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(54) **Ultrasonic diagnostic imaging method**

Diagnostisches Ultraschall-Bildgebungsverfahren

Procédé d'imagerie diagnostique à ultrasons

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Description

[0001] The present invention is in the field of the enhanced ultrasonography using an ultrasound contrast medium, and relates to an ultrasonic diagnostic imaging method capable of presenting, as diagnostic information, a microcirculation at the level of capillaries and the microstructure of a vascular flow relatively fast compared with capillaries.

[0002] An ultrasonic diagnosis is convenient in that beat pulsations of the heart or motions of a fetus can be obtained as a real-time display through a manipulation as simple as placing an ultrasonic probe to the body surface, and a screening can be performed repetitively due to its high safety; moreover, owing to its small system size in comparison with other diagnosis apparatus for X-ray imaging, CT imaging, MRI, etc., the ultrasonic diagnosis apparatus can be moved to a bedside, so that a screening can be readily performed at the bedside. Although the ultrasonic diagnostic apparatus varies with kinds of functions furnished therewith, the one small enough for an individual to carry around with one hand has been developed, and different from X-ray imaging or the like, an ultrasonic diagnosis has no exposure risk. The foregoing advantages enable the use of an ultrasonic diagnosis in the obstetrics department, home medical care, etc.

[0003] An intravenous ultrasound contrast medium has been commercialized, and the enhanced ultrasonography is thus being performed in recent years. This method aims to evaluate the dynamic state of a blood flow when examining, for example, the heart or liver by enhancing blood flow signals with the aid of an ultrasound contrast medium injected intravenously. In most of the contrast media, micro bubbles function as the reflection source. Bubbles, being a delicate material by nature, rupture upon ultrasonic irradiation, even at the ordinary diagnostic level, due to the mechanical function, which results in a decrease in signal strength from the scan surface. In order to observe the circulation dynamically in real time, it is therefore necessary to reduce the scan-caused disruption of bubbles relatively, for example, by producing an image through an ultrasonic transmission at a low acoustic pressure. Imaging through such a low acoustic pressure ultrasonic transmission reduces a signal-to-noise ratio (S/N ratio) as well, and various signal processing methods have been proposed to compensate for such a reduction.

[0004] Also, by exploiting the characteristic that the contrast medium bubbles rupture as described above, a method as follows has been proposed. That is, the method includes (A) observing the dynamic state of bubbles filling the scan plane under low acoustic pressure irradiation; (B) destroying bubbles within the plane (to be more exact, within the volume being irradiated) by switching the irradiation acoustic pressure to a high acoustic pressure, and (C) observing a way in which bubbles flow into the plane again. This method is disclosed, for example, in JP-A-11-155858, and is generally referred to as the replenishment method.

[0005] Incidentally, a representative diagnostic image extracted by the enhanced ultrasonography is roughly divided to two types. One is a diagnostic image of a relatively fast, thick blood vessel, and the other is a diagnostic image for a tiny blood flow at the level of capillaries (in the case of the liver, a blood flow giving rise to perfusion in the sinusoidal space). Problems with these images are that it is difficult to extract micro-vascular branches on the former vascular image, whereas in the latter, although signals from micro vessels are detected, the vascular branches are not extracted due to the limit of spatial resolution and merely an increase in luminance can be confirmed as a domain. In short, both the images fail to extract micro-vascular branches at the intermediate level. Blood flow information at this level, however, indicates the degree of progress of the shunt of vessels, regenerative nodules, etc., and is therefore said to be information of great importance for a differential diagnosis of a diffuse liver disease or a liver cancer.

[0006] The invention was devised in view of the foregoing problems, and therefore has an object to provide an ultrasonic diagnostic imaging method capable of extracting diagnostic information at the level of micro-vascular branches rapidly in an effective manner.

[0007] US Patent Application US2002/0055681A discloses ultrasonic apparatus for coherent imaging of ultrasonic contrast agents and detecting harmonic contrast agents. A dual display shows location of the contrast agent and a triggered contrast image. Pulses at different power levels can destroy contrast medium bubbles or image blood flow. Old and new frames are processed in an image persistence technique.

[0008] The present invention is in a method as defined in Claim 1.

[0009] This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

[0010] The invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram showing the configuration of an ultrasonic diagnostic apparatus 10;
FIG. 2 is a view used to explain an image generating circuit 25 in detail;
FIG. 3A and FIG. 3B are views used to explain a basic scan sequence the ultrasonic diagnostic apparatus 10 performs and the number of contrast medium bubbles at scans according to the sequence;
FIG. 4 shows an image of a (relatively thick) blood vessel into which a contrast medium flows abundantly;
FIG. 5 shows plural images of micro blood vessels through which a contrast medium flows less;

FIG. 6 shows a blood flow image on which even tiny blood flows are extracted;
FIG. 7 shows an image suitably presenting information of the structure (the vascular streams);
FIG. 8 is a view showing an example of switches, buttons, etc. provided to an input device 13;
FIG. 9A is a view showing a monitor 14 on which a replenishment image A and a pre-flash image B are displayed concurrently;
FIG. 9B is a view showing the monitor 14 on which arbitrary replenishment images having different time-phases are displayed concurrently;
FIG. 10 is a view showing another example of switches, buttons, etc. provided to the input device 13;
FIG. 11 is a view showing the monitor 14 on which the replenishment image A and the pre-flash image B are superimposed;
FIG. 12 shows a superimposed image in two hues generated through hue display processing;
FIG. 13 shows a superimposed image in four hues generated through the hue display processing;
FIG. 14 is a graph indicating a change of a contrast medium signal after replenishment, expressed by Equation (2);
FIG. 15 is a table showing the relation between n and V_c/V_0 calculated in accordance with Equation (7);
FIG. 16 is a flowchart detailing the flow of processing for imaging operations when a first image generating and displaying method is used;
FIG. 17 is a flowchart detailing the flow of processing for imaging operations when a second image generating and displaying method is used; and
FIG. 18 is a view showing still another example of switches, buttons, etc. provided to the input device 13.

[0011] A first example and a second example will now be described with reference to the accompanying drawings. Hereinafter, components having substantially the same functions and configurations will be labeled with the same reference numerals, and the description of such components will not be repeated unless the necessity arises.

(First Example)

[0012] FIG. 1 is a block diagram showing the configuration of an ultrasonic diagnostic apparatus 10 of this example. As is shown in the drawing, the ultrasonic diagnostic apparatus 10 includes an ultrasonic probe 12, an input device 13, a monitor 14, a transmission/ reception unit 21, a B-mode processing unit 22, a Doppler processing unit 23, an image generating circuit 25, an image memory 26, a control processor 27, a software storage portion 28, an internal storage device 29, and an interface portion 30. The ultrasonic transmission/reception unit 21 and the like built into the apparatus main body 11 may be in the form of hardware, such as integrated circuits, or they may be in the form of softwarily modularized software programs. The following description will describe functions of the components individually.

[0013] The ultrasonic probe 12 includes: plural piezoelectric transducers that generate ultrasonic waves according to a driving signal from the ultrasonic transmission/reception unit 21 and convert reflection waves from the subject to electrical signals; matching layers provided to the piezoelectric transducers; backing materials used to prevent backward propagation of ultrasonic waves from the piezoelectric transducers, etc. When an ultrasonic wave is transmitted to the subject P from the ultrasonic probe 12, the transmitted ultrasonic wave reflects consecutively on the discontinuous surfaces of acoustic impedance in tissues of the body, and reflections are received at the ultrasonic probe 12 as echo signals. The amplitude of the echo signals depends on a difference in acoustic impedance between the discontinuous surfaces on which reflection takes place. In a case where transmitted ultrasonic pulses are reflected on the surface of a blood flow, the heart wall or the like in motion, the echoes undergo frequency deviation by the Doppler effect, depending on the rate components of the moving substance in the ultrasonic transmission direction.

[0014] The input device 13 is connected to the apparatus main body 11, and includes various switches and buttons, a track ball 13s, a mouse 13c, a keyboard 13d, etc. through which the operator inputs all sorts of instructions, conditions, setting instructions of the region of interest (ROI), setting instructions of various image quality conditions, etc. into the apparatus main body 11.

[0015] The monitor 14 displays the morphologic information and blood flow information in the living body in the form of images according to video signals from the image generating circuit 25.

[0016] The transmission/reception unit 21 includes a trigger generating circuit, a delay circuit, a pulsar circuit, etc., all of which are not shown in the drawing. The pulsar circuit repetitively generates a rate pulse used to generate an ultrasonic wave to be transmitted, at a predetermined rate frequency, fr Hz (cycle: 1/fr sec.) The delay circuit gives each rate pulse a delay time needed to focus an ultrasonic wave to a beam shape and determine the transmission directivity for each channel. The trigger generating circuit impresses a driving pulse to the probe 12 at the timing based on the resulting rate pulse.

[0017] In order to perform a scan sequence described below at a command from the control processor 27, the transmission/reception unit 21 is furnished with a function of changing instantaneously a transmission frequency, a transmission driving voltage, etc. The transmission driving voltage, in particular, can be changed by a linear amplifier type oscillation circuit capable of switching its value instantaneously or a mechanism that electrically switches plural power supply units.

[0018] In addition, the transmission/reception unit 21 includes an amplifier circuit, an analog-to-digital converter, an adder, etc., all of which are not shown in the drawing. The amplifier circuit amplifies an echo signal captured via the probe 12 for each channel. The analog-to-digital converter gives the amplified echo signal a delay time needed to determine the reception directivity, after which the adder performs addition processing. The addition enhances the reflection components of the echo signals in a direction corresponding to the reception directivity, and the reception directivity and the transmission directivity together form an integrated beam for ultrasonic transmission and reception.

[0019] The B-mode processing unit 22 receives an echo signal from the transmission/reception unit 21, applies logarithmic amplification, envelope detection processing, etc. on the echo signal, and thereby generates data in which the signal strength is represented by the brightness of luminance. The data thus generated is sent to the image generating circuit 25, and displayed on the monitor 14 as a B-mode image that shows the strength of the reflection wave by luminance.

[0020] The Doppler processing unit 23 performs frequency analysis on the rate information from the echo signal received from the transmission/reception unit 21 to extract a blood flow, tissues, and contrast medium echo components due to the Doppler effect, and thereby finds blood flow information, such as the average rate, dispersion, and power, at a number of points. The blood flow information thus obtained is sent to the image generating circuit 25, and displayed in color on the monitor 14 as an average rate image, a dispersion image, or a power image, either solely or in combination.

[0021] The image generating circuit 25 converts a sequence of scanning line signals of ultrasound scans to a sequence of scanning line signals of a general video format typically used in TV sets or the like, and thereby generates an ultrasonic diagnostic image as a display image. The image generating circuit 25 has a built-in storage memory that stores image data, so that, for example, the operator is able to retrieve an image recorded during the screening after the diagnosis was made. Data before entering the image generating circuit 25 is also referred to as raw data.

[0022] FIG. 2 shows the image generating circuit 25 in detail. Initially, a signal processing circuit 25a performs filtering in such a manner that the image quality is determined at the level of a sequence of scanning line signals of ultrasound scans. An output from the signal processing circuit 25a is not only sent to a scan converter 25b, but also saved in the image memory 26. The scan converter 25b converts the sequence of scanning line signals of ultrasound scans into a sequence of scanning line signals of a general video format typically used in TV sets or the like. This output is sent to an image generating circuit 25c, which adjusts the luminance and contrast, performs image processing, such as spatial filtering, or synthesizes the output and character information and scales of various setting parameters, and outputs a resulting video signal to the monitor 14. A tomographic image showing the shape of tissues of the subject is thus displayed.

[0023] The image memory 26 comprises a storage memory used to store image data received from the signal processing circuit 25a. For example, the operator is able to retrieve the image data after the diagnosis was made, .and the image data can be played back like a still image or the image data of plural frames can be played back like a moving picture. The image memory 26 also stores an output signal (referred to as a radio frequency (RF) signal) immediately after the ultrasonic transmission/reception unit 21, an image luminance signal having passed through the transmission/reception unit 21, other raw data, image data acquired via the network, etc. as necessity arises.

[0024] The internal storage device 29 saves a scan sequence described below, control programs to generate and display images, diagnostic information (patient ID, remarks of the physician, etc.), diagnostic protocols, transmission/reception conditions, a correspondence table shown in FIG. 15 (described below,) and other data groups. Also, the internal storage device 29 is used to save images in the image memory 26 when necessity arises. Data in the internal storage device 29 can be transferred to a peripheral apparatus via the interface circuit 30.

[0025] The control processor 27 functions as an information processing unit (computer), and also controls the operations of the main body of the ultrasonic diagnostic apparatus. The control processor 27 reads out a control program to generate and display an image or the like, which will be described below, from the internal storage device 29 to be developed on the software storage portion 28, and performs computations, control, etc. involved in various kinds of processing.

[0026] The interface portion 30 is an interface for the input device 13, the network, and a new external storage device (not shown). Data, analysis results, etc. of the ultrasonic images or the like obtained by the apparatus can be transferred to other devices by the interface portion 30 via the network.

(Scan Sequence)

[0027] A basic scan sequence that the ultrasonic diagnostic apparatus 10 performs will now be described with reference to FIG. 3A and FIG. 3B. The scan sequence of this embodiment (hereinafter, referred to simply as the scan sequence) is used in contrast echoes with the aid of a contrast medium to perform transmissions at two kinds of acoustic pressure alternately: a transmission at a high acoustic pressure (hereinafter, referred to as the high acoustic pressure (ultrasonic) transmission) to destroy contrast medium bubbles, and a transmission at a low acoustic pressure (hereinafter, referred to as the low acoustic pressure (ultrasonic) transmission) to obtain a diagnostic image by preventing the disruption of bubbles as much as possible. A suitable contrast medium used in imaging according to this sequence is a so-called next-generation contrast medium, bubbles of which keep releasing harmonic signals without being destroyed when ultrasonic waves are transmitted at a low acoustic pressure, thereby enabling imaging over a long time.

[0028] FIG. 3A is a view used to explain the scan sequence, in which the abscissa is used for time and the ordinate is used for a degree of mechanical function to the bubbles derived from transmissions. Also, each line represents an ultrasound scan related to one frame, and the length of each line represents the strength of mechanical function of a transmission acoustic pressure in each frame.

[0029] In other words, each line represents an ultrasound scan for one frame under the transmission conditions set in such a manner that as the length of each line in the longitudinal direction becomes longer (larger), the transmission frequency becomes lower or a transmission driving acoustic pressure becomes higher, or a combination thereof. Thus, longer lines 41 correspond to scans (three frames, in the case of the drawing) through high acoustic pressure irradiation, and shorter lines 43 correspond to scans through low acoustic pressure irradiation. Hereinafter, a tomographic image obtained through low acoustic pressure irradiation is referred to as a replenishment image. Also, of all the scans through low acoustic pressure irradiation, a tomographic image obtained from a frame scan 43a, a frame immediately before the switching to high acoustic pressure irradiation, is referred to as a pre-flash image.

[0030] Because one frame comprises plural scanning lines, one line symbolically represents a few hundreds transmissions and receptions related to plural scanning lines.

[0031] FIG. 3B is a view showing a change of the number of contrast medium bubbles with time when scans are performed according to the sequence of FIG. 3A. The abscissa (elapsed time) of FIG. 3B corresponds to the abscissa (elapsed time) of FIG. 3A. Generally, the number of contrast medium bubbles is thought to have a positive correlation with echo signals. Thus, as is shown in the drawing, because only a small number of contrast medium bubbles rupture under low acoustic pressure irradiation, the number of bubbles flowing into the scan plane increases gradually, and an equilibrium state is thereby achieved in the case of an observation over a long time. When the transmission is switched to the high acoustic pressure transmission, bubbles within the plane suddenly start to rupture, and the bubbles are eliminated almost completely through plural times of irradiation for one frame or more, preferably about 10 frames. By switching the transmission again to the low acoustic pressure transmission to observe a replenishment image, the operator becomes able to observe a way in which the replenishment takes place. By repetitively performing this procedure, it is possible to observe the replenishment phenomenon repetitively from the pre-flash image.

(Logical Background)

[0032] From the result of attempts in observing micro-vascular branches, the inventor discovered that a time duration during which information as to the contrast medium bubbles flowing into micro-vascular branches can be obtained is merely 1 to 2 sec. after the replenishment starts to takes place, and thereafter, dominating signals are those at the level of capillaries that cannot be resolved. On the other hand, however, micro-vascular branches cannot be extracted satisfactorily by merely displaying information within 1 to 2 sec. as a conventional ultrasonic diagnostic image. The reason why will be described with reference to FIG. 4 through FIG. 7. The hatchings in each figure symbolically indicate contrasted regions.

[0033] FIG. 4 shows an image of a vessel into which a contrast medium flows abundantly. A contrast medium flows abundantly into a relatively thick vessel, and such a vascular structure can be understood only from an image like the one shown in FIG. 4.

[0034] FIG. 5 shows plural images of micro vessels through which a contrast medium flows less. On an image like any of those shown in FIG. 5, bubbles are present sparsely in one image at a given moment, which makes it impossible to understand the vascular structure. Even when one observes time-sequential diagnostic images, he often fails to observe a continuous flow.

[0035] FIG. 6 shows a blood flow image on which even a tiny blood flow is extracted. On an image like the one shown in FIG. 6, as has been described, the vascular branches cannot be extracted due to the limit of spatial resolution, and only an increase in luminance is confirmed as a domain, which makes identification of micro-vascular branches impossible.

[0036] One advantage of this embodiment is that, as is shown in FIG. 7, an image suitably presenting information of a structure (the vascular streams, herein) can be provided as one kind of diagnostic information. To this end, a method of generating and displaying a diagnostic image and a diagnostic information extracting function, etc. as described below are performed.

(Generation and Display of Diagnostic Image)

[0037] The method of generating and displaying a diagnostic image (an image the apparatus actively displays as an image effective for diagnostic) achieved by the ultrasonic diagnostic apparatus 10 is roughly divided to two types. Firstly, a first image generating and displaying method for generating a replenishment image according to plural low acoustic pressure transmissions to be displayed in real time while displaying a pre-flash image concurrently with the replenishment image will be described.

[0038] In the pre-operation of imaging, a high acoustic pressure period (T_H in FIG. 3) during which the high acoustic pressure ultrasonic transmission is performed, and a low acoustic pressure period (T_L in FIG. 3) during which the low acoustic pressure ultrasonic transmission is performed are set to arbitrary values respectively by a switch 13a and a switch 13b of the input device 13 shown in FIG. 8. The drawing shows a case where the high acoustic pressure ultrasonic transmission is performed for 0.5 sec. followed by the low acoustic pressure ultrasonic transmission for 2.0 sec. Herein, seconds are used as a pre-set unit for T_H and T_L; however, it may be configured in such a manner that these values are set in the unit of the number of frames.

[0039] By manipulating a start switch 13c after T_H and T_L are set, the scan sequence is started, according to which the high acoustic pressure ultrasonic transmission for T_H = 0.5 sec. and the low acoustic pressure ultrasonic transmission for T_L = 2 sec. Are performed repetitively. In this example case, a replenishment image obtained by these scans is displayed, and about 2 sec. later since the completion of the high acoustic pressure transmission, a pre-flash image is captured and displayed concurrently on the monitor 14.

[0040] FIG. 9A is a view showing the monitor 14 on which a pre-flash image A and a replenishment image B are displayed concurrently. On the monitor 14, the replenishment image B is displayed in real time like a moving picture, while the pre-flash image A is displayed like a still image. Also, when the transmission is switched to the following high acoustic pressure ultrasonic transmission or low acoustic pressure ultrasonic transmission, the replenishment image B or the pre-flash image A is sequentially updated to the latest image. The operator is thus able to observe in real time the replenishment state, in particular, a way in which the contrast medium flows into a fine perfusion at the level of capillaries, like a moving picture, while at the same time, he is able to observe the structure at the level of capillaries from the pre-flash image A being displayed like a still image.

[0041] The scans and the generation and display of images as described above are continued until the operator manipulates a stop switch 13d shown in FIG. 8. Alternatively, by manipulating a manual switch 13e, it is possible to perform the high acoustic pressure transmission alone for one shot (once) for a specified transmission time, without repetitively performing the high acoustic pressure transmission and the low acoustic pressure transmission.

[0042] A second image generating and displaying method will now be described. According to this method, a replenishment image related to the low acoustic pressure transmission at desired timing is generated as a diagnostic image to be displayed like a still image instead of the pre-flash image. Hereinafter, a replenishment image related to the low acoustic pressure transmission at desired timing and selected as a diagnostic image to be displayed like a still image is referred to as a selected image.

[0043] FIG. 10 is a view showing a switch group provided to the input device 13 used in the second image generating and displaying method. A selection time switch 13f allows the operator to arbitrary set timing (selection time t_s) at which the selected image is captured. In this example case, assume that the selection time t_s is set to a time when a predetermined time has elapsed since the time (reference time) at which the last high acoustic pressure transmission is switched to the low acoustic pressure transmission and acquisition of a first image (reference image) during the low acoustic pressure period T_L is started. Thus, in the case of FIG. 10, the selected image is captured 2 sec. later since the reference time.

[0044] Also, a switch 13g allows the operator to arbitrary set the low acoustic pressure period T_L. The low acoustic pressure period T_L is a time duration also starting from the reference time. Thus, in the case of FIG. 10, after the low acoustic pressure transmission has been continued for T_L = 6 sec. since the reference time, the transmission is switched to the high acoustic pressure transmission.

[0045] Herein, seconds are used as a pre-set unit for the selection time t_s and the low acoustic pressure period T_L; however, it may be configured in such a manner that these values are set in the unit of the number of frames.

[0046] When the respective times and time durations, etc. are set as shown in FIG. 10 by the pre-operation of imaging, the scan sequence is started by manipulating the start switch 13c, according to which the high acoustic pressure ultrasonic transmission is performed for T_H = 0.5 sec. and the low acoustic pressure ultrasonic transmission is performed for T_L = 6 sec. repetitively. In this example case, a replenishment image obtained from these scans is displayed, and the selected image is captured about 2 sec. later since the reference time to be displayed on the monitor 14 concurrently in the mode, for example, as the one shown in FIG. 9B. Further, low acoustic pressure irradiation is performed for 6 - 2 = 4 sec. continuously from the capturing of the selected image, so that the state of replenishment is shown as a replenishment image. It is thus possible to observe the state of replenishment in real time, in particular, fine perfusion at the level of capillaries in real time, for a longer period (6 sec.) than in the first image generating and displaying method.

[0047] The scans and the generation and display of images are continued until the operator manipulates the stop switch 13d shown in FIG. 10.

[0048] The display mode of an image according to the first and second image generating and displaying methods is not limited to those of FIG. 9A and FIG. 9B. For example, as is shown in FIG. 11, it may be a display mode in which the replenish image B and the pre-flash image A or the replenishment image and the selected image are superimposed for display. Such a display mode can enhance the visibility further. In addition, in any display mode, it is possible to make any of the replenishment image, the pre-flash image, and the selected image as a non-display image or back into a display image at arbitrary timing as needed.

(Diagnostic Information Extracting Function)

[0049] The diagnostic information extracting function provided to the ultrasonic diagnostic apparatus 10 will now be described. The diagnostic information extracted by this function includes a blood flow image obtained by the scan sequence (including an image at the level of capillaries), and a histological, physical quantity of a blood flow obtained from the blood flow image. The following description will describe extracting methods for extracting a blood flow image and a histological, physical quantity of a blood flow in this order. Each method is particularly useful in displaying the aforementioned replenishment image or the like.

[0050] A suitable blood flow image including an image at the level of capillaries can be extracted with the use of maximum value holding processing, weight update processing, and other luminance holding computations described below. Firstly, the maximum value holding processing performed on n replenishment images for frames F_1 through F_n included in the same period T_L will be described. The maximum value holding processing performed on images for the frames F_1 through F_n referred to herein is defined as a computation to generate a new image by selecting a maximum value $P_{max}(x, y)$ among spatially corresponding luminance values in the respective frames F_1 through F_n.

[0051] To be more specific, the replenishment image for a given frame F_i (i is an integer satisfying $1 \leq i \leq n$) comprises a set of spatially mapped luminance values $P_i(x, y)$, or a set of mere one-dimensional sequence data $P_i(x)$ of luminance values. The values of $P_i(x, y)$ or $P_i(x)$ may be the signal strength, signal amplitude, raw data values of RF data or the like instead of luminance; however, the luminance values are adopted herein. Generally, the respective data values having large numerical values means a higher level of echo signals. By exploiting the respective data values as such, the maximum value of the luminance values for all the pixels in the spatially corresponding frames F_1 through F_n is selected, and a computation is performed to generate a new image. According to the invention, this computation can be expressed by Equation (1):

$$P_{max}(x, y) = \max[P_1(x, y), \ldots, P_n(x, Y)] \qquad (1)$$

[0052] When the maximum value holding processing is used for a replenishment image, processing is performed in accordance with Equation (1) above each time a new frame belonging to the same low acoustic pressure period T_L is acquired, and the resulting image is displayed as a replenishment image. To the operator (observer), the image obtained in this manner seems as if it were showing a way in which capillaries are sequentially contrasted with time.

[0053] In this instance, it should be noted that when the maximum value holding processing is performed, only the images within 1 to 2 sec. from the reference time have to be used. Because when images over 2 sec. are included, the micro-vascular structure is covered and hidden as is shown, for example, in FIG. 3, which limits the advantages of contrast enhancement only as a domain.

[0054] The algorithm to achieve the maximum value holding processing is not limited to the one described above. For example, the same advantages can be achieved by the algorithm described below, not part of the present invention.

[0055] That is, given P_i (x, y) as the pixel luminance at each coordinate in the frame F_i for a current tomographic image, and $P_{i-1}(x, y)$ as the pixel luminance in the preceding image frame, then image computation processing expressed by the following equation is performed successively for i = 2 to n for these relative two frames.

If

$$P_i(x, y) > P_{i-1}(x, y)$$

then

$$P_i(x, y) = P_{i-1}(x, y)$$

Else

$$P_i(x, y) = P_{i-1}(x, y)$$

[0056] This algorithm is to update the value only for a pixel having a larger luminance value than the counterpart in the image related to the frame in the preceding stage. With the replenishment image or the like obtained in this manner, the operator is also able to observe a way in which capillaries are sequentially contrasted with time.

[0057] Another method for a suitable blood flow image including an image at the level of capillaries will now be described. This method, which is not part of the present invention, is to generate an image by applying weight update processing on n replenishment images for frames F_1 through F_n included in the same period T_L. The weight update processing referred to herein means a computation expressed by the following equation:

If

$$P_i(x, y) > P_{i-1}(x, y)$$

then

$$P_i(x, y) = A*P_i(x, y) + (1 - A)*P_{i-1}(x, y)$$

Else

$$P_i(x, y) = (A - 1)*P_i(x, y) + A*P_{i-1}(x, y)$$

[0058] By setting A to a value less than one and approximating to one (for example, 0.99), there can be expected functions that the maximum value is held for a short time (in this case, a time interval between the frame in the preceding stage and the current frame), and for a longer time, the luminance held before is attenuated. The operator is thus able to observe a way in which capillaries are sequentially contrasted with time from a replenishment image or the like obtained according to this method.

[0059] Incidentally, such maximum value holding processing or the like adopts computation means that projects a maximum value or an updated value in the time direction. Hence, effective time information cannot be obtained by displaying a resulting image intact after it has undergone the aforementioned processing.

[0060] In order to eliminate this problem, one may adopt hue display processing, which is particularly effective in displaying a replenishment image or the like having undergone the aforementioned processing. According to the hue display, images are displayed in different colors for time segments prespecified by the operator, which makes it possible to visually confirm which luminance displayed in the final image belongs to which time segment. The following description will describe the contents of the hue display processing in an example case where two time segments (a first time segment and a second time segment) are specified.

[0061] The operator first specifies a time at which the low acoustic pressure period T_L is divided to the first time segment and the second time segment. Herein, 2 sec. from the reference time is set as the dividing time, and a segment before the dividing time is referred to as the first time segment and a segment after the dividing time is referred to as the second time segment.

[0062] In the course of forward-feeding the images in the image memory, in a case where the current frame F_n is present in the first time segment, the maximum value holding processing, for example, is applied to the frames F_1 through F_n (that is, from the first frame to the current frame present in the first time segment), and an image A is generated as a result.

[0063] In a case where the current frame F_n is present within the second time segment, the luminance value holding computation is applied to the frames F_1, ..., F_n (that is, from the first frame to the current frame present in the first time segment and the second time segment) to generate an image A', while the image A is being generated.

[0064] Differential computation processing, that is, (image A' - image A), is then performed to generate a resulting image B. Finally, hue conversion is performed in such a manner that, for example, the image A is converted to a hue A (for example, red), and the resulting image B is converted to a hue B (for example, yellow). A superimposed image of these images is generated, and as is shown in FIG. 12, displayed on the monitor 14 as a replenishment image or the like.

[0065] The operator, by observing the replenishment image shown in FIG. 12, becomes able to readily and rapidly understand that the hue A is the region into which the contrast medium has flown within 2 sec. from the reference time (first time segment), and the hue B is the region into which the contrast medium has flown 2 sec. later since the reference time (second time segment).

[0066] According to the hue display processing, even when the luminance value holding computation, such as the maximum value holding processing and the weight update processing, is performed, it is possible to provide a suitable blood flow image containing information at the level of capillaries in the mode easy for the operator to observe, without losing time information.

[0067] While the hue display processing using two time segments has been described by way of example, it goes without saying that this method is applicable to an arbitrary number of time segments. The procedure in such a case is that the processing described above is performed for adjacent two segments, and N images each having a different hue are obtained, after which a superimposed image of these N images is generated and displayed as a final image. For example, in the case of a superimposed image where N = 4 (for example, four colors including red, yellow, green, and blue), an image as shown in FIG. 13 is displayed on the monitor 14.

[0068] When an image having undergone the hue display processing is displayed, it is preferable to display concurrently a color scale bar indicating the relation between the hues and the time segment or the elapsed time as are shown in FIG. 12 and FIG. 13.

(Calculation of Histological, Physical Quantity)

[0069] Calculation processing for a histological, physical quantity of a blood flow based on the blood flow image obtained by the scan sequence will now be described.

[0070] The principle of the physical quantity calculation processing is as follows. That is, in a case where the low acoustic pressure ultrasonic transmission has been performed for a sufficient time, T_m sec., the pre-flash image 43 shown in FIG. 3 is an image of a tomographic plane filled with blood flows, and the signal luminance within this image is therefore thought to be the maximum value at the region in question. Also, it goes without saying that T_m sec. is needed for each pixel luminance within the replenishment image immediately after high acoustic pressure irradiation to restore to, or nearly to that in the pre-flash image.

[0071] Assume that, during a given time duration, the luminance value of each pixel in the replenishment image reaches C% (for example, 50%) of that in the pre-flash image, then a shorter time than T_m is naturally given to this time duration. The time duration during which the luminance value of each pixel in the replenishment image reaches C% of the luminance value of the counterpart pixel in the pre-flash image is defined as a quasi-recovery time T_c. JP-A-11-89839, for example, has reported the technique to display hues with a consideration given to such a time duration for the pixel to reach C% luminance value. The histological meaning of the recovery time per se, however, is ambiguous by merely setting the numerical value to C% arbitrarily, which may not contribute much to clinical scenes.

[0072] For this reason, in this example, the region having reached the quasi-recovery time T_c is displayed in hue, and an average passing time T_{mtt} (an average time needed for a blood flow to pass through the tomographic plane), that is, a histological, physical quantity of a blood flow, is predicted from the quasi-recovery time T_c to be presented to the operator.

[0073] The inventor discovered from his studies that when a change of echo signals with time in an organ region within the replenishment image is observed, it shapes a curve as shown in FIG. 14. This curve can be satisfactorily approximated by Equation (2):

$$V(t) = V_0(1 - e^{-\beta t}) \qquad (2)$$

where V(t) is a linear signal strength before logarithmic conversion, V_0 is a signal strength after a sufficient time elapsed (for example, a signal strength of the pre-flash image), β is a constant, and t is a time duration. In particular, β is related to a flow rate (the reciprocal number 1/β is related to the passing time), and β becomes larger where the flow rate is high, and smaller where the flow rate is low.

[0074] When an increase in luminance of the replenishment image is represented by the curve expressed by Equation (2) above, the average passing time T_{mtt} is equal to 1/β. Assume that the signal strength reaches V_c t_c sec. later, then, Equation (3) below is established from Equation (2) above:

$$V_c = V_0(1 - e^{-\beta tc}) \qquad (3)$$

[0075] By solving Equation (3) above for β, we get Equation (4):

$$\beta = -1/t_C(\ln(1 - V_C/V_0)) \quad (4)$$

[0076] Thus, the average passing time T_{mtt} is given by Equation (5):

$$T_{mtt} = 1/\beta = -t_C(1/\ln(1 - V_C/V_0)) \quad (5)$$

[0077] Equation (5) apparently looks complicated; however, $T_{mtt} = t_c$ is established if V_c takes the value of Equation (6):

$$V_C = V_0((e-1)/e) = 0.63212*V_0 \quad (6)$$

[0078] In other words, an elapsed time (quasi-recovery time T_c needed to reach C = 63%) from the reference time, at which the replenishment image becomes about 0.63 time of pre-flash image, means the average passing time of the blood flow related to the patient.

[0079] This result can be extended further. That is, let t_c be a time at which V_c satisfies Equation (7):

$$V_C = V_0((e^{1/n} - 1)/e^{1/n}) \quad (7)$$

[0080] In this instance, there is established a relational expression, $T_{mtt} = t_c*n$, between the average passing time T_{mtt} and t_c. In other words, by finding the quasi-recovery time t_c, which is shorter than the original average passing time T_{mtt}, and multiplying t_c by n, it is possible to obtain the average passing time T_{mtt} without waiting for the physical time to elapse. According to this extension, Equation (6) above can be deemed as Equation (7), where n = 1.

[0081] FIG. 15 is a correspondence table indicating the relation between n and the value of V_c/V_0 computed in accordance with Equation (7) above. In practice, a diagnostic image is often displayed in the unit of decibels, and the drawing shows values converted to decibels for V_c/V_0 as well. This correspondence table is stored in the internal storage device 29.

[0082] In this example, a desired number for n is selected first and t_c needed for each pixel on the replenishment image to reach the value of V_c/V_0 corresponding to n is then computed, according to the logic described above. A value obtained by multiplying the resulting t_c by n is presented to the operator as the average passing time T_{mtt}, so that the average passing time T_{mtt} can be predicted without having to wait for contrast enhancement up to the pre-flash image.

[0083] To be more specific, at least one value for V_c/V_0 to be referred to is set first. Herein, assume that $V_c/V_0 = 0.39$ (n = 2) is set.

[0084] Subsequently, the signal strength of each pixel in the pre-flash image obtained through imaging is stored as P_0 = (x, y), while the pre-flash image is displayed on the monitor 14. Also, it is judged whether $P_i(x, y)/P_0(x, y) > 0.39$ is established for the signal strength $P_i(x, y)$ of each pixel in the replenishment image for each frame while the replenishment image is being displayed like a moving picture. When it is judged that $P_i(x, y)/P_0(x, y) > 0.39$ is established, hue display is performed by coloring the pixel with a new color tone (red). Also, while the replenishment image is being displayed, the numerical value of T_c*n (sec.), the product of the elapse time T_c from the reference time and n (n = 2, herein), is displayed as the average passing time T_{mtt}. When the high acoustic pressure transmission and the low acoustic pressure transmission are performed repetitively, the same processing is performed repetitively.

[0085] According to the method as described above, the operator, by visually confirming that specific pixels on the screen are displayed concurrently at the timing at which these pixels are colored, becomes able to visually confirm with ease that the average passing time T_{mtt} for the region of the subject corresponding to these pixels is equal to T_c*n (sec.) or less. The operator thus does not have to wait for the average passing time T_{mtt} to elapse, and is able to predict the average passing time T_{mtt}, that is, a histological, physical quantity of a blood flow, in one n'th time of the actual time duration, rapidly at high accuracy with ease.

(Series of Imaging Operations)

[0086] A series of imaging operations to perform the respective functions described above will now be described with reference to FIG. 16 and FIG. 17.

[0087] Firstly, imaging operations when the first image generating and displaying method is used will be described. FIG. 16 is a flowchart detailing the flow of the imaging processing when a blood flow image is extracted using the first image generating and displaying method. Initially, a high acoustic pressure transmission time is set to 0.5 sec. and a low acoustic pressure transmission time is set to 2 sec. (Step S0). After the settings, at an instruction from the operator via the start switch 13c of FIG. 8, the scan sequence is started, according to which the high acoustic pressure transmission is performed for 0.5 sec. and the low acoustic pressure transmission is performed for 2 sec. repetitively (Step S1). The scan conditions or the like are then switched to those of the initial high acoustic pressure transmission (Step S2), and the high acoustic pressure transmission is performed for 0.5 sec. (Step S3).

[0088] When the high acoustic pressure transmission has been performed for 0.5 sec., the scan conditions are switched to those of the low acoustic pressure transmission (Step S4), while at the same time, in a case where the luminance value holding computation has been applied on the replenishment image in the preceding stage, information related to the luminance vale holding computation in the preceding stage is reset (Step S5). After the information is reset, the low acoustic pressure ultrasonic transmission as well as new luminance value holding computation is started (Step S6), and continued for 2 sec. (Step S7). In the course from Steps S5 through S7, a replenishment image, which is obtained through the low acoustic pressure ultrasonic transmission and on which the luminance value holding computation is applied, is displayed on the monitor 14 in real time like a moving picture.

[0089] The pre-flash image is captured 2 sec. later since the start of the low acoustic pressure transmission, and displayed on the monitor 14 like a still image together with the replenishment image (Step S8). When the same scan sequence is repeated thereafter, processing from Steps S2 through S8 is performed again. On the other hand, when an end instruction is inputted via the stop switch 13d, the imaging according to the scan sequence is completed.

[0090] According to the imaging processing as described above, the pre-flash image, on which a micro-vascular branch structure is extracted due to the luminance value holding computation, is displayed on the monitor 14 each time the low acoustic pressure transmission and the high acoustic pressure transmission are repeated. The replenishment image is also displayed on the monitor 14 like a moving picture each time the low acoustic pressure transmission and the high acoustic pressure transmission are repeated. The operator is thus able to observe not only the dynamic state of living organs in real time from the replenishment image, but also the micro-vascular branch structure statically from the pre-flash image. It is thus possible to obtain diagnostic information at the level of micro-vascular branch rapidly in an effective manner.

[0091] For the imaging described above, calculation of a histological, physical quantity may be performed instead or together with the luminance value holding computation. In this case, calculation of a histological, physical quantity is performed instead of or in parallel with the luminance value holding computation in Steps S6 and S7, and the result is displayed in real time together with the replenishment image.

[0092] Imaging operations when the second image generating and displaying method is used will now be described. FIG. 17 is a flowchart detailing the flow of processing for the imaging operations when the second image generating and displaying method is used. The operator first sets, respectively via the switches 13f, 13a, 13g of FIG. 10, 2 sec. from the reference time as the timing at which a selected image is obtained, 0.5 sec. as a high acoustic pressure transmission time, and 6 sec. as a low acoustic pressure transmission time (Step S10). After the settings, at an instruction via the start switch 13c, the scan sequence is started, according to which the high acoustic pressure transmission is performed for 0.5 sec. and the low acoustic pressure transmission is performed for 6 sec. repetitively (Step S11). The scan conditions or the like are then switched to those of the initial high acoustic pressure transmission (Step S12), and the high acoustic pressure transmission is performed for 0.5 sec. (Step S13).

[0093] When the high acoustic pressure transmission has been performed for 0.5 sec., the scan conditions are switched to those of the low acoustic pressure transmission (Step S14), while at the same time information related to the luminance vale holding computation in the preceding stage is reset (Step S15). After the information is reset, the low acoustic pressure ultrasonic transmission as well as new luminance value holding computation is started (Step S16), and continued for 2 sec. (Step S17). In the course from Steps S15 through S17, a replenishment image is displayed on the monitor 14 in real time like a moving picture.

[0094] The selected image is captured 2 sec. later since the start of the low acoustic pressure transmission, and displayed on the monitor 14 like a still image together with the replenishment image (Step S18). The low acoustic pressure ultrasonic transmission is continued for further 4 sec. (6 - 2 sec.), and a corresponding replenishment image is displayed on the monitor 14 in real time like a moving picture (Step S19).

[0095] When the same scan sequence is repeated thereafter, processing from Steps S12 through S19 is performed again. On the other hand, when an end instruction is inputted via the stop switch 13d, the imaging according to the scan sequence is completed.

[0096] According to the imaging processing described above, the same advantages as those achieved by the imaging when the first image generating and displaying method is used can be achieved. For the imaging described above, calculation of a histological, physical quantity may be also performed instead of or together with the luminance value holding computation. In this case, calculation of a histological, physical quantity is performed instead of or in parallel with the luminance value holding computation in Steps S16 through S19, and the result is display in real time together with the replenishment image.

(Second Example)

[0097] A second example will now be described. This embodiment is to perform the first or second image generating and displaying method in the middle of or after the imaging.

[0098] As has been described, the ultrasonic diagnostic image obtained and observed in real time with the apparatus is also stored in the image memory 26. Hence, when the operator has observed images for a certain time, he generally stops the ultrasound scans through an input from a freeze button on the control panel, so that a series of tomographic images in the image memory 26 are played back. These images can be displayed either like a still image or a moving picture. Also, as is shown in FIG. 18, the operator is able to control the playback, stop, fast forwarding, backward feeding, etc. at arbitrary timing by means of playback buttons 13r and the track ball 13s provided to the input device 13.

[0099] In addition, as is shown in FIG. 18, in the case of the apparatus 10 of this embodiment, the input device 13 is provided with a maximum value holding button 13j used for the aforementioned luminance value holding computation, for example, for use in specifying whether the maximum value holding processing is to be enabled. While the maximum value holding button 13j remains OFF, conventional ultrasonic diagnostic images are displayed on the monitor frame by frame. On the other hand, when the maximum value holding button 13j is switched ON, a tomographic image frame being displayed at that point in time is registered as the reference image (F_1). Subsequently, as the operator feeds the display image forward to F_2, F_3, and so forth, the image generating circuit 25 applies the aforementioned maximum value holding computation on the images, including the reference image F_1 to the currently displayed tomographic image frame F_n ($n > 1$), and displays the result on the monitor 14.

[0100] The first image generating and displaying method or the like in the middle of or after the imaging as described above is also applicable to the time-sequential backward playback (that is, backward feeding of frames). For example, when the operator have F_m ($m < n$) be displayed through backward feeding of played back images after a tomographic image frame F_n ($n > 1$) is displayed, the image generating circuit 25 only has to perform the maximum value holding processing from F_n to F_m to generate an image again.

[0101] It should be noted that the obtained image may be susceptible to motions, such as breathing and heat beats, which gives rise to an offset of corresponding positions between the frames. When the maximum value holding computation or the like is performed directly in such a case, an adequate result may not be obtained.

[0102] In order to eliminate this problem, the ultrasonic diagnostic apparatus 10 is furnished with an image blurring adjusting function to adjust the position correspondence between frames, so that the luminance value holding processing, such as the maximum value holding processing, can be performed adequately. This adjustment is performed by depressing a fine-adjustment button 13k shown in FIG. 18. More concrete operations are as follows.

[0103] For example, in a case where the maximum value holding computation is currently applied to frames F_1 through F_n, then the mode is switched to the fine-adjustment mode when the fine-adjustment button 13k is depressed. In this fine-adjustment mode, for superimposed positions between a maximum value holding image (image A) of F_1 through F_{n-1} and an image of F_n (image B), a fine-adjustment displacement (dx, dy), which is a quantity of offset between the image A and the image B that needs to be cancelled out, is generated through manipulation of the track ball 13s or the like. Then, the position is fine-adjusted by mapping ($x + dx$, $y + dy$) of the image B to the coordinate (x, y) of the image A, and the fine-adjustment is confirmed by depressing the fine-adjustment button 13k again.

[0104] According to the configuration as above, the operator is able to perform the first or second image generating and displaying method at any desired timing. Also, in the event of an offset in position between frames, fine-adjustment is performed at arbitrary timing, so that more reliable diagnostic information can be obtained.

Claims

1. An ultrasonic diagnostic imaging method comprising obtaining an ultrasonic image by scanning, by means of ultrasonic waves, a specific region of a subject injected with contrast medium bubbles which have a characteristic of generating harmonic echoes without being destroyed when ultrasonic waves are transmitted at a low acoustic pressure and which enable imaging over a long time, comprising:

    using an ultrasonic probe (12) to transmit an ultrasonic wave to said subject and receive an echo signal from said ultrasonic wave;
    using a transmission/reception unit (21) arranged to perform, via said ultrasonic probe (12), a series of transmissions and receptions for obtaining respective echo signals of each of a plurality of frames (43) in a first period (TL) at a first acoustic pressure, which is an acoustic pressure not to destroy substantially said contrast medium bubbles but to obtain an image of blood flow circulation in said subject, and to perform a series of transmissions for each of a plurality of frames (41) in a second period (TH) at a second acoustic pressure to destroy said contrast medium bubbles;

using a control unit (27) to control said transmission/reception unit (21) in such a manner that all the transmissions and receptions in said first period are performed shortly after all transmissions in said second period have been performed;
using a memory to store a plurality of frames which are acquired in said first period (TL); **characterised in that** the method further comprises:

registering a first reference frame (F_1) from the plurality of frames in accordance to a selection by an user, after the series of transmissions and receptions in the first period (TL) and the series of transmissions in the second period (TH) are completed;
using an image generating unit (25) to generate first display images by performing a maximum luminance value holding computation from the first reference frame (F_1) to a second frame (F_n), the second frame (F_n) being included in the plurality of frames, and time-sequential forward or backward to the first reference frame (F_1), wherein the maximum of the luminance values at each position in said frames between the first reference frame (F_1) and the second frame (F_n) is held in said maximum luminance value holding computation, and using those held values in said display image, such that

$$P_{max}(x,y) = \max [P_1(x, y),\ldots\ldots,P_n(x, y)],$$

where $P_{max}(x, y)$ is the maximum of the luminance value for pixel (x, y), $P_1(x, y)$ is the luminance value for pixel (x, y) in the first reference frame and $P_n(x, y)$ is the luminance value for pixel (x, y) in the second frame ; and displaying said first display images on a display unit (14), wherein the luminance values are derived from B-mode processing of the received echo signals .

2. A method according to Claim 1, in which said image generating unit (25) generates said first display images by using the held values of the echo signals obtained in a latest frame in said first period (TL) as the first reference frame (F_1) or the second reference frame (Fn), when said transmission/reception unit (21) performs a series of transmissions for each of a plurality of frames (41) in another said second period (TH) at said second acoustic pressure after said series of said transmissions at the first acoustic pressure in said first period (TL).

3. A method according to Claim 1, in which said image generating unit (25) generates said first display image by using the held values of the echo signals obtained at a second point in time in said first period (TL) at which a predetermined time period has elapsed since a first point in time at which the transmission/reception unit (21) performs said series of transmissions for a last frame (41) in said second period (TH).

4. A method according to Claim 3, further comprising:

using a setting unit to set said second point in time to an arbitrary time,
wherein said image generating unit (25) generates said first display image according to an echo signal obtained in said first period at said second point in time set by said setting unit.

5. A method according to Claim 1, in which said image generating unit (25) updates said first display image time-sequentially by performing said maximum luminance value holding computation from time to time, using echo signals for respective frames obtained in said first period.

6. A method according to Claim 1, in which said image generating unit (25) generates a second display image using an echo signal corresponding to an arbitrary frame in said first period; and
said display unit (14) displays said first display image and said second display image concurrently.

7. A method according to Claim 6, in which said display unit (14) displays said first display image like a moving picture and said second display image like a still image.

8. A method according to Claim 6, in which said display unit (14) superimposes said first display image and said second display image for display.

9. A method according to Claim 1, in which said image generating unit (25) generates said first display image by:

generating a first intermediate image by performing said maximum luminance value holding computation according to echo signals of m frames obtained in said first period, and generating a second intermediate image by performing said maximum luminance value holding computation according to echo signals on n, where m < n, frames obtained in said first period;
generating a differential image between said second intermediate image and said first intermediate image;
converting said first intermediate image into a first hue and said differential image to a second hue; and
synthesizing said first intermediate image converted to said first hue and said differential image converted to said second hue.

10. A method according to Claim 1, further comprising:

selecting a reference frame at which said maximum luminance value holding computation is started,
wherein said image generating unit (25) starts said maximum luminance value holding computation from said selected reference frame.

11. A method according to Claim 1, wherein said display unit (14) compares an echo signal P_0 at each position of a reference frame, obtained as a last frame in said first period, with an echo signal P_i at each position of respective frames obtained in said first period, and changes a display mode including a hue, saturation, and brightness of the first display image for a coordinate at which echo signals P_i satisfy a relation $P_i/P_0 \geq (e^{1/n} - 1)/e^{1/n}$, n being a natural number.

12. A method according to Claim 11, further comprising:

using a time measuring unit to measure an elapsed time T from a time corresponding to said reference frame in said first period to a time corresponding to a latest frame among frames used for said luminance value holding computation related to said first display image,
wherein said display unit displays a numerical value of a product of said elapsed time T and said natural number n.

13. A method according to Claim 1 or 9, in which the control unit (27) controls said transmission/reception unit (21) in such a manner that a series of transmissions and receptions for obtaining echo signals of each of a plurality of frames (43) in a predetermined period (TL) at said first acoustic pressure and a series of transmissions and receptions for obtaining echo signals of each of a plurality of frames (41) in a predetermined period (TH) at said second acoustic pressure are performed alternately.

14. A method according to Claim 1 or 9, in which the control unit (27) controls said transmission/reception unit (21) in such a manner that the series of transmissions for each of the plurality of frames (43) in said first period (TL) are performed substantially under the same condition between the plurality of frames.

Patentansprüche

1. Ultraschall-Diagnosebildgebungsverfahren, das ein Erfassen eines Ultraschallbilds durch Abtasten mittels Ultraschallwellen eines bestimmten Bereichs eines mit Kontrastmittelblasen injizierten Subjektes umfasst, wobei die Kontrastmittelblasen die Eigenschaft haben, ohne zerstört zu werden, harmonische Echos zu erzeugen, wenn Ultraschallwellen bei einem niedrigem Schalldruck übertragen werden, und die über einen langen Zeitraum eine Bildgebung ermöglichen, mit:

Verwenden einer Ultraschallsonde (12), um eine Ultraschallwelle zu dem Subjekt zu senden und ein Echosignal von der Ultraschallwelle zu empfangen,
Verwenden einer Sende-/Empfangseinheit (21), die derart angeordnet ist, dass sie mittels der Ultraschallsonde (12) eine Reihe von Übertragungsvorgängen und Empfangsvorgängen durchführt, um jeweilige Echosignale von jedem einer Mehrzahl von Frames (43) in einer ersten Periode (TL) bei einem ersten Schalldruck zu erhalten, der ein Schalldruck ist, der im Wesentlichen die Kontrastmittelblasen nicht zerstört, sondern der ein Bild der Blutzirkulation in dem Subjekt gewinnen lässt, und um eine Reihe von Übertragungsvorgänge für jeden von einer Mehrzahl von Frames (41) in einer zweiten Periode (TH) bei einem zweiten Schalldruck durchzuführen, um die Kontrastmittelblasen zu zerstören,
Verwenden einer Steuereinheit (27), um die Sende-/Empfangseinheit (21) derart anzusteuern, dass alle Übertragungsvorgänge und Empfangsvorgänge in der ersten Periode kurz nach der Durchführung aller Übertra-

gungsvorgänge in der zweiten Periode ausgeführt werden,
Verwenden eines Speichers zum Speichern einer Mehrzahl von Frames, die in der ersten Periode (TL) erfasst werden,
dadurch gekennzeichnet, dass das Verfahren ferner umfasst:

Registrieren eines ersten Referenzframes (F1) aus der Mehrzahl von Frames gemäß einer Auswahl durch einen Benutzer, nachdem die Reihe von Übertragungsvorgängen und Empfangsvorgängen in der ersten Periode (TL) und die Reihe von Übertragungsvorgängen in der zweiten Periode (TH) durchgeführt wurden,
Verwenden einer Bilderzeugungseinheit (25), um erste Anzeigebilder zu erzeugen, indem eine Maximum-Luminanzwert-Halten-Berechnung von dem ersten Referenzframe (F1) zu einem zweiten Frame (Fn) durchgeführt wird, wobei der zweite Frame (Fn) in der Mehrzahl von Frames enthalten ist, und zeitsequentiell vorwärts oder rückwärts zu dem ersten Referenzframe (F1), wobei das Maximum der Luminanzwerte an jeder Position in den Frames zwischen dem ersten Referenzframe (F1) und dem zweiten Frame (Fn) in dem Maximum-Luminanzwert-Halten-Berechnung gehalten wird, und Verwenden dieser gehaltenen Werte in dem Anzeigebild, so dass

$$Pmax(x,y) = max[P1(x,y), ..., Pn(x, y)],$$

wobei Pmax(x, y) das Maximum des Luminanzwertes für Pixel (x, y) ist, P1(x, y) der Luminanzwert für Pixel (x, y) im ersten Referenzframe ist und Pn(x, y) der Luminanzwert für Pixel (x, y) im zweiten Frame ist,
und Anzeigen der ersten Anzeigebilder auf einer Anzeigeeinheit (14), wobei die Luminanzwerte aus B-Mode-Verarbeiten der empfangenen Echosignale abgeleitet werden.

2. Verfahren nach Anspruch 1, bei dem die Bilderzeugungseinheit (25) die ersten Anzeigebilder unter Verwendung der gehaltenen Werte der in einem letzten Frame in der ersten Periode (TL) erhaltenen Echosignale als den ersten Referenzframe (F1) oder den zweiten Referenzframe (Fn) erzeugt, wenn die Sende-/Empfangseinheit (21) eine Reihe von Übertragungsvorgängen für jeden einer Mehrzahl von Frames (41) in einer anderen der zweiten Periode (TH) bei dem zweiten Schalldruck nach der Reihe der Übertragungsvorgänge bei dem ersten Schalldruck in der ersten Periode (TL) durchführt.

3. Verfahren nach Anspruch 1, bei dem die Bilderzeugungseinheit (25) die ersten Anzeigebilder unter Verwendung der gehaltenen Werte der Echosignale erzeugt, die zu einem zweiten Zeitpunkt in der ersten Periode (TL) erhalten wurden, zu dem eine vorbestimmte Zeitdauer seit einem ersten Zeitpunkt vergangen ist, an dem die Sende-/Empfangseinheit (21) die Reihe von Übertragungsvorgänge für einen letzten Frame (41) in der zweiten Periode (TH) durchführt.

4. Verfahren nach Anspruch 3, ferner umfassend:

Verwenden einer Einstelleinheit, um den zweiten Zeitpunkt auf eine beliebige Zeit einzustellen,
wobei die Bilderzeugungseinheit (25) das erste Anzeigebild gemäß einem Echosignal erzeugt, das in der ersten Periode zu dem von der Einstellungseinheit eingestellten zweiten Zeitpunkt erhalten wird.

5. Verfahren nach Anspruch 1, bei dem die Bilderzeugungseinheit (25) das erste Anzeigebild zeitsequentiell aktualisiert, indem sie von Zeit zu Zeit die Maximum-Luminanzwert-Halten-Berechnung unter Verwendung von Echosignalen für entsprechende in der ersten Periode erhaltene Frames durchführt.

6. Verfahren nach Anspruch 1, bei dem die Bilderzeugungseinheit (25) ein zweites Anzeigebild unter Verwendung eines Echosignals erzeugt, das einem beliebigen Frame in der ersten Periode entspricht, und
die Anzeigeeinheit (14) das erste Anzeigebild und das zweite Anzeigebild gleichzeitig anzeigt.

7. Verfahren nach Anspruch 6, bei dem die Anzeigeeinheit (14) das erste Anzeigebild wie ein bewegtes Bild und das zweite Anzeigebild wie ein Standbild wiedergibt.

8. Verfahren nach Anspruch 6, bei dem die Anzeigeeinheit (14) das erste Anzeigebild und das zweite Anzeigebild zur Anzeige überlagert.

9. Verfahren nach Anspruch 1, bei dem die Bilderzeugungseinheit (25) das erste Anzeigebild erzeugt durch:

Erzeugen eines ersten Zwischenbildes durch Ausführen der Maximum-Luminanzwert-Halten-Berechnung gemäß Echosignalen von m Frames, die in der ersten Periode erhalten wurden, und Erzeugen eines zweiten Zwischenbildes durch Ausführen der Maximum-Luminanzwert-Halten-Berechnung gemäß Echosignalen auf n, wobei m < n, Frames, die in der ersten Periode erhalten wurden,
Erzeugen eines Differenzbildes zwischen dem zweiten Zwischenbild und dem ersten Zwischenbild,
Umwandeln des ersten Zwischenbildes in einen ersten Farbton und des Differentialbildes in einen zweiten Farbton, und
Synthetisieren des ersten Zwischenbildes, das in den ersten Farbton umgewandelt wurde, und des Differentialbildes, das in den zweiten Farbton umgewandelt wurde.

10. Verfahren nach Anspruch 1, ferner mit:

Auswählen eines Referenzframes, bei dem die Maximum-Luminanzwert-Halten-Berechnung gestartet wird, wobei die Bilderzeugungseinheit (25) die Maximum-Luminanzwert-Halten-Berechnung aus dem ausgewählten Referenzframe startet.

11. Verfahren nach Anspruch 1, wobei die Anzeigeeinheit (14) ein Echosignal P0 an jeder Position eines Referenzframes, der als letztes Bild in der ersten Periode erhalten wurde, mit einem Echosignal Pi an jeder Position der jeweiligen Bilder, die in der ersten Periode erhalten wurden, vergleicht und einen Anzeigemodus ändert, der einen Farbton, eine Sättigung und eine Helligkeit des ersten Anzeigebildes für eine Koordinate umfasst, bei der Echosignale Pi eine Beziehung $Pi/Po \geq (e^{1/n} - 1)/e^{1/n}$ erfüllen, wobei n eine natürliche Zahl ist.

12. Verfahren nach Anspruch 11, ferner mit:

Verwenden einer Zeitmesseinheit zum Messen einer verstrichenen Zeit T von einer Zeit, die dem Referenzframe in der ersten Periode entspricht, bis zu einer Zeit, die einem neuesten Frame unter den Frames entspricht, die für die Luminanzwert-Halten-Berechnung, die das erste Anzeigebild betrifft, verwendet werden,
wobei die Anzeigeeinheit einen numerischen Wert eines Produkts der abgelaufenen Zeit T und der natürlichen Zahl n anzeigt.

13. Verfahren nach Anspruch 1 oder 9, bei dem die Steuereinheit (27) die Sende-/Empfangseinheit (21) derart ansteuert, dass eine Reihe von Übertragungsvorgängen und Empfangsvorgängen zum Erhalten von Echosignalen von jedem einer Mehrzahl von Frames (43) in einer vorbestimmten Periode (TL) bei dem ersten Schalldruck und eine Reihe von Übertragungsvorgängen und Empfangsvorgängen zum Erhalten von Echosignalen von jedem von einer Mehrzahl von Frames (41) in einer vorbestimmten Periode (TH) bei dem zweiten Schalldruck abwechselnd durchgeführt werden.

14. Verfahren nach Anspruch 1 oder 9, bei dem die Steuereinheit (27) die Sende-/Empfangseinheit (21) derart steuert, dass die Reihe von Übertragungsvorgängen für jeden der mehreren Frames (43) in der ersten Periode (TL) im Wesentlichen unter der gleichen Bedingung zwischen der Mehrzahl von Frames durchgeführt wird.

Revendications

1. Procédé d'imagerie diagnostique à ultrasons comprenant l'étape consistant à obtenir une image ultrasonore, en balayant, au moyen d'ondes ultrasonores, une zone spécifique d'un sujet auquel ont été injectées des bulles de produit de contraste qui présentent la caractéristique de générer des échos harmoniques sans être détruites lorsque des ondes ultrasonores sont transmises à une faible pression acoustique, et qui permettent une imagerie sur une longue période de temps, comprenant les étapes ci-dessous consistant à :

utiliser une sonde ultrasonore (12) en vue de transmettre une onde ultrasonore audit sujet et de recevoir un signal d'écho provenant de ladite onde ultrasonore ;
utiliser une unité de transmission / réception (21) agencée de manière à mettre en oeuvre, par l'intermédiaire de ladite sonde ultrasonore (12), une série de transmissions et de réceptions pour obtenir des signaux d'écho respectifs de chacune d'une pluralité de trames (43) au cours d'une première période (TL) à une première pression acoustique, laquelle correspond à une pression acoustique permettant de ne pas détruire sensiblement

lesdites bulles de produit de contraste, mais permettant d'obtenir une image de la circulation sanguine dans ledit sujet, et à mettre en oeuvre une série de transmissions pour chacune d'une pluralité de trames (41) au cours d'une seconde période (TH), à une seconde pression acoustique permettant de détruire lesdites bulles de produit de contraste

utiliser une unité de commande (27) pour commander ladite unité de transmission / réception (21) de sorte que toutes les transmissions et réceptions au cours de ladite première période sont mises en oeuvre peu après que toutes les transmissions au cours de ladite seconde période ont été mises en oeuvre ;

utiliser une mémoire pour stocker une pluralité de trames qui sont acquises au cours de ladite première période (TL) ;

caractérisé en ce que le procédé comprend en outre les étapes ci-dessous consistant à :

enregistrer une première trame de référence (F_1) parmi la pluralité de trames, conformément à une sélection effectuée par un utilisateur, après que la série de transmissions et de réceptions au cours de la première période (TL) et la série de transmissions au cours de la seconde période (TH) sont achevées ;

utiliser une unité de génération d'images (25) en vue de générer des premières images d'affichage en mettant en oeuvre un calcul de maintien de valeurs de luminance maximales de la première trame de référence (F_1) à une seconde trame (F_n), la seconde trame (F_n) étant incluse dans la pluralité de trames, et étant située séquentiellement dans le temps vers l'avant ou vers l'arrière par rapport à la première trame de référence (F_1), dans lequel le maximum des valeurs de luminance à chaque position dans lesdites trames entre la première trame de référence (F_1) et la seconde trame (F_n) est maintenu dans ledit calcul de maintien de valeurs de luminance maximales, et utiliser ces valeurs maintenues dans ladite image d'affichage, de sorte que :

$$P_{max}(x, y) = \max[P_1(x, y), \ldots\ldots, P_n(x, y)],$$

où $P_{max}(x, y)$ correspond au maximum de la valeur de luminance pour un pixel (x, y), $P_1(x, y)$ correspond à la valeur de luminance pour le pixel (x, y) dans la première trame de référence et $P_n(x, y)$ correspond à la valeur de luminance pour le pixel (x, y) dans la seconde trame ; et

afficher lesdites premières images d'affichage sur une unité d'affichage (14), dans lequel les valeurs de luminance sont dérivées d'un traitement en mode B des signaux d'écho reçus.

2. Procédé selon la revendication 1, dans lequel ladite unité de génération d'images (25) génère lesdites premières images d'affichage en utilisant les valeurs maintenues des signaux d'écho obtenus dans une dernière trame au cours de ladite première période (TL), en tant que la première trame de référence (F_1) ou que la seconde trame de référence (F_n), lorsque ladite unité de transmission / réception (21) met en oeuvre une série de transmissions pour chacune d'une pluralité de trames (41) au cours d'une autre dite seconde période (TH) à ladite seconde pression acoustique, après ladite série desdites transmissions à la première pression acoustique au cours de ladite première période (TL).

3. Procédé selon la revendication 1, dans lequel ladite unité de génération d'images (25) génère ladite première image d'affichage en utilisant les valeurs maintenues des signaux d'écho obtenus à un second instant au cours de ladite première période (TL) auquel une période de temps prédéterminée s'est écoulée depuis un premier instant auquel l'unité de transmission / réception (21) met en oeuvre ladite série de transmissions pour une dernière trame (41) au cours de ladite seconde période (TH).

4. Procédé selon la revendication 3, comprenant en outre les étapes ci-dessous consistant à :

utiliser une unité de définition pour définir ledit second instant sur un temps arbitraire,

dans lequel ladite unité de génération d'images (25) génère ladite première image d'affichage selon un signal d'écho obtenu au cours de ladite première période audit second instant défini par ladite unité de définition.

5. Procédé selon la revendication 1, dans lequel ladite unité de génération d'images (25) met à jour ladite première image d'affichage de manière séquentielle dans le temps en mettant en oeuvre ledit calcul de maintien de valeurs de luminance maximales, périodiquement, en utilisant des signaux d'écho pour des trames respectives obtenues au cours de ladite première période.

6. Procédé selon la revendication 1, dans lequel ladite unité de génération d'images (25) génère une seconde image d'affichage en utilisant un signal d'écho correspondant à une trame arbitraire au cours de ladite première période ; et ladite unité d'affichage (14) affiche simultanément ladite première image d'affichage et ladite seconde image d'affichage.

7. Procédé selon la revendication 6, dans lequel ladite unité d'affichage (14) affiche ladite première image d'affichage sous la forme d'une image animée et ladite seconde image d'affichage sous la forme d'une image fixe.

8. Procédé selon la revendication 6, dans lequel ladite unité d'affichage (14) superpose ladite première image d'affichage et ladite seconde image d'affichage à des fins d'affichage.

9. Procédé selon la revendication 1, dans lequel ladite unité de génération d'images (25) génère ladite première image d'affichage :

en générant une première image intermédiaire en mettant en oeuvre ledit calcul de maintien de valeurs de luminance maximales selon des signaux d'écho de « m » trames obtenues au cours de ladite première période, et en générant une seconde image intermédiaire en mettant en oeuvre ledit calcul de maintien de valeurs de luminance maximales selon des signaux d'écho sur « n », où m < n, trames obtenues au cours de ladite première période ;
en générant une image différentielle entre ladite seconde image intermédiaire et ladite première image intermédiaire ;
en convertissant ladite première image intermédiaire en une première tonalité chromatique et ladite image différentielle en une seconde tonalité chromatique ; et
en synthétisant ladite première image intermédiaire convertie en ladite première tonalité chromatique et ladite image différentielle convertie en ladite seconde tonalité chromatique.

10. Procédé selon la revendication 1, comprenant en outre l'étape ci-dessous consistant à :

sélectionner une trame de référence à laquelle ledit calcul de maintien de valeurs de luminance maximales est démarré,
dans lequel ladite unité de génération d'images (25) démarre ledit calcul de maintien de valeurs de luminance maximales à partir de ladite trame de référence sélectionnée.

11. Procédé selon la revendication 1, dans lequel ladite unité d'affichage (14) compare un signal d'écho P_0 à chaque position d'une trame de référence, obtenue en tant qu'une dernière trame au cours de ladite première période, à un signal d'écho P_i à chaque position de trames respectives obtenues au cours de ladite première période, et modifie un mode d'affichage incluant une tonalité chromatique, une saturation et une luminosité de la première image d'affichage pour une coordonnée à laquelle les signaux d'écho P_i satisfont une relation $P_i/P_0 \geq (e^{1/n} - 1)/e^{1/n}$, « n » étant un nombre naturel.

12. Procédé selon la revendication 11, comprenant en outre l'étape ci-dessous consistant à :

utiliser une unité de mesure de temps en vue de mesurer un temps écoulé « T », d'un temps correspondant à ladite trame de référence au cours de ladite première période à un temps correspondant à une dernière trame parmi des trames utilisées pour ledit calcul de maintien de valeurs de luminance maximales connexe à ladite première image d'affichage ;
dans lequel ladite unité d'affichage affiche une valeur numérique d'un produit dudit temps écoulé « T » et dudit nombre naturel « n ».

13. Procédé selon la revendication 1 ou 9, dans lequel l'unité de commande (27) commande ladite unité de transmission / réception (21) de sorte qu'une série de transmissions et de réceptions pour obtenir des signaux d'écho de chacune d'une pluralité de trames (43) au cours d'une période prédéterminée (TL), à ladite première pression acoustique, et qu'une série de transmissions et de réceptions pour obtenir des signaux d'écho de chacune d'une pluralité de trames (41) au cours d'une période prédéterminée (TH), à ladite seconde pression acoustique, sont mises en oeuvre par alternance.

14. Procédé selon la revendication 1 ou 9, dans lequel l'unité de commande (27) commande ladite unité de transmission / réception (21) de sorte que les séries de transmissions pour chacune de la pluralité de trames (43) au cours de ladite première période (TL) sont mises en oeuvre sensiblement sous la même condition entre les trames de la pluralité de trames.

FIG. 1

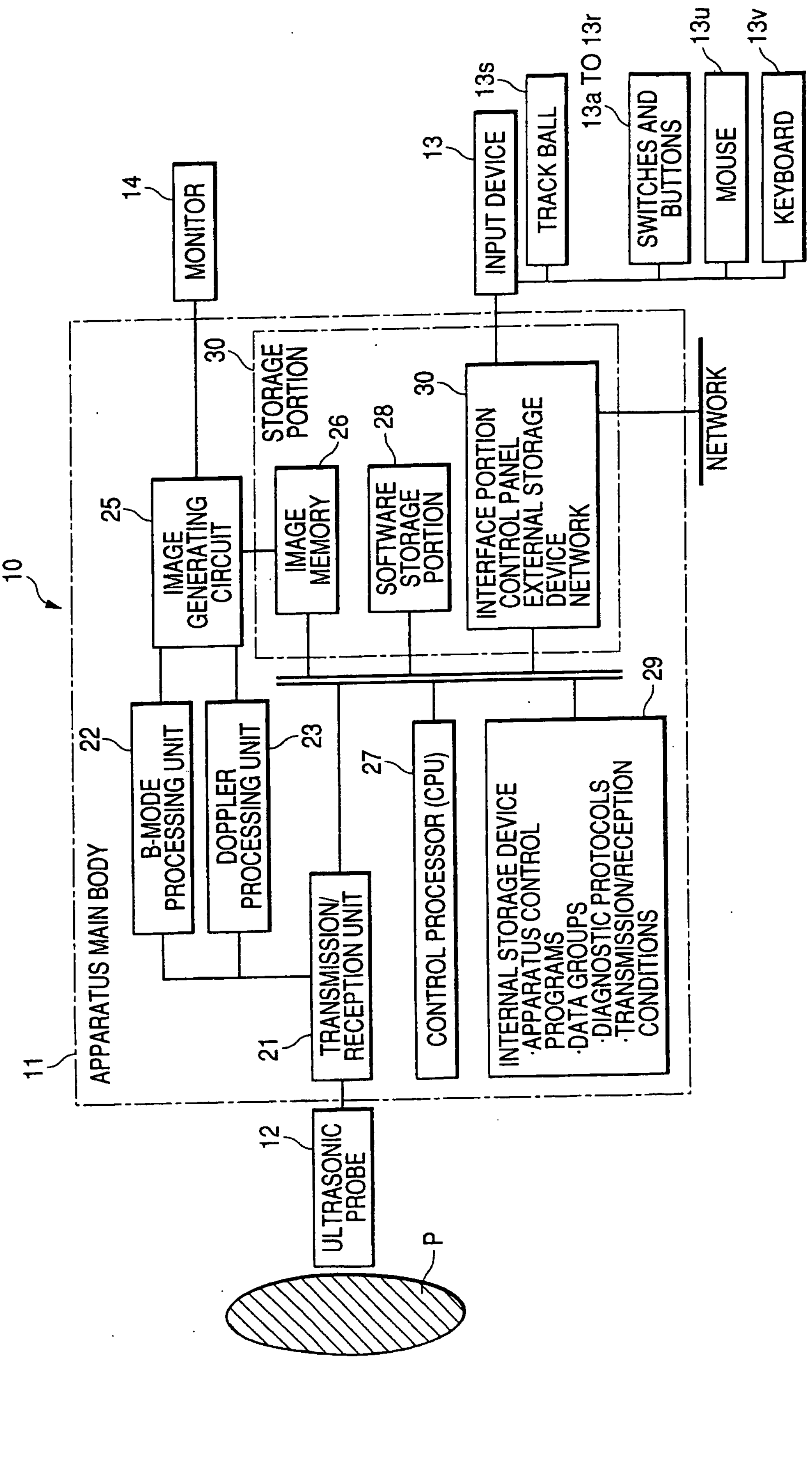
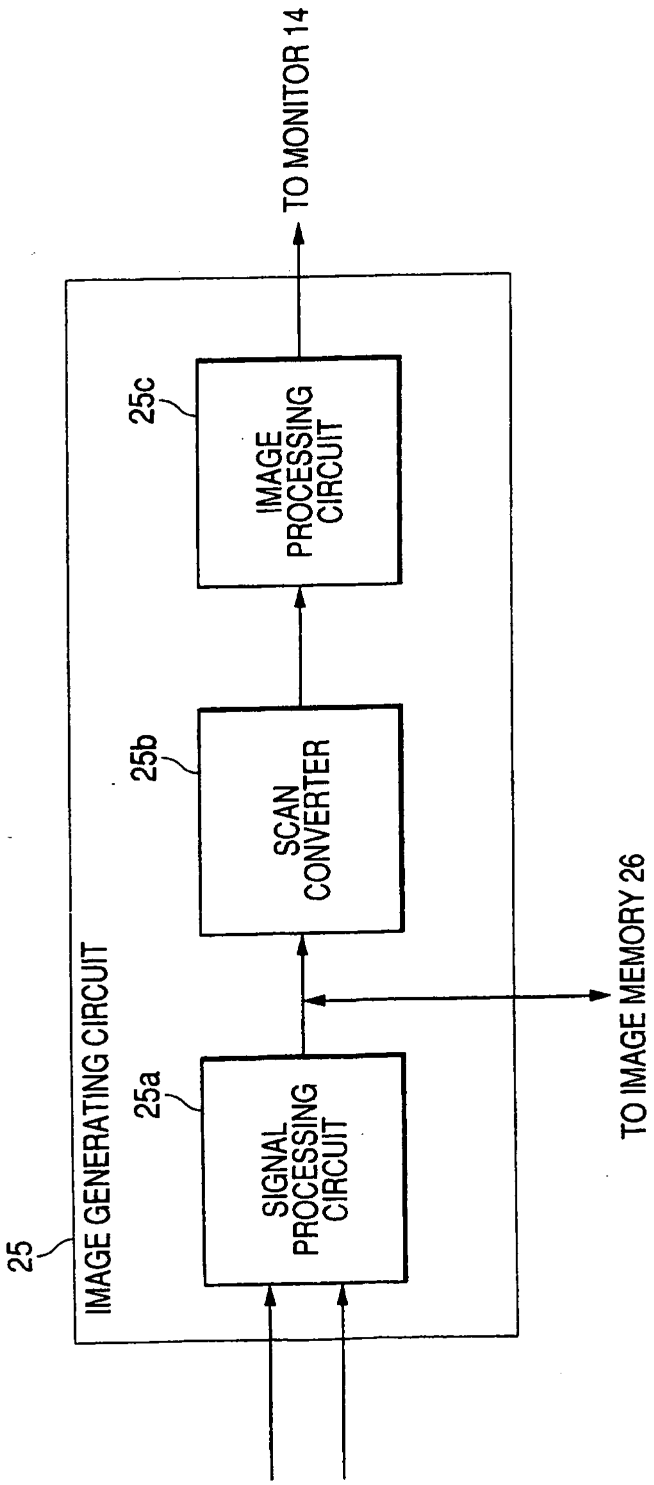

10
11
APPARATUS MAIN BODY
12
ULTRASONIC PROBE
P
21
TRANSMISSION/ RECEPTION UNIT
22
B-MODE PROCESSING UNIT
23
DOPPLER PROCESSING UNIT
25
IMAGE GENERATING CIRCUIT
14
MONITOR
30
STORAGE PORTION
26
IMAGE MEMORY
28
SOFTWARE STORAGE PORTION
30
INTERFACE PORTION
CONTROL PANEL
EXTERNAL STORAGE DEVICE
NETWORK
NETWORK
27
CONTROL PROCESSOR (CPU)
29
INTERNAL STORAGE DEVICE
·APPARATUS CONTROL PROGRAMS
·DATA GROUPS
·DIAGNOSTIC PROTOCOLS
·TRANSMISSION/RECEPTION CONDITIONS
13
INPUT DEVICE
13s
TRACK BALL
13a TO 13r
SWITCHES AND BUTTONS
13u
MOUSE
13v
KEYBOARD

FIG. 2


TO MONITOR 14
25c
IMAGE PROCESSING CIRCUIT
25b
SCAN CONVERTER
25a
SIGNAL PROCESSING CIRCUIT
25
IMAGE GENERATING CIRCUIT
TO IMAGE MEMORY 26

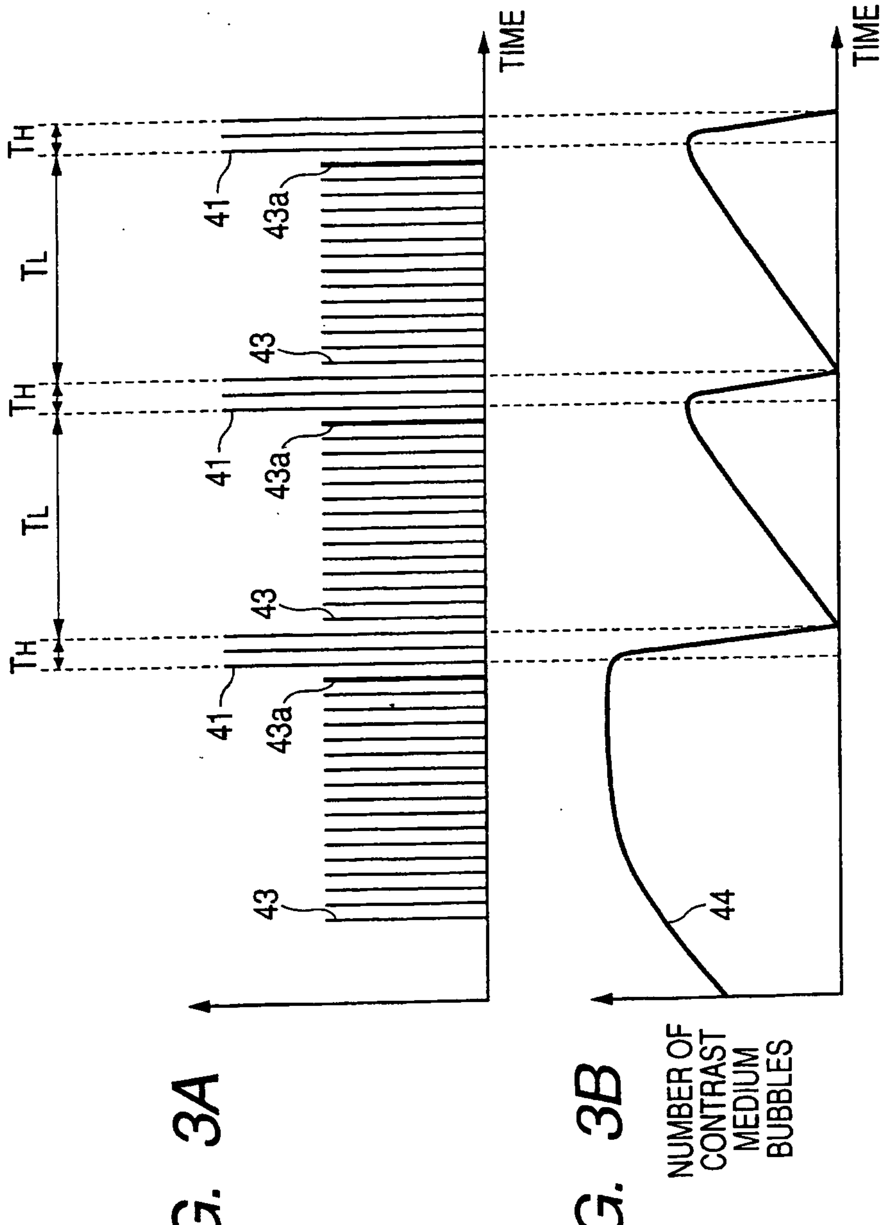

TIME
TH
TL
TH
TL
TH
41
43a
43
41
43a
43
41
43a
43
TIME
44
NUMBER OF CONTRAST MEDIUM BUBBLES

FIG. 3A

FIG. 3B

FIG. 4

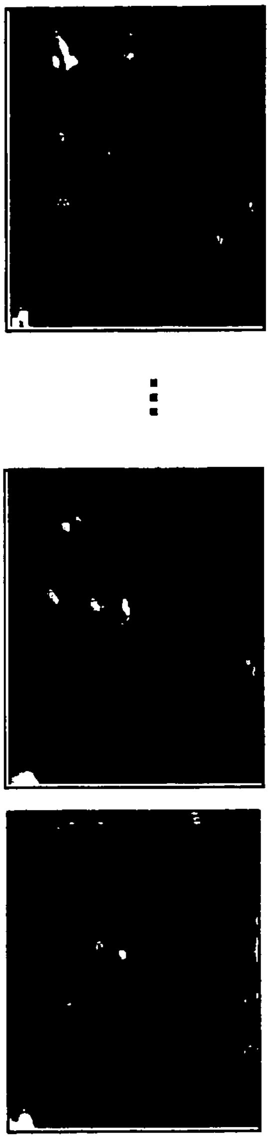


FIG. 5

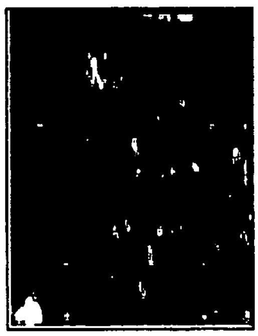


FIG. 6

FIG. 7

FIG. 8

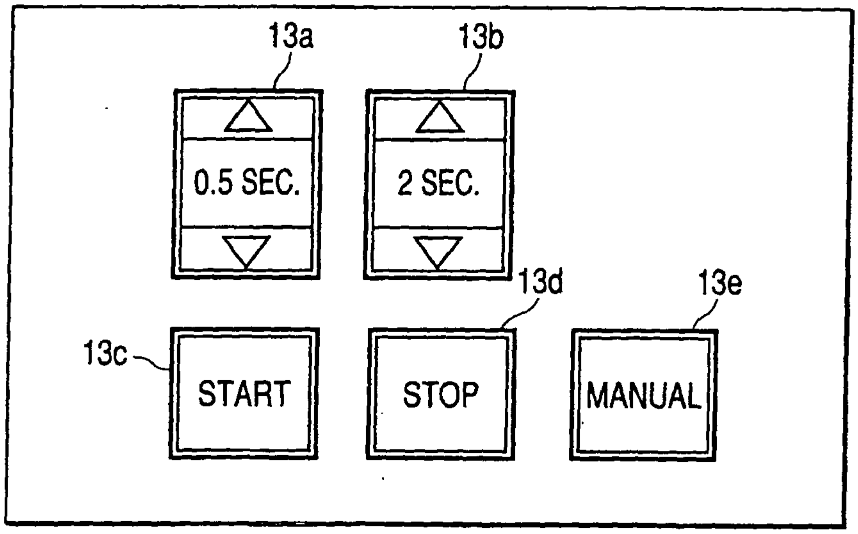


FIG. 9A

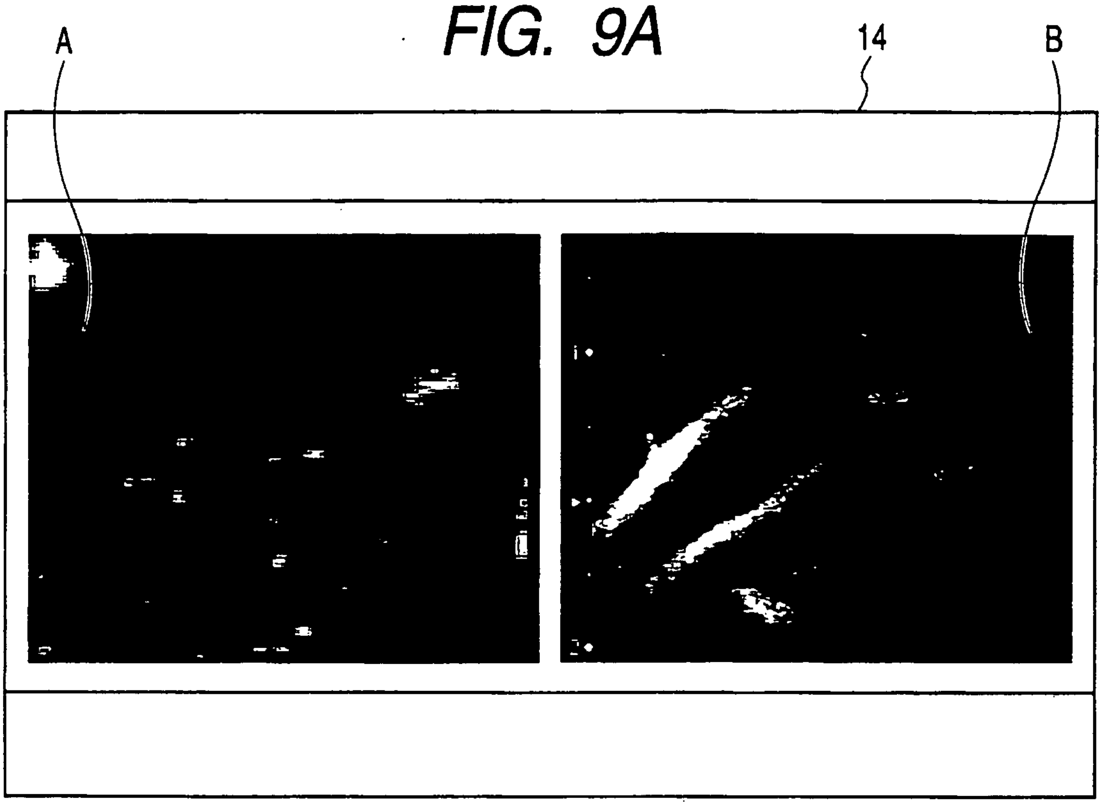


FIG. 9B

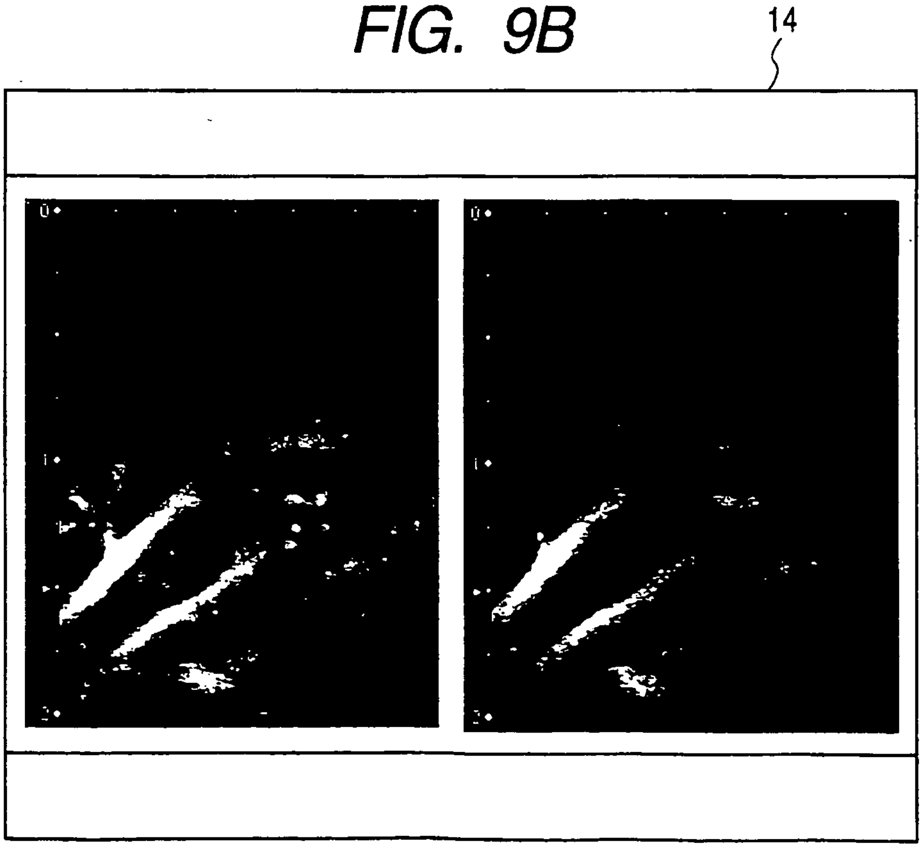


FIG. 10

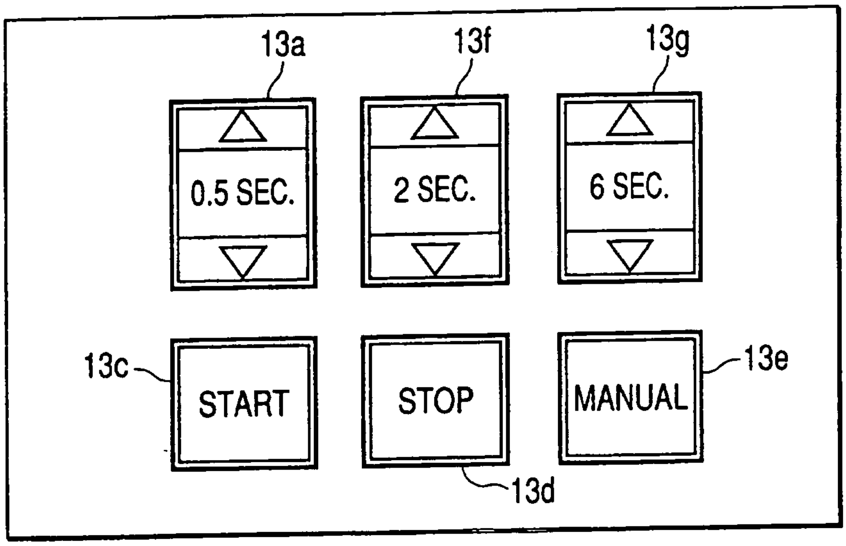


FIG. 11

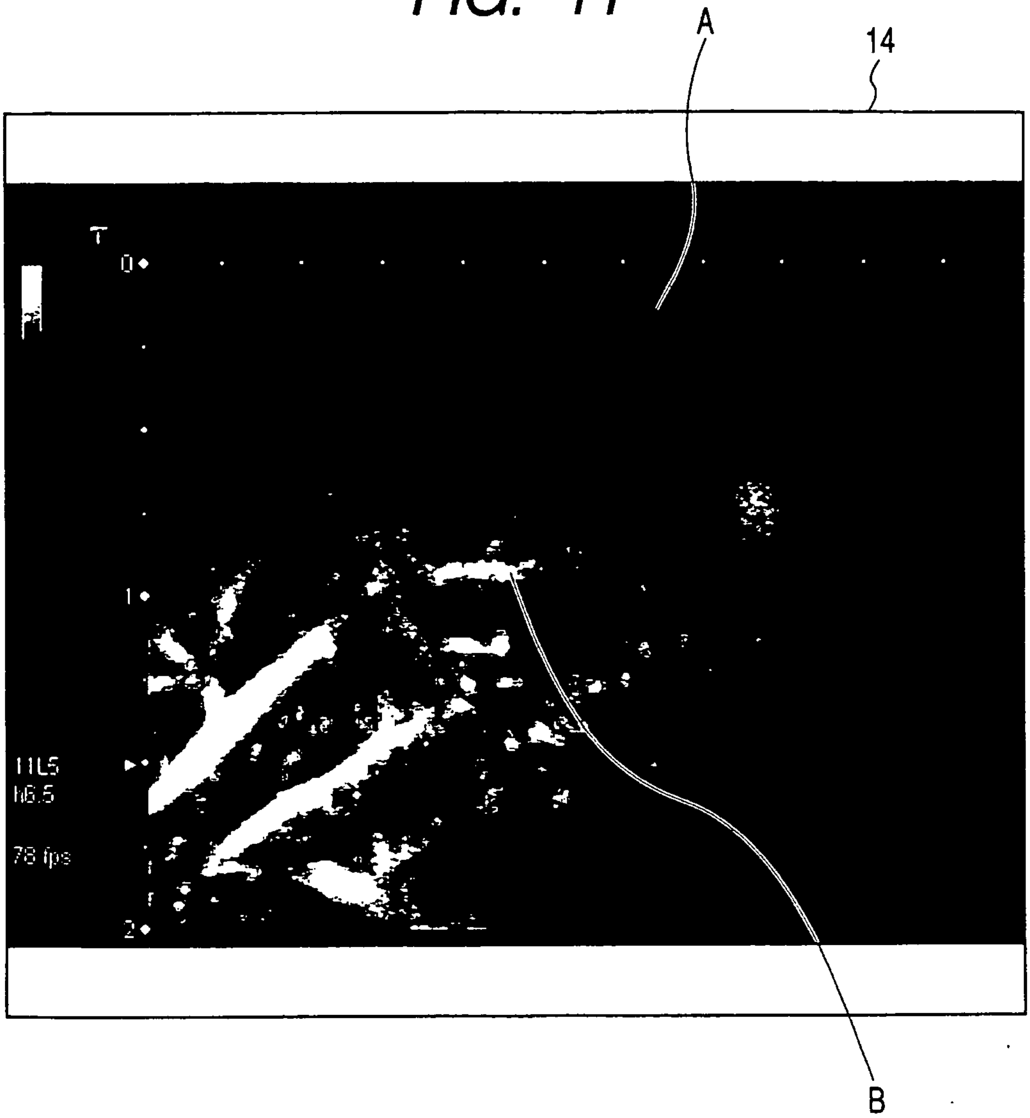


FIG. 12

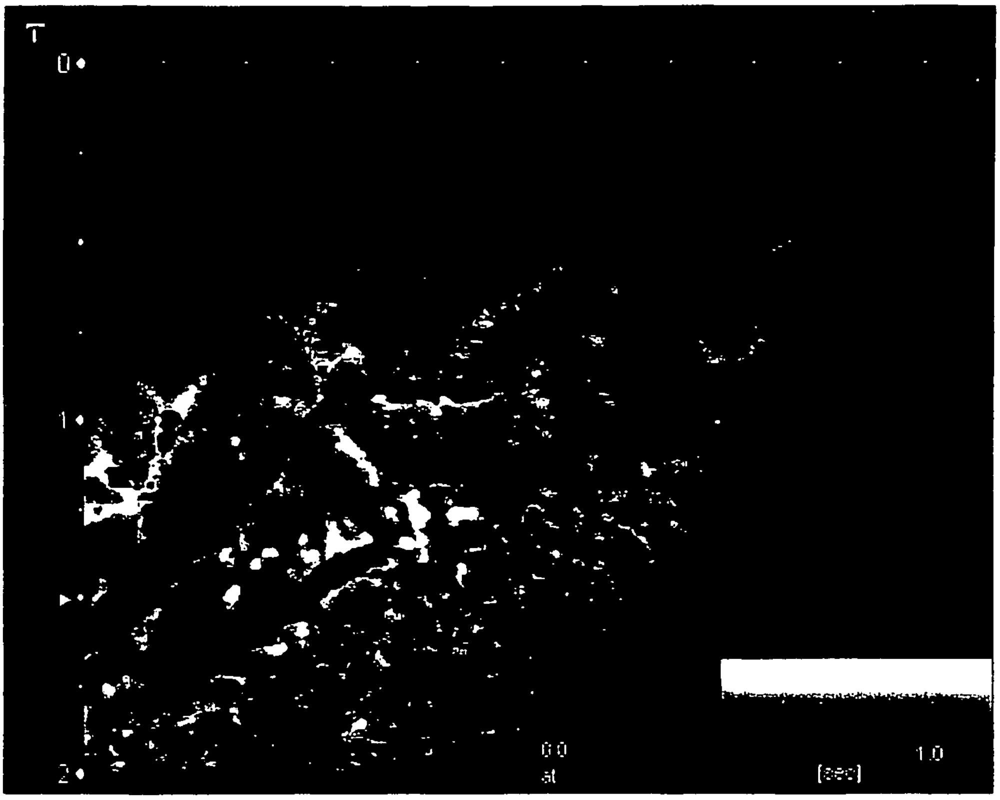


FIG. 13

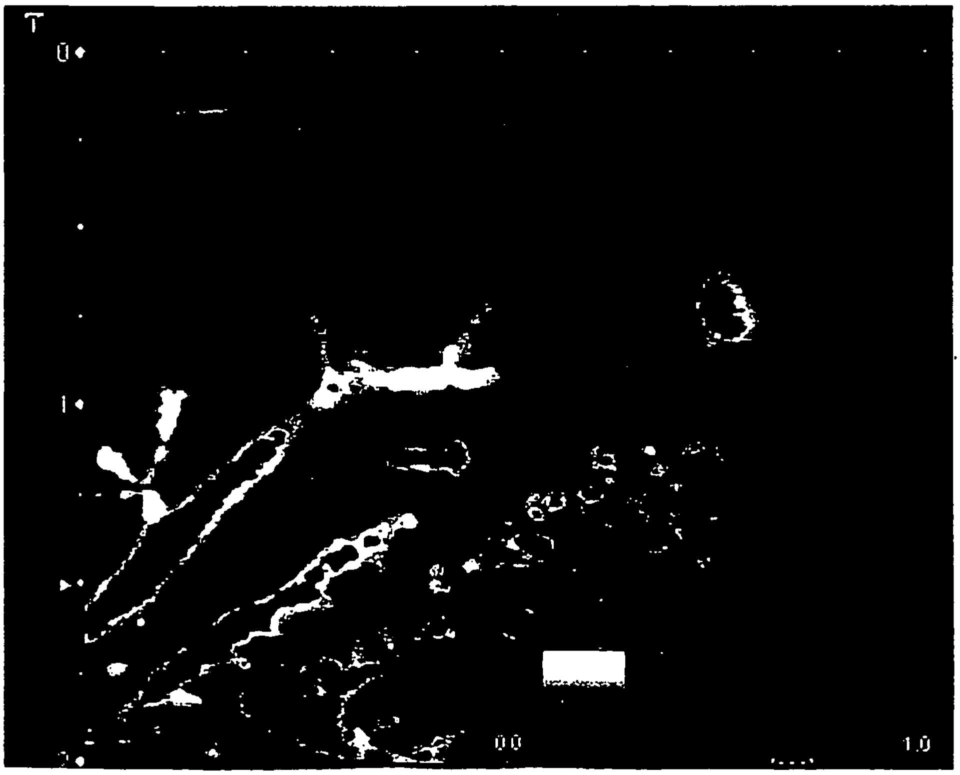


FIG. 14

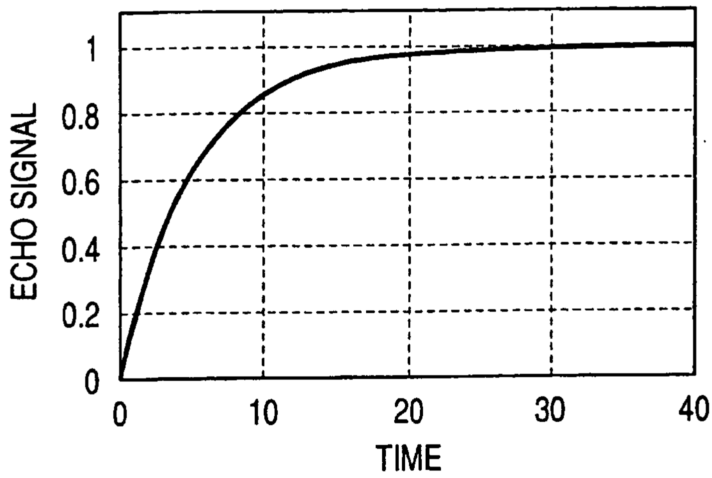


FIG. 15

n	Vc/V0	DECIBELS
1	0.632	-1.99
2	0.393	-4.05
3	0.283	-5.47
4	0.221	-6.55
5	0.181	-7.42
6	0.154	-8.14
7	0.133	-8.76
8	0.118	-9.30

FIG. 16

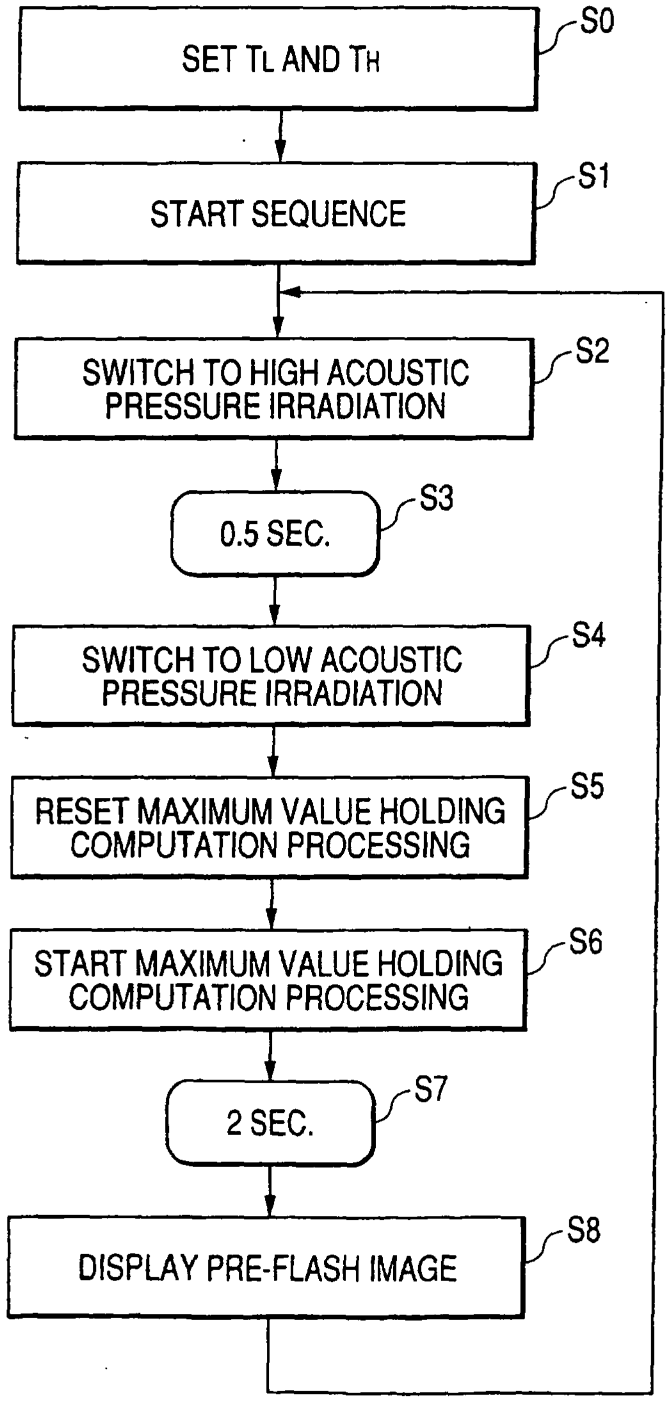

SET TL AND TH
S0
START SEQUENCE
S1
SWITCH TO HIGH ACOUSTIC PRESSURE IRRADIATION
S2
0.5 SEC.
S3
SWITCH TO LOW ACOUSTIC PRESSURE IRRADIATION
S4
RESET MAXIMUM VALUE HOLDING COMPUTATION PROCESSING
S5
START MAXIMUM VALUE HOLDING COMPUTATION PROCESSING
S6
2 SEC.
S7
DISPLAY PRE-FLASH IMAGE
S8

FIG. 17

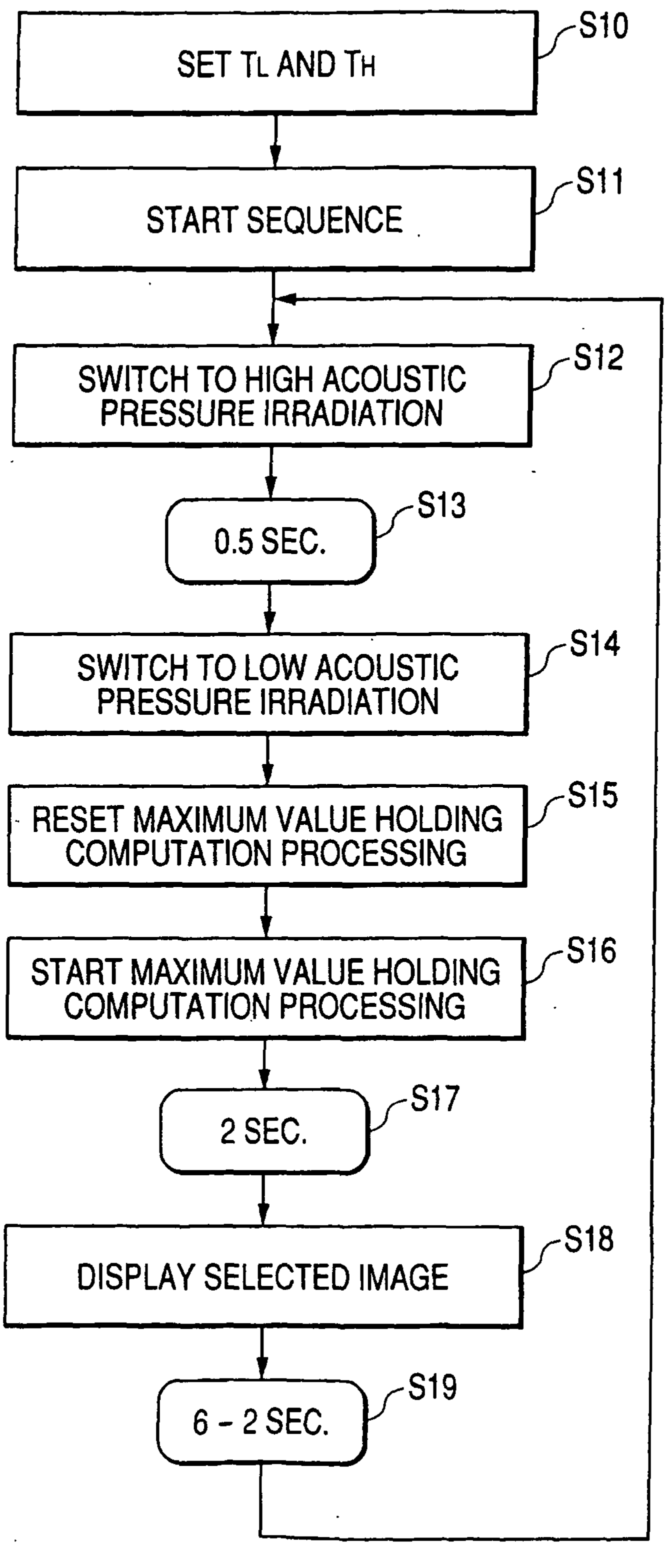
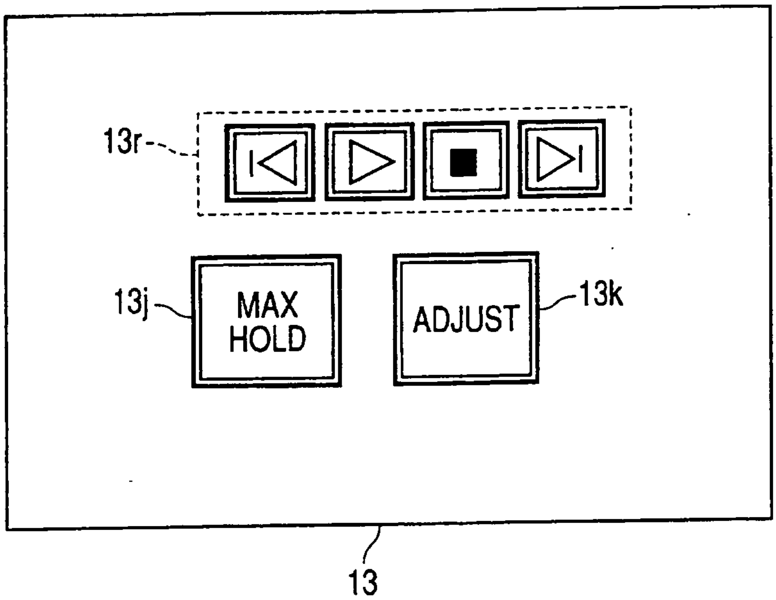

SET TL AND TH
S10
START SEQUENCE
S11
SWITCH TO HIGH ACOUSTIC PRESSURE IRRADIATION
S12
0.5 SEC.
S13
SWITCH TO LOW ACOUSTIC PRESSURE IRRADIATION
S14
RESET MAXIMUM VALUE HOLDING COMPUTATION PROCESSING
S15
START MAXIMUM VALUE HOLDING COMPUTATION PROCESSING
S16
2 SEC.
S17
DISPLAY SELECTED IMAGE
S18
6 - 2 SEC.
S19

FIG. 18



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 11155858 A **[0004]**
- US 20020055681 A **[0007]**
- JP 11089839 A **[0071]**

专利名称(译)	超声诊断成像方法		
公开(公告)号	EP1820452B1	公开(公告)日	2018-08-01
申请号	EP2007010953	申请日	2004-04-28
[标]申请(专利权)人(译)	株式会社东芝 东芝医疗系统株式会社		
申请(专利权)人(译)	株式会社东芝 东芝医疗系统公司		
当前申请(专利权)人(译)	东芝医疗系统公司		
[标]发明人	KAMIYAMA NAOHISA		
发明人	KAMIYAMA, NAOHISA		
IPC分类号	A61B8/06 A61B8/08 A61B8/13 G01S7/52 G01S15/89 A61B8/00		
CPC分类号	A61B8/06 A61B8/13 A61B8/481 G01S7/52038 G01S7/52041 G01S7/52074 G01S15/8979		
代理机构(译)	莫兰，DAVID		
优先权	2003124168 2003-04-28 JP		
其他公开文献	EP1820452A1		
外部链接	Espacenet		

摘要(译)

一种超声波诊断装置（10），其通过在增强型超声波检查中的预定定时切换来执行高声压和低声压超声波传输，并且同时显示通过低声压传输实时获得的补充图像，如运动图像，以及在切换到静止图像之类的高声压传输之前立即通过低声压传输获得的预闪光图像，以允许操作者理解毛细管水平处的结构。还可以在任意时刻显示通过低声压传输获得的所选图像而不是预闪光图像。