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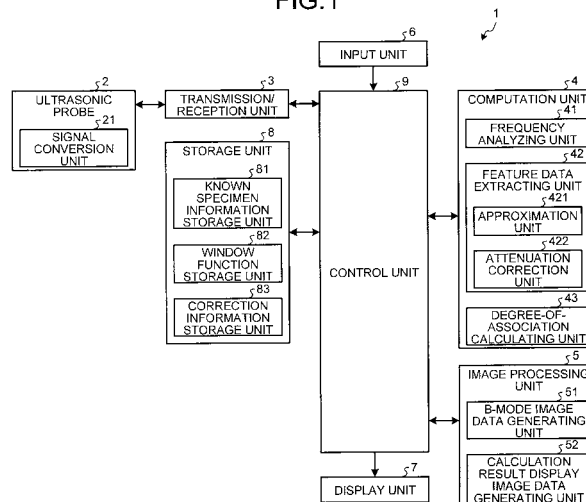
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(54) **ULTRASOUND OBSERVATION DEVICE, OPERATION METHOD OF ULTRASOUND OBSERVATION DEVICE, AND OPERATION PROGRAM OF ULTRASOUND OBSERVATION DEVICE**

(57) An ultrasonic observation apparatus includes: a frequency analyzing unit configured to calculate a frequency spectrum by analyzing a frequency of a received ultrasonic wave; a feature data extracting unit configured to extract feature data of the frequency spectrum by performing an approximation to the frequency spectrum; a storage unit configured to store feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens, and to store the plural known specimens as being classified into plural groups based upon information of each of the

known specimens; a degree-of-association calculating unit configured to calculate a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group; an image processing unit configured to generate ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result of the degree-of-association calculating unit; and a display unit configured to be capable of displaying the image corresponding to the ultrasonic image data generated by the image processing unit.

FIG.1



**Description**

## Field

5 **[0001]** The present invention relates to an ultrasonic observation apparatus for observing a specimen tissue by use of ultrasonic wave, an operation method of the ultrasonic observation apparatus, and an operating program of the ultrasonic observation apparatus.

## Background

10 **[0002]** There has conventionally been known an ultrasonic elastography as an examination technology of breast cancer by use of ultrasonic wave (e.g., see Patent Literature 1). The ultrasonic elastography is a technique of utilizing a phenomenon that a hardness of a cancer or a tumor tissue in a living body is different depending on a disease progression or on the living body. In this technique, a distorted amount or elasticity of a body tissue in an examination  
15 region is measured by use of ultrasonic wave with the examination region being externally pressed, and the result of the measurement is displayed as a tomographic view.

## Citation List

20 Patent Literature

**[0003]** Patent Literature 1: WO 2005/122906 A

## Summary

25 Technical Problem

**[0004]** However, in the abovementioned ultrasonic elastography, there is a problem in that it is difficult to transmit applied pressure to the lower part of a vascular channel, such as a blood vessel or a lymph channel. Therefore, when  
30 a tumor is formed near the vascular channel, a border of the tumor becomes indistinct, which makes it difficult to distinguish tumor invasion in the vascular channel. Thus, in the ultrasonic elastography, it is sometimes difficult to observe a specimen or distinct tissue characterization with accuracy.

**[0005]** Moreover, in the ultrasonic elastography, there is another problem in that the reliability of a measurement result is low because pressure or compression speed applied by an examiner varies from person to person when compression  
35 is applied to the screening location.

**[0006]** The present invention has been made in view of the above and it is an object of the present invention to provide an ultrasonic observation apparatus, an operation method of the ultrasonic observation apparatus, and an operating program of the ultrasonic observation apparatus capable of observing a specimen with accuracy and enhancing the observation result in terms of reliability.  
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## Solution to Problem

**[0007]** In order to solve the abovementioned problem and achieve the object, an ultrasonic observation apparatus according to the invention transmits an ultrasonic wave to a specimen and receives the ultrasonic wave reflected on the  
45 specimen. The ultrasonic observation apparatus includes: a frequency analyzing unit configured to calculate a frequency spectrum by analyzing a frequency of the received ultrasonic wave; a feature data extracting unit configured to extract feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated by the frequency analyzing unit; a storage unit configured to store feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens, and to store the plural known specimens as  
50 being classified into plural groups based upon information of each of the known specimens; a degree-of-association calculating unit configured to calculate a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group stored in the storage unit; an image processing unit configured to generate ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result of the degree-of-association calculating unit; and a display unit configured to be capable of displaying the image corresponding to the ultrasonic image data generated by the image processing unit.  
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**[0008]** In the ultrasonic observation apparatus according to the invention, the feature data extracting unit extracts plural feature data. The storage unit stores an average of the respective feature data in each of the plural groups. The

degree-of-association calculating unit sets feature data space having at least any one of the plural feature data as a component, and calculates, as the degree of association, a distance on the feature data space between a specimen point that has a feature data, which serves as the component of the feature data space, out of the feature data of the frequency spectrum of the specimen as a coordinate on the feature data space, and a known specimen average point that has an average of the feature data, which serve as the component of the feature data space, out of the feature data in the group of the plural known specimens as a coordinate on the feature data space.

**[0009]** In the ultrasonic observation apparatus according to the invention, the image processing unit determines a pixel value of the ultrasonic image data according to the distance between the specimen point and the known specimen average point.

**[0010]** In the ultrasonic observation apparatus according to the invention, the degree-of-association calculating unit calculates a standard deviation of a feature data in a new population formed by adding a feature data of the specimen to the feature data belonging to the same group, and calculates the difference between the standard deviation and the standard deviation of the feature data belonging to the same group as the degree of association.

**[0011]** In the ultrasonic observation apparatus according to the invention, the image processing unit determines the pixel value of the ultrasonic image data according to the difference between the standard deviation of the feature data in the new population and the standard deviation of the feature data belonging to the same group.

**[0012]** In the ultrasonic observation apparatus according to the invention, the plural specimens having the feature data belonging to the same group have the same tissue characterization.

**[0013]** In the ultrasonic observation apparatus according to the invention, the feature data extracting unit extracts the feature data by performing an attenuation correction process for reducing a contribution of an attenuation caused according to a reception depth and a frequency of the ultrasonic wave during the propagation of the ultrasonic wave to the frequency spectrum calculated by the frequency analyzing unit, and by performing an approximation process to the frequency spectrum.

**[0014]** In the ultrasonic observation apparatus according to the invention, the feature data extracting unit includes: an approximation unit configured to extract pre-correction feature data, which is an amount before the attenuation correction process, through an execution of the approximation process to the frequency spectrum calculated by the frequency analyzing unit; and an attenuation correction unit configured to extract the feature data of the frequency spectrum by performing the attenuation correction process to the pre-correction feature data extracted by the approximation unit.

**[0015]** In the ultrasonic observation apparatus according to the invention, the feature data extracting unit includes: an attenuation correction unit configured to execute the attenuation correction process to the frequency spectrum; and an approximation unit configured to extract the feature data of the frequency spectrum by performing the approximation process to the frequency spectrum that is corrected by the attenuation correction unit.

**[0016]** In the ultrasonic observation apparatus according to the invention, the approximation unit approximates the frequency spectrum with a polynomial according to a regression analysis.

**[0017]** In the ultrasonic observation apparatus according to the invention, the approximation unit approximates the frequency spectrum with a primary expression, and extracts plural feature data including at least two of a slope of the primary expression, an intercept of the primary expression, and an intensity determined by using the slope, the intercept, and a specific frequency included in a frequency band of the frequency spectrum.

**[0018]** In the ultrasonic observation apparatus according to the invention, the attenuation correction unit makes a great correction, as the reception depth of the ultrasonic wave is larger.

**[0019]** An operation method according to the invention is a method of an ultrasonic observation apparatus that transmits an ultrasonic wave to a specimen and receives the ultrasonic wave reflected on the specimen. The operation method includes: a frequency analyzing step including calculating a frequency spectrum by analyzing a frequency of the received ultrasonic wave by a frequency analyzing unit; a feature data extracting step including extracting feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated at the frequency analyzing step, by a feature data extracting unit; a degree-of-association calculating step including reading a feature data of each group from a storage unit that stores feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens and that stores the plural known specimens as being classified into plural groups based upon information of each of the known specimens, and including calculating a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group, by a degree-of-association calculating unit; an image processing step including generating ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result obtained at the degree-of-association calculating step, by an image processing unit; and an image display step including displaying the image corresponding to the ultrasonic image data generated at the image processing step on a display unit.

**[0020]** An operating program according to the invention is a program of an ultrasonic observation apparatus that transmits an ultrasonic wave to a specimen and receives the ultrasonic wave reflected on the specimen. The operating program instructs the ultrasonic observation apparatus to perform: a frequency analyzing step including calculating a

frequency spectrum by analyzing a frequency of the received ultrasonic wave by a frequency analyzing unit; a feature data extracting step including extracting feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated at the frequency analyzing step, by a feature data extracting unit; a degree-of-association calculating step including reading a feature data of each group from a storage unit that stores feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens and that stores the plural known specimens as being classified into plural groups based upon information of each of the known specimens, and including calculating a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group, by a degree-of-association calculating unit; an image processing step including generating ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result obtained at the degree-of-association calculating step, by an image processing unit; and an image display step including displaying the image corresponding to the ultrasonic image data generated at the image processing step on a display unit. Advantageous Effects of Invention

**[0021]** According to the present invention, plural known specimens are classified into plural groups based upon the feature data of the frequency spectrum extracted on the basis of the ultrasonic wave reflected on each of the plural known specimens, and the degree of association between the feature data of the specimen extracted based upon the frequency spectrum of the ultrasonic signal and each group by using the statistic of the population including the feature data of each group. The ultrasonic image data having the display manner corresponding to the feature data of the specimen is generated based upon the calculation result. Accordingly, the difference in the tissue can clearly be distinguished without using the distorted amount or elasticity of the living tissue.

#### Brief Description of Drawings

#### **[0022]**

FIG. 1 is a block diagram illustrating a configuration of an ultrasonic observation apparatus according to a first embodiment of the present invention.

FIG. 2 is a flowchart illustrating an outline of a process of the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 3 is a view illustrating a display example of a B-mode image on a display unit of the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 4 is a flowchart illustrating an outline of a process executed by a frequency analyzing unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 5 is a view schematically illustrating a data array of one sound ray.

FIG. 6 is a view illustrating an example (first example) of a frequency spectrum calculated by the frequency analyzing unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 7 is a view illustrating an example (second example) of a frequency spectrum calculated by the frequency analyzing unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 8 is a view illustrating a new straight line determined by a feature data after an attenuation correction is performed to the feature data related to the straight line illustrated in FIG. 6.

FIG. 9 is a flowchart illustrating an outline of a process executed by a degree-of-association calculating unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 10 is a view illustrating an example of a feature data space set by the degree-of-association calculating unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 11 is a view illustrating an example of a way of assigning a color component to each pixel in calculation result display image data.

FIG. 12 is a view illustrating another example of a way of assigning a color component to each pixel in calculation result display image data.

FIG. 13 is a view illustrating a display example of a calculation result display image displayed on the display unit in the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 14 is a view schematically illustrating the image illustrated in FIG. 13 in black and white.

FIG. 15 is a view describing an effect of the attenuation correction process executed by the ultrasonic observation apparatus according to the first embodiment of the present invention.

FIG. 16 is a flowchart illustrating an outline of a process of an ultrasonic observation apparatus according to a second embodiment of the present invention.

FIG. 17 is a view schematically illustrating an outline of an attenuation correction process executed by the ultrasonic observation apparatus according to the second embodiment of the present invention.

FIG. 18 is a view describing a feature data space set by a degree-of-association calculating unit in an ultrasonic

observation apparatus according to a third embodiment of the present invention, and a standard deviation of a feature point in the feature data space.

FIG. 19 is a view illustrating a relationship between an absolute value of a difference in the standard deviation in the feature data space and a magnitude of a red component.

## Description of Embodiments

**[0023]** Embodiments for carrying out the present invention (hereinafter referred to as "embodiments") will be described below with reference to the attached drawings.

### (First Embodiment)

**[0024]** FIG. 1 is a block diagram illustrating a configuration of an ultrasonic observation apparatus according to a first embodiment of the present invention. The ultrasonic observation apparatus illustrated in FIG. 1 is an apparatus for observing a specimen by use of ultrasonic wave.

**[0025]** An ultrasonic observation apparatus 1 includes an ultrasonic probe 2 that outputs an ultrasonic pulse to the outside, and that receives an externally reflected ultrasonic echo, a transmission/reception unit 3 that transmits and receives an electric signal to and from the ultrasonic probe 2, a computation unit 4 that performs predetermined computation to an electric echo signal obtained by converting the ultrasonic echo, an image processing unit 5 that generates image data corresponding to the electric echo signal obtained by converting the ultrasonic echo, an input unit 6 that is realized by using an interface such as a keyboard, a mouse, or a touch panel for accepting an input of various information, a display unit 7 that is realized by using a display panel such as a liquid crystal panel or an organic EL panel, and that can display various information including the image generated by the image processing unit 5, a storage unit 8 that stores information involved with plural known specimens, and that stores the plural known specimens classified into plural groups, and a control unit 9 that controls the operation of the ultrasonic observation apparatus 1.

**[0026]** The ultrasonic probe 2 includes a signal conversion unit 21 that converts the electric pulse signal received by the transmission/reception unit 3 into an ultrasonic pulse (acoustic pulse signal), and that converts the ultrasonic echo reflected on an external specimen into an electric echo signal. The ultrasonic probe 2 may be the one that allows an ultrasonic vibrator to mechanically scan, or the one that allows plural ultrasonic vibrators to electronically scan.

**[0027]** The transmission/reception unit 3 is electrically connected to the ultrasonic probe 2, transmits the pulse signal to the ultrasonic probe 2, and receives an echo signal, which is a reception signal, from the ultrasonic probe 2. Specifically, the transmission/reception unit 3 generates a pulse signal based upon a waveform and transmission timing, set beforehand, and transmits the generated pulse signal to the ultrasonic probe 2.

**[0028]** The transmission/reception unit 3 is electrically connected to the ultrasonic probe 2, transmits the pulse signal to the ultrasonic probe 2, and receives an echo signal from the ultrasonic probe 2. Specifically, the transmission/reception unit 3 generates a pulse signal based upon a waveform and transmission timing, set beforehand, and transmits the generated pulse signal to the ultrasonic probe 2. The transmission/reception unit 3 performs a process such as an amplification or filtering to the received echo signal, and then, generates a digital RF signal through an A/D conversion. Then, it outputs the digital RF signal. When the ultrasonic probe 2 is configured to electronically scan plural ultrasonic vibrators, the transmission/reception unit 3 has a multichannel circuit for synthesizing beams corresponding to the plural ultrasonic vibrators.

**[0029]** The computation unit 4 includes a frequency analyzing unit 41 that performs fast Fourier transform (FFT) to the digital RF signal outputted from the transmission/reception unit 3 so as to analyze a frequency of the echo signal, a feature data extracting unit 42 that performs an attenuation correction process for reducing a contribution of an attenuation generated according to the reception depth and the frequency of the ultrasonic wave, and an approximation process to the frequency spectrum (power spectrum) calculated by the frequency analyzing unit 41 during the propagation of the ultrasonic wave, in order to extract a feature data of a specimen, and a degree-of-association calculating unit 43 that calculates a degree of association between the feature data extracted by the feature data extracting unit 42 and each of the plural groups stored in the storage unit 8.

**[0030]** The frequency analyzing unit 41 calculates the frequency spectrum of each sound ray (line data) by performing the fast Fourier transform to a FFT data group including predetermined amount of data. The frequency spectrum indicates a different tendency depending upon a tissue characterization of the specimen. This is because the frequency spectrum has a correlation with the size of the specimen serving as a scattering substance scattering the ultrasonic wave, a density, and an acoustic impedance.

**[0031]** The feature data extracting unit 42 includes an approximation unit 421 that calculates a pre-correction feature data, which is an amount before the execution of the attenuation correction process, by performing the approximation process to the frequency spectrum calculated by the frequency analyzing unit 41, and an attenuation correction unit 422 that extracts the feature data by performing the attenuation correction process to the pre-correction feature data approx-

imated by the approximation unit 421.

**[0032]** The approximation unit 421 approximates the frequency spectrum with a primary expression according to a regression analysis, thereby extracting the pre-correction feature data characterizing the approximated primary expression. Specifically, the approximation unit 421 calculates a slope  $a_0$  and an intercept  $b_0$  of the primary expression according to the regression analysis, and calculates the intensity of a specific frequency within a frequency band of the frequency spectrum as the pre-correction feature data. In the first embodiment, the approximation unit 421 is supposed to calculate an intensity (Mid-band fit)  $c_0 = a_0 f_{MID} + b_0$  at a center frequency  $f_{MID} = (f_{LOW} + f_{HIGH})/2$ . However, this is only one example. The "intensity" here means any one of parameters including a voltage, power, sound pressure, and acoustic energy.

**[0033]** Among the three feature data, the slope  $a_0$  has a correlation with the size of the scattering body of the ultrasonic wave, and it is generally considered that the slope has a smaller value, as the size of the scattering body is large. The intercept  $b_0$  has a correlation with the size of the scattering body, the difference in the acoustic impedance, and the density (concentration) of the scattering body. Specifically, it is considered that the intercept  $b_0$  has a larger value, as the size of the scattering body is large, as the acoustic impedance is large, and as the density (concentration) of the scattering body is large. The intensity at the center frequency  $f_{MID}$  (hereinafter merely referred to as "intensity")  $c_0$  is an indirect parameter derived from the slope  $a_0$  and the intercept  $b_0$ , and it gives a spectrum intensity at the center in the effective frequency band. Therefore, it is considered that the intensity  $c_0$  has not only a correlation with the size of the scattering body, the difference in the acoustic impedance, and the density of the scattering body, but also a correlation with the brightness of the B-mode image to a certain extent. The approximate polynomial calculated by the feature data extracting unit 42 is not limited to the primary expression, but a second-order or higher-order approximate polynomial may be used.

**[0034]** The correction executed by the attenuation correction unit 422 will be described. An attenuation amount  $A$  of the ultrasonic wave can be expressed as:

$$A = 2\alpha z f \quad (1)$$

Here,  $\alpha$  is an attenuation rate,  $z$  is a reception depth of the ultrasonic wave, and  $f$  is a frequency. As is apparent from the equation (1), the attenuation amount  $A$  is in proportion to the frequency  $f$ . The specific value of the attenuation rate  $\alpha$  for a living body is 0 to 1.0 (dB/cm/MHz), and more preferably 0.3 to 0.7 (dB/cm/MHz). The attenuation rate is determined according to a type of an organ to be observed. For example, when the organ to be observed is pancreas, it is determined that  $\alpha = 0.6$  (dB/cm/MHz). It can be configured in the first embodiment that the value of the attenuation rate  $\alpha$  can be changed by the input from the input unit 6.

**[0035]** The attenuation correction unit 422 corrects the pre-correction feature data (slope  $a_0$ , intercept  $b_0$ , intensity  $c_0$ ) extracted by the approximation unit 421 as described below.

$$a = a_0 + 2\alpha z \quad (2)$$

$$b = b_0 \quad (3)$$

$$c = c_0 + 2\alpha z f_{MID} (= a f_{MID} + b) \quad (4)$$

As is apparent from the equations (2) and (4), the attenuation correction unit 422 makes a correction with a large correction amount, as the reception depth  $z$  of the ultrasonic wave is larger. According to the equation (3), the correction involved with the intercept is an identical transformation. This is because the intercept is not subject to the attenuation, since the intercept is the frequency component corresponding to the frequency 0 (Hz).

**[0036]** The degree-of-association calculating unit 43 calculates the degree of association between the feature data extracted by the feature data extracting unit 42 and each of the groups by using a statistic of a population including at least the feature data of the respective groups stored in the storage unit 8. More specifically, the degree-of-association calculating unit 43 sets a feature data space, which has at least any one of the plural feature data extracted by the feature data extracting unit 42 as a component, and calculated, as the degree of association, the distance on the feature data space between a specimen point having the feature data, serving as the component in the set feature data space,

out of the feature data of the frequency spectrum of the specimen as a coordinate in the feature data space, and a known specimen average point having an average of the feature data serving as the component in the feature data space out of the feature data of the plural groups of the known specimens as the coordinate of the feature data space.

**[0037]** The average and standard deviation of the feature data of the frequency spectrum of the ultrasonic reception signal reflects a change in a cell level such as an enlarged nucleus, and heteromorphy of nucleus in a specimen, or a change in a tissue such as increased fibra in interstitium, or replacement of a parenchymal tissue into a fiber, and it indicates a unique value according to the tissue characterization. The "tissue characterization" here means any one of a cancer, endocrine tumor, mucinous tumor, normal tissue, and vessel channel. When the specimen is a pancreas, the tissue characterization includes chronic pancreatitis, and autoimmune pancreatitis. In view of the above circumstance, the groups stored in the storage unit 8 are desirably determined according to the type of the tissue characterization. Therefore, it is supposed in the description below that the groups stored in the storage unit 8 are determined according to the type of the tissue characterization.

**[0038]** The image processing unit 5 includes a B-mode image data generating unit 51 that generates B-mode image data from the echo signal, and a calculation result display image data generating unit 52 that generates calculation result display image data that is ultrasonic image data for displaying the calculation result of the degree of association by using the calculation result of the degree of association calculated by the degree-of-association calculating unit 43 and the B-mode image data generated by the B-mode image data generating unit 51.

**[0039]** The B-mode image data generating unit 51 performs, to the digital signal, a signal processing using a known technique such as a bandpass filter, logarithmic conversion, gain process or contrast process, and generates the B-mode image data by decimating the data according to a data step width determined by a display range of the image on the display unit 7.

**[0040]** The calculation result display image data generating unit 52 generates the calculation result display image data by using the B-mode image data generated by the B-mode image data generating unit 51, the feature data extracted by the feature data extracting unit 42, and the result calculated by the degree-of-association calculating unit 43.

**[0041]** The storage unit 8 includes a known specimen information storage unit 81 that stores information of the known specimen, a window function storage unit 82 that stores a window function used for the frequency analyzing process executed by the frequency analyzing unit 41, and a correction information storage unit 83 that stores correction information referred to during the execution of the process by the attenuation correction unit 42.

**[0042]** The known specimen information storage unit 81 stores the feature data of the frequency spectrum extracted from the known specimen in association with the tissue characterization of the known specimen. The known specimen information storage unit 81 also stores the average and standard deviation of the feature data of the frequency spectrum involved with the known specimen together with all data of the feature data of the known specimen, wherein the average and the standard deviation is calculated for each of the groups classified based upon the information including the tissue characterization of the known specimen. The feature data of the known specimen is extracted in the same manner as in the first embodiment. It is to be noted that the process of extracting the feature data of the known specimen is not necessarily executed by the ultrasonic observation apparatus 1. It is desirable that the information of the known specimen stored in the known specimen information storage unit 81 has high reliability for the tissue characterization. The window function storage unit 82 stores at least any one of window functions of Hamming, Hanning, and Blackman. The correction information storage unit 83 stores information involved with the transformation of the equations (2) to (4).

**[0043]** The storage unit 8 is realized by ROM that preliminarily stores an operating program of the ultrasonic observation apparatus according to the first embodiment or a program of starting a predetermined OS, and RAM that stores operation parameters or data for each process.

**[0044]** The components, other than the ultrasonic probe 2, of the ultrasonic observation apparatus 1 thus configured are realized by using a computer provided with a CPU having a computation and control functions. The CPU provided to the ultrasonic observation apparatus 1 reads the information memorized and stored in the storage unit 8 and various programs including the operating program of the ultrasonic observation apparatus from the storage unit 8, thereby executing the computation process involved with the operation method of the ultrasonic observation apparatus according to the first embodiment.

**[0045]** The operating program of the ultrasonic observation apparatus according to the first embodiment can be recorded on a computer-readable recording medium, such as hard disk, flash memory, CD-ROM, DVD-ROM, or flexible disk.

**[0046]** FIG. 2 is a flowchart illustrating an outline of a process of the ultrasonic observation apparatus 1 having the above-mentioned configuration. In FIG. 2, the ultrasonic observation apparatus 1 firstly measures a new specimen by the ultrasonic probe 2 (step S1).

**[0047]** Then, the B-mode image data generating unit 51 generates the B-mode image data by using the echo signal for the B-mode image outputted from the transmission/reception unit 3 (step S2).

**[0048]** Next, the control unit 9 makes control to display the B-mode image corresponding to the B-mode image data generated by the B-mode image data generating unit 51 onto the display unit 7 (step S3). FIG. 3 is a view illustrating a

display example of the B-mode image on the display unit 7. The B-mode image 100 in FIG. 3 is a grayscale image in which values of R (red), G (green), and B (blue), which are variables when an RGB color system is employed as a color space, are matched to one another.

[0049] Then, the frequency analyzing unit 41 calculates the frequency spectrum by performing the frequency analysis according to the FFT calculation (step S4). The process (step S4) executed by the frequency analyzing unit 41 will be described in detail with reference to FIG. 4. Firstly, the frequency analyzing unit 41 sets a sound ray number L of a sound ray that is a subject to be analyzed to an initial value  $L_0$  (step S21). The initial value  $L_0$  may be applied to a sound ray that the transmission/reception unit 3 receives first, or may be applied to a sound ray corresponding to one of boundary positions on the left and on the right of a region of interest set by the input unit 6.

[0050] Next, the frequency analyzing unit 41 calculates all frequency spectrums on plural data positions set on one sound ray. Firstly, the frequency analyzing unit 41 sets an initial value  $Z_0$  on a data position Z (corresponding to the reception depth) representative of a series of data group (FFT data group) acquired for the FFT calculation (step S22). FIG. 5 is a view schematically illustrating a data array of one sound ray. On the sound ray LD illustrated in FIG. 5, a white rectangle or a black rectangle indicates one data. The sound ray LD is discretized with a time interval corresponding to the sampling frequency (e.g., 50 MHz) in the A/D conversion executed by the transmission/reception unit 3. In FIG. 5, the first data on the sound ray LD is set as the initial value  $Z_0$  on the data position Z. FIG. 5 illustrates only one example, and any position can be set as the position of the initial value  $Z_0$ . For example, the data position Z corresponding to the upper end of the region of interest may be set as the initial value  $Z_0$ .

[0051] Then, the frequency analyzing unit 41 acquires the FFT data group on the data position Z (step S23), and allows the window function stored in the window function storage unit 82 to work on the acquired FFT data group (step S24). Allowing the window function to work on the FFT data group as described above avoids that the FFT data group becomes discontinuity on the boundary, and can prevent the occurrence of artifacts.

[0052] Next, the frequency analyzing unit 41 determines whether the FFT data group on the data position Z is a normal data group or not (step S25). The FFT data group has to have a power-of-2 data number. The data number of the FFT data group is supposed to be  $2^n$  (n is a positive integer) hereinafter. The case where the FFT data group is normal means that the data position Z is on the  $2^{n-1}$ -th position from the head of the FFT data group. In other words, the case where the FFT data group is normal means that there are  $2^{n-1} - 1$  (= N) data before the data position Z, and there are  $2^{n-1}$  (= M) data after the data position Z. In FIG. 5, the FFT data groups  $F_2$ ,  $F_3$ , and  $F_{K-1}$  are normal, but the FFT data groups  $F_1$  and  $F_K$  are abnormal. In FIG. 5, it is set such that  $n = 4$  (N = 7, M = 8).

[0053] When the FFT data group on the data position Z is normal as a result of the determination in step S25 (step S25: Yes), the frequency analyzing unit 41 moves to a later-described step S27.

[0054] When the FFT data group on the data position Z is abnormal as a result of the determination in step S25 (step S25: No), the frequency analyzing unit 41 inserts zero data by a deficiency to generate the normal FFT data group (step S26). The window function is worked on the FFT data group that is determined to be abnormal in step S25 before the zero data is added. Therefore, even if the zero data is inserted to the FFT data group, a data discontinuity does not occur. The frequency analyzing unit 41 moves to the later-described step S27 after step S26.

[0055] In step S27, the frequency analyzing unit 41 acquires the frequency spectrum by performing the FFT calculation by use of the FFT data group (step S27). FIGS. 6 and 7 are views illustrating the frequency spectrum calculated by the frequency analyzing unit 41. In FIGS. 6 and 7, an abscissa axis f indicates a frequency, and an ordinate axis I indicates an intensity. In frequency spectrum curves  $C_1$  and  $C_2$  illustrated in FIGS. 6 and 7 respectively, the lower-limit frequency  $f_{LOW}$  and the upper-limit frequency  $f_{HIGH}$  of the frequency spectrum are parameters determined based upon the frequency band of the ultrasonic probe 2 and the frequency band of the pulse signal transmitted by the transmission/reception unit 3. For example, they are set such that  $f_{LOW} = 3$  MHz, and  $f_{HIGH} = 10$  MHz. A straight line  $L_1$  illustrated in FIG. 6 and a straight line  $L_2$  illustrated in FIG. 7 will be described for the later-described feature data extracting process. In the first embodiment, the curve and the straight line are composed of a set of discrete points. This is applied to the later-described embodiments.

[0056] Next, the frequency analyzing unit 41 adds a predetermined data step width D to the data position Z to calculate the data position Z of the FFT data group that is the next subject to be analyzed (step S28). The data step width D desirably agrees with the data step width utilized for generating the B-mode image data by the B-mode image data generating unit 51. However, if the computation amount of the frequency analyzing unit 41 is intended to be reduced, the data step width larger than the data step width utilized by the B-mode image data generating unit 51 may be set. FIG. 5 illustrates the case where  $D = 15$ .

[0057] Then, the frequency analyzing unit 41 determines whether the data position Z is larger than a final data position  $Z_{max}$  or not (step S29). The final data position  $Z_{max}$  may be a data length of the sound ray LD, or may be the data position corresponding to the lower end of the region of interest. When the data position Z is larger than the final data position  $Z_{max}$  as a result of the determination (step S29: Yes), the frequency analyzing unit 41 increments the sound ray number L by 1 (step S30). On the other hand, when the data position Z is not more than the final data position  $Z_{max}$  (step S29: No), the frequency analyzing unit 41 returns to step S23. In this way, the frequency analyzing unit 41 performs the FFT



calculation to the  $\lceil (Z_{\max} - Z_0) / D \rceil + 1 (= K)$  FFT data groups with respect to one sound ray LD. Here,  $[X]$  indicates the maximum integer not exceeding  $X$ .

**[0058]** When the sound ray number  $L$  to which 1 is added in step S30 is larger than a final sound ray number  $L_{\max}$  (step S31: Yes), the frequency analyzing unit 41 returns to the main routine illustrated in FIG. 2. On the other hand, when the sound ray number  $L$  to which 1 is added in step S30 is not more than the final sound ray number  $L_{\max}$  (step S31: No), the frequency analyzing unit 41 returns to step S22.

**[0059]** In this way, the frequency analyzing unit 41 executes the FFT calculation  $K$  times to each of  $(L_{\max} - L_0 + 1)$  sound rays. The final sound ray number  $L_{\max}$  may be applied to the final sound ray received by the transmission/reception unit 3, or may be applied to the sound ray corresponding to one of left and right boundaries of the region of interest, for example. The total number  $(L_{\max} - L_0 + 1) \times K$  of the FFT calculation executed to all sound rays by the frequency analyzing unit 41 is set as  $P$  below.

**[0060]** Subsequent to the frequency analyzing process in step S4 described above, the approximation unit 421 extracts the pre-correction feature data by performing the regression analysis to  $P$  frequency spectrums calculated by the frequency analyzing unit 41 as the approximation process (step S5). Specifically, the approximation unit 421 calculates the primary expression, which approximates the frequency spectrum in the frequency band ( $f_{\text{LOW}} < f < f_{\text{HIGH}}$ ), according to the regression analysis, thereby extracting the slope  $a_0$ , the intercept  $b_0$ , and the intensity  $c_0$  characterizing the primary expression as the pre-correction feature data. The straight line  $L_1$  in FIG. 6 and the straight line  $L_2$  in FIG. 7 are regression lines obtained by performing the regression analysis to the frequency spectrum curves  $C_1$  and  $C_2$  respectively in step S5.

**[0061]** Thereafter, the attenuation correction unit 422 performs the attenuation correction process to the pre-correction feature data extracted by the approximation unit 421 (step S6). For example, when the sampling frequency of the data is 50 MHz, the time interval of the data sampling is 20 (nsec). If the sound speed is supposed to be 1530 (m/sec), the sampling distance interval of the data becomes  $1530 \text{ (m/sec)} \times 20 \text{ (nsec)} / 2 = 0.0153 \text{ k (mm)}$ . If the data step number from the first data of the sound ray LD to the data position of the FFT data group that is the subject for the process is  $k$ , the data position  $Z$  becomes  $0.0153 \text{ k (mm)}$ . The attenuation correction unit 422 calculates the slope  $a$ , the intercept  $b$ , and the intensity  $c$ , which are the feature data of the frequency spectrum, by substituting the data position  $Z$  obtained in this way into the reception depth  $z$  in the above-mentioned equations (2) to (4). FIG. 8 is a view illustrating a straight line determined by the feature data obtained by performing the attenuation process to the feature data involved with the straight line  $L_1$  illustrated in FIG. 6. The equation representing the straight line  $L_1'$  illustrated in FIG. 8 is:

$$I = af + b = (a_0 + 2\alpha Z)f + b_0 \quad (5)$$

As is apparent from the equation (5), the straight line  $L_1'$  has a slope larger than that of the straight line  $L_1$ , and an intercept equal to the intercept of the straight line  $L_1$ .

**[0062]** Thereafter, the degree-of-association calculating unit 43 calculates the degree of association between the specimen and the groups of the known specimens stored in the storage unit 8 based upon the feature data extracted by the feature data extracting unit 42 and the known specimen information stored in the known specimen information storage unit 81 (step S7).

**[0063]** The process (step S7) executed by the degree-of-association calculating unit 43 will be described in detail with reference to the flowchart in FIG. 9. Firstly, the degree-of-association calculating unit 43 sets the feature data space used for calculating the degree of association (step S41). In the first embodiment, the independent parameters are two out of the three feature data that are the slope  $a$ , the intercept  $b$ , and the intensity  $c$ . Therefore, a two-dimensional space having any two of the three feature data as components can be set as the feature data space. Alternatively, a one-dimensional space having any one of the three feature data as a component can be set as the feature data space. In step S41, it is supposed that the feature data space to be set is determined beforehand. However, an operator may select a desired feature data space by the input unit 6.

**[0064]** FIG. 10 is a view illustrating an example of the feature data space set by the degree-of-association calculating unit 43. In the feature data space illustrated in FIG. 10, the abscissa axis indicates the intercept  $b$ , and the ordinate axis indicates the intensity  $c$ . A point  $Sp$  in FIG. 10 indicates a point (hereinafter referred to as a "specimen point") having the intercept  $b$  and the intensity  $c$  calculated for the specimen to be examined as a coordinate in the feature data space. Regions  $G_\mu$ ,  $G_v$ , and  $G_\rho$  illustrated in FIG. 10 respectively indicate groups in which a tissue characterization of the known specimen stored in the known specimen information storage unit 81 is  $\mu$ ,  $v$ , and  $\rho$ . In the case of FIG. 10, three groups  $G_\mu$ ,  $G_v$ , and  $G_\rho$  are present in the regions not intersecting with one another in the feature data space.

**[0065]** In the first embodiment, even in obtaining the feature data of the known specimen, the grouping is executed by using the feature data, which is obtained by performing the attenuation correction to the pre-correction feature data of the frequency spectrum obtained by the frequency analysis, as an index. Therefore, the different groups can clearly be separated. Since the feature data to which the attenuation correction is performed is used in the first embodiment,

in particular, the regions of the respective groups can be obtained as being clearly separated, compared to the case where the feature data that is extracted without being subjected to the attenuation correction is used.

**[0066]** After step S41, the degree-of-association calculating unit 43 calculates distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$  on the feature data space between the specimen point Sp and respective points  $\mu_0$ ,  $v_0$ , and  $p_0$  (these points are hereinafter referred to as "known specimen average points") that are included in the groups  $G_{\mu}$ ,  $G_v$ , and  $G_p$ , and that have an average of the intercepts  $b$  and the intensities  $c$  of the frequency spectrum of the FFT data group as the coordinate in the feature data space (step S42). The degree-of-association calculating unit 43 calculates the distance between all specimen points of the frequency spectrum and the known specimen average point on the feature data space in step S42. If the scale of the  $b$ -axis component and the scale of the  $c$ -axis component on the feature data space are greatly different, a weighting is desirably executed in order to equalize the contribution of each distance, as needed.

**[0067]** Next, the degree-of-association calculating unit 43 outputs the distance calculated in step S42 as the calculation result (step S43). Thus, the degree-of-association calculation process in step S7 is ended.

**[0068]** The degree-of-association calculating unit 43 may determine the tissue characterization of the specimen based upon the calculation result subsequent to step S43. In this case, however, the known specimen information storage unit 81 has to store the feature data of the known specimen and the tissue characterization in association with each other. When the specimen point Sp is extremely apart from the known specimen average points  $\mu_0$ ,  $v_0$ , and  $p_0$ , the reliability of the determination result of the tissue characterization is low even if the minimum values of the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$  are obtained. Therefore, when the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$  are greater than a predetermined threshold value, the degree-of-association calculating unit 43 may output an error signal. When any two of the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$  assume the minimum value, the degree-of-association calculating unit 43 may select all tissue characterizations corresponding to the minimum value as candidates, or may select any one of the tissue characterization according to a prescribed rule. In the latter case, a method in which a priority order of the tissue characterization having high malignancy such as a cancer is set high may be employed. When any two or more of the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$  assume the minimum value, the degree-of-association calculating unit 43 may output an error signal.

**[0069]** After step S7 described above, the calculation result display image data generating unit 52 generates the calculation result display image data by using the B-mode image data generated by the B-mode image data generating unit 51, the feature data calculated by the feature data extracting unit 42, and the result calculated by the degree-of-association calculating unit 43 (step S8). In this case, the calculation result display image data generating unit 52 assigns a color component (a variable composing a color space) serving as visual information to each pixel according to the distance between the specimen point Sp and the known specimen average point on the feature data space. For example, in the feature data space illustrated in FIG. 10, a red component (R) is assigned to the distance  $d_{\mu}$  between the specimen point Sp and the known specimen average point  $\mu_0$ , a green component (G) is assigned to the distance  $d_v$  between the specimen point Sp and the known specimen average point  $v_0$ , and a blue component (B) is assigned to the distance  $d_p$  between the specimen point Sp and the known specimen average point  $p_0$ , and the pixel value is changed according to the distance.

**[0070]** FIG. 11 is a view illustrating an example of a way of assigning the color component to each pixel in the calculation result display image data. Specifically, FIG. 11 is a view illustrating the relationship between the distance  $d_{\mu}$  between the specimen point Sp and the known specimen average point  $\mu_0$  on the feature data space and the magnitude of the red component R. In FIG. 11, the red component R assumes 255 (the maximum value in 8-bit notation), when the distance  $d_{\mu}$  satisfies  $0 \leq d_{\mu} \leq d_{\mu 0}$ . The value of the red component R linearly decreases when the distance  $d_{\mu}$  satisfies  $d_{\mu 0} < d_{\mu} \leq d_{\mu 1}$ , and when the distance  $d_{\mu}$  satisfies  $d_{\mu} > d_{\mu 1}$ , it becomes zero. The magnitude of the red component has been described above. The magnitudes of the green component and the blue component can be determined according to the distances  $d_v$  and  $d_p$ , respectively. The color space may be composed of variables of complementary colors such as cyan, magenta, and yellow, instead of the variables of the RGB color system. Alternatively, three attributes of light (color phase, brightness, saturation), which are different from the others, may be assigned to the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$ . In this case, the attribute value is changed according to the distance. A pattern determined according to the distance may be assigned to any one of the distances  $d_{\mu}$ ,  $d_v$ , and  $d_p$ .

**[0071]** FIG. 12 is a view illustrating another example of a way of assigning the color component to each pixel in the calculation result display image data, and it is a view illustrating the relationship between the distance  $d_{\mu}$  and the magnitude of the red component R as in FIG. 11. In FIG. 12, the value of the red component R is zero when the distance  $d_{\mu}$  satisfies  $0 \leq d_{\mu} \leq d_{\mu 0}$ . When the distance  $d_{\mu}$  satisfies  $d_{\mu 0} < d_{\mu} \leq d_{\mu 1}$ , the red component R linearly increase, and when the distance  $d_{\mu}$  satisfies  $d_{\mu} > d_{\mu 1}$ , it assumes 255. As described above, the magnitude of the color component assigned to each pixel in the calculation result display image data may arbitrarily be set.

**[0072]** The display unit 7 displays the calculation result display image generated by the calculation result display image data generating unit 52 (step S9). FIG. 13 is a view illustrating a display example of the calculation result display image displayed on the display unit 7. FIG. 14 is a view schematically illustrating the image illustrated in FIG. 13 in black and white. Compared to the B-mode image 100, an calculation result display image 300 illustrated in these figures are colored, so that the color difference according to each group is made clear. More specifically, the calculation result

display image data 300 roughly includes a green region 300g and a red region 300r. The boundary between two regions is illustrated with a yellow color (not illustrated in FIG. 14). As illustrated in FIG. 14, each region is not formed of a single color. For example, the green region 300g is a region where greenish pixels are collected. Similarly, the red region 300r is a region where reddish pixels are collected. Therefore, an observer can clearly recognize the difference in the groups, i.e., the difference in the tissue characterization.

**[0073]** FIG. 15 is a view describing the effect of the attenuation correction process executed by the ultrasonic observation apparatus 1. An image 400 in FIG. 15 is a calculation result display image to which the attenuation correction is not executed. The calculation result display image in this case is a grayscale image in which the intercept  $b$  is equally assigned to R (red), G (green), and B (blue) with respect to the B-mode image generated by the B-mode image data generating unit 51. In the calculation result display image 400, the signal intensity is reduced due to the influence of the attenuation on the region (lower region in FIG. 14) having the large reception depth, so that the image becomes dark. On the other hand, a calculation result display image 500 obtained by performing the attenuation correction to the same B-mode image has uniform brightness over the screen.

**[0074]** According to the first embodiment of the present invention, plural known specimens are classified into plural groups based upon the feature data of the frequency spectrum extracted on the basis of the ultrasonic wave reflected on each of the plural known specimens, and the degree of association between the feature data of the specimen extracted based upon the frequency spectrum of the ultrasonic signal and each group by using the statistic of the population including the feature data of each group. The ultrasonic image data having the display manner corresponding to the feature data of the specimen is generated based upon the calculation result. Accordingly, the difference in the tissue can clearly be distinguished without using the distorted amount or elasticity of the living tissue. Consequently, the specimen can precisely be observed, whereby the reliability in the observation result can be enhanced.

**[0075]** In the first embodiment, the attenuation correction is performed to the pre-correction feature data extracted from the frequency spectrum. Therefore, the influence of the attenuation caused by the propagation of the ultrasonic wave can be eliminated, whereby the tissue characterization can be distinguished with higher accuracy.

(Second Embodiment)

**[0076]** In the second embodiment of the present invention, the feature data extracting process executed by the feature data extracting unit is different from that in the first embodiment. The configuration of the ultrasonic observation apparatus according to the second embodiment is the same as that of the ultrasonic observation apparatus 1 in the first embodiment. Therefore, the components corresponding to those in the ultrasonic observation apparatus 1 are identified by the same numerals in the description below.

**[0077]** In the feature data extracting process in the second embodiment, the attenuation correction unit 422 firstly performs the attenuation correction process to the frequency spectrum calculated by the frequency analyzing unit 41. Thereafter, the approximation unit 421 performs the approximation process to the frequency spectrum to which the attenuation correction is performed by the attenuation correction unit 422, thereby extracting the feature data of the frequency spectrum.

**[0078]** FIG. 16 is a flowchart illustrating the outline of the process of the ultrasonic observation apparatus according to the second embodiment. In FIG. 16, the processes in steps S51 to S54 respectively correspond to the processes in steps S1 to S4 in FIG. 2.

**[0079]** In step S55, the attenuation correction unit 422 performs the attenuation correction process to the frequency spectrum calculated by the frequency analyzing unit 41 according to the FFT calculation (step S55). FIG. 17 is a view schematically illustrating the outline of the process in step S55. As illustrated in FIG. 17, the attenuation correction unit 422 performs the correction in which the attenuation amount  $A$  in the above-mentioned equation (1) is added to the intensity  $I$  to all frequencies  $f$ , thereby obtaining a new frequency spectrum curve  $C_3'$  with respect to the frequency spectrum curve  $C_3$ . Thus, the frequency spectrum from which the contribution of the attenuation caused by the propagation of the ultrasonic wave is reduced can be obtained.

**[0080]** Thereafter, the approximation unit 421 extracts the feature data of the frequency spectrum by performing the regression analysis to all frequency spectrums to which the attenuation correction is executed by the attenuation correction unit 422 (step S56). Specifically, the approximation unit 421 calculates the slope  $a$ , the intercept  $b$ , and the intensity  $c$  at the center frequency  $f_{MID}$  according to the regression analysis. A straight line  $L_3$  illustrated in FIG. 17 is a regression line (intercept  $b_3$ ) obtained by performing the feature data extracting process to the frequency spectrum curve  $C_3$  in step S56.

**[0081]** The processes in steps S57 to S59 respectively correspond to the processes in steps S7 to S9 in FIG. 2.

**[0082]** Even in the second embodiment, the degree-of-association calculating unit 43 can be configured to determine the tissue characterization of the specimen by using the calculated degree of association, as in the first embodiment. In this case, the known specimen information storage unit 81 stores the feature data of the known specimen in association with the tissue characterization.

**[0083]** According to the second embodiment of the present invention, plural known specimens are classified into plural groups based upon the feature data of the frequency spectrum extracted on the basis of the ultrasonic wave reflected on each of the plural known specimens, and the degree of association between the feature data of the specimen extracted based upon the frequency spectrum of the ultrasonic signal and each group by using the statistic of the population including the feature data of each group. The ultrasonic image data having the display manner corresponding to the feature data of the specimen is generated based upon the calculation result. Accordingly, the difference in the tissue can clearly be distinguished without using the distorted amount or elasticity of the living tissue. Consequently, the specimen can precisely be observed, whereby the reliability in the observation result can be enhanced.

**[0084]** In the present second embodiment, the feature data is extracted after the attenuation correction is performed to the frequency spectrum. Therefore, the influence of the attenuation caused by the propagation of the ultrasonic wave can be eliminated, whereby the tissue characterization can be distinguished with higher accuracy.

(Third Embodiment)

**[0085]** In the third embodiment of the present invention, the tissue characterization determining process executed by the degree-of-association calculating unit is different from that in the first embodiment. The configuration of the ultrasonic observation apparatus according to the third embodiment is the same as that of the ultrasonic observation apparatus 1 in the first embodiment. Therefore, the components corresponding to those in the ultrasonic observation apparatus 1 are identified by the same numerals in the description below.

**[0086]** The degree-of-association calculating unit 43 forms new populations by adding feature data (a, b, c) to the groups  $G_\mu$ ,  $G_v$ , and  $G_p$  (see FIG. 10) composing the tissue characterizations  $\mu$ ,  $v$ , and  $p$ , and then, obtains the standard deviation for each feature data in the data composing each tissue characterization. As in the first embodiment, the degree-of-association calculating unit 43 may determine the tissue characterization of the specimen by using the calculated degree of association. In this case, the known specimen information storage unit 81 stores the feature data of the known specimen in association with the tissue characterization.

**[0087]** Then, the degree-of-association calculating unit 43 calculates the difference (hereinafter merely referred to as "difference in the standard deviation") between the standard deviation of each feature data in the groups  $G_\mu$ ,  $G_v$ , and  $G_p$  in the original population including only the known specimens and the standard deviation of each feature data in the groups  $G_\mu$ ,  $G_v$ , and  $G_p$  in the new population to which a new specimen is added. Here, the degree-of-association calculating unit 43 may calculate the difference in the standard deviation for only the standard deviation of the feature data selected beforehand from plural feature data. In this case, the operator may select any feature data, or the ultrasonic observation apparatus 1 may automatically select any feature data.

**[0088]** FIG. 18 is a view schematically illustrating the standard deviation of each group and the standard deviation of the new population, when the feature data space illustrated in FIG. 10 is used. In FIG. 18, the standard deviation of the intercept b is supposed to be  $\sigma_{\mu 1}$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{\mu 2}$  in the group  $G_\mu$ . The standard deviation of the intercept b is supposed to be  $\sigma_{v 1}$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{v 2}$  in the group  $G_v$ . The standard deviation of the intercept b is supposed to be  $\sigma_{p 1}$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{p 2}$  in the group  $G_p$ . On the other hand, the standard deviation of the intercept b is supposed to be  $\sigma_{\mu 1}'$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{\mu 2}'$  in the population formed by adding the specimen point Sp to the group  $G_\mu$ . The standard deviation of the intercept b is supposed to be  $\sigma_{v 1}'$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{v 2}'$  in the population formed by adding the specimen point Sp to the group  $G_v$ . The standard deviation of the intercept b is supposed to be  $\sigma_{p 1}'$ , and the standard deviation of the intensity c is supposed to be  $\sigma_{p 2}'$  in the population formed by adding the specimen point Sp to the group  $G_p$ . In this case, the above-mentioned difference in the standard deviation is obtained such as  $\Delta\sigma_{\mu 1} = \sigma_{\mu 1}' - \sigma_{\mu 1}$ ,  $\Delta\sigma_{\mu 2} = \sigma_{\mu 2}' - \sigma_{\mu 2}$ ,  $\Delta\sigma_{v 1} = \sigma_{v 1}' - \sigma_{v 1}$ , .... When the variables in the RGB color system are used, the red component, the green component, and the blue component may respectively be assigned to the differences in the standard deviation  $\Delta\sigma_{\mu 1}$ ,  $\Delta\sigma_{v 1}$ , and  $\Delta\sigma_{p 1}$  in the intercept b, for example. Alternatively, three attributes of light (color phase, brightness, saturation), which are different from the others, may be assigned to the differences in the standard deviation  $\Delta\sigma_{\mu 1}$ ,  $\Delta\sigma_{v 1}$ , and  $\Delta\sigma_{p 1}$ . In this case, the attribute value is changed according to the difference in the standard deviation. A pattern determined according to the distance may be assigned to any one of the differences in the standard deviation  $\Delta\sigma_{\mu 1}$ ,  $\Delta\sigma_{v 1}$ , and  $\Delta\sigma_{p 1}$ .

**[0089]** FIG. 19 is a view illustrating one example of the relationship between the absolute value  $|\Delta\sigma_{\mu 1}| = |\sigma_{\mu 1}' - \sigma_{\mu 1}|$  and the magnitude of the red component R. In FIG. 19, when the absolute value  $|\Delta\sigma_{\mu 1}|$  satisfies  $0 \leq |\Delta\sigma_{\mu 1}| \leq |\Delta\sigma_{\mu 10}|$ , the magnitude of the red component R is 255 (8-bit notation). When the absolute value  $|\Delta\sigma_{\mu 1}|$  satisfies  $|\Delta\sigma_{\mu 10}| < |\Delta\sigma_{\mu 1}| \leq |\Delta\sigma_{\mu 11}|$ , the magnitude of the red component R linearly decreases, and when the absolute value  $|\Delta\sigma_{\mu 1}|$  satisfies  $|\Delta\sigma_{\mu 1}| > |\Delta\sigma_{\mu 11}|$ , it is zero. Even in the third embodiment, the magnitude of the color component assigned to each pixel in the calculation result display image data may arbitrarily be set.

**[0090]** The degree-of-association calculating unit 43 may calculate a value, which is obtained by weighting to the difference in the standard deviation of all feature data for each group, and may determine the tissue characterization

corresponding to the group having the minimum value as the tissue characterization of the specimen. In this case, when the feature data has the slope  $a$ , the intercept  $b$ , and the intensity  $c$ , the degree-of-association calculating unit 43 calculates  $w_a$  (the difference in the standard deviation of  $a$ ) +  $w_b$  (the difference in the standard deviation of  $b$ ) +  $w_c$  (the difference in the standard deviation of  $c$ ) by setting the weights respectively corresponding to the slope  $a$ , the intercept  $b$ , and the intensity  $c$  as  $w_a$ ,  $w_b$ , and  $w_c$ , and determines the tissue characterization of the specimen based upon the calculated value. The operator may arbitrarily set the weights  $w_a$ ,  $w_b$ , and  $w_c$ , or the ultrasonic observation apparatus 1 may automatically set the weights  $w_a$ ,  $w_b$ , and  $w_c$ .

**[0091]** The degree-of-association calculating unit 43 may calculate a square root of a value obtained by performing the weighting to the square of the difference in the standard deviation of all feature data for each group, and may determine the tissue characterization corresponding to the group having the minimum square root as the tissue characterization of the specimen. In this case, when the feature data has the slope  $a$ , the intercept  $b$ , and the intensity  $c$ , the degree-of-association calculating unit 43 calculates  $\{w'_a \cdot (\text{the difference in the standard deviation of } a)^2 + w'_b \cdot (\text{the difference in the standard deviation of } b)^2 + w'_c \cdot (\text{the difference in the standard deviation of } c)^2\}^{1/2}$  by setting the weights respectively corresponding to the slope  $a$ , the intercept  $b$ , and the intensity  $c$  as  $w'_a$ ,  $w'_b$ , and  $w'_c$ , and determines the tissue characterization of the specimen based upon the calculated value. The operator may arbitrarily set the weights  $w'_a$ ,  $w'_b$ , and  $w'_c$ , or the ultrasonic observation apparatus 1 may automatically set the weights  $w'_a$ ,  $w'_b$ , and  $w'_c$ .

**[0092]** According to the third embodiment described above, the specimen can precisely be observed, whereby the reliability in the observation result can be enhanced, as in the first embodiment. According to the third embodiment, the influence of the attenuation caused by the propagation of the ultrasonic wave can be eliminated, whereby the tissue characterization can be distinguished with higher accuracy.

**[0093]** In the third embodiment, the degree-of-association calculating unit 43 determines the tissue characterization based upon the difference in the standard deviation of each feature data between the original population and the population formed by adding a new specimen. However, this is only one example. For example, the degree-of-association calculating unit 43 may determine the tissue characterization based upon the difference in the average of each feature data between the original population and the population formed by adding a new specimen.

**[0094]** The embodiments for carrying out the present invention have been described above. The present invention is not limited to the above-mentioned first to third embodiments. Specifically, the present invention can include various forms without departing from the technical scope described in the claims.

#### Reference Signs List

#### [0095]

1	ULTRASONIC OBSERVATION APPARATUS
2	ULTRASONIC PROBE
3	TRANSMISSION/RECEPTION UNIT
4	COMPUTATION UNIT
5	IMAGE PROCESSING UNIT
6	INPUT UNIT
7	DISPLAY UNIT
8	STORAGE UNIT
9	CONTROL UNIT
21	SIGNAL CONVERSION UNIT
41	FREQUENCY ANALYZING UNIT
42	FEATURE DATA EXTRACTING UNIT
43	DEGREE-OF-ASSOCIATION CALCULATING UNIT
51	B-MODE IMAGE DATA GENERATING UNIT
52	CALCULATION RESULT DISPLAY IMAGE DATA GENERATING UNIT
81	KNOWN SPECIMEN INFORMATION STORAGE UNIT
82	WINDOW FUNCTION STORAGE UNIT
83	CORRECTION INFORMATION STORAGE UNIT
100	B-MODE IMAGE
300, 400, 500	CALCULATION RESULT DISPLAY IMAGE
300g	GREEN REGION
300r	RED REGION
421	APPROXIMATION UNIT
422	ATTENUATION CORRECTION UNIT

## Claims

1. An ultrasonic observation apparatus that transmits an ultrasonic wave to a specimen, and receives the ultrasonic wave reflected on the specimen, comprising:

a frequency analyzing unit configured to calculate a frequency spectrum by analyzing a frequency of the received ultrasonic wave;

a feature data extracting unit configured to extract feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated by the frequency analyzing unit;

a storage unit configured to store feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens, and to store the plural known specimens as being classified into plural groups based upon information of each of the known specimens;

a degree-of-association calculating unit configured to calculate a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group stored in the storage unit;

an image processing unit configured to generate ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result of the degree-of-association calculating unit; and

a display unit configured to be capable of displaying the image corresponding to the ultrasonic image data generated by the image processing unit.

2. The ultrasonic observation apparatus according to claim 1, wherein  
the feature data extracting unit extracts plural feature data,  
the storage unit stores an average of the respective feature data in each of the plural groups,  
the degree-of-association calculating unit sets feature data space having at least any one of the plural feature data as a component, and calculates, as the degree of association, a distance on the feature data space between a specimen point that has a feature data, which serves as the component of the feature data space, out of the feature data of the frequency spectrum of the specimen as a coordinate on the feature data space, and a known specimen average point that has an average of the feature data, which serve as the component of the feature data space, out of the feature data in the group of the plural known specimens as a coordinate on the feature data space.

3. The ultrasonic observation apparatus according to claim 2, wherein  
the image processing unit determines a pixel value of the ultrasonic image data according to the distance between the specimen point and the known specimen average point.

4. The ultrasonic observation apparatus according to claim 1, wherein  
the degree-of-association calculating unit calculates a standard deviation of a feature data in a new population formed by adding a feature data of the specimen to the feature data belonging to the same group, and calculates the difference between the standard deviation and the standard deviation of the feature data belonging to the same group as the degree of association.

5. The ultrasonic observation apparatus according to claim 4, wherein  
the image processing unit determines the pixel value of the ultrasonic image data according to the difference between the standard deviation of the feature data in the new population and the standard deviation of the feature data belonging to the same group.

6. The ultrasonic observation apparatus according to any one of claims 1 to 5, wherein  
the plural specimens having the feature data belonging to the same group have the same tissue characterization.

7. The ultrasonic observation apparatus according to any one of claims 1 to 6, wherein  
the feature data extracting unit extracts the feature data by performing an attenuation correction process for reducing a contribution of an attenuation caused according to a reception depth and a frequency of the ultrasonic wave during the propagation of the ultrasonic wave to the frequency spectrum calculated by the frequency analyzing unit, and by performing an approximation process to the frequency spectrum.

8. The ultrasonic observation apparatus according to claim 7, wherein  
the feature data extracting unit includes:

an approximation unit configured to extract pre-correction feature data, which is an amount before the attenuation correction process, through an execution of the approximation process to the frequency spectrum calculated by the frequency analyzing unit; and

an attenuation correction unit configured to extract the feature data of the frequency spectrum by performing the attenuation correction process to the pre-correction feature data extracted by the approximation unit.

9. The ultrasonic observation apparatus according to claim 7, wherein the feature data extracting unit includes:

an attenuation correction unit configured to execute the attenuation correction process to the frequency spectrum; and

an approximation unit configured to extract the feature data of the frequency spectrum by performing the approximation process to the frequency spectrum that is corrected by the attenuation correction unit.

10. The ultrasonic observation apparatus according to claim 8 or 9, wherein the approximation unit approximates the frequency spectrum with a polynomial according to a regression analysis.

11. The ultrasonic observation apparatus according to claim 10, wherein the approximation unit approximates the frequency spectrum with a primary expression, and extracts plural feature data including at least two of a slope of the primary expression, an intercept of the primary expression, and an intensity determined by using the slope, the intercept, and a specific frequency included in a frequency band of the frequency spectrum.

12. The ultrasonic observation apparatus according to any one of claims 8 to 11, wherein the attenuation correction unit makes a great correction, as the reception depth of the ultrasonic wave is larger.

13. An operation method of an ultrasonic observation apparatus that transmits an ultrasonic wave to a specimen, and receives the ultrasonic wave reflected on the specimen, comprising:

a frequency analyzing step including calculating a frequency spectrum by analyzing a frequency of the received ultrasonic wave by a frequency analyzing unit;

a feature data extracting step including extracting feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated at the frequency analyzing step, by a feature data extracting unit;

a degree-of-association calculating step including reading a feature data of each group from a storage unit that stores feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens and that stores the plural known specimens as being classified into plural groups based upon information of each of the known specimens, and including calculating a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group, by a degree-of-association calculating unit;

an image processing step including generating ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result obtained at the degree-of-association calculating step, by an image processing unit; and

an image display step including displaying the image corresponding to the ultrasonic image data generated at the image processing step on a display unit.

14. An operating program of an ultrasonic observation apparatus that transmits an ultrasonic wave to a specimen, and receives the ultrasonic wave reflected on the specimen, wherein the operating program instructs the ultrasonic observation apparatus to perform:

a frequency analyzing step including calculating a frequency spectrum by analyzing a frequency of the received ultrasonic wave by a frequency analyzing unit;

a feature data extracting step including extracting feature data of the frequency spectrum by performing an approximation to the frequency spectrum calculated at the frequency analyzing step, by a feature data extracting unit;

a degree-of-association calculating step including reading a feature data of each group from a storage unit that stores feature data of a frequency spectrum extracted based upon the ultrasonic wave reflected respectively from plural known specimens and that stores the plural known specimens as being classified into plural groups

based upon information of each of the known specimens, and including calculating a degree of association between the feature data extracted by the feature data extracting unit and each group by using a statistics of a population including at least the feature data of each group, by a degree-of-association calculating unit;  
an image processing step including generating ultrasonic image data having a display manner corresponding to the feature data of the specimen based upon the calculation result obtained at the degree-of-association calculating step, by an image processing unit; and  
an image display step including displaying the image corresponding to the ultrasonic image data generated at the image processing step on a display unit.

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FIG.1

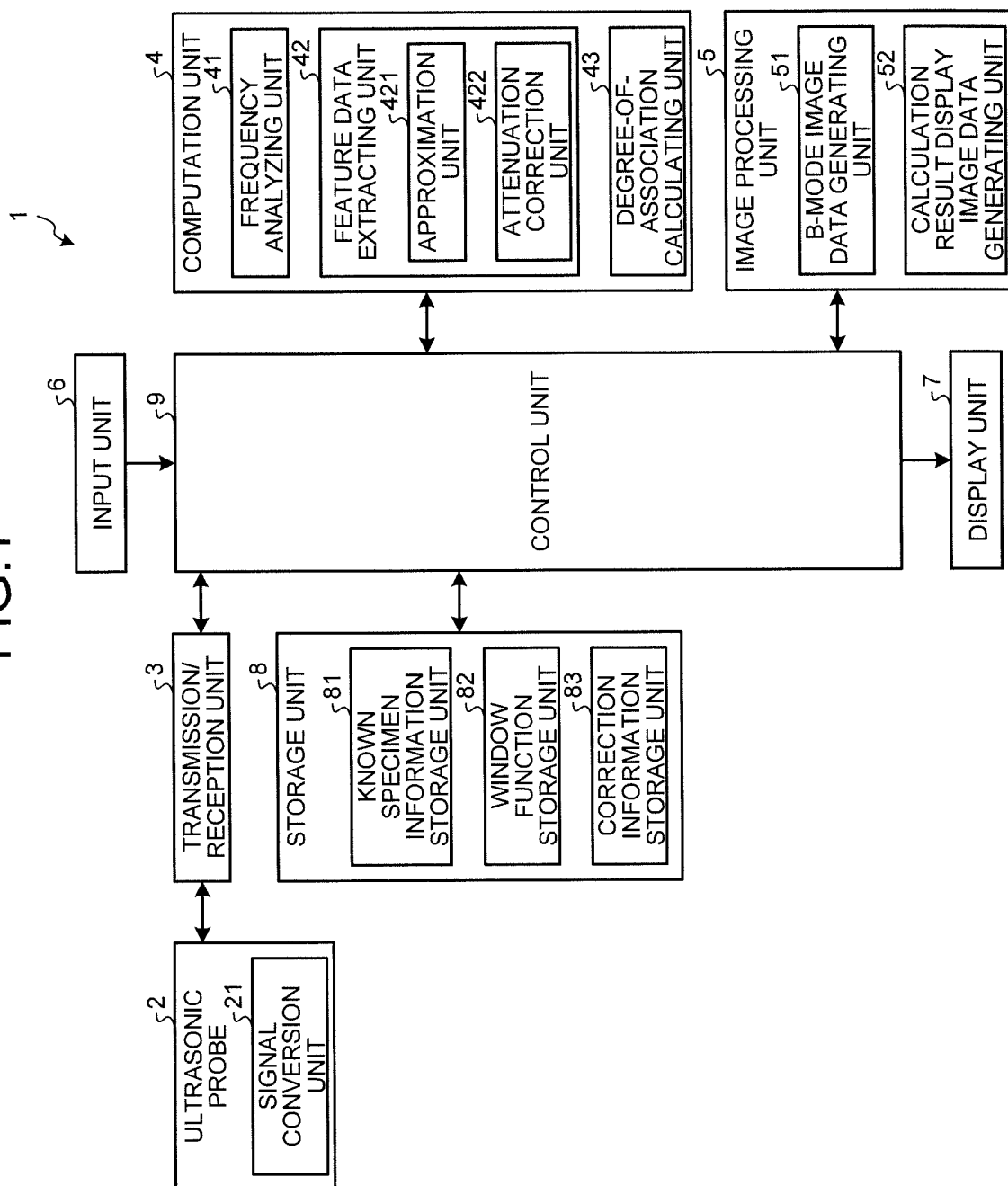


FIG.2

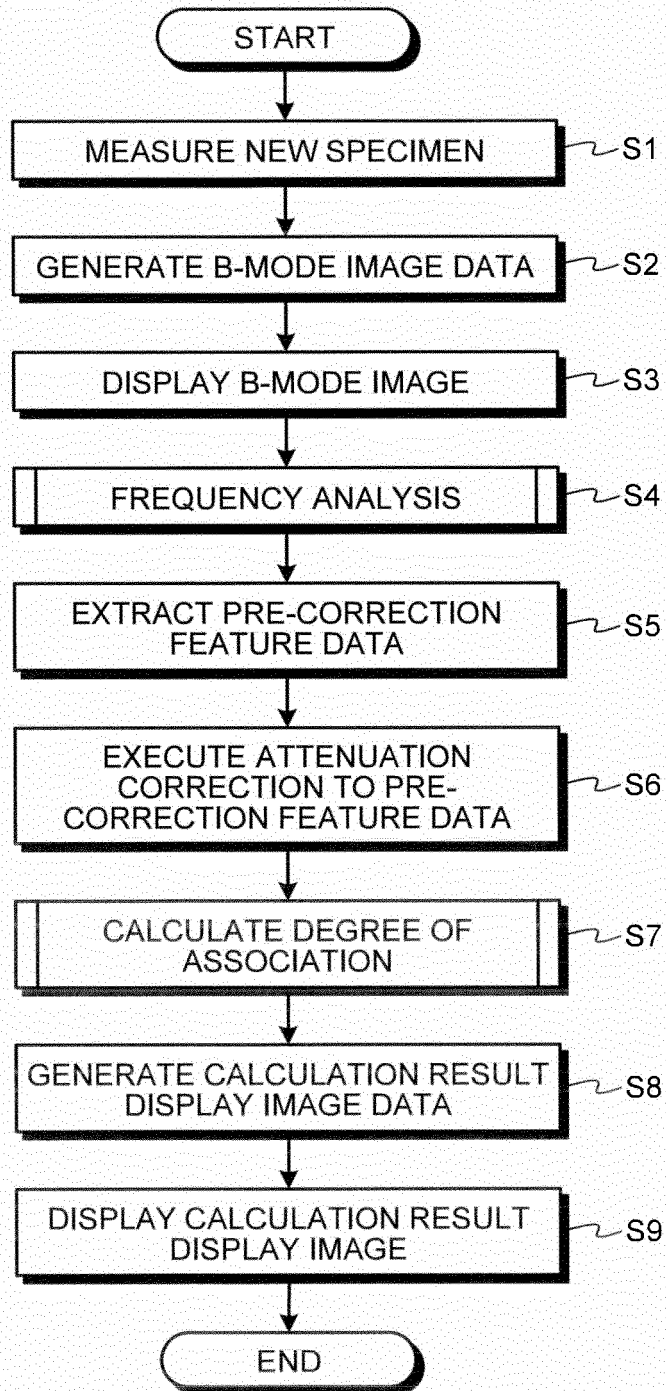


FIG.3

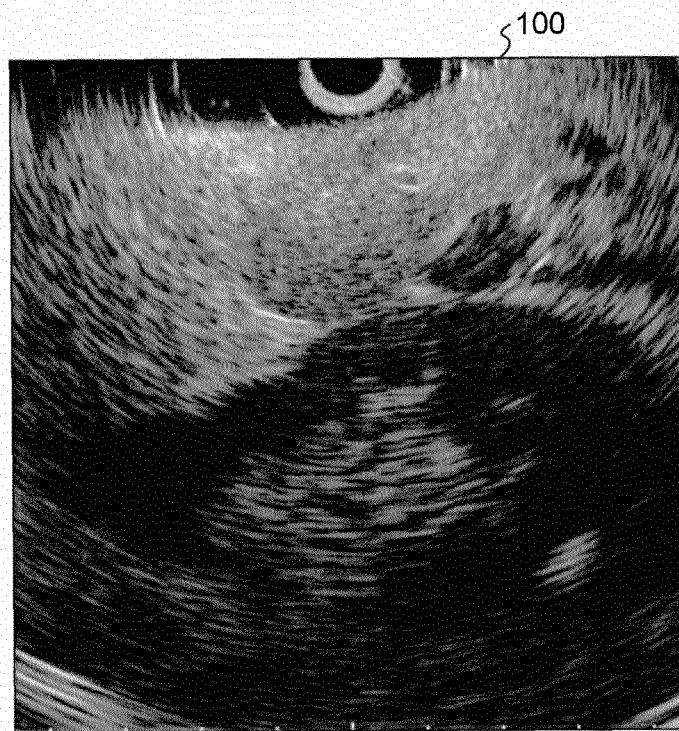


FIG.4

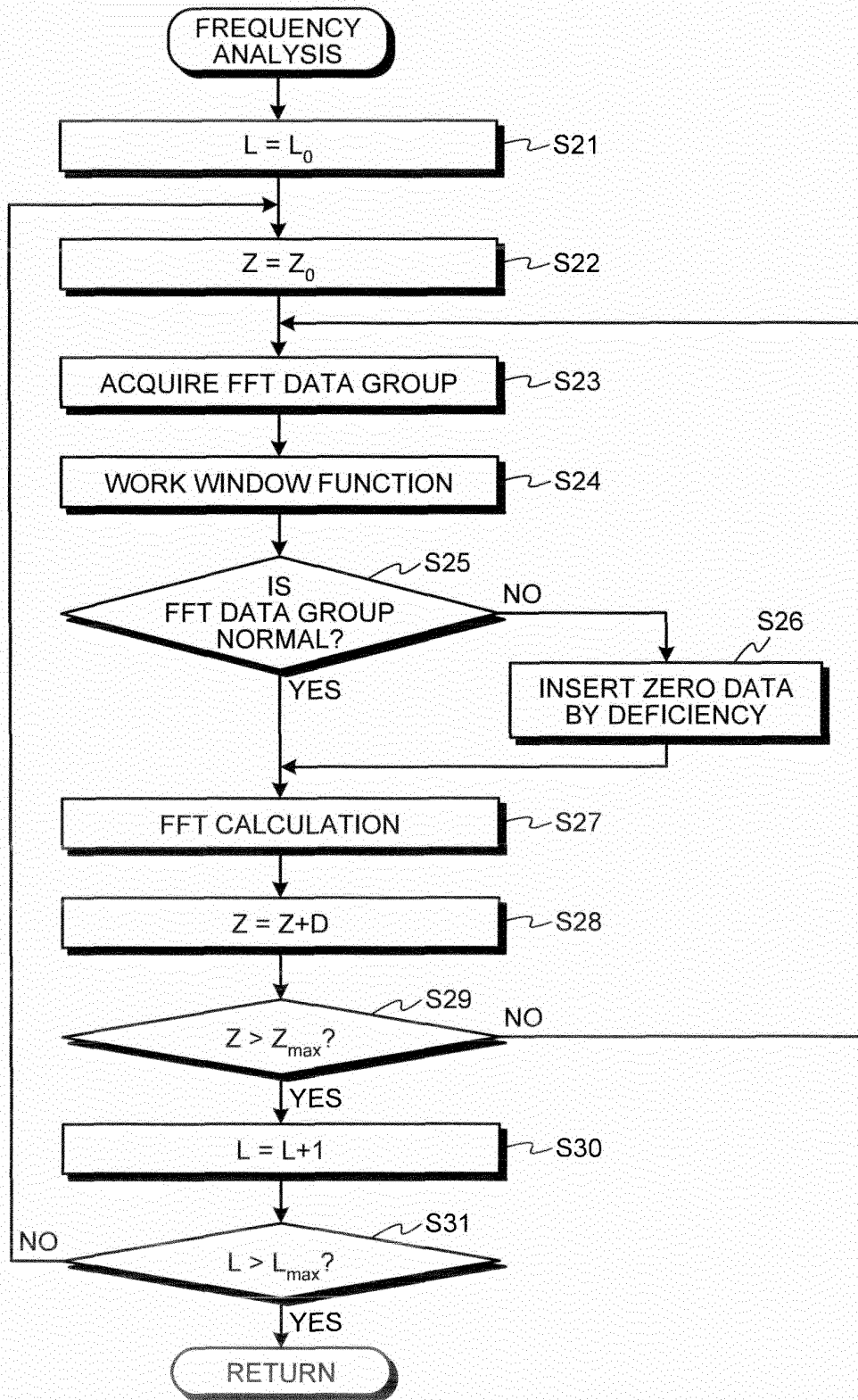


FIG.5

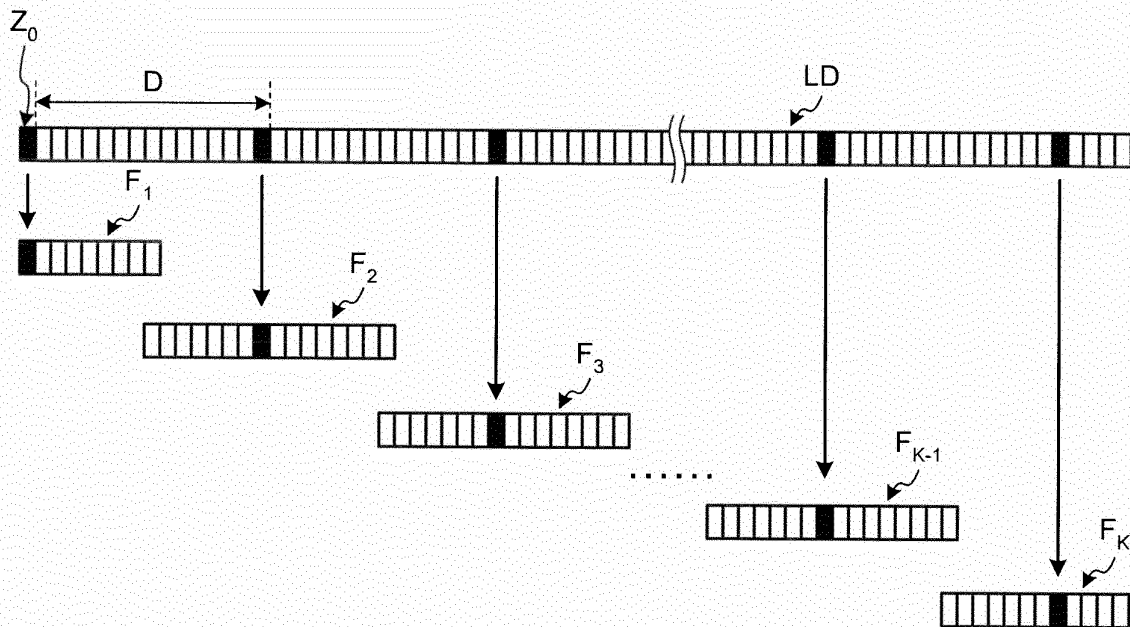


FIG.6

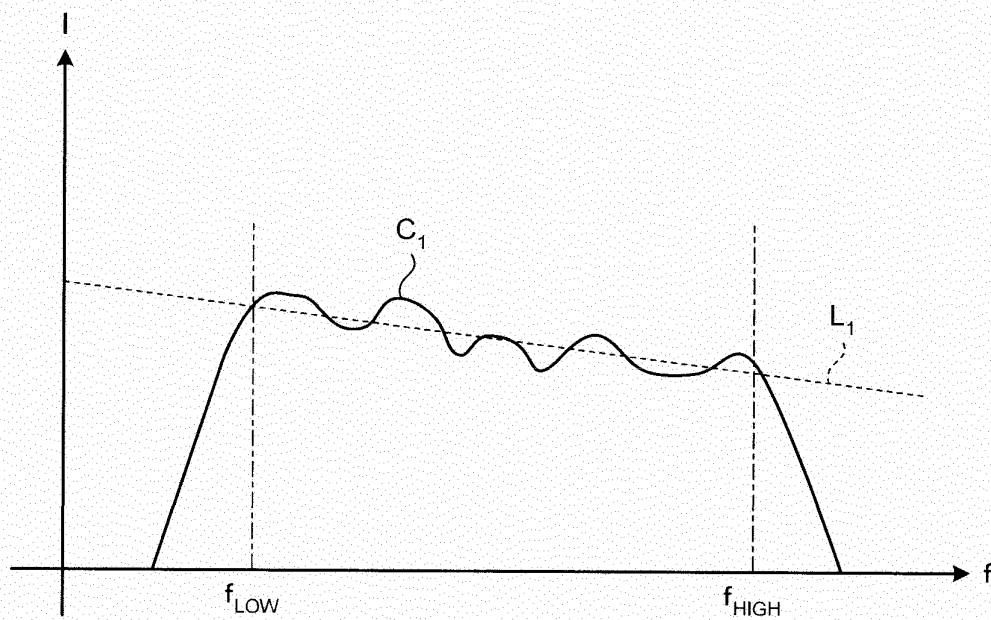


FIG.7

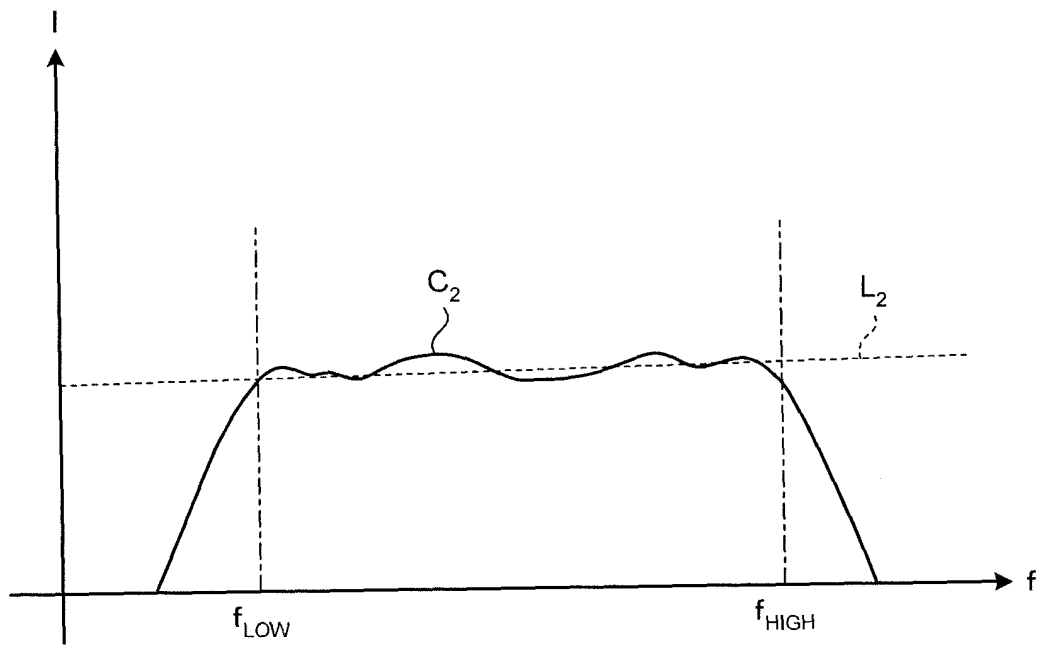


FIG.8

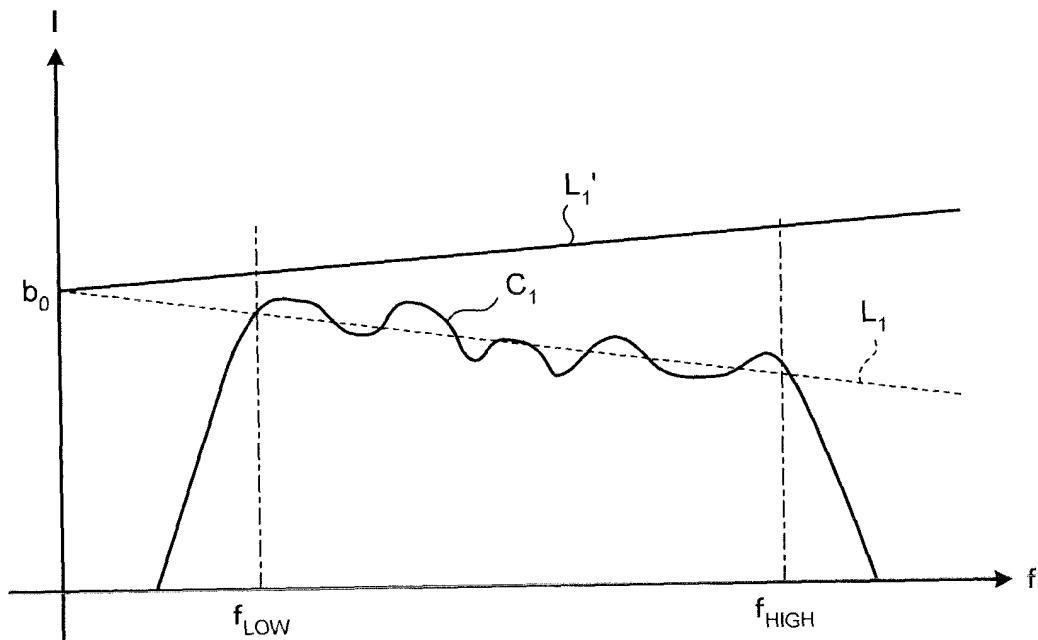


FIG.9

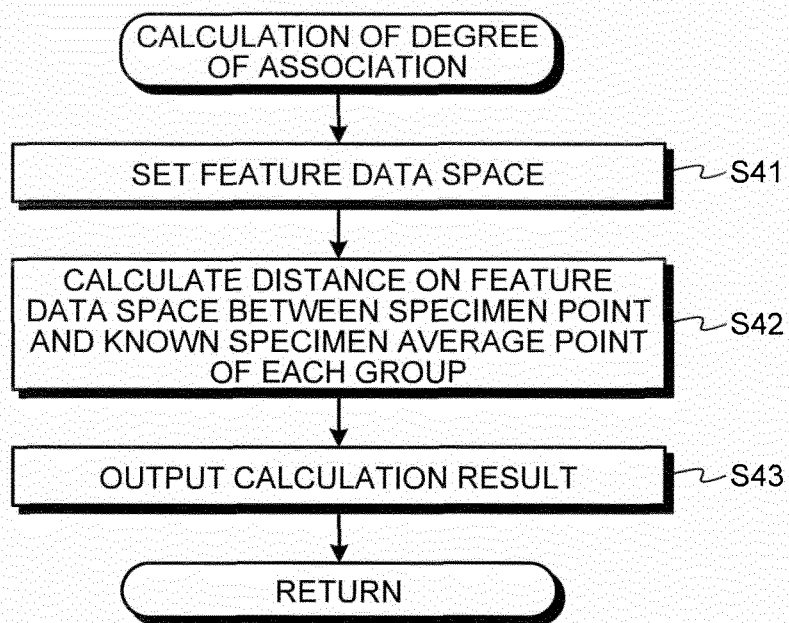


FIG.10

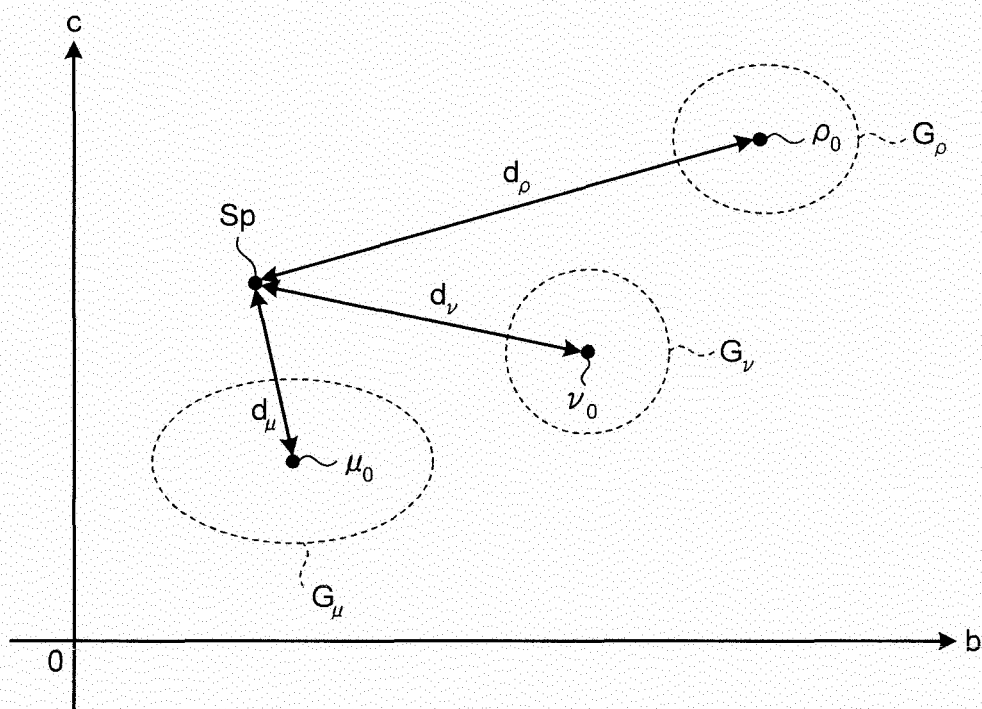


FIG.11

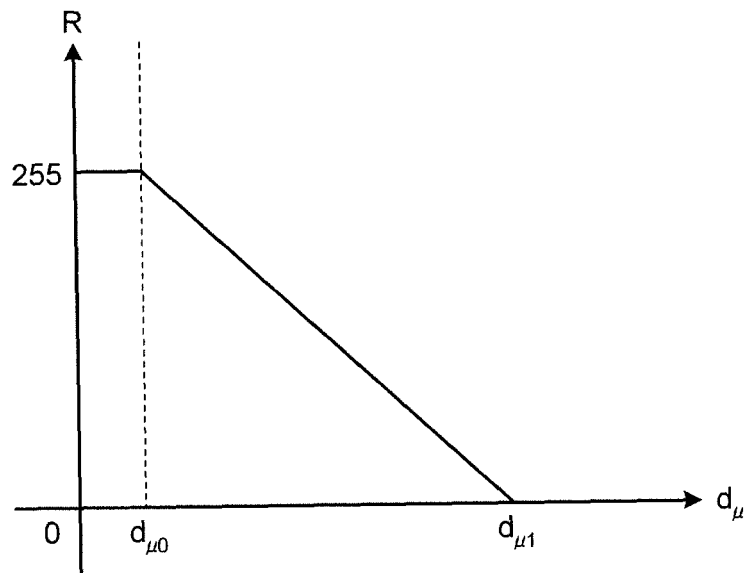


FIG.12

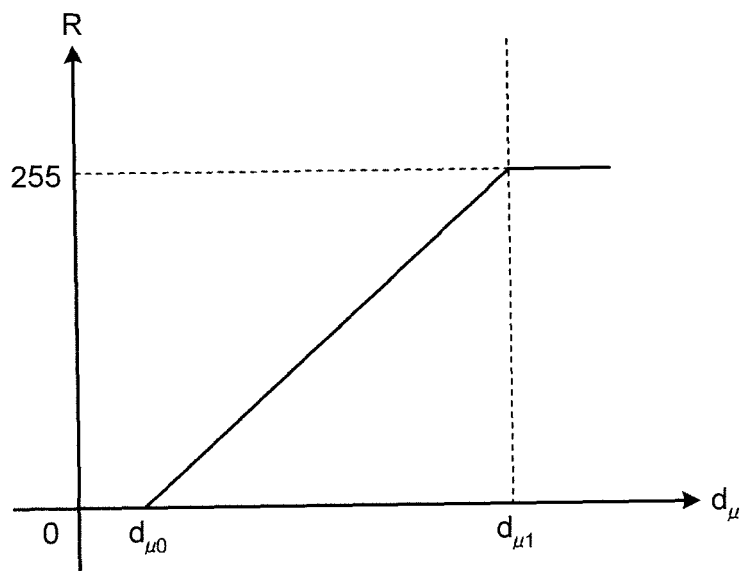




FIG.13

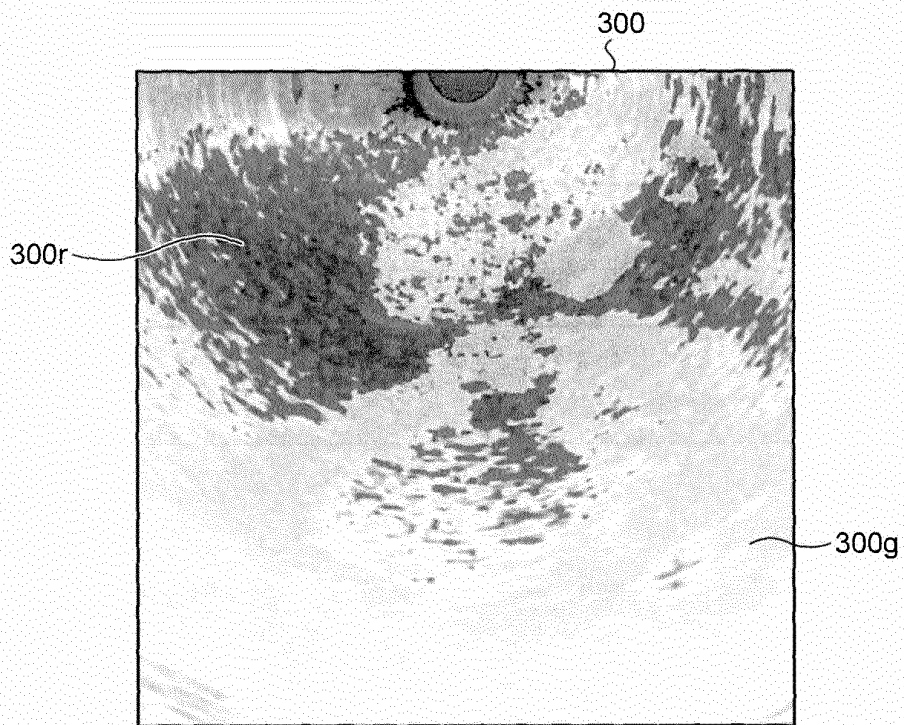


FIG.14

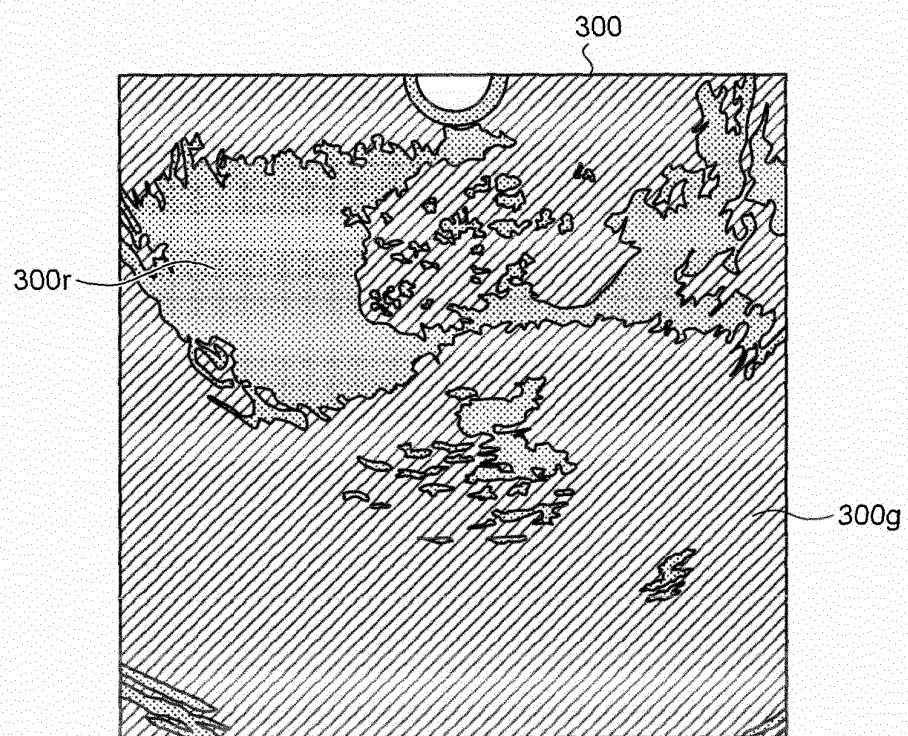


FIG.15

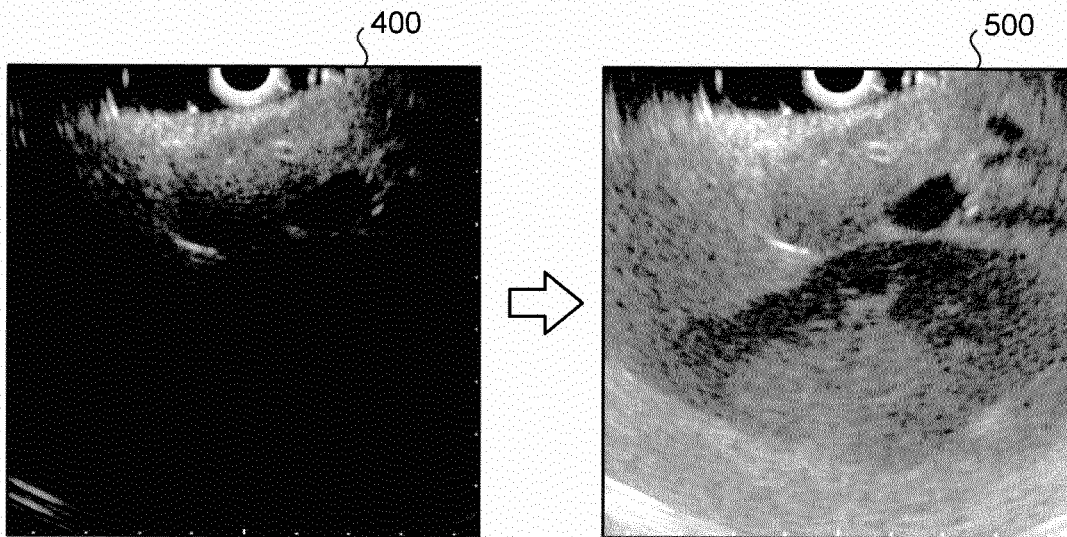


FIG.16

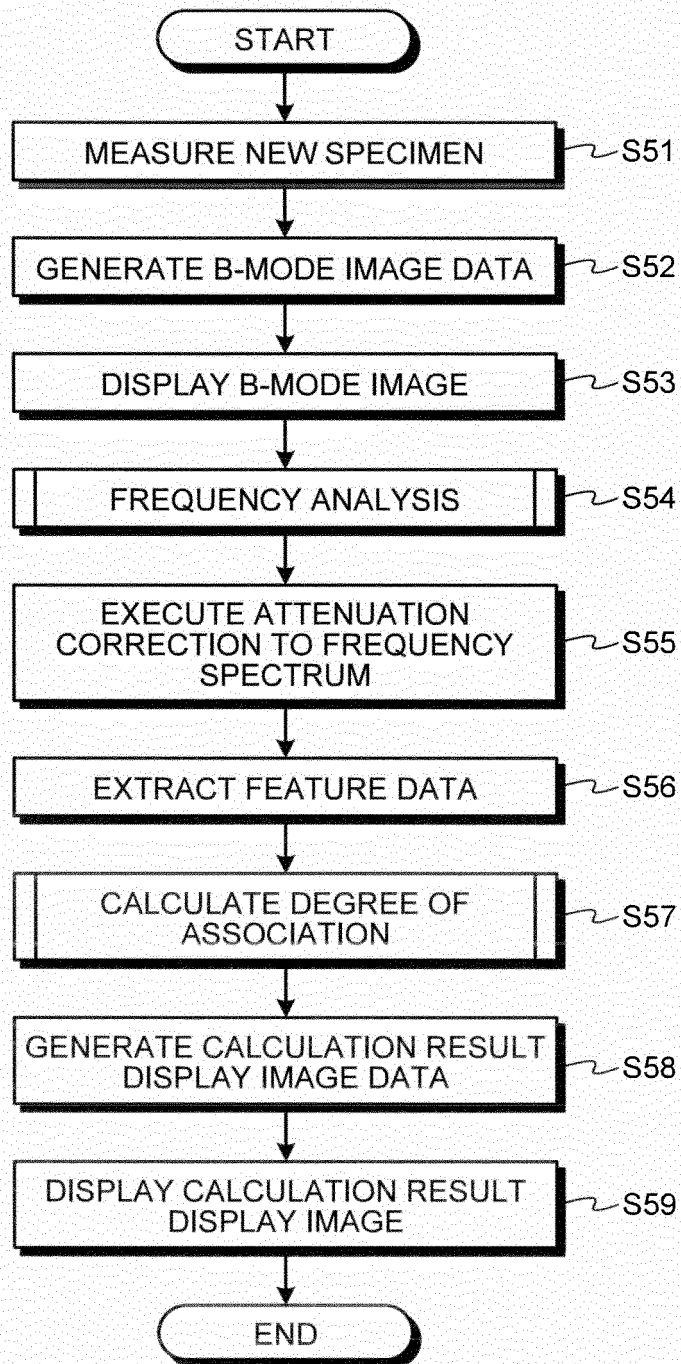


FIG.17

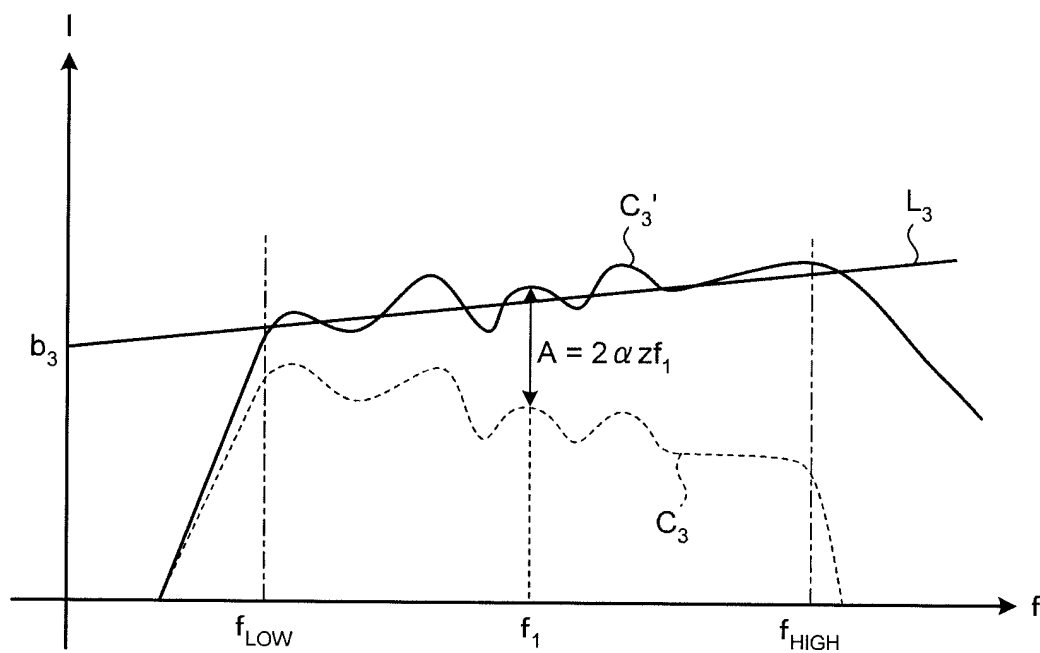


FIG.18

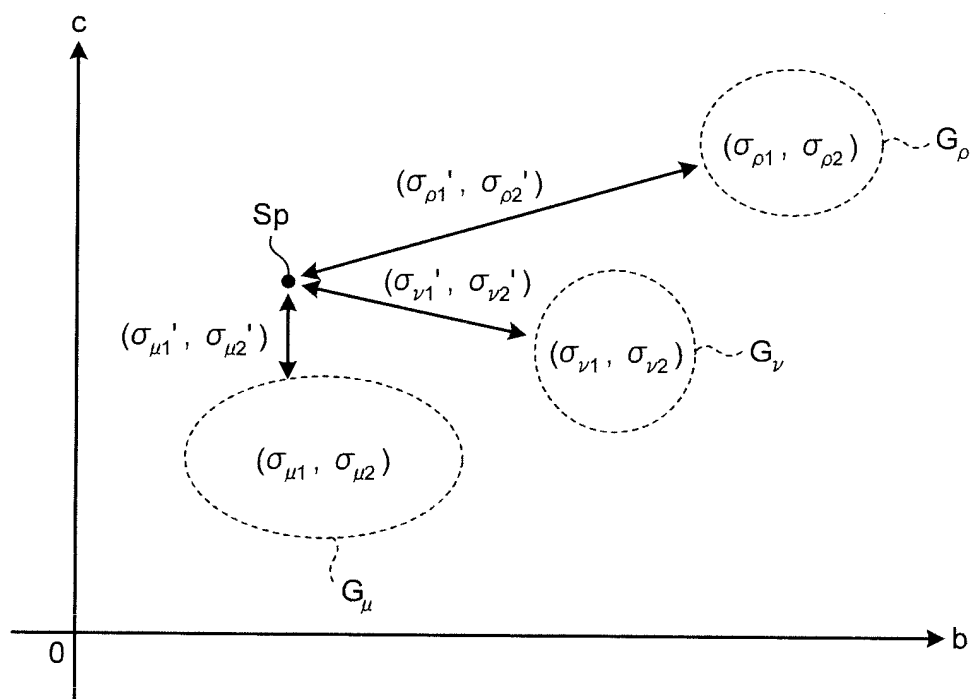
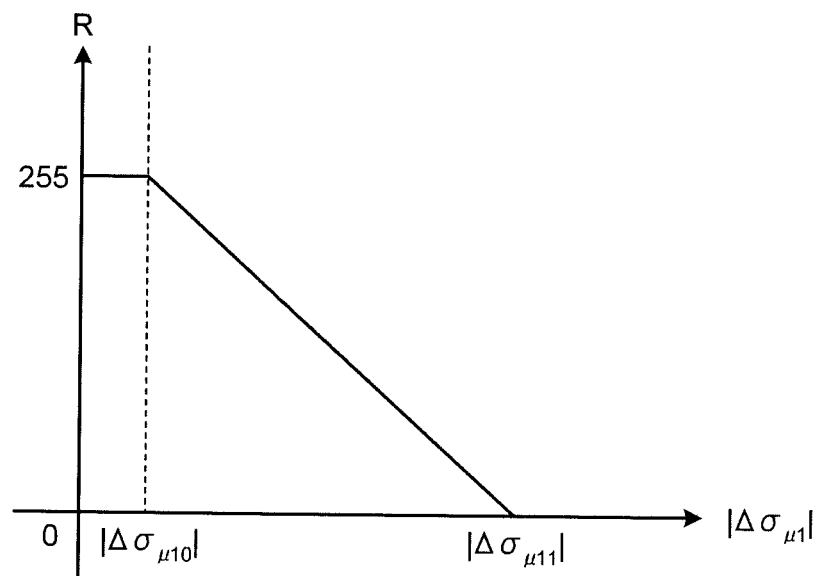


FIG.19



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/076602

## A. CLASSIFICATION OF SUBJECT MATTER

A61B8/08(2006.01) i

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B8/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2007-524431 A (The Cleveland Clinic Foundation), 30 August 2007 (30.08.2007), entire text; all drawings; particularly, paragraphs [0027], [0032], [0040] to [0042] & US 2004/0152983 A1 & EP 1599122 A & WO 2004/069027 A2 & CA 2514962 A & AU 2004210153 A	1, 13, 14
X	JP 2009-523059 A (Boston Scientific Scimed, Inc.), 18 June 2009 (18.06.2009), entire text; all drawings & US 2007/0160275 A1 & EP 1977361 A & WO 2007/082218 A2 & CA 2636199 A	1, 13, 14



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;"

document member of the same patent family

Date of the actual completion of the international search

18 January, 2012 (18.01.12)

Date of mailing of the international search report

31 January, 2012 (31.01.12)

Name and mailing address of the ISA/

Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/076602

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2005-253827 A (Fuji Photo Film Co., Ltd.), 22 September 2005 (22.09.2005), entire text; all drawings & US 2005/0203405 A1	1-14
A	JP 2004-49925 A (Medison Co., Ltd.), 19 February 2004 (19.02.2004), entire text; all drawings & US 2004/0019276 A1 & KR 10-2004-0009255 A	1-14
A	JP 2007-97671 A (Toshiba Corp.), 19 April 2007 (19.04.2007), entire text; all drawings (Family: none)	1-14

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- WO 2005122906 A [0003]



专利名称(译)	超声波观察装置，超声波观察装置的操作方法，超声波观察装置的操作程序		
公开(公告)号	<a href="#">EP2554124A4</a>	公开(公告)日	2013-02-06
申请号	EP2011840691	申请日	2011-11-11
[标]申请(专利权)人(译)	奥林巴斯医疗株式会社		
申请(专利权)人(译)	奥林巴斯医疗系统股份有限公司.		
当前申请(专利权)人(译)	奥林巴斯医疗系统股份有限公司.		
[标]发明人	MIYAKI HIRONAKA		
发明人	MIYAKI, HIRONAKA		
IPC分类号	A61B8/00 A61B8/08		
CPC分类号	A61B8/461 A61B8/0825 A61B8/485 A61B8/5207 A61B8/5269 G01S7/52042 G01S7/52071		
优先权	2010253285 2010-11-11 JP		
其他公开文献	EP2554124A1 EP2554124B1		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

一种超声波观测装置，包括：频率分析单元，被配置为通过分析接收的超声波的频率来计算频谱；特征数据提取单元，被配置为通过执行对频谱的近似来提取频谱的特征数据；存储单元，被配置为存储基于分别从多个已知样本反射的超声波提取的频谱的特征数据，并且基于每个已知样本的信息将多个已知样本存储为多个组；关联度计算单元，被配置为通过使用至少包括每个组的特征数据的总体的统计来计算由特征数据提取单元提取的特征数据与每个组之间的关联度；图像处理单元，被配置为基于关联度计算单元的计算结果生成具有与样本的特征数据对应的显示方式的超声图像数据；显示单元，被配置为能够显示与由图像处理单元生成的超声图像数据相对应的图像。