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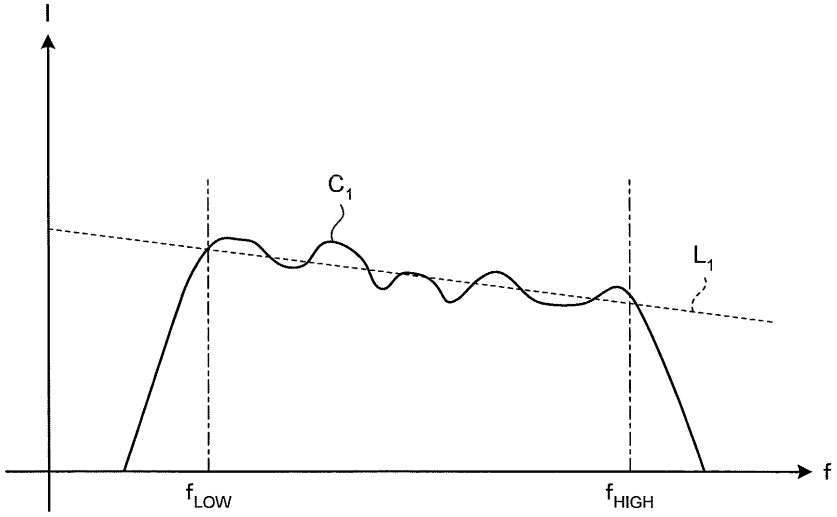
(54) ULTRASOUND OBSERVATION DEVICE, OPERATING METHOD FOR ULTRASOUND OBSERVATION DEVICE, AND OPERATING PROGRAM FOR ULTRASOUND OBSERVATION DEVICE

(57) An ultrasonic observation apparatus amplifies a signal of an ultrasonic wave received from a sample with an amplification factor according to a receiving depth; generates B-mode image data in which the amplitude of the signal of the amplified ultrasonic wave is converted into brightness and displayed; performs amplification-correction to make the amplification factor constant with respect to the signal of the amplified ultrasonic wave regardless of the receiving depth; calculates a frequency spectrum by analyzing the frequency of the amplification-corrected signal of the ultrasonic wave; extracts feature data of the frequency spectrum by approximating the calculated frequency spectrum; performs correction, on one of the frequency spectrum and the feature data, to reduce the contribution of the attenuation of the strength accompanying the transmission of the ultrasonic wave; and generates feature data image data to display visual information corresponding to the feature data.

FIG.8



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Description

TECHNICAL FIELD

[0001] The present invention relates to an ultrasonic observation apparatus which observes the tissue of a sample using ultrasonic waves, an operation method of the ultrasonic observation apparatus, and an operation program of the ultrasonic observation apparatus.

BACKGROUND ART

[0002] Hitherto, an ultrasonic elastography technique has been known as a technique for examining breast cancer or the like using ultrasonic waves (for example, see Patent Literature 1). Ultrasonic elastography is a technique using the fact that the hardness of cancer or tumor tissue in vivo varies depending on the progress of a disease or a living body. In this technique, in a state in which an examination site is pressed from the outside, the distortion amount or elastic modulus of a living tissue in the examination site is measured using ultrasonic waves, and the result of the measurement is displayed as a tomographic image.

[0003] In the observation using ultrasonic waves, attenuation caused by the transmission of an ultrasonic wave is corrected to perform A/D conversion in an optimum range, and thus Sensitivity Time Control (STC) correction is usually performed on received data (analog signal) for generating a B-mode image to add a higher amplification factor to the received data at a deep position (for example, see Patent Literature 2).

Citation List

Patent Literature

[0004]

Patent Literature 1: WO 2005/122906
Patent Literature 2: Japanese Laid-open Patent Publication No. 10-216143

DISCLOSURE OF INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0005] In the above-mentioned STC correction, the amplitude of an analog signal waveform is amplified evenly over the entire frequency band only and an effect of correcting the attenuation dependent on the frequency is not achieved. Therefore, when the B-mode image using the amplitude of the ultrasonic wave is generated, a sufficient effect is obtainable by performing the STC correction, but, there is problem that when tissue characteristics of a sample are identified based on a frequency spectrum, influence of the attenuation accompanying the transmission of the ultrasonic wave is not able to be correctly eliminated and accuracy of the identification is reduced.

[0006] To solve this problem, when the B-mode image is generated, a received signal subjected to the STC correction may be output, while when generating an image based on the frequency spectrum, a new transmission different from a transmission for generating the B-mode image may be performed and a received signal not subjected to the STC correction may be output. However, in this case, there is a problem that a frame rate of image data generated based on the received signal is reduced.

[0007] 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, a method of operating the ultrasonic observation apparatus, and an operation program of the ultrasonic observation apparatus that are able to correctly eliminate influence of attenuation accompanying transmission of an ultrasonic wave and prevent a reduction in a frame rate of image data generated based on a received ultrasonic wave.

MEANS FOR SOLVING PROBLEM

[0008] To solve the above problem and achieve the above object, an ultrasonic observation apparatus according to the present invention is an ultrasonic observation apparatus which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample, and the apparatus includes a signal amplifier which amplifies a signal of the ultrasonic wave received from the sample with an amplification factor according to a receiving depth; a B-mode image data generator which generates B-mode image data in which the amplitude of the signal of the ultrasonic wave

amplified by the signal amplifier is converted into brightness and displayed; an amplification corrector which performs amplification correction to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified by the signal amplifier regardless of the receiving depth; a frequency analyzer which calculates a frequency spectrum by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected by the amplification corrector; a feature data extractor which extracts feature data of the sample by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and a feature data image data generator which generates feature data image data to display visual information corresponding to the feature data extracted by the feature data extractor.

[0009] Moreover, in the above invention, the ultrasonic observation apparatus is characterized in that the amplification factor in performing the amplification using the signal amplifier monotonically increases at a receiving depth of up to a predetermined receiving depth.

[0010] Moreover, in the above invention, the ultrasonic observation apparatus is characterized in that the feature data extractor has: an approximation unit which extracts pre-correction feature data before performing the attenuation correction process by subjecting the frequency spectrum calculated by the frequency analyzer to the approximation process; and an attenuation corrector which extracts feature data of the frequency spectrum by subjecting the pre-correction feature data extracted by the approximation unit to the attenuation correction process.

[0011] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the feature data extractor has: an attenuation corrector which subjects the frequency spectrum to the attenuation correction process; and an approximation unit which extracts feature data of the frequency spectrum by subjecting the frequency spectrum corrected by the attenuation corrector to the approximation process.

[0012] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the greater the receiving depth of the ultrasonic wave, the greater the correction amount the attenuation corrector performs correction with.

[0013] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention further includes a controller which allows the correction of the amplification corrector and the correction of the attenuation corrector to be collectively performed.

[0014] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the approximation unit approximates the frequency spectrum with a polynomial through regression analysis.

[0015] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the approximation unit approximates the frequency spectrum with a linear expression, and extracts a plurality of pieces of feature data including at least two of a gradient of the linear expression, an intercept of the linear expression, and a strength which is determined using the gradient, the intercept, and a specific frequency included in the frequency band of the frequency spectrum.

[0016] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention further includes: a storage unit which stores the feature data of the frequency spectrum extracted on the basis of ultrasonic waves reflected by a plurality of known samples in association with tissue characteristics of the plurality of known samples; and a tissue characteristic determination unit which determines a tissue characteristic of a predetermined area of the sample by using the feature data stored in association with the plurality of known samples in the storage unit and the feature data extracted by the feature data extractor.

[0017] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the feature data extractor extracts a plurality of pieces of feature data, the storage unit stores averages of the respective pieces of feature data in groups classified in accordance with the tissue characteristics with respect to the plurality of known samples, and the tissue characteristic determination unit sets a feature data space having at least one of the plurality of pieces of feature data as a component, and determines a tissue characteristic of the sample on the basis of a distance on the feature data space between a sample point which has, as a coordinate of the feature data space, feature data which is a component of the feature data space from among the pieces of feature data of the frequency spectrum of the sample and a known sample average point which has, as a coordinate of the feature data space, an average of feature data which is a component of the feature data space from among the respective pieces of feature data in the groups of the plurality of known samples.

[0018] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is characterized in that the tissue characteristic determination unit calculates a standard deviation of the feature data in a population in which the feature data of the sample is added to the groups classified in accordance with the tissue characteristics of the plurality of known samples, and determines, as a tissue characteristic of the sample, a tissue characteristic corresponding to a group having feature data which is minimum in terms of a difference between the standard deviation and a standard deviation of feature data in the groups.

[0019] Moreover, in the above invention, the ultrasonic observation apparatus according to the present invention is

characterized in that the visual information is a variable constituting a color space.

[0020] Moreover, a method of operating an ultrasonic observation apparatus according to the present invention is a method of operating an ultrasonic observation apparatus which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample and the method includes : a signal amplifying step of amplifying, using a signal amplifier, a signal of the ultrasonic wave received from the sample per receiving depth with an amplification factor read from a storage unit that stores amplification factor information according to a receiving depth; a B-mode image data generating step of generating B-mode image data in which the amplitude of the signal of the ultrasonic wave amplified at the signal amplifying step is converted into brightness for display using a B-mode image data generator; an amplifying-correction step of performing amplification correction using an amplification corrector to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified at the signal amplifying step regardless of the receiving depth; a frequency analyzing step of calculating a frequency spectrum using a frequency analyzer by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected at the amplifying-correction step; a feature data extracting step of extracting feature data of the sample using a feature data extractor by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and a feature data image data generating step of generating feature data image data using a feature data image data generator to display visual information corresponding to the feature data extracted at the feature data extracting step.

[0021] Moreover, an operation program of an ultrasonic observation apparatus according to the present invention causes an ultrasonic observation apparatus, which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample, to perform: a signal amplifying step of amplifying, using a signal amplifier, a signal of the ultrasonic wave received from the sample per receiving depth with an amplification factor read from a storage unit that stores amplification factor information according to a receiving depth; a B-mode image data generating step of generating B-mode image data in which the amplitude of the signal of the ultrasonic wave amplified at the signal amplifying step is converted into brightness for display using a B-mode image data generator; an amplifying-correction step of performing amplification correction using an amplification corrector to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified at the signal amplifying step regardless of the receiving depth; a frequency analyzing step of calculating a frequency spectrum using a frequency analyzer by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected at the amplifying-correction step; a feature data extracting step of extracting feature data of the sample using a feature data extractor by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and a feature data image data generating step of generating feature data image data using a feature data image data generator to display visual information corresponding to the feature data extracted at the feature data extracting step.

EFFECT OF THE INVENTION

[0022] According to the present invention, by generating B-mode image data on the basis of a signal which is subjected to STC correction for amplification with an amplification factor according to a receiving depth, and after performing amplification correction for offsetting the influence of the STC correction and making the amplification factor spectrum-constant, performing an approximation process and an attenuation correction process with respect to the frequency spectrum to reduce the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave, feature data of a sample is extracted and feature data image data is generated to display visual information corresponding to the extracted feature data, and therefore, not only the influence of the attenuation accompanying the transmission of the ultrasonic wave is properly eliminated in the feature data image data but also it is unnecessary to distinguish between the signal for the B-mode image and the signal for the feature data image in sending them. Therefore, it is possible to properly eliminate the influence of the attenuation accompanying the transmission of the ultrasonic wave, and also prevent reduction in the frame rate of image data generated on the basis of the received ultrasonic wave.

BRIEF DESCRIPTION OF DRAWINGS

[0023]

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

FIG. 2 is a diagram illustrating the relationship between a receiving depth and an amplification factor in an amplification

process which is performed by a signal amplifier of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 3 is a diagram illustrating the relationship between a receiving depth and an amplification factor in an amplification process which is performed by an amplification corrector of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 4 is a flowchart illustrating the outline of a process of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 5 is a diagram illustrating a display example of a B-mode image in a display unit of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 6 is a flowchart illustrating the outline of a process which is performed by a frequency analyzer of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 7 is a diagram schematically illustrating data arrangement of one acoustic ray.

FIG. 8 is a diagram illustrating an example (first example) of a frequency spectrum which is calculated by the frequency analyzer of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 9 is a diagram illustrating an example (second example) of a frequency spectrum which is calculated by the frequency analyzer of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 10 is a diagram illustrating a new straight line which is determined by feature data after the feature data related to the straight line shown in FIG. 8 is subjected to attenuation correction.

FIG. 11 is a flowchart illustrating the outline of a process which is performed by a tissue characteristic determination unit of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 12 is a diagram illustrating an example of a feature data space which is set by the tissue characteristic determination unit of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 13 is a diagram illustrating a display example of a determination result display image which is displayed by the display unit of the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 14 is a diagram explaining an effect of an attenuation correction process which is performed by the ultrasonic observation apparatus according to the first embodiment of the invention.

FIG. 15 is a flowchart illustrating the outline of a process which is performed by an ultrasonic observation apparatus according to a second embodiment of the invention.

FIG. 16 is a diagram schematically illustrating the outline of an attenuation correction process which is performed by the ultrasonic observation apparatus according to the second embodiment of the invention.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

[0024] Hereinafter, modes (hereinafter, referred to as "embodiments") for carrying out the invention will be described with reference to the accompanying drawings.

(First Embodiment)

[0025] FIG. 1 is a block diagram illustrating the configuration of an ultrasonic observation apparatus according to a first embodiment of the invention. The ultrasonic observation apparatus 1 illustrated in FIG. 1 is an apparatus which observes a sample using ultrasonic waves.

[0026] The ultrasonic observation apparatus 1 is provided with an ultrasonic probe 2 which outputs an ultrasonic pulse to the outside and receives an externally-reflected ultrasonic echo, a sending/receiving unit 3 which sends and receives an electric signal to and from the ultrasonic probe 2, a computing unit 4 which subjects an electric echo signal obtained by converting an ultrasonic echo to predetermined computing, an image processor 5 which generates image data corresponding to an electric echo signal obtained by converting an ultrasonic echo, an input unit 6 which is realized using an interface such as a keyboard, a mouse, and a touch panel and receives input of various information, a display unit 7 which is realized using a display panel formed of liquid crystal, organic EL, or the like and displays various information including an image generated by the image processor 5, a storage unit 8 which stores various information including information related to the tissue characteristics of known samples, and a controller 9 which controls the operation of the ultrasonic observation apparatus 1.

[0027] The ultrasonic probe 2 has a signal converter 21 which converts an electric pulse signal received from the sending/receiving unit 3 into an ultrasonic pulse (acoustic pulse signal) and converts an ultrasonic echo reflected from an exterior sample into an electric echo signal. The ultrasonic probe 2 may mechanically scan an ultrasonic transducer, or may electronically scan a plurality of ultrasonic transducers.

[0028] The sending/receiving unit 3 is electrically connected to the ultrasonic probe 2 to send a pulse signal to the ultrasonic probe 2 and to receive an echo signal as a received signal from the ultrasonic probe 2. Specifically, the sending/receiving unit 3 generates a pulse signal on the basis of a waveform and sending timing which are set in advance,

and sends the generated pulse signal to the ultrasonic probe 2.

[0029] The sending/receiving unit 3 has a signal amplifier 31 which amplifies an echo signal. Specifically, the signal amplifier 31 performs STC correction so that the higher the receiving depth of an echo signal, the higher the amplification factor the signal is amplified with. FIG. 2 is a diagram illustrating the relationship between a receiving depth of an echo signal and an amplification factor. A receiving depth z shown in FIG. 2 is an amount which is calculated on the basis of an elapsed time from a time point at which reception of an ultrasonic wave is started. As shown in FIG. 2, an amplification factor β linearly increases from β_0 to β_{th} ($> \beta_0$) with an increase of the receiving depth z when the receiving depth z is less than a threshold z_{th}. In addition, the amplification factor β takes a certain value β_{th} when the receiving depth z is equal to or greater than the threshold z_{th}. The value of the threshold z_{th} is a value at which the ultrasonic signal received from a sample is almost attenuated and noise is thus dominant. More generally, the amplification factor β may monotonically increase with an increase of the receiving depth z when the receiving depth z is less than the threshold z_{th}.

[0030] The sending/receiving unit 3 subjects the echo signal amplified by the signal amplifier 31 to a process such as filtering, and then A/D converts the processed signal to generate and output a digital RF signal. In the case where the ultrasonic probe 2 electronically scans a plurality of ultrasonic transducers, the sending/receiving unit 3 has a multichannel circuit for beam synthesis corresponding to the plurality of ultrasonic transducers.

[0031] The computing unit 4 has an amplification corrector 41 which performs amplification correction to make the amplification factor constant with respect to the digital RF signal output from the sending/receiving unit 3 regardless of the receiving depth, a frequency analyzer 42 which subjects the digital RF signal subjected to the amplification correction to fast Fourier transform (FFT) to analyze the frequency, a feature data extractor 43 which subjects the frequency spectrum (power spectrum) calculated by the frequency analyzer 42 to an approximation process and a correction process for reducing the contribution of the attenuation of the ultrasonic wave depending on the receiving depth and the frequency of the ultrasonic wave to extract the feature data of the frequency spectrum, and a tissue characteristic determination unit 44 which determines the tissue characteristic of a predetermined area of a sample by using the feature data extracted by the feature data extractor 43.

[0032] FIG. 3 is a diagram illustrating the relationship between a receiving depth and an amplification factor in the amplification process which is performed by the amplification corrector 41. As shown in FIG. 3, the amplification factor of the amplification process which is performed by the amplification corrector 41 is a maximum value β_{th}-β_0 at a receiving depth of zero, is linearly reduced at a receiving depth of up to a receiving depth z_{th}, and is zero at the receiving depth z_{th} or greater. When a digital RF signal is amplified with such an amplification factor, the influence of the STC correction in the signal amplifier 31 can be offset, and a signal of the certain amplification factor β_{th} can be output. Of course, the relationship between the receiving depth z and the amplification factor β achieved in the amplification corrector 41 varies in accordance with the relationship between the receiving depth and the amplification factor in the signal amplifier 31.

[0033] For each acoustic ray (line data), the frequency analyzer 42 subjects an FFT data group formed of a predetermined data amount to a fast Fourier transform to calculate a frequency spectrum. The frequency spectrum tends to vary depending on the tissue characteristic of a sample. The reason for this is that the frequency spectrum is correlated with the size, density, acoustic impedance, and the like of a sample as a scatterer which scatters an ultrasonic wave.

[0034] The feature data extractor 43 has an approximation unit 431 which approximates the frequency spectrum calculated by the frequency analyzer 41 to calculate pre-correction feature data before performing an attenuation correction process, and an attenuation corrector 432 which subjects the pre-correction feature data approximated by the approximation unit 431 to an attenuation correction process to extract the feature data.

[0035] The approximation unit 431 approximates the frequency spectrum with a linear expression through regression analysis to extract pre-correction feature data characterizing the linear expression. Specifically, the approximation unit 431 calculates a gradient a_0 and an intercept b_0 of the linear expression through regression analysis, and calculates, as pre-correction feature data, a strength at a specific frequency in the frequency band in the frequency spectrum. In the first embodiment, although the approximation unit 431 calculates a strength (Mid-band fit) $C_0 = a_0 f_{MID} + bo$ at a center frequency $f_{MID} = (F_{LOW} + f_{HIGH}) / 2$, this is just an example. Here, the "strength" is any of parameters such as voltage, electric power, sound pressure, acoustic energy, and the like.

[0036] It is thought that among the three pieces of feature data, the gradient a_0 is correlated with the size of an ultrasonic scatterer, and generally, the greater the size of the scatterer, the less the value of the gradient. In addition, the intercept b_0 is correlated with the size of a scatterer, the difference in the acoustic impedance, the density (concentration) of a scatterer, and the like. Specifically, it is thought that the greater the size of the scatterer, the greater the value of the intercept b_0, the greater the size of the acoustic impedance, the greater the value of the intercept b_0, and the greater the density (concentration) of the scatterer, the greater the value of the intercept b_0. The strength c_0 at the center frequency f_{MID} (hereinafter, simply referred to as "strength") is an indirect parameter derived from the gradient a_0 and the intercept b_0, and gives a spectrum strength at the center in an effective frequency band. Therefore, it is thought that the strength c_0 is correlated to some degree with the brightness of a B-mode image in addition to the size of a scatterer, the difference in the acoustic impedance, and the density of a scatterer. The approximate polynomial which is calculated by the feature data extractor 43 is not limited to the linear expression, and a quadratic or higher-order approximate

polynomial can also be used.

[0037] The correction which is performed by the attenuation corrector 432 will be described. An ultrasonic attenuation amount A can be represented as follows:

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

Here, α is an attenuation rate, z is the receiving depth of an ultrasonic wave, and f is a frequency. As is obvious from Expression (1), the attenuation amount A is proportional to the frequency f. The specific value of the attenuation rate α is, in the case of a living body, in the range of 0 to 1.0 (dB/cm/MHz), and preferably 0.3 to 0.7 (dB/cm/MHz), and it is determined in accordance with the type of an observation target organ. For example, when the observation target organ is a pancreas, α = 0.6 (dB/cm/MHz) is determined. In the first embodiment, a configuration can also be employed in which the value of the attenuation rate α can be changed by an input from the input unit 6.

[0038] The attenuation corrector 432 corrects the pre-correction feature data (gradient a_0, intercept b_0, strength C_0) extracted by the approximation unit 421 as follows.

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

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

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

As is obvious from Expressions (2) and (4), the greater the receiving depth z of the ultrasonic wave, the greater the correction amount the attenuation corrector 432 performs correction with. In addition, according to Expression (3), the correction related to the intercept is an identical transformation. The reason for this is that the intercept is a frequency component corresponding to 0 frequency (Hz) and is not subjected to attenuation.

[0039] The tissue characteristic determination unit 44 calculates, for each feature data, an average and a standard deviation of the feature data of the frequency spectrum extracted by the feature data extractor 43 and corrected by the attenuation corrector 432. The tissue characteristic determination unit 44 determines the tissue characteristic of a predetermined area of a sample by using the calculated average and standard deviation and by using averages and standard deviations of the feature data of frequency spectrums of known samples which are stored in the storage unit 8. Here, the "predetermined area" is an area in an image which is designated by an operator of the ultrasonic observation apparatus 1, who has seen the image generated by the image processor 5, using the input unit 6 (hereinafter, referred to as "area of interest"). In addition, the "tissue characteristic" is any of cancer, endocrine tumor, mucinous tumor, normal tissue, normal blood vessel, and the like. When the sample is a pancreas, chronic pancreatitis, autoimmune pancreatitis, and the like are also included as tissue characteristics.

[0040] The average and the standard deviation of the feature data which are calculated by the tissue characteristic determination unit 44 reflect a change at a cell level such as enlargement of a nucleus and variants and a change in the tissue such as hyperplasia of fibers and substitution with fibers of a parenchymal tissue in an interstitium, and shows unique values in accordance with the tissue characteristic. Accordingly, the tissue characteristic of a predetermined area of a sample can be accurately determined by using the average and the standard deviation of the feature data.

[0041] The image processor 5 has a B-mode image data generator 51 which generates B-mode image data from an echo signal, a feature data image data generator 52 which generates feature data image data to display visual information corresponding to the feature data of a sample, and a determination result display image data generator 53 which generates determination result display image data to display a determination result of the tissue characteristic of the area of interest and information related to the determination result by using the data output by the B-mode image data generator 51 and the computing unit 4.

[0042] The B-mode image data generator 51 subjects a digital signal to a signal process using a known technique such as a band-pass filter, logarithmic transformation, gain processing, or contrast processing, and performs data culling according to a data step width determined in accordance with the display range of an image in the display unit 7 to generate B-mode image data.

[0043] The visual information to be used in generating the feature data image data by the feature data image data generator 52 is a variable constituting a color space such as a RGB color system having R (red), G (green), and B (blue) as variables.

[0044] The determination result display image data generator 53 generates determination result display image data including the B-mode image data generated by the B-mode image data generator 51, the feature data image data generated by the feature data image data generator 52, the feature data extracted by the feature data extractor 43, and the determination result obtained by determination of the tissue characteristic determination unit 44.

[0045] The storage unit 8 is provided with a known sample information storage unit 81 which stores information of known samples, an amplification factor information storage unit 82 which stores information of the amplification factor referred to when the signal amplifier 31 and the amplification corrector 41 perform an amplification process, a window function storage unit 83 which stores a window function to be used in the frequency analysis process which is performed by the frequency analyzer 42, and a correction information storage unit 84 which stores correction information referred to when the attenuation corrector 432 performs a process.

[0046] The known sample information storage unit 81 stores feature data of the frequency spectrums extracted with respect to known samples in association with the tissue characteristics of the known samples. In addition, the known sample information storage unit 81 stores, with respect to the feature data of the frequency spectrum related to the known samples, an average and a standard deviation calculated for each of the groups classified on the basis of the tissue characteristics of the known samples in addition to all pieces of feature data of the known samples. Here, the feature data of the known samples is extracted in the same manner as in the first embodiment. However, there is no need that the ultrasonic observation apparatus 1 should perform the process of extracting the feature data of the known samples. It is desirable that the information of the known samples stored in the known sample information storage unit 81 has high reliability in terms of the tissue characteristics. The amplification factor information storage unit 82 stores the relationships between the amplification factor and the receiving depth, which are shown in FIGS. 2 and 3. The window function storage unit 83 stores at least one of the window functions such as Hamming, Hanning, and Blackman. The correction information storage unit 84 stores information related to the conversion of Expressions (2) to (4).

[0047] The storage unit 8 is realized using a ROM which stores an operating program of the ultrasonic observation apparatus according to the first embodiment, a program for operating a predetermined OS, and the like in advance, a RAM which stores computing parameters and data of the respective processes, or the like.

[0048] The constituent elements other than the ultrasonic probe 2 of the ultrasonic observation apparatus 1 having the above-described functions and configurations are realized using a computer provided with a CPU having a computing function and a control function. The CPU of the ultrasonic observation apparatus 1 reads out the information stored in the storage unit 8 and various programs including the above-described operating program of the ultrasonic observation apparatus from the storage unit 8 to execute a computing process related to a method of operating the ultrasonic observation apparatus according to the first embodiment.

[0049] The operating program of the ultrasonic observation apparatus according to the first embodiment can also be stored on a computer readable recording medium such as a hard disk, a flash memory, a CD-ROM, a DVD-ROM, or a flexible disk to be widely distributed.

[0050] FIG. 4 is a flowchart illustrating the outline of a process of the ultrasonic observation apparatus 1 having the above-described configurations. In FIG. 4, first, the ultrasonic observation apparatus 1 measures a new sample using the ultrasonic probe 2 (Step S1).

[0051] Next, the signal amplifier 31 receiving an echo signal from the ultrasonic probe 2 amplifies the echo signal (Step S2). Here, the signal amplifier 31 performs amplification on the basis of the relationship between the amplification factor and the receiving depth shown in FIG. 2.

[0052] Then, the B-mode image data generator 51 generates B-mode image data using an echo signal for a B-mode image which is output from the sending/receiving unit 3 (Step S3).

[0053] Next, the controller 9 controls the display unit 7 to display a B-mode image corresponding to the B-mode image data generated by the B-mode image data generator 51 (Step S4). FIG. 5 is a diagram illustrating a display example of a B-mode image in the display unit 7. A B-mode image 100 shown in FIG. 5 is a gray scale image in which values of R (red), G (green), and B (blue), which are variables when a RGB color system is employed as a color space, are matched.

[0054] Then, when an area of interest is set through the input unit 6 (Step S5: Yes), the amplification corrector 41 performs correction to make the amplification factor constant with respect to the signal output from the sending/receiving unit 3 regardless of the receiving depth (Step S6). Here, the amplification corrector 41 performs an amplification process on the basis of the relationship between the amplification factor and the receiving depth shown in FIG. 3.

[0055] On the other hand, when no area of interest is set (Step S5: No), the ultrasonic observation apparatus 1 terminates the process when an instruction for terminating the process is input by the input unit 6 (Step S7: Yes). On the contrary, when no area of interest is set (Step S5: No), the ultrasonic observation apparatus 1 returns to Step S5 when an instruction for terminating the process is not input by the input unit 6 (Step S7: No).

[0056] After Step S6, the frequency analyzer 42 calculates a frequency spectrum by analyzing the frequency through FFT computing (Step S8). In the Step S8, the entire image area can also be set as an area of interest.

[0057] Here, the process which is performed by the frequency analyzer 42 (Step S8) will be described in detail with reference to the flowchart shown in FIG. 6. First, the frequency analyzer 42 sets an acoustic ray number L of an acoustic

ray which is an analysis target as an initial value L_0 (Step S21). The initial value L_0 may be imparted to, for example, an acoustic ray which is initially received by the sending/receiving unit 3, or an acoustic ray corresponding to a boundary position on one of the right and left sides of the area of interest set by the input unit 6.

[0058] Next, the frequency analyzer 42 calculates frequency spectrums of all of a plurality of data positions set on one acoustic ray. First, the frequency analyzer 42 sets an initial value Z_0 of a data position Z (corresponding to the receiving depth) representing a series of data groups (FFT data groups) acquired for FFT computing (Step S22). FIG. 7 is a diagram schematically illustrating data arrangement of one acoustic ray. In an acoustic ray LD shown in FIG. 7, the white or black rectangle means one data. The acoustic ray LD is made discrete at time intervals corresponding to a sampling frequency (for example, 50 MHz) in A/D conversion which is performed by the sending/receiving unit 3. FIG. 7 shows the case in which the first data of the acoustic ray LD is set as the initial value Z_0 of the data position Z. FIG. 7 is a just an example, and the position of the initial value Z_0 can be arbitrarily set. For example, a data position Z corresponding to an upper end position of the area of interest may be set as the initial value Z_0.

[0059] Then, the frequency analyzer 42 acquires an FFT data group at the data position Z (Step S23) and allows a window function stored in the window function storage unit 83 to act on the acquired FFT data group (Step S24). When the window function acts on the FFT data group in this manner, discontinuity of the FFT data groups at the boundary can be avoided, and an artifact can be prevented from occurring.

[0060] Next, the frequency analyzer 42 determines whether or not the FFT data group at the data position Z is a normal data group (Step S25). Here, it is necessary for the FFT data group to have the number of pieces of data being a power of two. Hereinafter, the FFT data group has 2^n (n is a positive integer) pieces of data. The normal FFT data group means that the data position Z is a 2^{n-1}-th position from the front in the FFT data group. In other words, the normal FFT data group means that there are 2^{n-1} -1 (= N) pieces of data before the data position Z, and there are 2^{n-1} (= M) pieces of data after the data position Z. In FIG. 7, the FFT data groups F_2, F_3, and F_{K-1} are normal, and the FFT data groups F_1 and F_K are abnormal. In FIG. 7, n = 4 is set (N = 7, M = 8).

[0061] As a result of the determination in Step S25, when the FFT data group at the data position Z is normal (Step S25: Yes), the frequency analyzer 42 proceeds to Step S27 to be described later.

[0062] As a result of the determination in Step S25, when the FFT data group at the data position Z is not normal (Step S25: No), the frequency analyzer 42 generates a normal FFT data group by inserting zero data by a shortfall (Step S26). For the FFT data group which has been determined to be abnormal in Step S25, a window function acts before the addition of zero data. Therefore, data discontinuity does not occur even when zero data is inserted into the FFT data group. After Step S26, the frequency analyzer 42 proceeds to Step S27 to be described later.

[0063] In Step S27, the frequency analyzer 42 obtains a frequency spectrum by performing FFT computing using the FFT data group (Step S27). FIGS. 8 and 9 are diagrams illustrating an example of the frequency spectrum calculated by the frequency analyzer 42. In FIGS. 8 and 9, a horizontal axis f represents a frequency, and a vertical axis I represents a strength. In frequency spectrum curves C_1 and C_2 shown in FIGS. 8 and 9, respectively, a minimum frequency f_{LOW} and a maximum frequency T_{HIGH} of the frequency spectrum are parameters which are determined on the basis of the frequency band of the ultrasonic probe 2, the frequency band of the pulse signal sent from the sending/receiving unit 3, and the like. For example, f_{LOW} = 3 MHz, and F_{HIGH} = 10 MHz. A straight line L_1 shown in FIG. 8 and a straight line L_2 shown in FIG. 9 will be described in a description about a feature data extraction process. In the first embodiment, the curve and the straight line are formed of a set of discrete points. The same is true of embodiments to be described later.

[0064] Next, the frequency analyzer 42 adds a predetermined data step width D to the data position Z to calculate a data position Z of a FFT data group which is a next analysis target (Step S28). Here, it is desirable that the data step width D is made equal to a data step width which is used in generating B-mode image data by the B-mode image data generator 51. However, when the computing amount in the frequency analyzer 42 is to be reduced, the data step width D may be set to be greater than the data step width which is used by the B-mode image data generator 51. FIG. 7 shows the case in which D = 15.

[0065] Then, the frequency analyzer 42 determines whether or not the data position Z is greater than a final data position Z_{max} (Step S29). Here, the final data position Z_{max} may be a data length of the acoustic ray LD, or may be a data position corresponding to a lower end of the area of interest. As a result of the determination, when the data position Z is greater than the final data position Z_{max} (Step S29: Yes), the frequency analyzer 42 increases an acoustic ray number L by 1 (Step S30). On the other hand, when the data position Z is equal to or less than the final data position Z_{max} (Step S29: No), the frequency analyzer 42 returns to Step S23. In this manner, regarding one acoustic ray LD, the frequency analyzer 42 subjects $[\{(Z_{max} - Z_0)/D\} + 1]$ (= K) FFT data groups to FFT computing. Here, [X] represents a maximum integer not exceeding X.

[0066] When the acoustic lay number L increased in Step S30 is greater than a final acoustic ray number L_{max} (Step S31: Yes), the frequency analyzer 42 returns to the main routine shown in FIG. 4. On the other hand, when the acoustic lay number L increased in Step S30 is equal to or less than the final acoustic ray number L_{max} (Step S31: No), the frequency analyzer 42 returns to Step S22.

[0067] In this manner, the frequency analyzer 42 performs FFT computing K times for each of $(L_{max} - L_0 + 1)$ acoustic

rays. The final acoustic ray number L_{max} may be imparted to, for example, an acoustic ray which is finally received by the sending/receiving unit 3, or an acoustic ray corresponding to a boundary on one of the right and left sides of the area of interest. Hereinafter, the total number $(L_{max} - L_0 + 1) \times K$ of FFT computing operations performed for all of the acoustic rays by the frequency analyzer 42 is represented by P.

[0068] Next to the above-described frequency analysis process in Step S8, the approximation unit 431 subjects the P frequency spectrums calculated by the frequency analyzer 42 to regression analysis as an approximation process to extract pre-correction feature data (Step S9). Specifically, the approximation unit 431 calculates a linear expression for approximating the frequency spectrum of the frequency band $f_{LOW} < f < T_{HIGH}$ through regression analysis, and thus extracts a gradient a_0, an intercept b_0, and a strength c_0 characterizing the linear expression as pre-correction feature data. The straight line L_1 shown in FIG. 8 and the straight line L_2 shown in FIG. 9 are regression lines which are obtained by subjecting the frequency spectrum curves C_1 and C_2 to a feature data extraction process in Step S9.

[0069] Then, the attenuation corrector 432 subjects the pre-correction feature data extracted by the approximation unit 431 to an attenuation correction process (Step S10). For example, when a sampling frequency of the data is 50 MHz, the time interval of data sampling is 20 (nsec). Here, when the speed of sound is 1,530 (m/sec), the distance interval of data sampling is 1,530 (m/sec) $\times$ 20 (nsec)/2 = 0.0153 (mm). When the number of data steps from the first data of the acoustic ray LD to a data position of the FFT data group of the processing target is k, the data position Z is 0.0153k (mm). The attenuation corrector 432 substitutes the value of the data position Z obtained as above for the receiving depths z of the above-described Expressions (2) to (4) to calculate a gradient a, an intercept b, and a strength c which are feature data of the frequency spectrum. FIG. 10 is a diagram illustrating a straight line which is determined by feature data, related to the straight line L_1 shown in FIG. 8, subjected to attenuation correction. The expression representing a straight line L_1' shown in FIG. 10 is as follows:

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

As is obvious from Expression (5), the straight line L_1' is inclined greater than the straight line L_1 and has the same intercept value as that of the straight line L_1.

[0070] Then, the tissue characteristic determination unit 44 determines a tissue characteristic in the area of interest of the sample on the basis of the feature data extracted by the feature data extractor 43 and corrected by the attenuation corrector 432 and the known sample information stored in the known sample information storage unit 81 (Step S11).

[0071] Here, the process (Step S11) which is performed by the tissue characteristic determination unit 44 will be described in detail with reference to the flowchart shown in FIG. 11. First, the tissue characteristic determination unit 44 sets a feature data space to be used in determining the tissue characteristic (Step S41). In the first embodiment, two of the three pieces of feature data, that is, a gradient a, an intercept b, and a strength c, are independent parameters. Accordingly, a two-dimensional space with optional two of the three pieces of feature data as components can be set as a feature data space. In addition, a one-dimensional space with optional one of the three pieces of feature data as a component can also be set as the feature data space. In Step S41, although the feature data space to be set is determined in advance, the operator may select a desired feature data space through the input unit 6.

[0072] FIG. 12 is a diagram illustrating an example of the feature data space set by the tissue characteristic determination unit 44. In the feature data space shown in FIG. 12, the horizontal axis represents the intercept b, and the vertical axis represents the strength c. The point Sp shown in FIG. 12 represents a point having the intercept b and the strength c as coordinates of the feature data space, which have been calculated with respect to a sample as a determination target (hereinafter, this point is referred to as "sample point"). In addition, the areas G_μ, G_ν, and G_ρ shown in FIG. 12 represent groups in which the tissue characteristics of known samples stored in the known sample information storage unit 81 are μ, ν, and ρ, respectively. In the case shown in FIG. 12, each of the three groups G_μ, G_ν, and G_ρ is present in an area which does not intersect with other groups on the feature data space.

[0073] In the first embodiment, even when obtaining the feature data of known samples, tissue characteristics are classified and determined using the feature data as an index, obtained by subjecting the pre-correction feature data of the frequency spectrum obtained by frequency analysis to attenuation correction. Accordingly, the tissue characteristics different from each other can be sharply distinguished. Particularly, in the first embodiment, since feature data subjected to attenuation correction is used, the areas of the respective tissue characteristics in the feature data space can be separated more clearly than in the case in which feature data extracted without performing attenuation correction is used.

[0074] After Step S41, the tissue characteristic determination unit 44 calculates distances d_μ, d_ν, and d_ρ on the feature data space between the sample point Sp and points μ_0, ν_0, and ρ_0 (hereinafter, these points are referred to as "known sample average points") which have, as coordinates in the feature data space, an average of the intercept b and an average of the strength c of the frequency spectrum of the FFT data group included in the groups G_μ, G_ν, and G_ρ, respectively (Step S42). Here, when the scales of the b-axis component and the c-axis component in the feature data space are significantly different from each other, it is desirable to appropriately perform weighting for approximately

equalizing the contribution of each distance.

[0075] Next, the tissue characteristic determination unit 44 determines tissue characteristics of all of sample points including the sample point Sp on the basis of the distances calculated in Step S42 (Step S43). For example, in the case shown in FIG. 12, the distance d_μ is the minimum, and thus the tissue characteristic determination unit 44 determines that the tissue characteristic of the sample is μ. When the sample point Sp is extremely distant from the known sample average points μ_0, ν_0, and po, the result of the tissue characteristic determination has low reliability even when minimum values of the distances d_μ, d_ν, and d_ρ are obtained. Therefore, when d_μ, d_ν, and d_ρ are greater than a predetermined threshold, the tissue characteristic determination unit 44 may output an error signal. In addition, when values of two or more of d_μ, d_ν, and d_ρ are minimum, the tissue characteristic determination unit 44 may select all of the tissue characteristics corresponding to the minimum values as candidates, or may select any one tissue characteristic in accordance with a predetermined rule. Examples of the latter case include a method in which the priority of a highly malignant tissue characteristic such as cancer is set to be high. In addition, when values of two or more of d_μ, d_ν, and d_ρ are minimum, the tissue characteristic determination unit 44 may output an error signal.

[0076] Then, the tissue characteristic determination unit 44 outputs the distance calculation result in Step S42 and the determination result in Step S43 (Step S44). Accordingly, the tissue characteristic determination process in Step S11 is terminated.

[0077] After the above-described Step S11, the feature data image data generator 52 generates feature data image data to display visual information corresponding to the feature data extracted by the feature data extractor 43 (Step S12).

[0078] Next, the determination result display image data generator 53 generates determination result display image data using the B-mode image data generated by the B-mode image data generator 51, the feature data calculated by the feature data extractor 43, the feature data image data generated by the feature data image data generator 52, and the determination result obtained by the tissue characteristic determination unit 44 (Step S13).

[0079] Then, the display unit 7 displays the determination result display image generated by the determination result display image data generator 53 (Step S14). FIG. 13 is a diagram illustrating a display example of the determination result display image which is displayed by the display unit 7. A determination result display image 200 shown in FIG. 13 has an information display unit 201 which displays various related information including the result of the tissue characteristic determination and an image display unit 202 which displays a feature data image to display the feature data on the basis of the B-mode image.

[0080] The information display unit 201 displays identification information (ID number, name, sex, and the like) of a sample, the tissue characteristic determination result calculated by the tissue characteristic determination unit 44, information related to the feature data in determining the tissue characteristic, and ultrasonic image quality information such as gain and contrast. Here, as the information related to the feature data, it is possible to perform a display using averages and standard deviations of the feature data of the frequency spectrums of FFT data of Q groups positioned inside the area of interest. Specifically, the information display unit 201 can display, for example, gradient = 1.5 ± 0.3 (dB/MHz), intercept = -60 ± 2 (dB), and strength = -50 ± 1.5 (dB).

[0081] A feature data image 300 which is displayed on the image display unit 202 is a gray scale image in which regarding the B-mode image 100 shown in FIG. 5, the intercept b is uniformly assigned to R (red), G (green), and B (blue).

[0082] When the display unit 7 displays the determination result display image 200 having the above-described configuration, the operator can more accurately grasp the tissue characteristic of the area of interest. The determination result display image is not limited to the above-described configuration. For example, the feature data image and the B-mode image may be displayed next to each other as the determination result display image. Accordingly, the difference between both of the images can be recognized on the one screen.

[0083] FIG. 14 is a diagram explaining an effect of the attenuation correction process which is performed by the ultrasonic observation apparatus 1. An image 400 shown in FIG. 14 is a feature data image when attenuation correction is not performed. In the case of the feature data image 400, the signal strength is reduced due to the influence of attenuation in an area with a high receiving depth (lower area in FIG. 14), whereby the image becomes dark. On the contrary, it is found that in the feature data image 300 subjected to the attenuation correction, an image having uniform brightness is obtained over the entire screen.

[0084] The feature data images 300 shown in FIGS. 13 and 14 are just an example. For example, three feature data items a', b', and c' can be assigned to R, G, and B, respectively, to display a feature data image by a color image. In this case, since the tissue characteristic is expressed with a unique color, the operator can grasp the tissue characteristic of the area of interest on the basis of the color distribution of the image. In addition, the color space may be formed of, in place of the RGB color system, variables which are complementary colors such as cyan, magenta, and yellow, and feature data may be assigned to the respective variables. In addition, the B-mode image data and the color image data may be mixed at a predetermined ratio to generate the feature data image data. In addition, only the area of interest may be substituted with color image data to generate the feature data image data.

[0085] According to the above-described the first embodiment of the invention, B-mode image data is generated on the basis of a signal which is subjected to STC correction for amplification with an amplification factor according to the

receiving depth. In addition, pre-correction feature data is extracted by performing amplification correction for offsetting the influence of the STC correction and for thereby making the amplification factor spectrum-constant, and by then calculating the frequency spectrum, feature data of a sample is extracted by subjecting the extracted pre-correction feature data to attenuation correction, and feature data image data is generated to display visual information corresponding to the extracted feature data. Accordingly, the influence of the attenuation accompanying the transmission of an ultrasonic wave is eliminated in the feature data image data, and it is not necessary to separately send a signal for a B-mode image and a signal for a feature data image. Accordingly, it is possible to properly eliminate the influence of the attenuation accompanying the transmission of an ultrasonic wave, and also possible to prevent a reduction in the frame rate of image data generated on the basis of the received ultrasonic wave.

[0086] In addition, according to the first embodiment, since the tissue characteristic of a predetermined area of a sample is determined by using the feature data of the frequency spectrum properly subjected to attenuation correction, the difference between tissues can be sharply distinguished without using the distortion amount or elastic modulus of a living tissue. Accordingly, the tissue characteristic can be accurately distinguished and the reliability of the observation result can be improved.

[0087] As a modified example of the first embodiment, the controller 9 may allow the amplification correction process using the amplification corrector 41 and the attenuation correction process using the attenuation corrector 432 to be collectively performed. For this process, the amplification process in Step S6 of FIG. 4 is deleted and the definition of the attenuation amount of the attenuation correction process in Step S10 of FIG. 4 is changed as in the following Expression (6):

$$A' = 2\alpha z f + \gamma(z) \tag{6}$$

Here, $\gamma(z)$ on the right side is a difference between the amplification factors β and β_0 at the receiving depth z, and is represented as follows:

$$\gamma(z) = -\{(\beta_{th} - \beta_0)/z_{th}\}z + \beta_{th} - \beta_0 \quad (z \leq z_{th}) \tag{7}$$

$$\gamma(z) = 0 \quad (z > z_{th}) \tag{8}$$

(Second Embodiment)

[0088] A second embodiment of the invention is different from the first embodiment in terms of the feature data extraction which is performed by the feature data extractor. The configuration of an ultrasonic observation apparatus according to the second embodiment is the same as that of the ultrasonic observation apparatus 1 described in the first embodiment. Accordingly, in the following description, constituent elements corresponding to the constituent elements of the ultrasonic observation apparatus 1 will be denoted by the same signs.

[0089] In the feature data extraction process in the second embodiment, first, an attenuation corrector 432 subjects a frequency spectrum calculated by a frequency analyzer 42 to an attenuation correction process. Then, an approximation unit 431 subjects the frequency spectrum subjected to the attenuation correction using the attenuation corrector 432 to an approximation process to extract feature data of the frequency spectrum.

[0090] FIG. 15 is a flowchart illustrating the outline of a process of the ultrasonic observation apparatus according to the second embodiment. In FIG. 15, processes in Steps S51 to S58 sequentially correspond to the processes in Steps S1 to S8 of FIG. 4.

[0091] In Step S59, the attenuation corrector 432 subjects the frequency spectrum calculated by the frequency analyzer 42 through FFT computing to attenuation correction (Step S59). FIG. 16 is a diagram schematically illustrating the outline of the attenuation correction process in Step S59. As shown in FIG. 16, the attenuation corrector 432 corrects a frequency spectrum curve C_3 at all of frequencies f so that the attenuation amount A of the above-described Expression (1) is added to a strength I, thereby obtaining a new frequency spectrum curve C_3'. Accordingly, a frequency spectrum can be obtained in which the contribution of attenuation accompanying the transmission of an ultrasonic wave is reduced.

[0092] Then, the approximation unit 431 subjects all of the frequency spectrums subjected to the attenuation correction using the attenuation corrector 432 to regression analysis to extract feature data of the frequency spectrum (Step S60). Specifically, the approximation unit 431 performs regression analysis, thereby calculating a gradient a and an intercept b of a linear expression and a strength c at a center frequency F_{MID}. A straight line L_3 shown in FIG. 16 is a regression line (intercept b_3) which is obtained by subjecting the frequency spectrum curve C_3 to a feature data extraction process

in Step S60.

[0093] Processes in Steps S61 to S64 sequentially correspond to the processes in Steps S11 to S14 of FIG. 4.

[0094] According to the above-described the second embodiment of the invention, B-mode image data is generated on the basis of a signal which is subjected to STC correction for amplification with an amplification factor according to the receiving depth. In addition, amplification correction for offsetting the influence of the STC correction and for thereby making the amplification factor spectrum-constant is performed, a frequency spectrum is calculated and subjected to attenuation correction, and then feature data is extracted and feature data image data is generated to display visual information corresponding to the extracted feature data. Accordingly, the influence of the attenuation accompanying the transmission of an ultrasonic wave is eliminated in the feature data image data, and it is not necessary to separately send a signal for a B-mode image and a signal for a feature data image. Accordingly, as in the above-described the first embodiment, it is possible to properly eliminate the influence of the attenuation accompanying the transmission of an ultrasonic wave, and also possible to prevent a reduction in the frame rate of image data generated on the basis of the received ultrasonic waves.

[0095] In addition, according to the second embodiment, since the tissue characteristic of a predetermined area of a sample is determined by using the feature data of the frequency spectrum properly subjected to attenuation correction, the difference between tissues can be sharply distinguished without using the distortion amount or elastic modulus of a living tissue. Accordingly, the tissue characteristic can be accurately distinguished and the reliability of the observation result can be improved.

[0096] Also, in the second embodiment, the amplification correction process in Step S56 of FIG. 15 can be deleted and the attenuation amount in performing the attenuation correction of the frequency spectrum in Step S59 of FIG. 15 can be processed as A' of Expression (6).

(Third Embodiment)

[0097] A third embodiment of the invention is different from the first embodiment in terms of the tissue characteristic determination process in the tissue characteristic determination unit. The configuration of an ultrasonic observation apparatus according to the third embodiment is the same as that of the ultrasonic observation apparatus 1 described in the first embodiment. Accordingly, in the following description, constituent elements corresponding to the constituent elements of the ultrasonic observation apparatus 1 will be denoted by the same signs.

[0098] A tissue characteristic determination unit 44 adds feature data (a, b, c) to groups G_μ, G_ν, and G_ρ (see FIG. 12) which constitute tissue characteristics μ, ν, and ρ, respectively, to constitute a new population, and then obtains a standard deviation for each feature data of data constituting each tissue characteristic.

[0099] Then, the tissue characteristic determination unit 44 calculates a difference (hereinafter, simply referred to as "standard deviation difference") between the standard deviation of each feature data of the groups G_μ, G_ν, and G_ρ in the original population formed of known samples and the standard deviation of each feature data of the groups G_μ, G_ν, and G_ρ in the new population having new samples added thereto, and determines the tissue characteristic corresponding to the group including the feature data which is minimum in the standard deviation difference as a tissue characteristic of the sample.

[0100] Here, the tissue characteristic determination unit 44 may calculate the standard deviation difference only with respect to the standard deviation of feature data selected in advance from a plurality of pieces of feature data. In this case, the feature data may be arbitrarily selected by an operator, or may be automatically selected by the ultrasonic observation apparatus 1.

[0101] In addition, the tissue characteristic determination unit 44 may calculate a value for each group, by performing appropriate weighting to the standard deviation differences of all pieces of feature data and adding the weighted values, and may determine the tissue characteristic corresponding to the group which is minimum in terms of the value as a tissue characteristic of the sample. In this case, for example, when the feature data includes a gradient a, an intercept b, and a strength c, the tissue characteristic determination unit 44 calculates w_a·(standard deviation difference of a) + w_b·(standard deviation difference of b) + w_c·(standard deviation difference of c) (where w_a, w_b, and w_c are weights corresponding to the gradient a, the intercept b, and the strength c, respectively), and determines the tissue characteristic of the sample on the basis of the calculated value. The values of the weights w_a, w_b, and w_c may be arbitrarily set by an operator, or may be automatically set by the ultrasonic observation apparatus 1.

[0102] In addition, the tissue characteristic determination unit 44 may calculate a square root of a value which is calculated for each group by performing appropriate weighting to the squares of the standard deviation differences of all pieces of feature data and adding the weighted values, and may determine the tissue characteristic corresponding to the group which is minimum in terms of the square root as a tissue characteristic of the sample. In this case, for example, when the feature data includes a gradient a, an intercept b, and a strength c, the tissue characteristic determination unit 44 calculates $\{w'_a$·(standard deviation difference of a)^2 + w'_b·(standard deviation difference of b)^2 + w'_c·(standard deviation difference of c)$^2\}^{1/2}$ (where w'_a, w'_b, and w'_c are weights corresponding to the gradient a, the intercept

b, and the strength c, respectively), and determines the tissue characteristic on the basis of the calculated value. Also, in this case, the values of the weights w'_a, w'_b, and w'_c may be arbitrarily set by an operator, or may be automatically set by the ultrasonic observation apparatus 1.

[0103] According to the above-described the third embodiment of the invention, as in the above-described the first embodiment, it is possible to properly eliminate the influence of the attenuation accompanying the transmission of an ultrasonic wave, and also possible to prevent a reduction in the frame rate of image data generated on the basis of the received ultrasonic wave.

[0104] In addition, according to the third embodiment, the tissue characteristic can be accurately distinguished, and the reliability of the observation result can be improved. In addition, the influence of the attenuation accompanying the transmission of an ultrasonic wave is eliminated and thus the tissue characteristic can be determined with higher accuracy.

[0105] In the third embodiment, although the tissue characteristic determination unit 44 determines the tissue characteristic on the basis of a change in the standard deviations of the respective pieces of feature data between the original population and the population having new samples added thereto, this is just an example. For example, the tissue characteristic determination unit 44 may determine the tissue characteristic on the basis of a change in the averages of the respective pieces of feature data between the original population and the population having new samples added thereto.

[0106] Although the embodiments of the invention have been described as above, the invention is not limited only to the above-described first to third embodiments. That is, the invention can be implemented in various forms without departing from the technical idea described in the claims.

EXPLANATIONS OF LETTERS OR NUMERALS

[0107]

1	ultrasonic observation apparatus
2	ultrasonic probe
3	sending/receiving unit
4	computing unit
5	image processor
6	input unit
7	display unit
8	storage unit
9	controller
21	signal converter
31	signal amplifier
41	amplification corrector
42	frequency analyzer
43	feature data extractor
44	tissue characteristic determination unit
51	B-mode image data generator
52	feature data image data generator
81	known sample information storage unit
82	amplification factor information storage unit
83	window function storage unit
84	correction information storage unit
100	B-mode image
200	determination result display image
201	information display unit
202	image display unit
300, 400	feature data image
431	approximation unit
432	attenuation corrector

Claims

1. An ultrasonic observation apparatus which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample, the apparatus comprising:

   a signal amplifier which amplifies a signal of the ultrasonic wave received from the sample with an amplification factor according to a receiving depth;
   a B-mode image data generator which generates B-mode image data in which the amplitude of the signal of the ultrasonic wave amplified by the signal amplifier is converted into brightness and displayed;
   an amplification corrector which performs amplification correction to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified by the signal amplifier regardless of the receiving depth;
   a frequency analyzer which calculates a frequency spectrum by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected by the amplification corrector;
   a feature data extractor which extracts feature data of the sample by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and
   a feature data image data generator which generates feature data image data to display visual information corresponding to the feature data extracted by the feature data extractor.

2. The ultrasonic observation apparatus according to claim 1,
   wherein the amplification factor in performing the amplification using the signal amplifier monotonically increases at a receiving depth of up to a predetermined receiving depth.

3. The ultrasonic observation apparatus according to claim 1 or 2,
   wherein the feature data extractor comprises:

   an approximation unit which extracts pre-correction feature data before performing the attenuation correction process by subjecting the frequency spectrum calculated by the frequency analyzer to the approximation process; and
   an attenuation corrector which extracts feature data of the frequency spectrum by subjecting the pre-correction feature data extracted by the approximation unit to the attenuation correction process.

4. The ultrasonic observation apparatus according to claim 1 or 2,
   wherein the feature data extractor comprises:

   an attenuation corrector which subjects the frequency spectrum to the attenuation correction process; and
   an approximation unit which extracts feature data of the frequency spectrum by subjecting the frequency spectrum corrected by the attenuation corrector to the approximation process.

5. The ultrasonic observation apparatus according to claim 3 or 4,
   wherein the greater the receiving depth of the ultrasonic wave, the greater the correction amount the attenuation corrector performs correction with.

6. The ultrasonic observation apparatus according to any one of claims 3 to 5, further comprising:

   a controller which allows the correction of the amplification corrector and the correction of the attenuation corrector to be collectively performed.

7. The ultrasonic observation apparatus according to any one of claims 3 to 6,
   wherein the approximation unit approximates the frequency spectrum with a polynomial through regression analysis.

8. The ultrasonic observation apparatus according to claim 7,
   wherein the approximation unit approximates the frequency spectrum with a linear expression, and extracts a plurality of pieces of feature data including at least two of a gradient of the linear expression, an intercept of the linear expression, and a strength which is determined using the gradient, the intercept, and a specific frequency included in the frequency band of the frequency spectrum.

9. The ultrasonic observation apparatus according to any one of claims 1 to 8, further comprising:

a storage unit which stores the feature data of the frequency spectrum extracted on the basis of ultrasonic waves reflected by a plurality of known samples in association with tissue characteristics of the plurality of known samples; and
a tissue characteristic determination unit which determines a tissue characteristic of a predetermined area of the sample by using the feature data stored in association with the plurality of known samples in the storage unit and the feature data extracted by the feature data extractor.

10. The ultrasonic observation apparatus according to claim 9,
wherein the feature data extractor extracts a plurality of pieces of feature data,
the storage unit stores averages of the respective pieces of feature data in groups classified in accordance with the tissue characteristics with respect to the plurality of known samples, and
the tissue characteristic determination unit sets a feature data space having at least one of the plurality of pieces of feature data as a component, and determines a tissue characteristic of the sample on the basis of a distance on the feature data space between a sample point which has, as a coordinate of the feature data space, feature data which is a component of the feature data space from among the pieces of feature data of the frequency spectrum of the sample and a known sample average point which has, as a coordinate of the feature data space, an average of feature data which is a component of the feature data space from among the respective pieces of feature data in the groups of the plurality of known samples.

11. The ultrasonic observation apparatus according to claim 9,
wherein the tissue characteristic determination unit calculates a standard deviation of the feature data in a population in which the feature data of the sample is added to the groups classified in accordance with the tissue characteristics of the plurality of known samples, and determines, as a tissue characteristic of the sample, a tissue characteristic corresponding to a group having feature data which is minimum in terms of a difference between the standard deviation and a standard deviation of feature data in the groups.

12. The ultrasonic observation apparatus according to any one of claims 1 to 11,
wherein the visual information is a variable constituting a color space.

13. A method of operating an ultrasonic observation apparatus which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample, the method comprising:

a signal amplifying step of amplifying, using a signal amplifier, a signal of the ultrasonic wave received from the sample per receiving depth with an amplification factor read from a storage unit that stores amplification factor information according to a receiving depth;
a B-mode image data generating step of generating B-mode image data in which the amplitude of the signal of the ultrasonic wave amplified at the signal amplifying step is converted into brightness for display using a B-mode image data generator;
an amplifying-correction step of performing amplification correction using an amplification corrector to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified at the signal amplifying step regardless of the receiving depth;
a frequency analyzing step of calculating a frequency spectrum using a frequency analyzer by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected at the amplifying-correction step;
a feature data extracting step of extracting feature data of the sample using a feature data extractor by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and
a feature data image data generating step of generating feature data image data using a feature data image data generator to display visual information corresponding to the feature data extracted at the feature data extracting step.

14. An operation program of an ultrasonic observation apparatus which sends an ultrasonic wave to a sample and receives the ultrasonic wave reflected by the sample, the program causing the ultrasonic observation apparatus to perform:

a signal amplifying step of amplifying, using a signal amplifier, a signal of the ultrasonic wave received from the

sample per receiving depth with an amplification factor read from a storage unit that stores amplification factor information according to a receiving depth;

a B-mode image data generating step of generating B-mode image data in which the amplitude of the signal of the ultrasonic wave amplified at the signal amplifying step is converted into brightness for display using a B-mode image data generator;

an amplifying-correction step of performing amplification correction using an amplification corrector to make the amplification factor constant with respect to the signal of the ultrasonic wave amplified at the signal amplifying step regardless of the receiving depth;

a frequency analyzing step of calculating a frequency spectrum using a frequency analyzer by analyzing the frequency of the signal of the ultrasonic wave amplification-corrected at the amplifying-correction step;

a feature data extracting step of extracting feature data of the sample using a feature data extractor by performing, with respect to the frequency spectrum calculated by the frequency analyzer, an approximation process and an attenuation correction process for reducing the contribution of the attenuation occurring in accordance with the receiving depth of the ultrasonic wave and the frequency in transmitting the ultrasonic wave; and

a feature data image data generating step of generating feature data image data using a feature data image data generator to display visual information corresponding to the feature data extracted at the feature data extracting step.

FIG.1

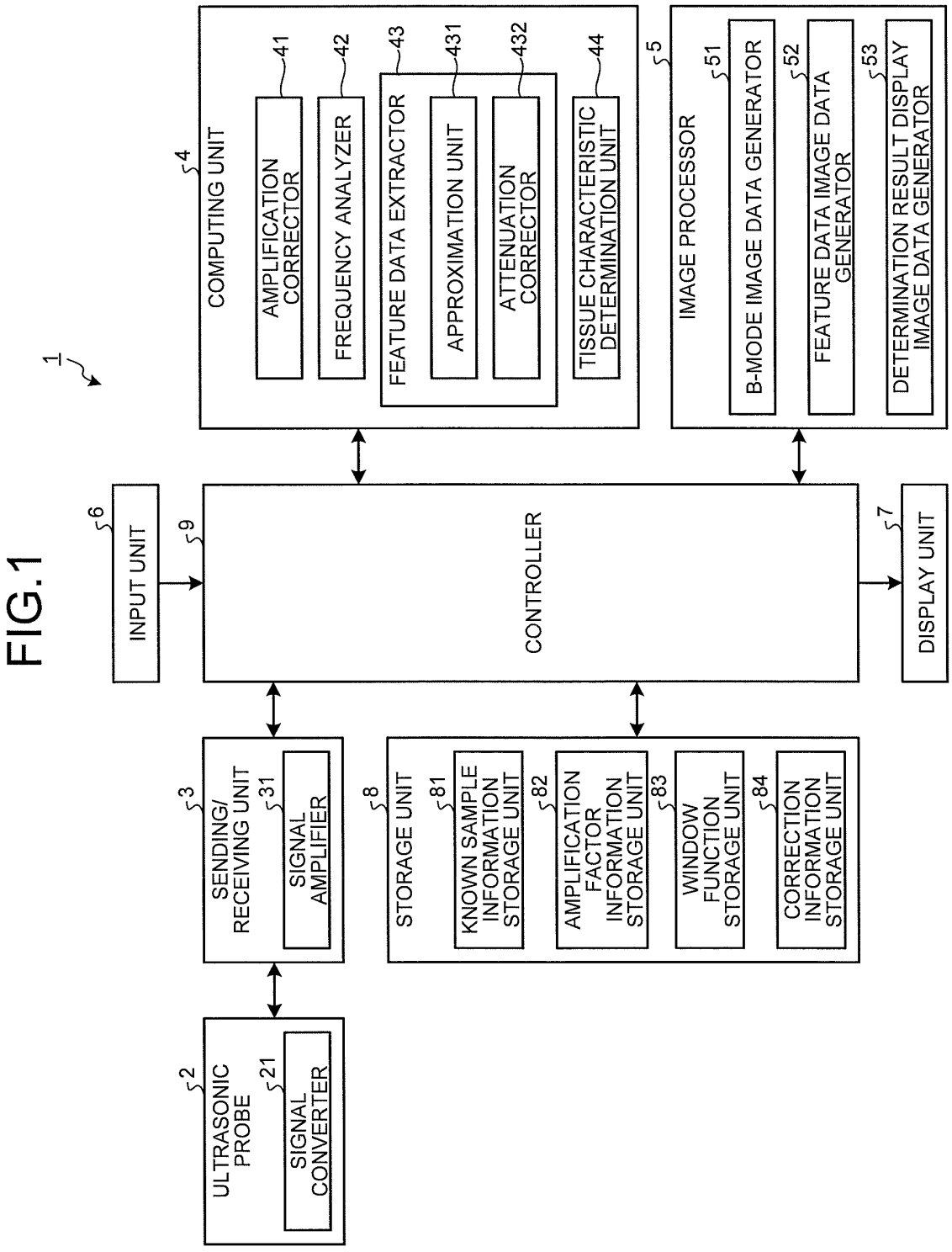

1
ULTRASONIC PROBE
2
SIGNAL CONVERTER
21
SENDING/ RECEIVING UNIT
3
SIGNAL AMPLIFIER
31
INPUT UNIT
6
CONTROLLER
9
DISPLAY UNIT
7
COMPUTING UNIT
4
AMPLIFICATION CORRECTOR
41
FREQUENCY ANALYZER
42
FEATURE DATA EXTRACTOR
43
APPROXIMATION UNIT
431
ATTENUATION CORRECTOR
432
TISSUE CHARACTERISTIC DETERMINATION UNIT
44
IMAGE PROCESSOR
5
B-MODE IMAGE DATA GENERATOR
51
FEATURE DATA IMAGE DATA GENERATOR
52
DETERMINATION RESULT DISPLAY IMAGE DATA GENERATOR
53
STORAGE UNIT
8
KNOWN SAMPLE INFORMATION STORAGE UNIT
81
AMPLIFICATION FACTOR INFORMATION STORAGE UNIT
82
WINDOW FUNCTION STORAGE UNIT
83
CORRECTION INFORMATION STORAGE UNIT
84

FIG.2

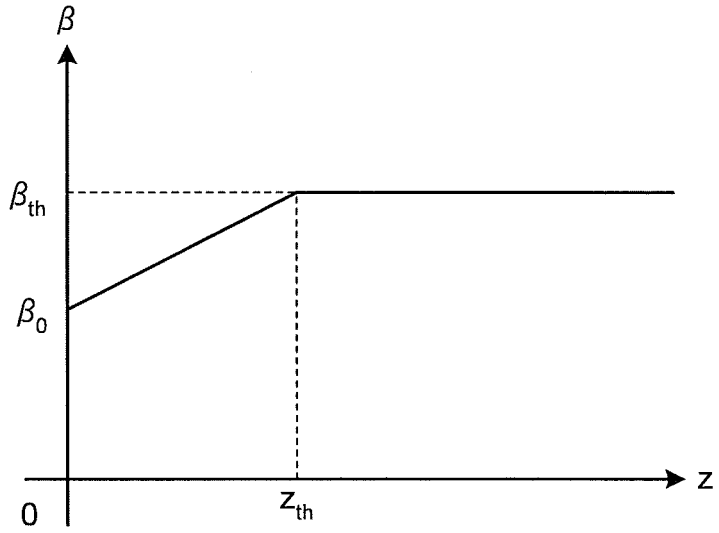


FIG.3

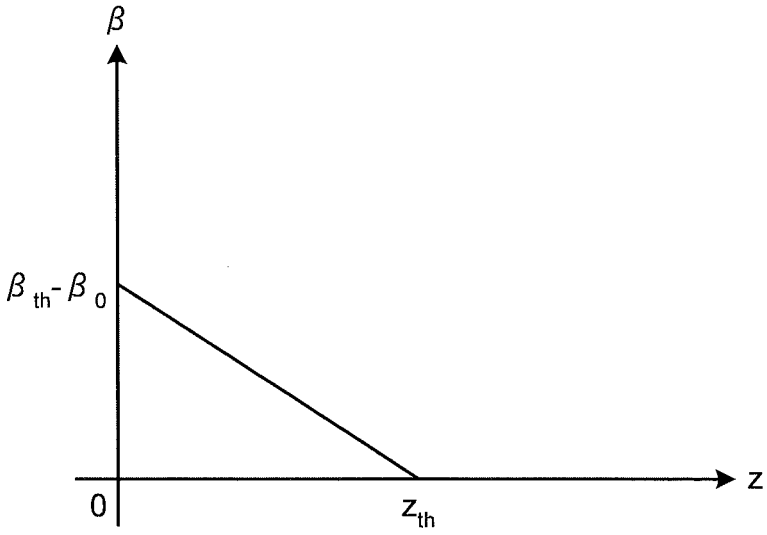


FIG.4

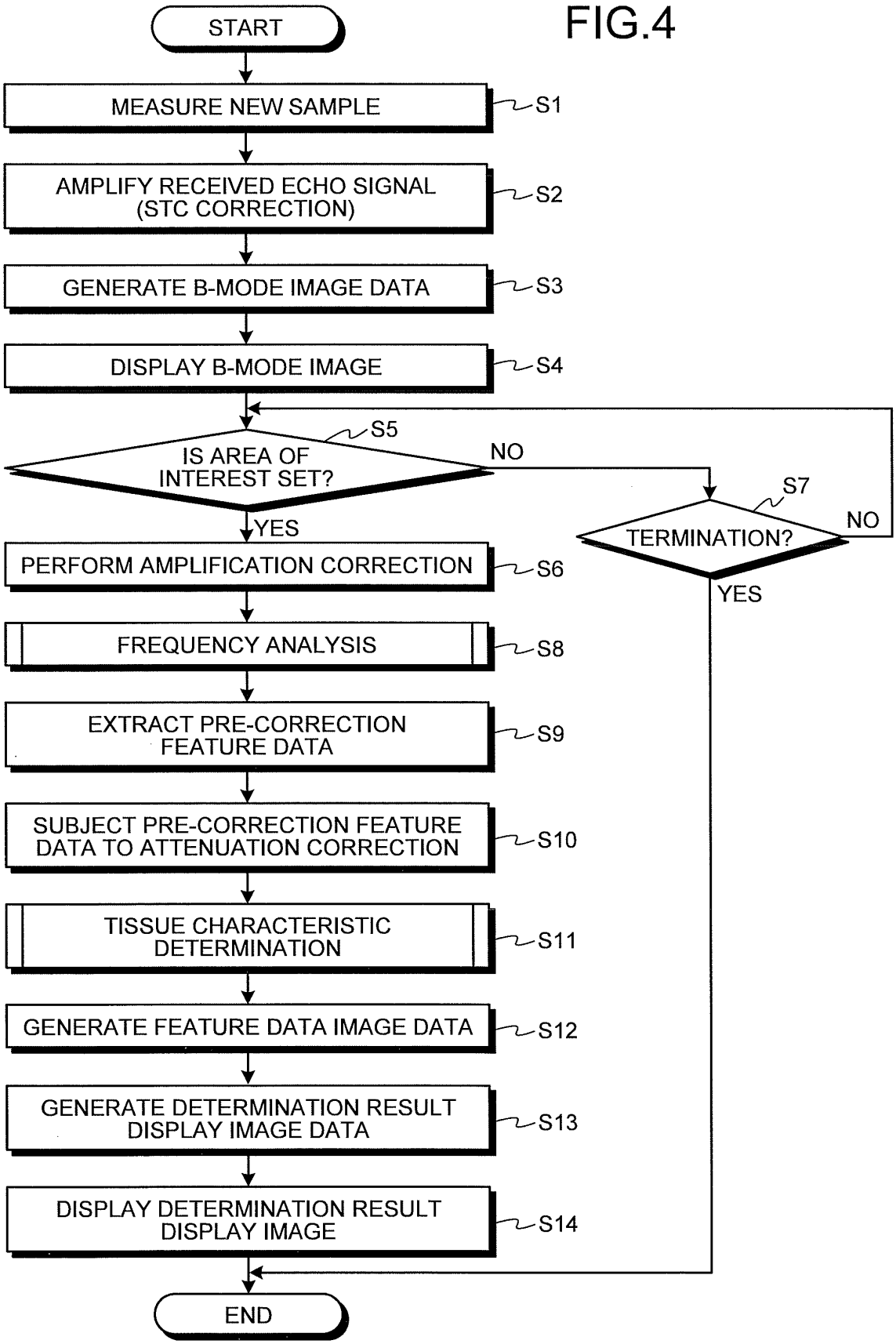

START
MEASURE NEW SAMPLE
S1
AMPLIFY RECEIVED ECHO SIGNAL (STC CORRECTION)
S2
GENERATE B-MODE IMAGE DATA
S3
DISPLAY B-MODE IMAGE
S4
S5
IS AREA OF INTEREST SET?
NO
YES
S7
TERMINATION?
NO
YES
PERFORM AMPLIFICATION CORRECTION
S6
FREQUENCY ANALYSIS
S8
EXTRACT PRE-CORRECTION FEATURE DATA
S9
SUBJECT PRE-CORRECTION FEATURE DATA TO ATTENUATION CORRECTION
S10
TISSUE CHARACTERISTIC DETERMINATION
S11
GENERATE FEATURE DATA IMAGE DATA
S12
GENERATE DETERMINATION RESULT DISPLAY IMAGE DATA
S13
DISPLAY DETERMINATION RESULT DISPLAY IMAGE
S14
END

FIG.5

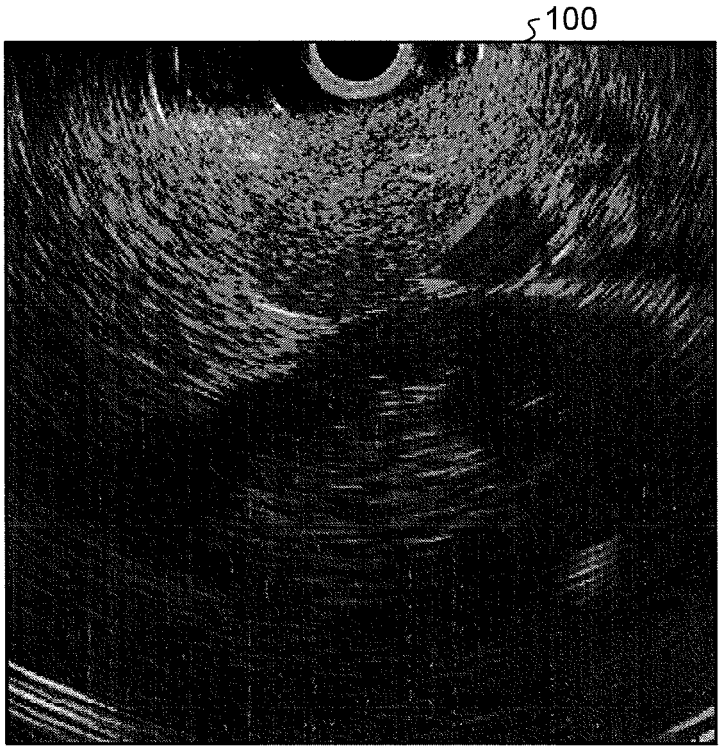


FIG.6

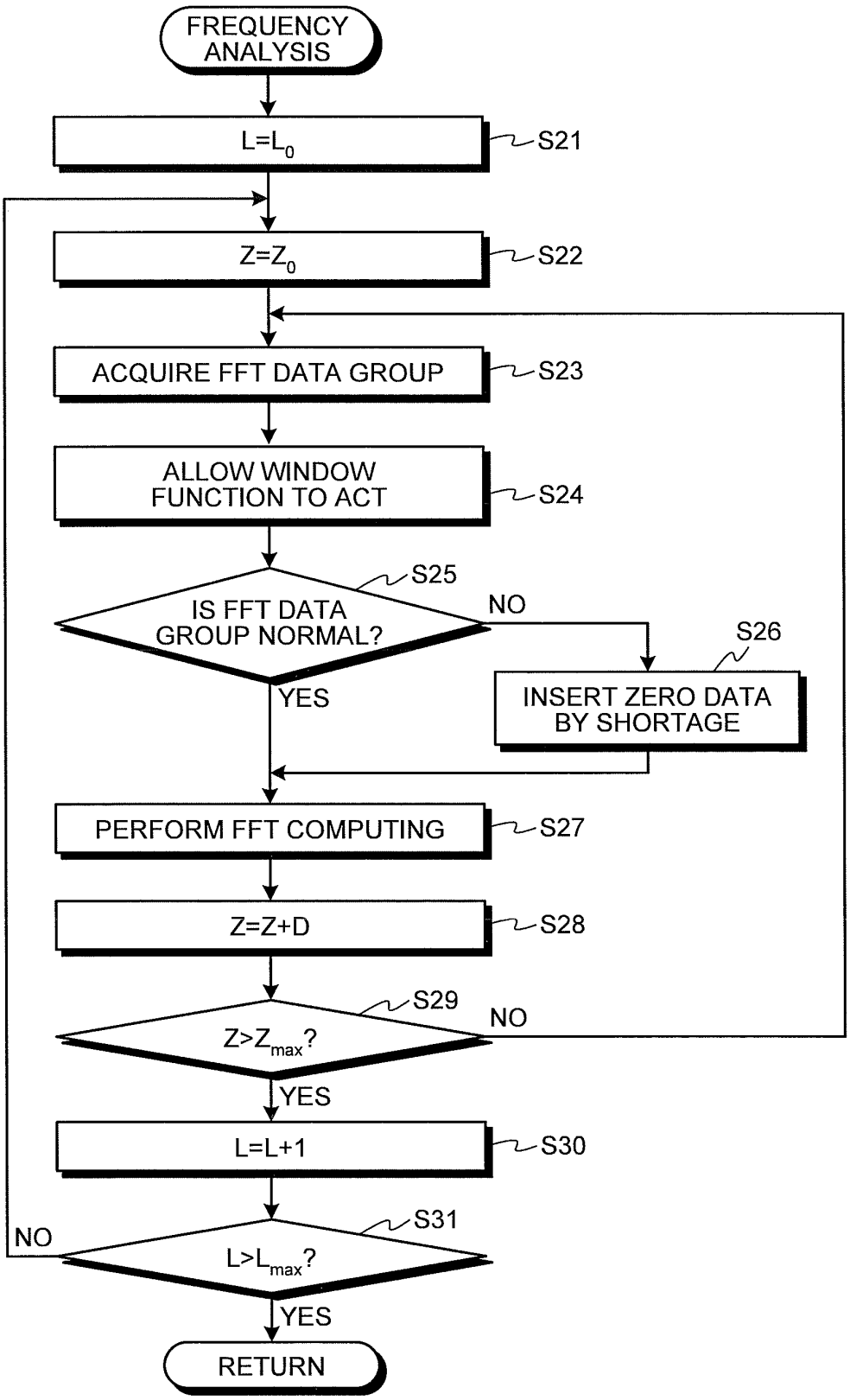

FREQUENCY ANALYSIS
L=L0
S21
Z=Z0
S22
ACQUIRE FFT DATA GROUP
S23
ALLOW WINDOW FUNCTION TO ACT
S24
S25
IS FFT DATA GROUP NORMAL?
NO
S26
INSERT ZERO DATA BY SHORTAGE
YES
PERFORM FFT COMPUTING
S27
Z=Z+D
S28
S29
Z>Zmax?
NO
YES
L=L+1
S30
S31
NO
L>Lmax?
YES
RETURN

FIG.7

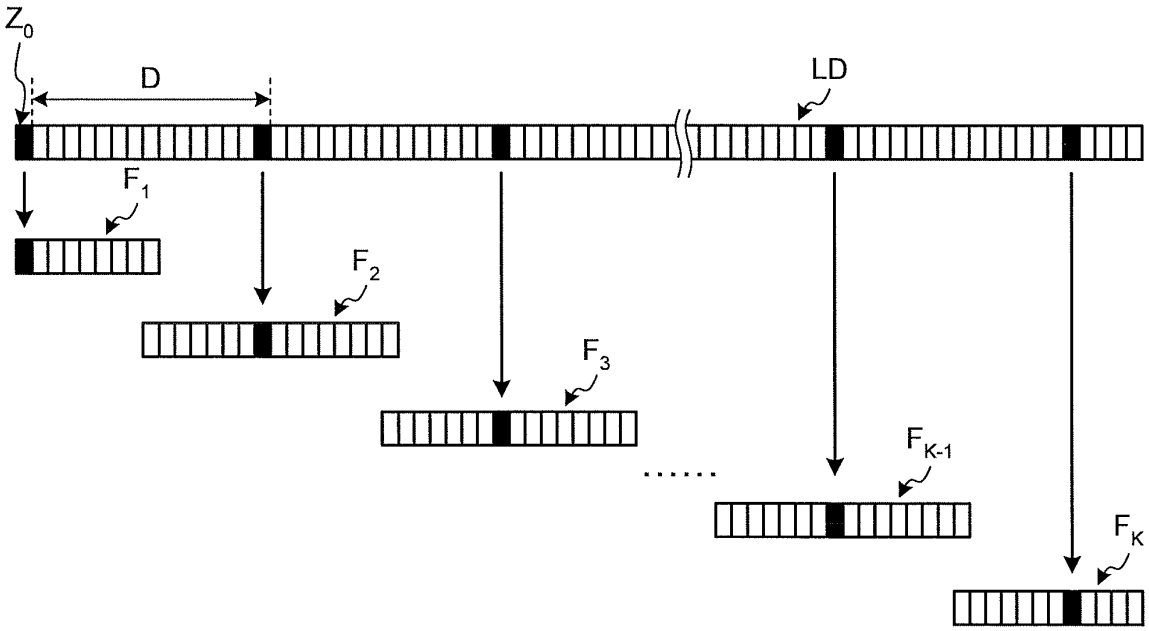


FIG.8

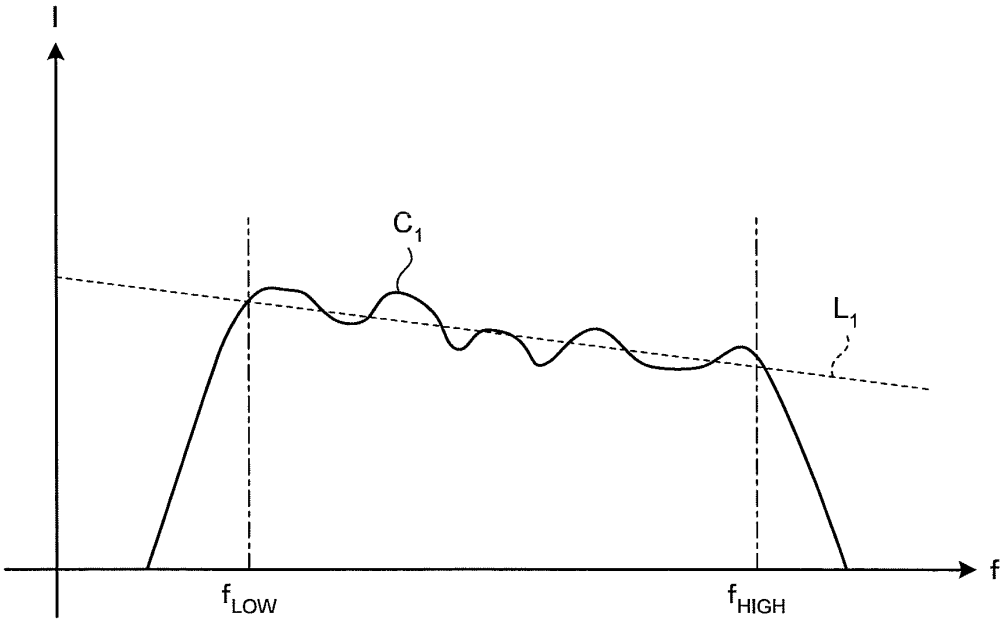


FIG.9

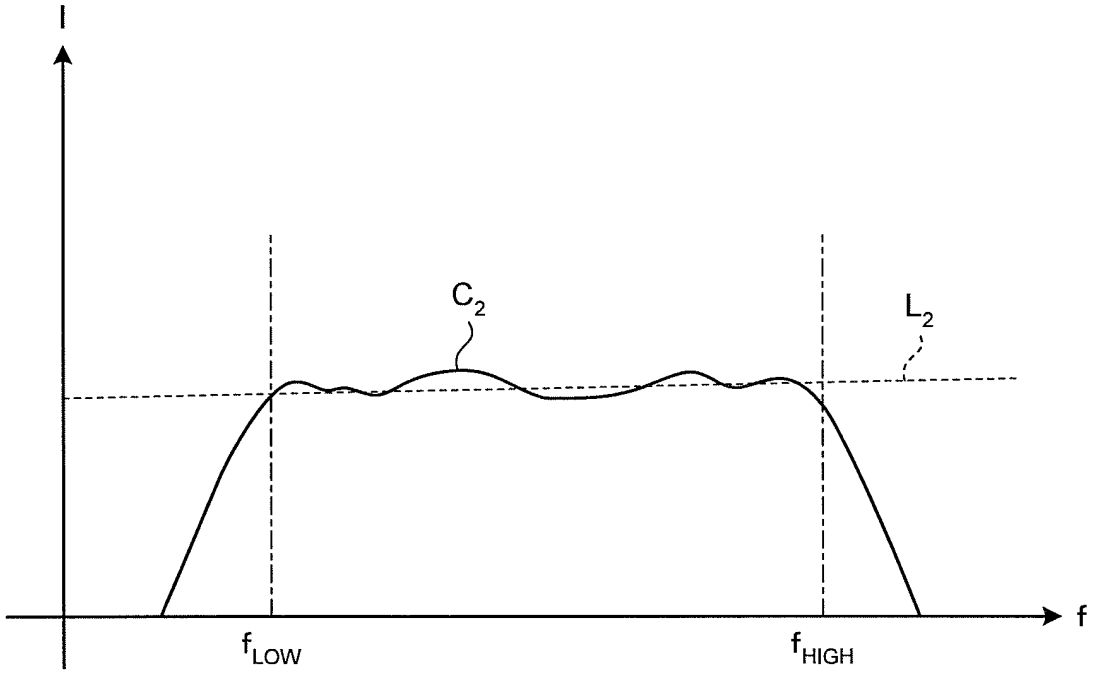


FIG.10

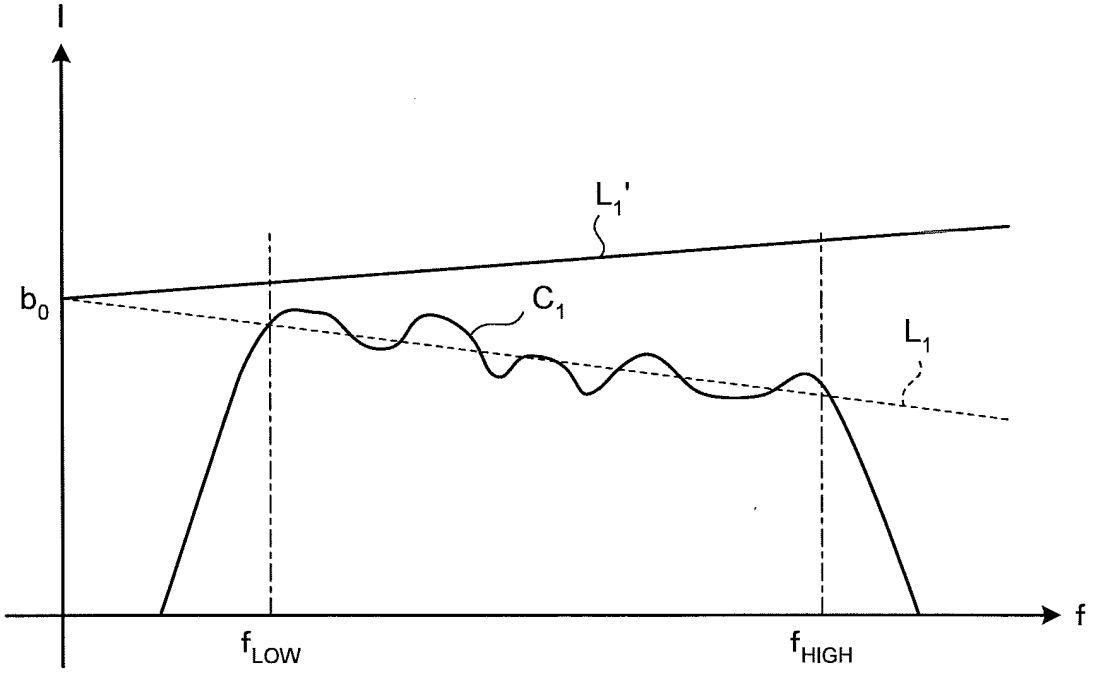


FIG.11

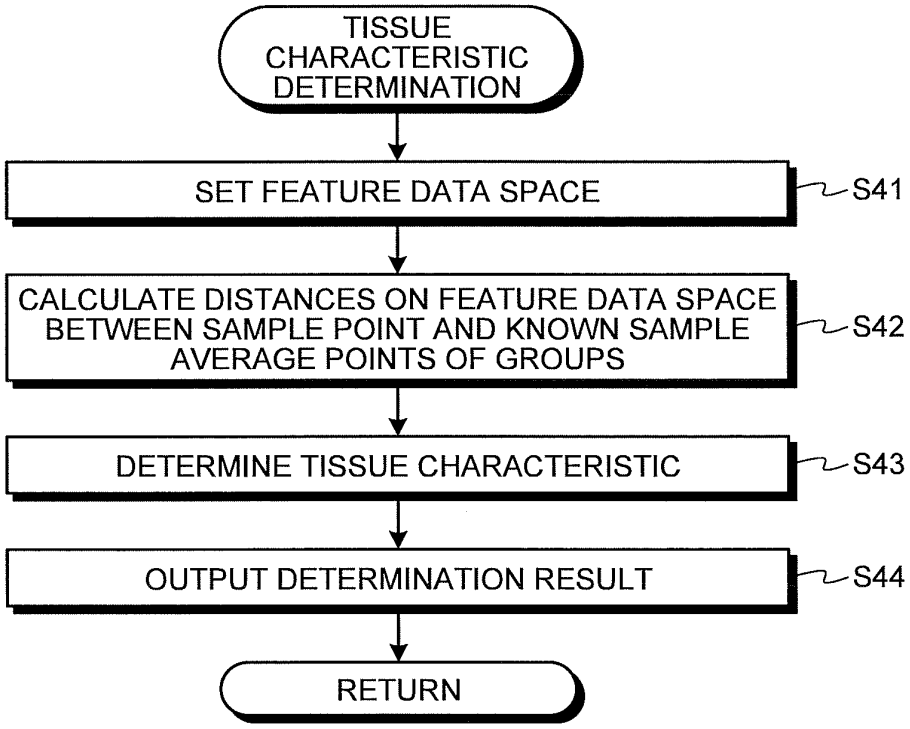

TISSUE CHARACTERISTIC DETERMINATION
SET FEATURE DATA SPACE
S41
CALCULATE DISTANCES ON FEATURE DATA SPACE BETWEEN SAMPLE POINT AND KNOWN SAMPLE AVERAGE POINTS OF GROUPS
S42
DETERMINE TISSUE CHARACTERISTIC
S43
OUTPUT DETERMINATION RESULT
S44
RETURN

FIG.12

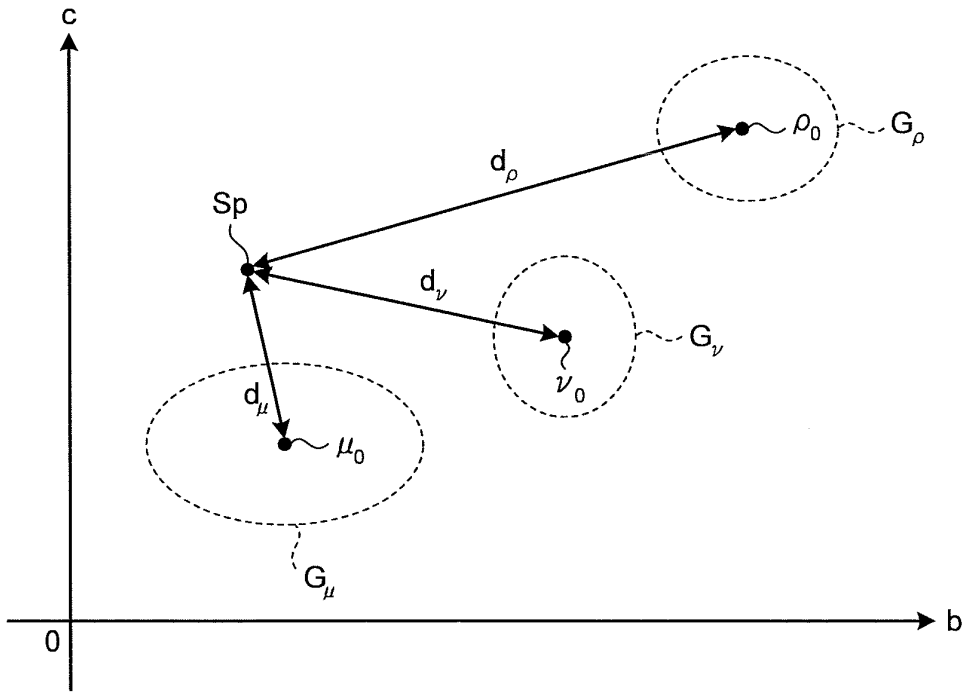

c
b
0
Sp
d_ρ
d_ν
d_μ
ρ_0
ν_0
μ_0
G_ρ
G_ν
G_μ

FIG.13

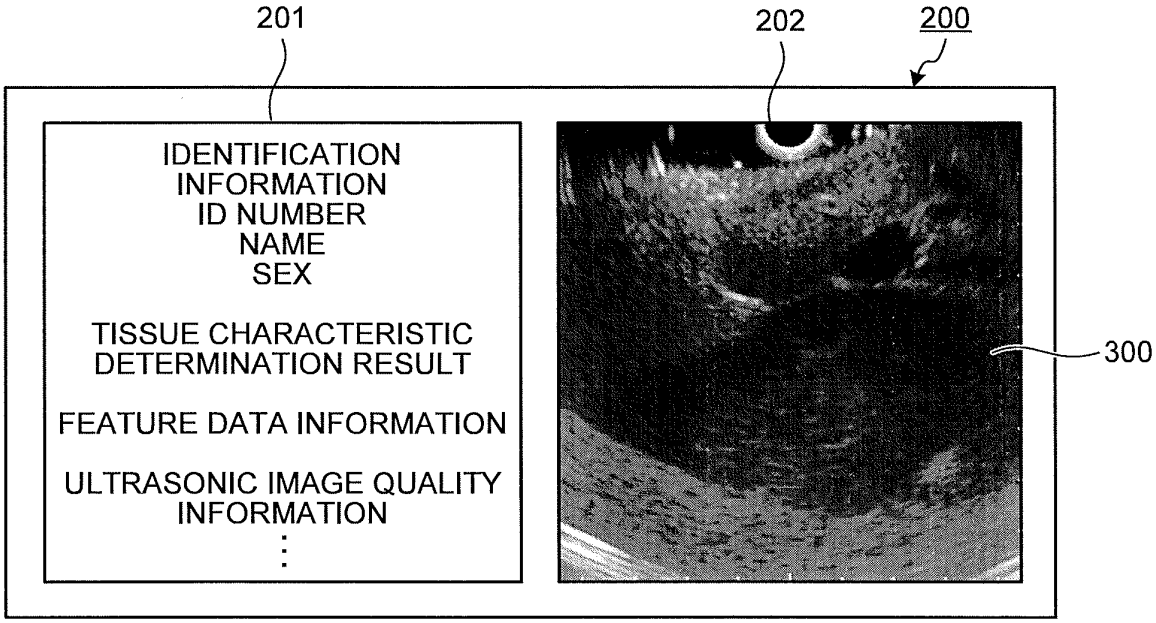

201
202
200
IDENTIFICATION INFORMATION
ID NUMBER
NAME
SEX
TISSUE CHARACTERISTIC DETERMINATION RESULT
FEATURE DATA INFORMATION
ULTRASONIC IMAGE QUALITY INFORMATION
300

FIG.14

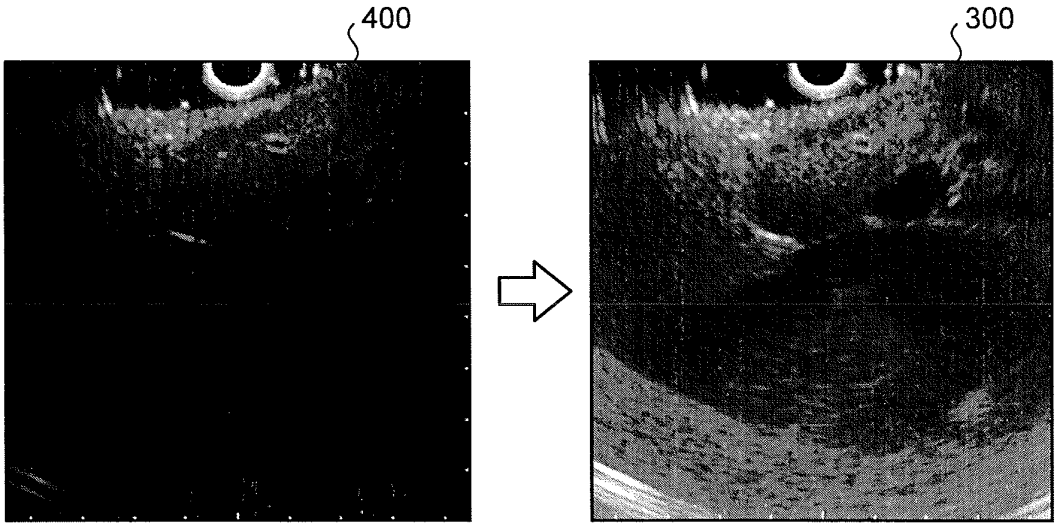

400
300

FIG.15

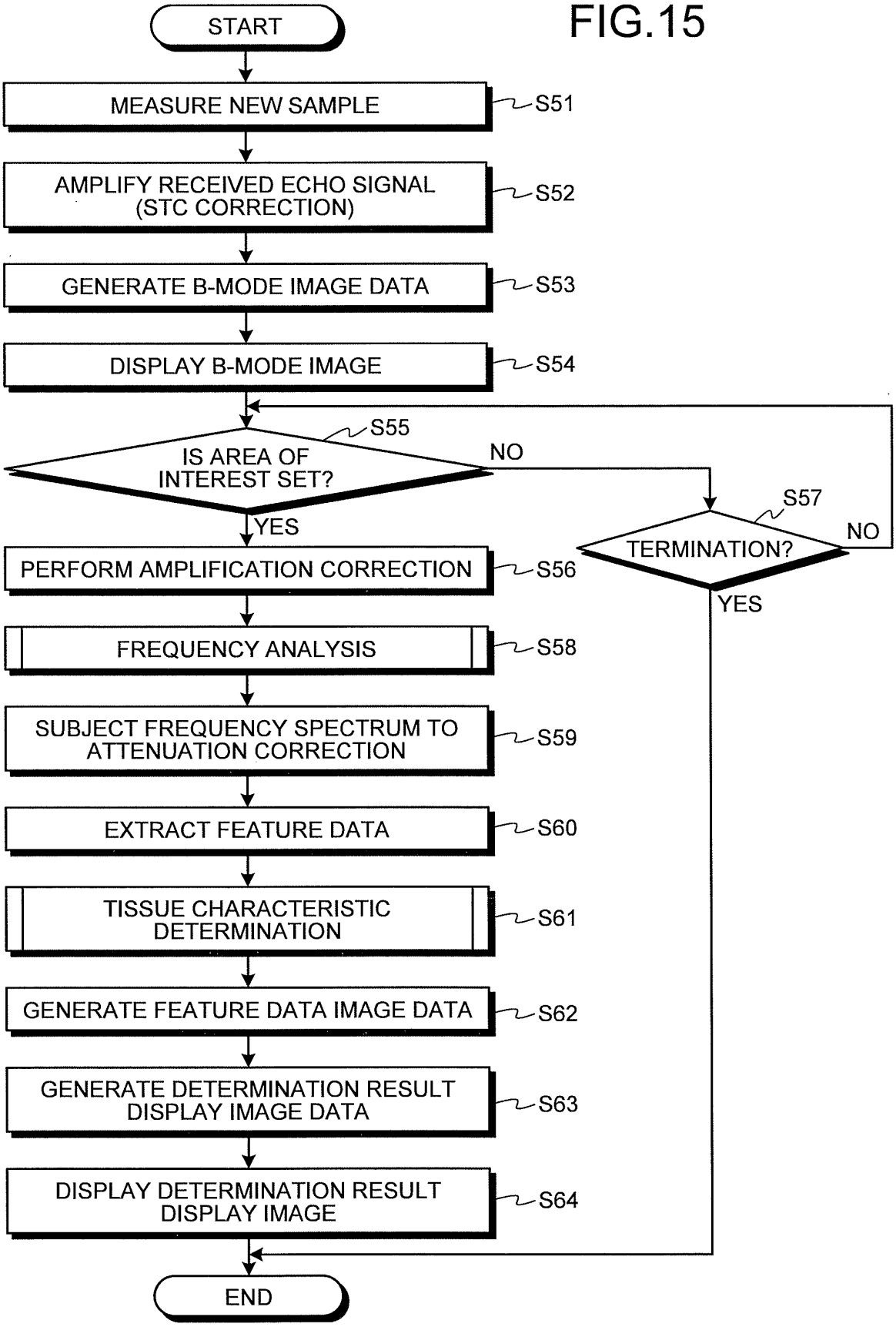
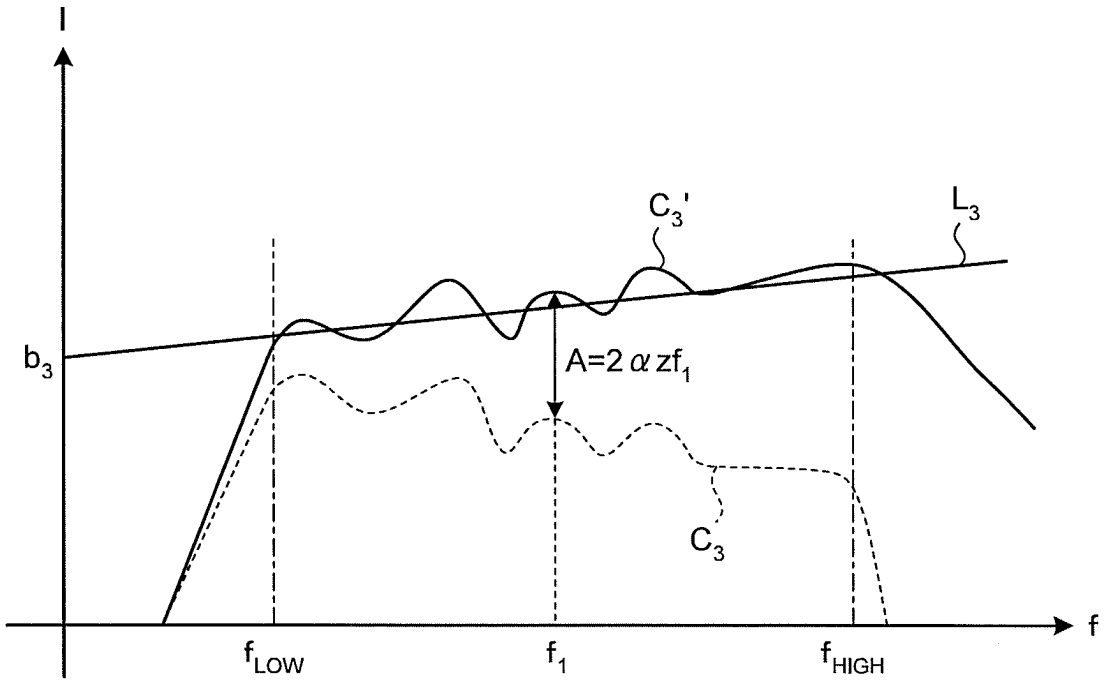

START
MEASURE NEW SAMPLE
S51
AMPLIFY RECEIVED ECHO SIGNAL (STC CORRECTION)
S52
GENERATE B-MODE IMAGE DATA
S53
DISPLAY B-MODE IMAGE
S54
S55
IS AREA OF INTEREST SET?
NO
YES
S57
TERMINATION?
NO
YES
PERFORM AMPLIFICATION CORRECTION
S56
FREQUENCY ANALYSIS
S58
SUBJECT FREQUENCY SPECTRUM TO ATTENUATION CORRECTION
S59
EXTRACT FEATURE DATA
S60
TISSUE CHARACTERISTIC DETERMINATION
S61
GENERATE FEATURE DATA IMAGE DATA
S62
GENERATE DETERMINATION RESULT DISPLAY IMAGE DATA
S63
DISPLAY DETERMINATION RESULT DISPLAY IMAGE
S64
END

FIG.16



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/076027

A. CLASSIFICATION OF SUBJECT MATTER
A61B8/00(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)
A61B8/00

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)
WPI, PubMed, CiNii

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Yasuyoshi SAITO et al., "Measurement of Ultrasonic Backscattering Property Caused by Change in the Scatterer's Radius for Assessment of Red Blood Cell Aggregation", Technical Report of IEICE, US2008-36, 2008.09, pages 25 to 28	1-14
Y	US 2006/0064014 A1 (Tony Falco), 23 March 2006 (23.03.2006), paragraphs [0033] to [0034]; fig. 6 & US 2010/0099989 A1 & EP 1871232 A & WO 2006/032134 A2 & DE 602005027617 D & CA 2581127 A & AT 506011 T	1-14

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
07 February, 2012 (07.02.12)	14 February, 2012 (14.02.12)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/076027

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	M.Sareen et.al., Normalization and backscatter spectral analysis of human carotid arterial data acquired using a clinical linear array ultrasound imaging system, Conf.Proc.IEEE Eng.Med.Biol.Soc. 2008, 2008, pp.2968-2971	1-14
Y	A.Katouzian et.al., Challenges in atherosclerotic plaque characterization with intravascular ultrasound (IVUS): from data collection to classification., IEEE Trans. Inf.Technol.Biomed., 2008.05, 12(3), pp.315-327	1-14
Y	JP 2006-524115 A (Wisconsin Alumni Research Foundation), 26 October 2006 (26.10.2006), claims & US 2004/0243001 A1 & US 2004/0215075 A1 & US 2005/0165309 A1 & EP 1615545 A & EP 1711846 A & WO 2004/093671 A2 & WO 2005/073755 A1	1-14
Y	JP 2009-82624 A (Olympus Medical Systems Corp.), 23 April 2009 (23.04.2009), entire text; fig. 4 (Family: none)	1-14
A	JP 2004-310639 A (Ricoh Co., Ltd.), 04 November 2004 (04.11.2004), paragraphs [0055] to [0069] (Family: none)	10,11
A	JP 2005-110833 A (Aloka Co., Ltd.), 28 April 2005 (28.04.2005), abstract (Family: none)	12

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2005122906 A **[0004]**
- JP 10216143 A **[0004]**

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	EP2599441A1	公开(公告)日	2013-06-05
申请号	EP2011840305	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)	OLYMPUS CORPORATION		
[标]发明人	MIYAKI HIRONAKA		
发明人	MIYAKI,HIRONAKA		
IPC分类号	A61B8/00		
CPC分类号	G01S7/52098 A61B8/08 A61B8/485 A61B8/5207 A61B8/5223 A61B8/5292 G01S7/52033 G01S7/52036		
优先权	2010253290 2010-11-11 JP		
其他公开文献	EP2599441B1 EP2599441A4		
外部链接	Espacenet		

摘要(译)

超声波观测装置根据接收深度以放大系数放大从样本接收的超声波的信号。产生B模式图像数据，其中放大的超声波的信号的幅度被转换成亮度并被显示;无论接收深度如何，都进行放大校正以使放大因子相对于放大的超声波的信号恒定;通过分析超声波的放大校正信号的频率来计算频谱;通过近似计算的频谱提取频谱的特征数据;在频谱和特征数据之一上进行校正，以减小伴随超声波传输的强度衰减的影响;生成特征数据图像数据，以显示与特征数据对应的视觉信息。

FIG.8