超声换能器输出的接收信号产生B模式图像和M模式图像，并且从接收的超声换能器的接收信号产生B模式图像谐波；用于超声探头的致动控制器，其在来自基波的接收信号的输出和来自谐波的接收信号的输出之间的预定定时切换超声换能器。

