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(54) **ULTRASOUND OBSERVATION APPARATUS, METHOD FOR OPERATING ULTRASOUND OBSERVATION APPARATUS, AND COMPUTER-READABLE RECORDING MEDIUM**

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(57) **ABSTRACT**

An ultrasound observation apparatus includes: a calculation unit that calculates features of frequency spectra obtained by analyzing a frequency of an ultrasound signal; a setting unit that uses each attenuation factor candidate value per unit length and per unit frequency that give different attenuation characteristics, in each divided region obtained by dividing an ultrasound image, to perform attenuation correction on the features of the frequency spectra for removing an influence of ultrasound, and thereby calculates a preliminarily corrected feature of each frequency spectrum for each attenuation factor candidate value, and sets an optimum attenuation factor among attenuation factor candidate values; and a correction unit that calculates a cumulative attenuation factor per unit frequency at a sampling point, using an optimum attenuation factor of a divided region present between a surface of an ultrasound transducer and the sampling point, and performs attenuation correction on the features using the cumulative attenuation factor.

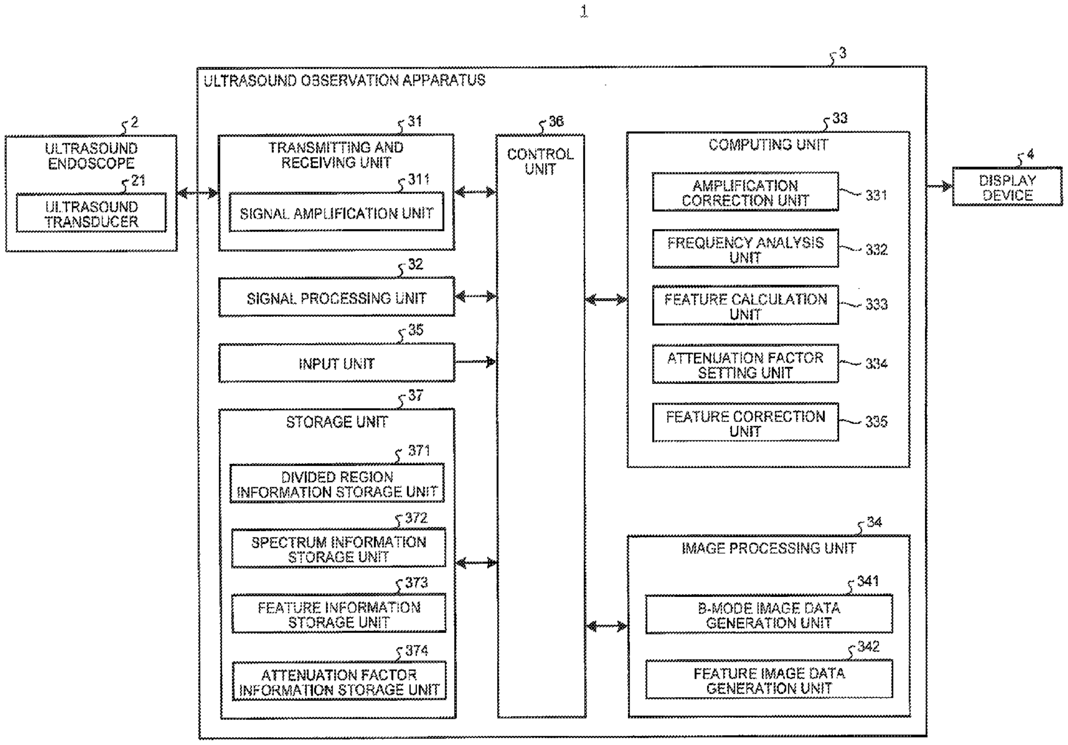


FIG. 1

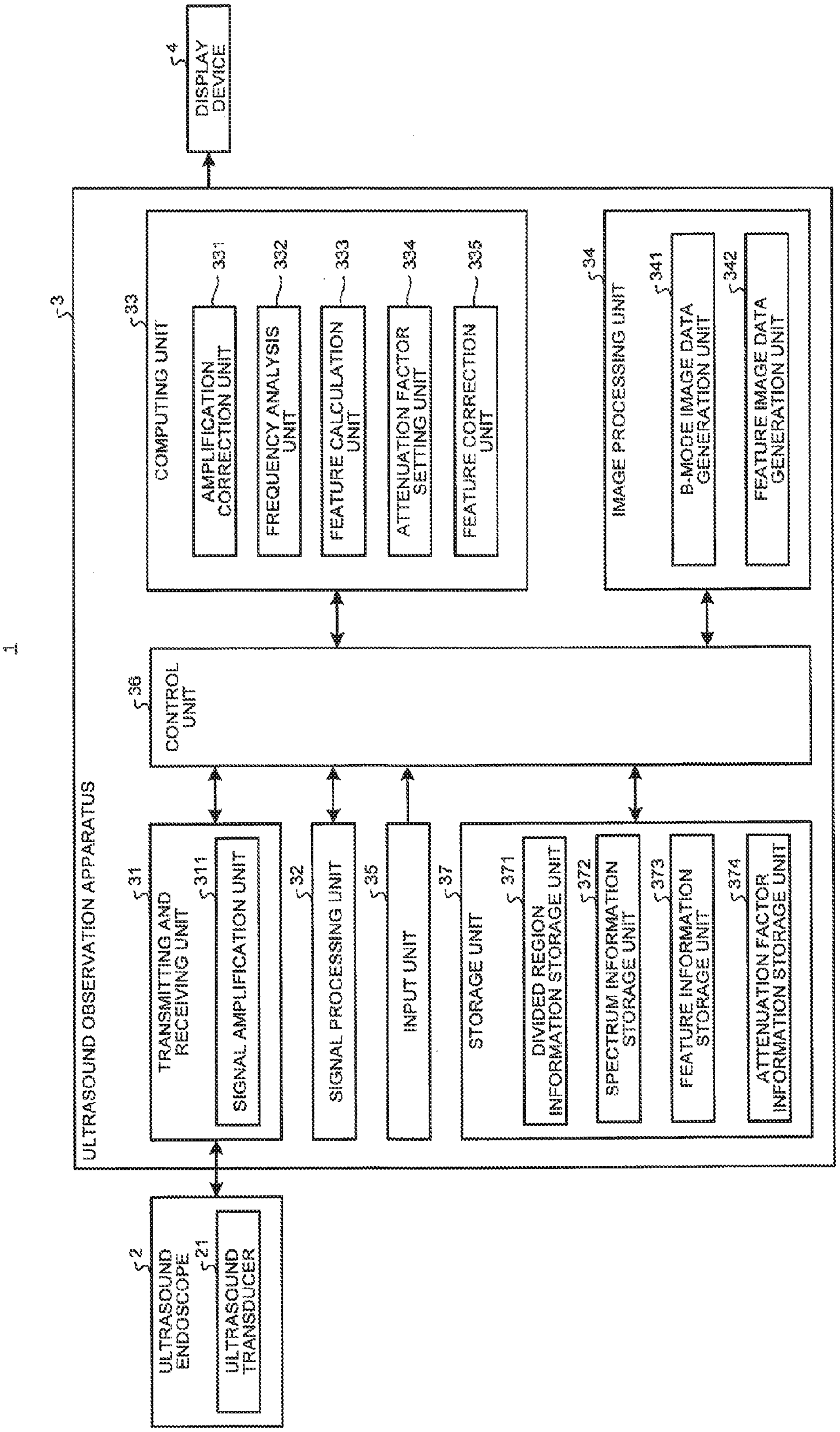

1
3
ULTRASOUND OBSERVATION APPARATUS
2
ULTRASOUND ENDOSCOPE
21
ULTRASOUND TRANSDUCER
31
TRANSMITTING AND RECEIVING UNIT
311
SIGNAL AMPLIFICATION UNIT
32
SIGNAL PROCESSING UNIT
35
INPUT UNIT
37
STORAGE UNIT
371
DIVIDED REGION INFORMATION STORAGE UNIT
372
SPECTRUM INFORMATION STORAGE UNIT
373
FEATURE INFORMATION STORAGE UNIT
374
ATTENUATION FACTOR INFORMATION STORAGE UNIT
36
CONTROL UNIT
33
COMPUTING UNIT
331
AMPLIFICATION CORRECTION UNIT
332
FREQUENCY ANALYSIS UNIT
333
FEATURE CALCULATION UNIT
334
ATTENUATION FACTOR SETTING UNIT
335
FEATURE CORRECTION UNIT
34
IMAGE PROCESSING UNIT
341
B-MODE IMAGE DATA GENERATION UNIT
342
FEATURE IMAGE DATA GENERATION UNIT
4
DISPLAY DEVICE

FIG.2

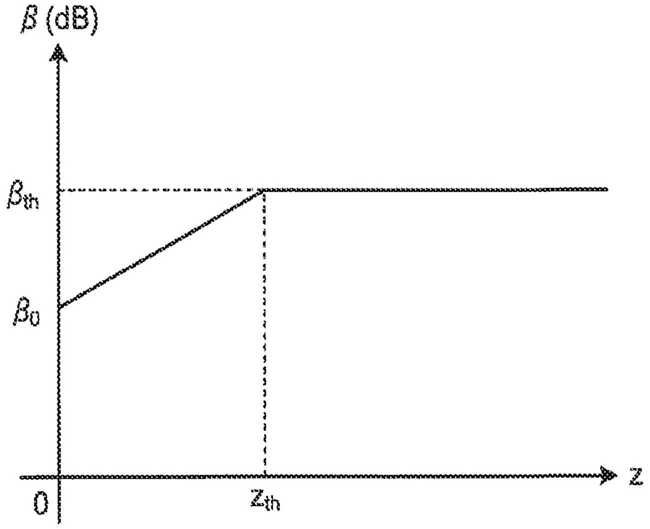


FIG.3

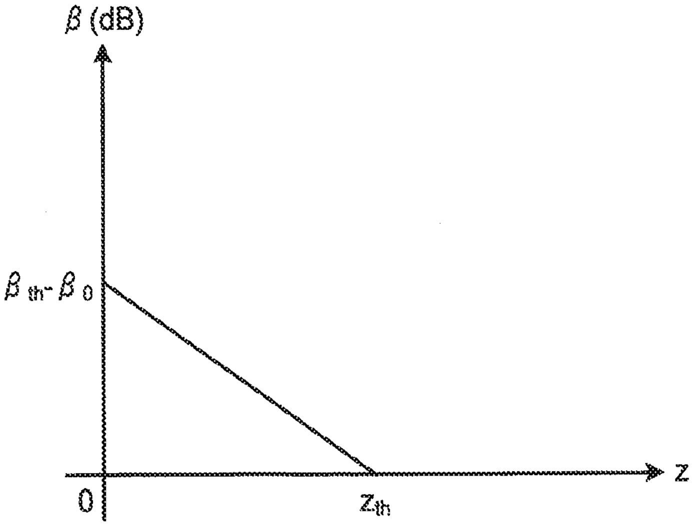


FIG.4

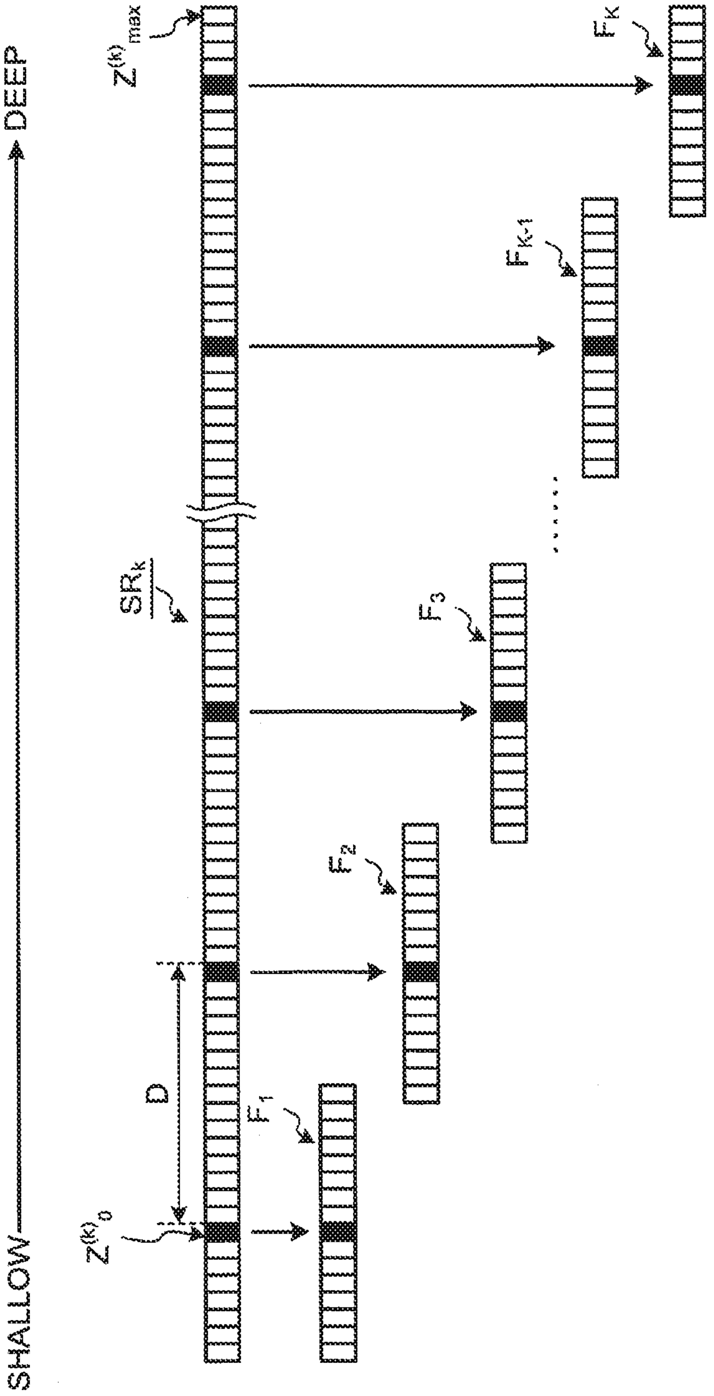


FIG.5

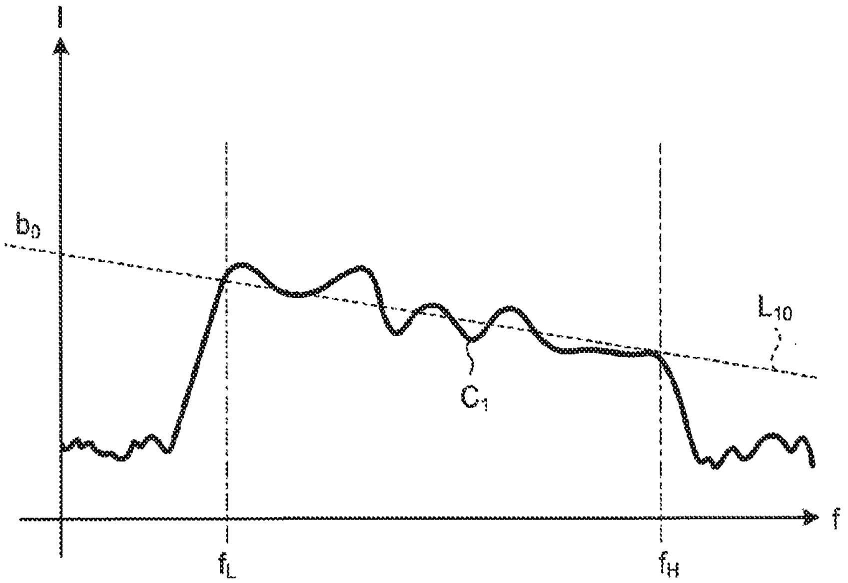

I
b0
L10
C1
f
fL
fH

FIG.6

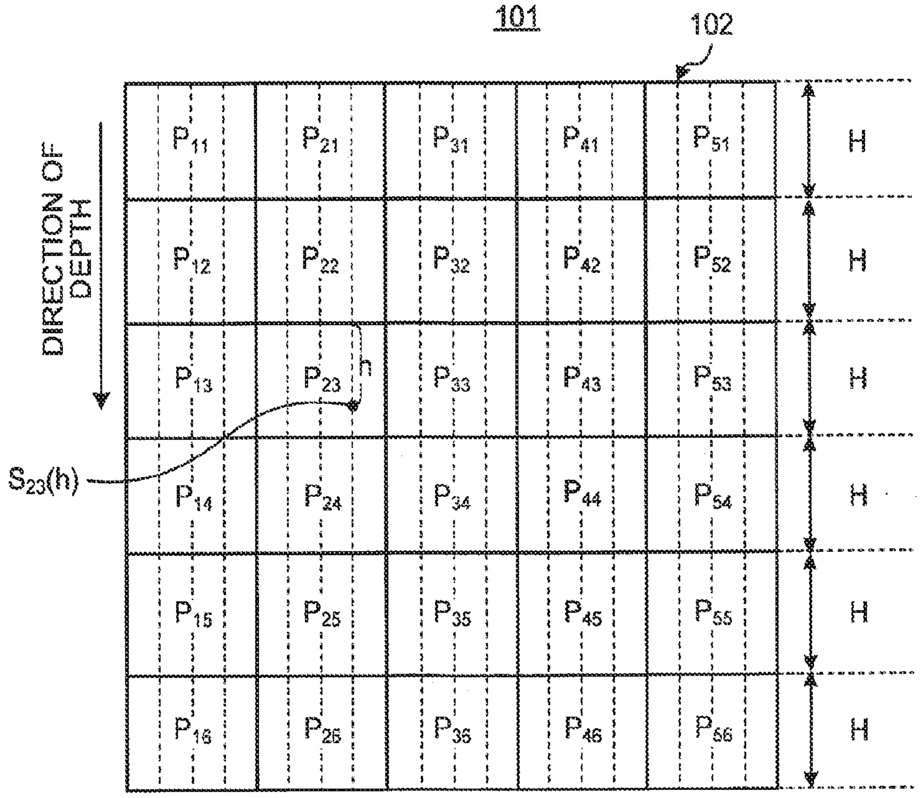

101
102
DIRECTION OF DEPTH
S23(h)
h
P11
P21
P31
P41
P51
P12
P22
P32
P42
P52
P13
P23
P33
P43
P53
P14
P24
P34
P44
P54
P15
P25
P35
P45
P55
P16
P26
P36
P46
P56
H
H
H
H
H
H

FIG.7

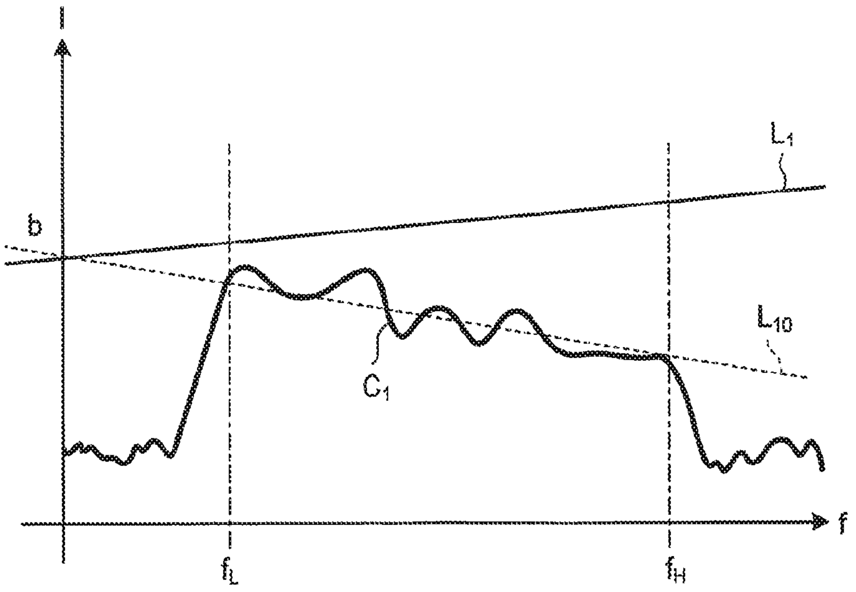


FIG.8

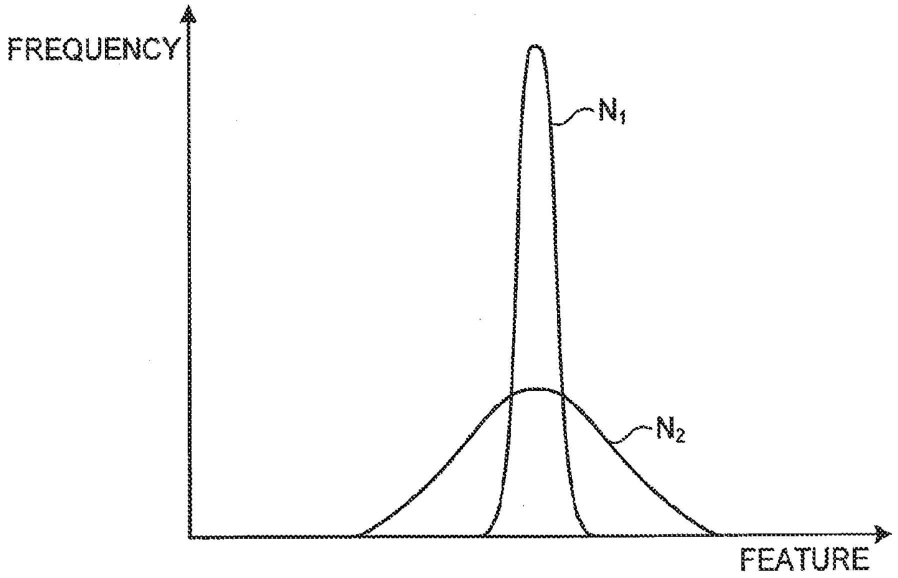


FIG.9

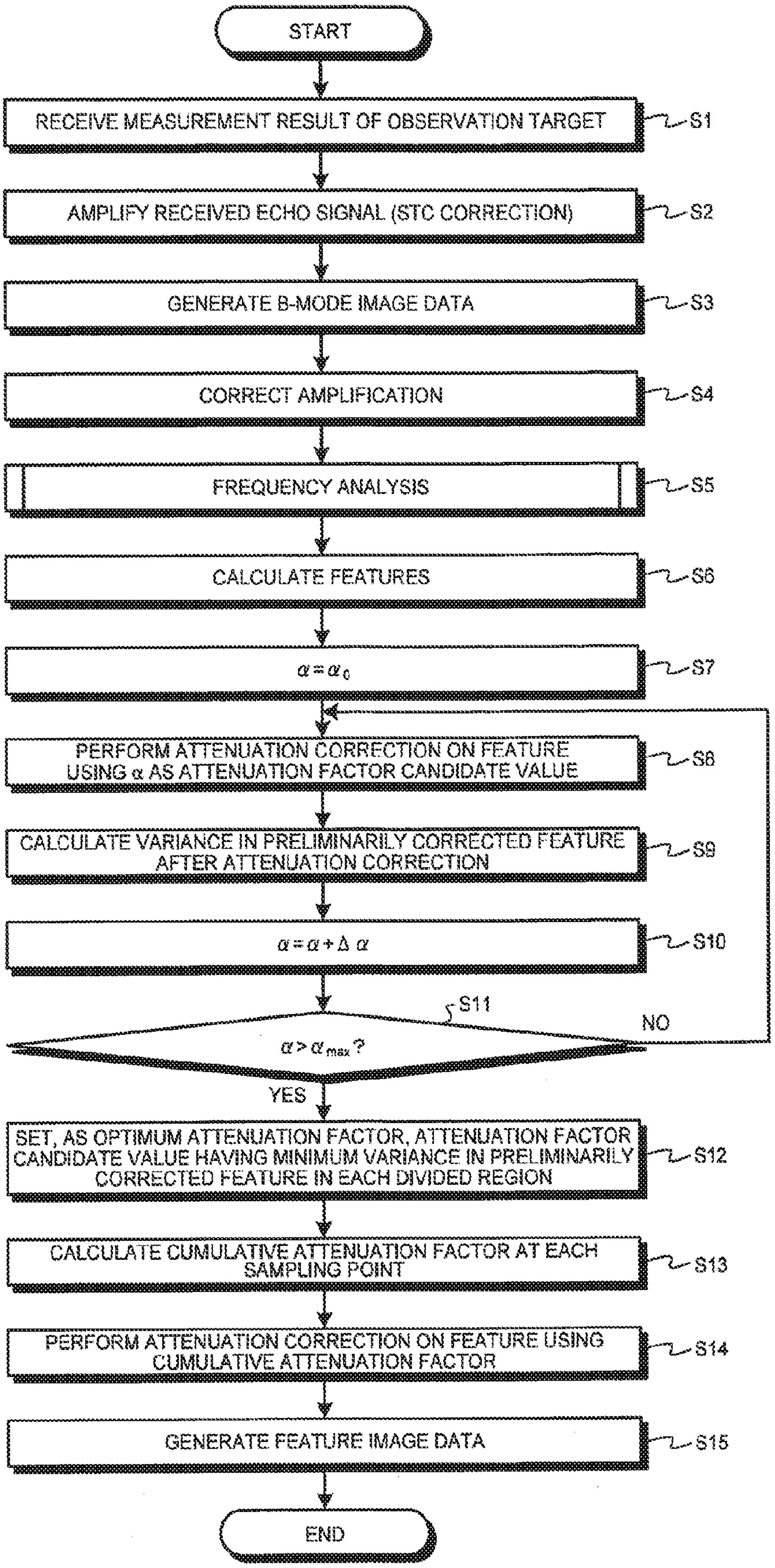

START
RECEIVE MEASUREMENT RESULT OF OBSERVATION TARGET
S1
AMPLIFY RECEIVED ECHO SIGNAL (STC CORRECTION)
S2
GENERATE B-MODE IMAGE DATA
S3
CORRECT AMPLIFICATION
S4
FREQUENCY ANALYSIS
S5
CALCULATE FEATURES
S6
α=α0
S7
PERFORM ATTENUATION CORRECTION ON FEATURE USING α AS ATTENUATION FACTOR CANDIDATE VALUE
S8
CALCULATE VARIANCE IN PRELIMINARILY CORRECTED FEATURE AFTER ATTENUATION CORRECTION
S9
α=α+Δα
S10
S11
α>αmax?
NO
YES
SET, AS OPTIMUM ATTENUATION FACTOR, ATTENUATION FACTOR CANDIDATE VALUE HAVING MINIMUM VARIANCE IN PRELIMINARILY CORRECTED FEATURE IN EACH DIVIDED REGION
S12
CALCULATE CUMULATIVE ATTENUATION FACTOR AT EACH SAMPLING POINT
S13
PERFORM ATTENUATION CORRECTION ON FEATURE USING CUMULATIVE ATTENUATION FACTOR
S14
GENERATE FEATURE IMAGE DATA
S15
END

FIG.10

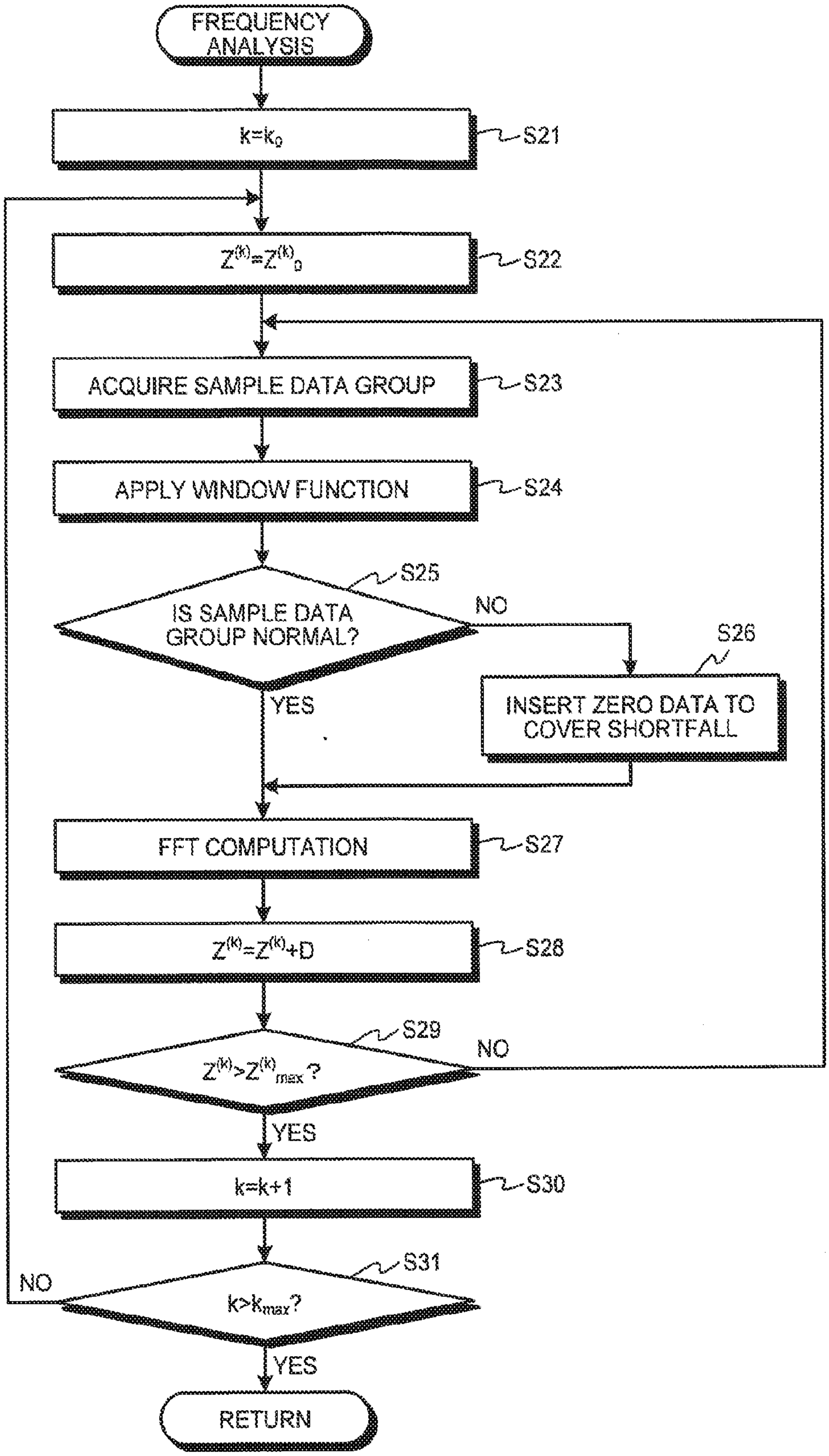

FREQUENCY ANALYSIS
k=k_0
S21
Z^(k)=Z^(k)_0
S22
ACQUIRE SAMPLE DATA GROUP
S23
APPLY WINDOW FUNCTION
S24
S25
IS SAMPLE DATA GROUP NORMAL?
NO
S26
INSERT ZERO DATA TO COVER SHORTFALL
YES
FFT COMPUTATION
S27
Z^(k)=Z^(k)+D
S28
S29
NO
Z^(k)>Z^(k)_max?
YES
k=k+1
S30
S31
NO
k>k_max?
YES
RETURN

FIG.11

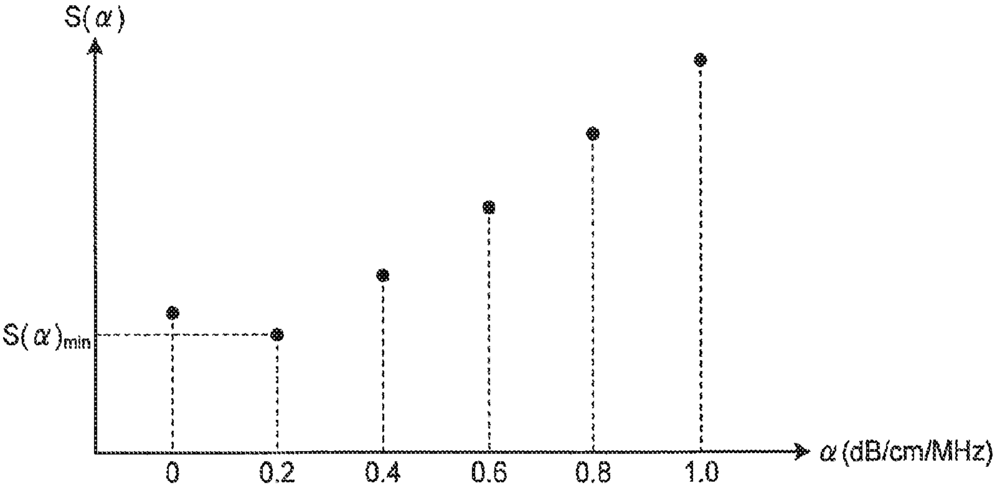

S(α)
S(α)min
0
0.2
0.4
0.6
0.8
1.0
α (dB/cm/MHz)

FIG.12

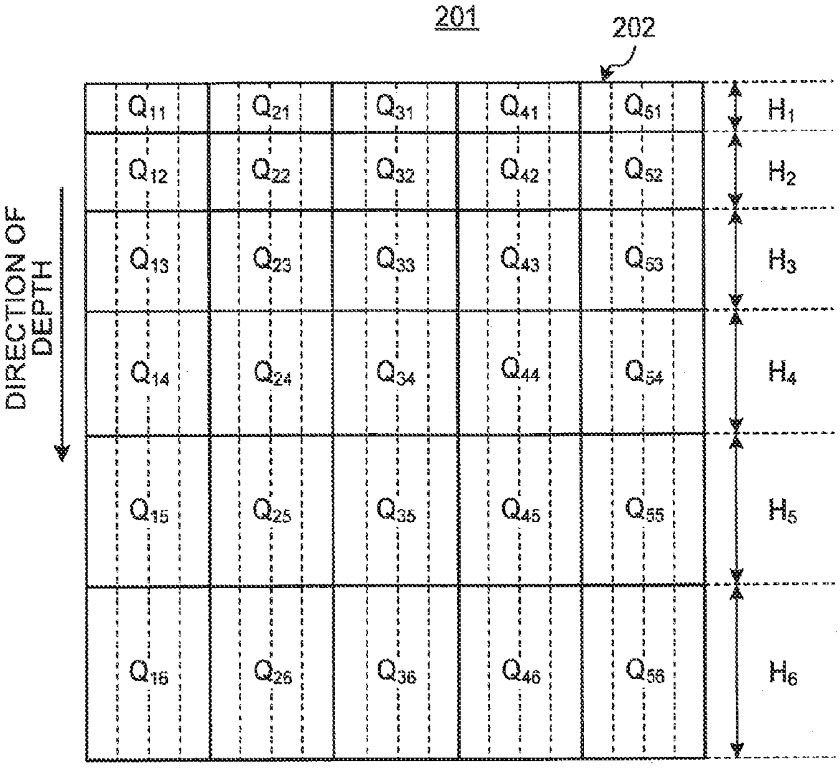
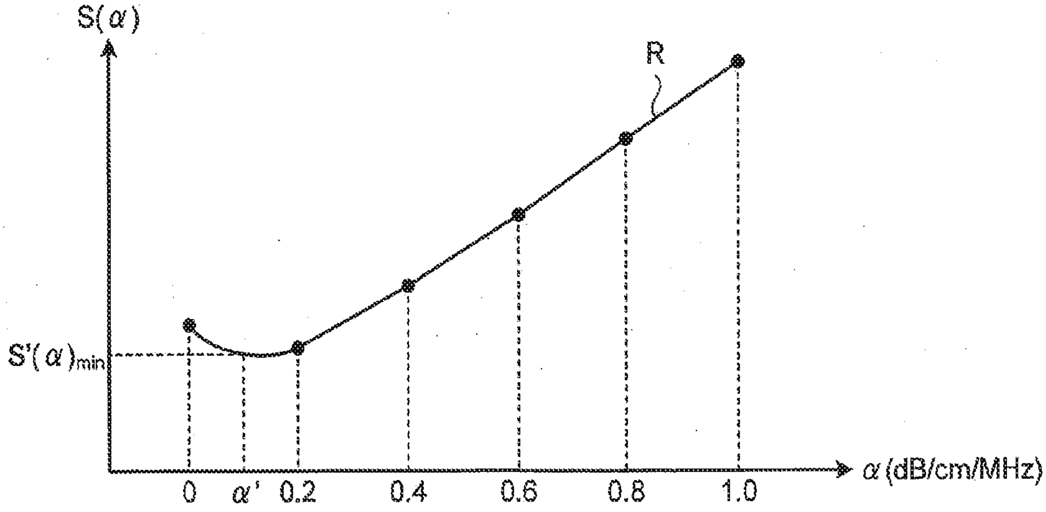

201
202
DIRECTION OF DEPTH
Q11
Q21
Q31
Q41
Q51
Q12
Q22
Q32
Q42
Q52
Q13
Q23
Q33
Q43
Q53
Q14
Q24
Q34
Q44
Q54
Q15
Q25
Q35
Q45
Q55
Q16
Q26
Q36
Q46
Q56
H1
H2
H3
H4
H5
H6

FIG.13



ULTRASOUND OBSERVATION APPARATUS, METHOD FOR OPERATING ULTRASOUND OBSERVATION APPARATUS, AND COMPUTER-READABLE RECORDING MEDIUM

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application is a continuation of PCT international application Ser. No. PCT/JP2015/078548, filed on Oct. 7, 2015 which designates the United States, incorporated herein by reference, and which claims the benefit of priority from Japanese Patent Application No. 2014-259474, filed on Dec. 22, 2014, incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The disclosure relates to an ultrasound observation apparatus for observing tissue of an observation target using ultrasound, a method for operating the ultrasound observation apparatus, and a computer-readable recording medium.

[0004] 2. Related Art

[0005] A conventional technology, which makes a correction for compensating a reception signal for the frequency-dependent attenuation of living tissue in an ultrasound observation apparatus that observes tissue of an observation target using ultrasound, has been known (refer to, for example, JP 2010-246640 A). In this technology, an ultrasound image is formed using a reception signal obtained by sequentially performing a dynamic correction process in accordance with the depth of a receiving point and a pulse compression process on a reflected wave from a subject.

SUMMARY

[0006] In some embodiments, an ultrasound observation apparatus is configured to generate an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target. The ultrasound observation apparatus includes: a frequency analysis unit configured to analyze a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal; a feature calculation unit configured to calculate features of the plurality of frequency spectra; an attenuation factor setting unit configured to use each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby to calculate a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and to set an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and a feature correction unit configured to calculate a cumulative attenuation factor per unit frequency at a sampling point, using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions by the attenuation factor setting unit, and to perform attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

[0007] In some embodiments, a method for operating an ultrasound observation apparatus is provided. The ultrasound observation apparatus is configured to generate an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target. The method includes: by a frequency analysis unit, analyzing a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal; by a feature calculation unit, calculating features of the plurality of frequency spectra; by an attenuation factor setting unit, using each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby calculating a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and setting an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and by a feature correction unit, calculating a cumulative attenuation factor per unit frequency at a sampling point by using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions, and performing attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

[0008] In some embodiments, a non-transitory computer-readable recording medium with an executable program stored thereon is provided. The program causes an ultrasound observation apparatus that is configured to generate an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target, to execute: by a frequency analysis unit, analyzing a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal; by a feature calculation unit, calculating features of the plurality of frequency spectra; by an attenuation factor setting unit, using each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby calculating a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and setting an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and by a feature correction unit, calculating a cumulative attenuation factor per unit frequency at a sampling point by using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions, and performing attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

[0009] The above and other features, advantages and technical and industrial significance of this invention will be better understood by reading the following detailed description of presently preferred embodiments of the invention, when considered in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a block diagram illustrating a functional configuration of an ultrasound diagnosis system including an ultrasound observation apparatus according to an embodiment of the present invention;

[0011] FIG. **2** is a diagram illustrating the relationship between the reception depth and an amplification factor in an amplification process that is performed by a signal amplification unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0012] FIG. **3** is a diagram illustrating the relationship between the reception depth and the amplification factor in an amplification correction process that is performed by an amplification correction unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0013] FIG. **4** is a diagram schematically illustrating data arrangement in one sound ray of an ultrasound signal;

[0014] FIG. **5** is a diagram illustrating an example of a frequency spectrum calculated by a frequency analysis unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0015] FIG. **6** is a diagram schematically illustrating an example of the setting of divided regions in an ultrasound image;

[0016] FIG. **7** is a diagram illustrating a straight line having, as parameters, preliminarily corrected features corrected by an attenuation factor setting unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0017] FIG. **8** is a diagram schematically illustrating an example of distributions of preliminarily corrected features that have been corrected for attenuation for the same observation target based respectively on two different attenuation factor candidate values;

[0018] FIG. **9** is a flowchart illustrating an overview of a process that is performed by the ultrasound observation apparatus according to the embodiment of the present invention;

[0019] FIG. **10** is a flowchart illustrating an overview of a process that is executed by the frequency analysis unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0020] FIG. **11** is a diagram illustrating an overview of a process that is performed by the attenuation factor setting unit of the ultrasound observation apparatus according to the embodiment of the present invention;

[0021] FIG. **12** is a diagram illustrating another example of the setting of divided regions in an ultrasound image; and

[0022] FIG. **13** is a diagram illustrating an overview of another method for the setting of an optimum attenuation factor that is performed by the attenuation factor setting unit of the ultrasound observation apparatus according to the embodiment of the present invention.

DETAILED DESCRIPTION

[0023] Modes for carrying out the present invention (hereinafter referred to as the “embodiment(s)”) will be described below with reference to the accompanying drawings.

[0024] FIG. **1** is a block diagram illustrating a functional configuration of an ultrasound diagnosis system including an ultrasound observation apparatus according to an embodiment of the present invention. An ultrasound diagnosis system **1** illustrated in FIG. **1** includes an ultrasound endoscope **2** that transmits ultrasound to a subject as an observation target and receives the ultrasound reflected from the subject, an ultrasound observation apparatus **3** that generates an ultrasound image based on the ultrasound signal acquired by the ultrasound endoscope **2**, and a display device **4** that displays the ultrasound image generated by the ultrasound observation apparatus **3**.

[0025] The ultrasound endoscope **2** includes, in its distal end portion, an ultrasound transducer **21** that converts an electric pulse signal received from the ultrasound observation apparatus **3** into an ultrasound pulse (acoustic pulse) to apply the ultrasound pulse to the subject, and also converts an ultrasound echo reflected from the subject into an electric echo signal expressed as a voltage change to output the echo signal. The ultrasound transducer **21** can be any of a convex transducer, a linear transducer, and a radial transducer. The ultrasound endoscope **2** may be one that scans mechanically with the ultrasound transducer **21**, or one that is provided with a plurality of elements in array form as the ultrasound transducer **21** to electronically switches the elements for transmission and reception and delay the transmission and reception by the elements for the purpose of scanning electronically. The ultrasound transducer **21** shall hereinafter be a linear transducer in the embodiment for explanation purposes.

[0026] The ultrasound endoscope **2** generally includes an imaging optical system and an imaging element. The ultrasound endoscope **2** is inserted into the digestive tract (esophagus, stomach, duodenum, or large intestine) or respiratory organ (trachea or bronchus) of the subject to enable the capturing of the digestive tract or respiratory organ, and its surrounding organ (such as pancreas, gallbladder, bile duct, biliary tract, lymph node, mediastinal organ, or blood vessel). Moreover, the ultrasound endoscope **2** includes a light guide that guides illumination light that is applied to the subject upon imaging. The light guide includes a distal end portion that reaches a distal end of an insertion portion into the subject of the ultrasound endoscope **2**, and a proximal end portion connected to a light source device that emits the illumination light.

[0027] The ultrasound observation apparatus **3** includes: a transmitting and receiving unit **31** that is electrically connected to the ultrasound endoscope **2** to transmit a transmission signal (pulse signal) including a high voltage pulse to the ultrasound transducer **21** based on a predetermined waveform and transmission timing, and also receive an echo signal being an electric reception signal from the ultrasound transducer **21**, and accordingly to generate and output digital radio frequency (RF: Radio Frequency) signal data (hereinafter referred to as RF data); a signal processing unit **32** that generates digital reception data for B-mode based on the RF data received from the transmitting and receiving unit **31**; a computing unit **33** that performs a predetermined computation on the RF data received from the transmitting and receiving unit **31**; an image processing unit **34** that generates various kinds of image data; an input unit **35** that is realized by user interfaces such as a keyboard, mouse, and touchscreen, and accepts various information inputs; a control unit **36** that controls the entire ultrasound diagnosis system **1**; and a storage unit **37** that stores various kinds of information necessary for the operation of the ultrasound observation apparatus **3**.

[0028] The transmitting and receiving unit **31** includes a signal amplification unit **311** that amplifies an echo signal. The signal amplification unit **311** performs STC (Sensitivity Time Control) correction that amplifies an echo signal at a higher amplification factor as the reception depth of the echo signal is increased. FIG. **2** is a diagram illustrating the relationship between the reception depth and the amplification factor in the amplification process that is performed by the signal amplification unit **311**. The reception depth z illustrated in FIG. **2** is a quantity calculated based on the time elapsed from the start of reception of ultrasound. As illustrated in FIG. **2**, an amplification factor β (dB) is increased linearly from β_0 to β_{th} ($>\beta_0$) with increasing reception depth z if the reception depth z is less than a threshold z_{th}. Moreover, the amplification factor β (dB) takes a constant value β_{th} if the reception depth z is equal to or more than the threshold z_{th}. The value of the threshold z_{th} is a value that results in the attenuation of most of an ultrasound signal received from an observation target and predominant noise. More generally, the amplification factor β is simply required to increase monotonously with increasing reception depth z if the reception depth z is less than the threshold z_{th}. The relationship illustrated in FIG. **2** is stored in the storage unit **37** in advance.

[0029] After performing processing such as filtering on the echo signal amplified by the signal amplification unit **311**, the transmitting and receiving unit **31** performs A/D conversion to generate RF data in the time domain and outputs the RF data to the signal processing unit **32** and the computing unit **33**. If the ultrasound endoscope **2** is configured to scan electronically with the ultrasound transducer **21** provided with a plurality of elements in array form, the transmitting and receiving unit **31** has a multi-channel circuit for beam synthesis corresponding to the plurality of elements.

[0030] A frequency band of the pulse signal transmitted by the transmitting and receiving unit **31** is desirably a wide band that covers most of a linear response frequency band of electroacoustic conversion from a pulse signal to an ultrasound pulse in the ultrasound transducer **21**. Moreover, various processing frequency bands of the echo signal in the signal amplification unit **311** is desirably a wide band that covers most of a linear response frequency band of electroacoustic conversion from an ultrasound echo to an echo signal by the ultrasound transducer **21**. Consequently, it becomes possible to accurately make an approximation in executing a frequency spectrum approximation process, which will be described below.

[0031] The transmitting and receiving unit **31** also has a function of transmitting various control signals output by the control unit **36** to the ultrasound endoscope **2** and also receiving various kinds of information including an ID for identification from the ultrasound endoscope **2** to transmit the information to the control unit **36**.

[0032] The signal processing unit **32** performs known processing such as band-pass filtering, envelope detection, and logarithmic conversion on the RF data, and generates digital reception data for B-mode. In the logarithmic conversion, a decibel value representation is used taking the common logarithm of a quantity obtained by dividing the RF data by a reference voltage. The signal processing unit **32** outputs the generated reception data for B-mode to the image processing unit **34**. The signal processing unit **32** is realized by a Central Processing Unit (CPU), various arithmetic circuits, and the like.

[0033] The computing unit **33** includes: an amplification correction unit **331** that performs amplification correction on the RF data output by the transmitting and receiving unit **31** to make the amplification factor constant irrespective of the reception depth; a frequency analysis unit **332** that performs the fast Fourier transform (FFT) on the RF data on which the amplification correction has been performed for a frequency analysis and, accordingly, to calculate a plurality of frequency spectra in accordance with the reception depths and receiving directions of an ultrasound signal; a feature calculation unit **333** that calculates features of each frequency spectrum; an attenuation factor setting unit **334** that, in each divided region obtained by dividing an ultrasound image into a plurality of regions, uses each of a plurality of attenuation factor candidate values per unit length and per unit frequency that gives different attenuation characteristics from each other of when ultrasound propagates through an observation target to perform attenuation correction that removes the influence of the ultrasound on the features of each frequency spectrum, and accordingly, to calculate preliminarily corrected features of each frequency spectrum for each attenuation factor candidate value and set an optimum attenuation factor for the observation target from the plurality of attenuation factor candidate values based on the calculation result; and a feature correction unit **335** that uses an optimum attenuation factor of a divided region present between the surface of the ultrasound transducer and a sampling point among the optimum attenuation factors set respectively for the divided regions by the attenuation factor setting unit **334** to calculate a cumulative attenuation factor per unit frequency at the sampling point, and performs attenuation correction on the features with the cumulative attenuation factor to calculate corrected features. The computing unit **33** is realized by using a CPU, various arithmetic circuits, and the like.

[0034] FIG. **3** is a diagram illustrating the relationship between the reception depth and the amplification factor in the amplification correction process that is performed by the amplification correction unit **331**. As illustrated in FIG. **3**, the amplification factor β (dB) in the amplification process that is performed by the amplification correction unit **331** takes a maximum value $\beta_{th}-\beta_0$ when the reception depth z is zero, reduces linearly until the reception depth z reaches from zero to the threshold z_{th}, and is zero when the reception depth z is equal to or more than the threshold z_{th}. The relationship illustrated in FIG. **3** is stored in the storage unit **37** in advance. The amplification correction unit **331** performs amplification correction on the digital RF data based on the relationship illustrated in FIG. **3**. Accordingly, it is possible to cancel the influence of the STC correction in the signal amplification unit **311** and output a signal with a constant amplification factor β_{th}. The relationship between the reception depth z and the amplification factor β in the amplification correction process that is performed by the amplification correction unit **331** is naturally different depending on the relationship between the reception depth and the amplification factor in the amplification process that is performed by the signal amplification unit **311**.

[0035] The reason why such amplification correction is performed is hereinafter described. The STC correction is a correction process that amplifies the amplitude of an analog signal waveform uniformly over the entire frequency band and with the amplification factor that increases monotonously with respect to the depth, and accordingly removes the influence of attenuation from the amplitude of the analog signal waveform. Hence, if a B-mode image is generated which displays the amplitude of an echo signal after conversion into luminance, and if uniform tissue is scanned, the luminance value becomes constant irrespective of the depth due to the performance of the STC correction. In other words, it is possible to obtain an effect that removes the influence of attenuation from the luminance value of the B-mode image.

[0036] On the other hand, if the calculation and analysis result of a frequency spectrum of ultrasound is used as in the embodiment, there is a problem that the influence of attenuation associated with the propagation of ultrasound cannot always be removed accurately even in the STC correction. This is because the amount of attenuation is generally different depending on the frequency (refer to equation (1) described below), but the amplification factor of the STC correction changes according only to the distance and is not frequency dependent.

[0037] In order to solve the above-mentioned problem, it is conceivable that a reception signal on which the STC correction has been performed is output when a B-mode image is generated, while, at the time of generating an image based on a frequency spectrum, a new transmission different from the transmission for generating the B-mode image is performed to output a reception signal on which the STC correction has not been performed. However, in this case, there is a problem that the frame rate of image data generated based on the reception signal is reduced.

[0038] Hence, in the embodiment, the amplification correction unit **331** corrects the amplification factor for a signal on which the STC correction has been performed for a B-mode image in order to remove the influence of the STC correction while maintaining the frame rate of image data generated.

[0039] The frequency analysis unit **332** samples RF data (line data) of each sound ray corrected for amplification by the amplification correction unit **331** at predetermined time intervals, and generates sample data. The frequency analysis unit **332** performs the FFT process on sample data groups to calculate a frequency spectrum at a plurality of points (data positions) on the RF data.

[0040] FIG. **4** is a diagram schematically illustrating data arrangement in one sound ray of an ultrasound signal. In a sound ray SR_k illustrated in FIG. **4**, a white or black rectangle indicates data at one sample point. Moreover, in the sound ray SR_k, data located at a further right position is sample data from a deeper point when measurements are taken along the sound ray SR_k from the ultrasound transducer **21** (refer to an arrow in FIG. **4**). The sound ray SR_k is discretized at intervals of time corresponding to a sampling frequency (for example, 50 MHz) in A/D conversion performed by the transmitting and receiving unit **31**. FIG. **4** illustrates a case where the position of the eighth data of the sound ray SR_k of number k is set as an initial value $Z^{(k)}_0$ in the direction of the reception depth z. However, the position of the initial value can be set freely. The result of the calculation made by the frequency analysis unit **332** is obtained in a complex number and stored in the storage unit **37**.

[0041] A data group F_j (j=1, 2, . . . , K) illustrated in FIG. **4** is a sample data group targeted for the FFT process. The sample data group is generally required to have the number of pieces of data being a power of 2 for the FFT process. In this sense, the sample data group F_j (j=1, 2, . . . , K−1) includes 16 (=2^4) pieces of data and is a normal data group, while a sample data group F_k includes 12 pieces of data and therefore is an abnormal data group. When the FFT process is performed on the abnormal data group, a process is performed in which zero data covering the shortfall is inserted to generate a normal sample data group. In this regard, a detailed description is given when the process of the frequency analysis unit **332** is described (refer to FIG. **10**).

[0042] FIG. **5** is a diagram illustrating an example of the frequency spectrum calculated by the frequency analysis unit **332**. "Frequency spectrum" here indicates the "distribution of frequencies at an intensity at some reception depth z" obtained by performing the FFT process on a sample data group. Moreover, "intensity" here indicates any of, for example, parameters such as the voltage of an echo signal, the power of the echo signal, the sound pressure of the ultrasound echo, and the sound energy of the ultrasound echo, the amplitudes and time integrated values of these parameters, and their combinations.

[0043] In FIG. **5**, the horizontal axis represents a frequency f. Moreover, in FIG. **5**, the vertical axis represents the common logarithm (expressed in decibels) of a quantity obtained by dividing an intensity I_0 by a reference intensity I_c (constant), $I=10\log_{10}(I_0/I_c)$. In FIG. **5**, the reception depth z is constant. A straight line L_{10} illustrated in FIG. **5** is described below. In the embodiment, a curve and a straight line each include a set of discrete points.

[0044] In a frequency spectrum C_1 illustrated in FIG. **5**, a lower-limit frequency f_L and an upper-limit frequency f_H of a frequency band, which is used for a subsequent computation, are parameters that are determined based on the frequency band of the ultrasound transducer **21**, the frequency band of a pulse signal transmitted by the transmitting and receiving unit **31**, and the like. For example, f_L=3 MHz, and f_H=10 MHz. In FIG. **5**, the frequency band determined by the lower-limit frequency f_L and the upper-limit frequency f_H is hereinafter referred to as the "frequency band U."

[0045] If the observation target is living tissue, the frequency spectrum generally indicates a different tendency depending on the characteristics of the living tissue that is scanned with ultrasound. This is because the frequency spectrum has a correlation to the size, number density, acoustic impedance, and the like of a scatterer that scatters ultrasound. The "characteristics of the living tissue" herein indicates, for example, a malignant tumor (cancer), a benign tumor, an endocrine tumor, a mucinous tumor, normal tissue, a cyst, and a vas.

[0046] The feature calculation unit **333** performs a regression analysis on a frequency spectrum in a predetermined frequency band and approximates the frequency spectrum by a linear expression, thereby calculating features that characterize the linear expression approximated. For example, in a case of the frequency spectrum C_1 illustrated in FIG. **5**, the feature calculation unit **333** performs a regression analysis in the frequency band U to obtain the approximate straight line L_{10}. Suppose that the approximate straight line L_{10} is expressed below in a linear expression of the frequency f, $I=a_0f+b_0$. The feature calculation unit **333** calculates, as the features corresponding to the straight line L_{10}, a slope a_0, an intercept b_0, and a midband fit $c_0=a_0f_M+b_0$ that is a value of the intensity I at a center frequency in the frequency band U, $f_M=(f_s+f_e)/2$. The feature calculation unit **333** may approximate the frequency spectrum by a quadratic or higher order polynomial using a regression analysis.

[0047] Among the three features before correction, the slope a_0 is considered to have a correlation with the size of the scatterer of ultrasound, and generally have a smaller value as the scatterer is increased in size. Moreover, the intercept b_0 has a correlation with scatterer size, difference in acoustic impedance, scatterer number density (concentration), and the like. Specifically, the intercept b_0 is considered to have a larger value as the scatterer is increased in size, have a larger value as the difference in acoustic impedance is increased, and have a larger value as the number density of the scatterer is increased. The midband fit c_0 is an indirect parameter that is derived from the slope a_0 and the intercept b_0, and gives the intensity of a spectrum at the center of the effective frequency band. Hence, the midband fit c_0 is considered to have some correlation with the luminance of a B-mode image in addition to the scatterer size, the difference in acoustic impedance, and the scatterer number density.

[0048] The attenuation factor setting unit **334** performs attenuation correction on the features in each divided region obtained by dividing an ultrasound image into a plurality of regions, using the attenuation factor that gives the amount of attenuation of ultrasound per unit length and per unit frequency. FIG. **6** is a diagram schematically illustrating an example of the setting of divided regions in an ultrasound image. FIG. **6** illustrates a case where an ultrasound image **101** that forms a rectangular shape is divided into 30 divided regions P_{ij} (i=1 to 5, j=1 to 6). Broken lines of FIG. **6** indicate sound rays. In the case of FIG. **6**, all of the divided regions P_{ij} have the same area. Hence, a depth H in the direction of depth from a surface position **102** of the ultrasound transducer **21** in the divided region P_{ij} (hereinafter referred to as the height H of the divided region P_{ij}) is constant. Information related to the divided region P_{ij} is stored in a divided region information storage unit **371** of the storage unit **37**. The number of sound rays is only a mere example, and is not limited to the case illustrated in FIG. **6**. Moreover, FIG. **6** illustrates an ultrasound image of a case where the ultrasound transducer **21** is a linear transducer, and accordingly the ultrasound image forms a rectangular shape. However, it is needless to say that the outer shape of the ultrasound image is different if the ultrasound transducer **21** is of another type.

[0049] The amount of attenuation A (f, z) of ultrasound is attenuation that occurs while ultrasound travels between the reception depth 0 and the reception depth z, and is defined as an intensity change (a difference expressed in decibels) before and after the round trip. The amount of attenuation A (f, z) is empirically known to be proportional to the frequency in uniform tissue, and is expressed by the following equation (1):

$$A(f,z)=2\alpha zf \tag{1}$$

[0050] Here, the proportionality constant α is a quantity called the attenuation factor, and gives the amount of attenuation of ultrasound per unit length and per unit frequency. Moreover, z is the reception depth of ultrasound, and f is the frequency. If the observation target is a living body, a specific value of the attenuation factor α is determined in accordance with the region of the living body. The unit of the attenuation factor α is, for example, dB/cm/MHz.

[0051] The attenuation factor setting unit **334** sets an optimum attenuation factor from a plurality of attenuation factor candidate values. At this point in time, the attenuation factor setting unit **334** performs attenuation correction on the features (the slope a_0, the intercept b_0, and the midband fit c_0) calculated by the feature calculation unit **333** in accordance with equations (2) to (4) illustrated below, using the attenuation factor candidate value α, to calculate preliminarily corrected features a, b, and c.

$$a=a_0+2\alpha z \tag{2}$$

$$b=b_0 \tag{3}$$

$$c=c_0+A(f_M,z)=c_0+2\alpha zf_M(=af_M+b) \tag{4}$$

[0052] As is clear from equations (2) and (4), the attenuation factor setting unit **334** makes corrections in which the amount of correction is increased with increasing reception depth z of ultrasound. Moreover, according to equation (3), the correction related to the intercept is the identity transformation. This is because the intercept is a frequency component corresponding to a frequency of zero (Hz) and is not influenced by attenuation.

[0053] FIG. **7** is a diagram illustrating a straight line having, as parameters, the preliminarily corrected features a, b, and c corrected as the parameters by the attenuation factor setting unit **334**. An equation of a straight line L_1 is expressed as

$$I=af+b=(a_0+2\alpha z)f+b_0 \tag{5}$$

[0054] As is clear from equation (5), the straight line L_1 is larger in slope ($a>a_0$) and the same in intercept ($b=b_0$) compared to the straight line L_{10} before attenuation correction.

[0055] The attenuation factor setting unit **334** sets an attenuation factor candidate value having minimal statistical dispersion of the preliminarily corrected feature calculated for each attenuation factor candidate value, as the optimum attenuation factor, in each divided region. In the embodiment, the variance is applied as a quantity indicating statistical dispersion. In this case, the attenuation factor setting unit **334** sets an attenuation factor candidate value having a minimum variance as the optimum attenuation factor. Two of the above-mentioned preliminarily corrected features a, b, and c are independent. In addition, the preliminarily corrected feature b is not dependent on the attenuation factor. Therefore, if the optimum attenuation factor is set for the preliminarily corrected features a, c, the attenuation factor setting unit **334** is simply required to calculate the variance of one of the preliminarily corrected features a and c.

[0056] However, it is more preferable that, the variance of the preliminarily corrected feature a be applied if the attenuation factor setting unit **334** sets the optimum attenuation factor using the preliminarily corrected feature a, and the variance of the preliminarily corrected feature c be applied if setting the optimum attenuation factor using the preliminarily corrected feature c. This is because equation (1) that gives the amount of attenuation A (f, z) is simply ideal, but the following equation (6) is more appropriate in practice.

$$A(f,z)=2\alpha zf+2\alpha_1 z \tag{6}$$

[0057] α_1 of the second term on the right-hand side of equation (6) is a coefficient indicating the magnitude of a change in signal intensity in proportion to the reception depth z of ultrasound, and is a coefficient indicating a change in signal intensity that occurs due to nonuniformity of tissue of the observation target, a change in the number of channels upon beam synthesis, and the like. Because of the second term on the right-hand side of equation (6), when the optimum attenuation factor is set using the preliminarily corrected feature c, it is possible to correct attenuation more accurately with the application of the variance of the preliminarily corrected feature c (refer to equation (4)). On the other hand, if the optimum attenuation factor is set using the preliminarily corrected feature a being a coefficient that is proportional to the frequency f, it is possible to remove the influence of the second term on the right-hand side of equation (6) and correct attenuation more accurately with the application of the variance of the preliminarily corrected feature a.

[0058] The reason why the optimum attenuation factor can be set based on statistical dispersion is hereinafter described. It is considered that, if the optimum attenuation factor is applied to an observation target, a feature converges to a value specific to the observation target irrespective of the distance between the observation target and the ultrasound transducer **21**, and statistical dispersion is reduced. On the other hand, it is considered that, if an attenuation factor candidate value that is not fit for the observation target is set as the optimum attenuation factor, the attenuation correction is excessive or insufficient. Accordingly, the feature varies according to the distance to the ultrasound transducer **21**, and the statistical dispersion of the feature is increased. Therefore, it can be said that an attenuation factor candidate value having minimal statistical dispersion is the optimum attenuation factor for the observation target.

[0059] FIG. **8** is a diagram schematically illustrating an example of distributions of preliminarily corrected features that have been corrected for attenuation for the same observation target based respectively on two different attenuation factor candidate values. In FIG. **8**, the horizontal axis indicates the preliminarily corrected feature, and the vertical axis indicates the frequency. Two distribution curves N_1 and N_2 illustrated in FIG. **8** have the same sum of frequencies. In the case illustrated in FIG. **8**, the distribution curve N_1 has less statistical dispersion (less variance) of the feature than the distribution curve N_2, and has a crest that forms a steep shape. Therefore, if setting the optimum attenuation factor from the two attenuation factor candidate values corresponding to the two distribution curves N_1 and N_2, the attenuation factor setting unit **334** sets the attenuation factor candidate value corresponding to the distribution curve N_1 as the optimum attenuation factor.

[0060] The feature correction unit **335** calculates a cumulative attenuation factor per unit frequency at a sampling point (hereinafter simply referred to as the cumulative attenuation factor) using an optimum attenuation factor of each divided region, and performs attenuation correction on the features using the cumulative attenuation factor. The cumulative attenuation factor at a given sampling point is calculated using the distance from the surface of the ultrasound transducer **21** and an optimum attenuation factor of a divided region present in between with the surface. A cumulative attenuation factor $\gamma_{IJ}(h)$ at a sampling point $S_{IJ}(h)$ whose distance from a boundary on a side close to the ultrasound transducer **21** is h ($0<h\leq H$) in a divided region P_{IJ} ($1\leq I\leq i_{max}$, $1\leq J\leq j_{max}$; I and J are constants) is expressed as:

$$\gamma_{IJ}(h)=[\Sigma_{j=1,2,\ldots,J-1}(2H\cdot\alpha(P_{IJ}))]+2h\cdot\alpha(P_{IJ}) \tag{7}.$$

[0061] Here, $\Sigma_{j=1,2,\ldots,J-1}$ indicates the sum over j=1 to J−1, and $\alpha(P_{IJ})$ represents the optimum attenuation factor in the divided region P_{IJ}. The first term on the right-hand side of equation (7) is the sum of those obtained by multiplying the round-trip distance 2H of ultrasound of each divided region by the optimum attenuation factor $\alpha(P_{IJ})$. The second term on the right-hand side of equation (7) is obtained by multiplying the round-trip distance 2h of ultrasound to the sampling point $S_{IJ}(h)$ in the divided region P_{IJ} by the optimum attenuation factor $\alpha(P_{IJ})$ in the divided region P_{IJ}. In this manner, the feature correction unit **335** accumulates the attenuation factors from the surface of the ultrasound transducer **21** to calculate the cumulative attenuation factor $\gamma_{IJ}(h)$. Assuming that the unit of the optimum attenuation factor is dB/cm/MHz, the unit of the cumulative attenuation factor is dB/MHz.

[0062] For example, FIG. **6** illustrates a case where I=2 and J=3 (where $i_{max}=5$ and $j_{max}=6$) in equation (7). In this case, from equation (7), a cumulative attenuation factor $\gamma_{23}(h)$ at a sampling point $S_{23}(h)$ is

$$\gamma_{23}(h)=2H\cdot\alpha(P_{21})+2H\cdot\alpha(P_{22})+2h\cdot\alpha(P_{23}) \tag{8}.$$

[0063] The feature correction unit **335** performs attenuation correction on the features at the sampling point $S_{IJ}(h)$ using the cumulative attenuation factor $\gamma_{IJ}(h)$ as follows:

$$a_{IJ}(h)=a_0+2\gamma_{IJ}(h) \tag{9}$$

$$b_{IJ}(h)=b_0 \tag{10}$$

$$c_{IJ}(h)=c_0+2f_M\gamma_{IJ}(h) \tag{11}$$

[0064] The image processing unit **34** includes a B-mode image data generation unit **341** that generates B-mode image data being an ultrasound image that displays the amplitude of an echo signal after conversion into luminance, and a feature image data generation unit **342** that generates feature image data that shows information on the features calculated by the feature calculation unit **333**.

[0065] The B-mode image data generation unit **341** performs signal processing on the reception data for B-mode received from the signal processing unit **32**, using known technologies such as gain processing and contrast processing, and also, for example, reduces data in accordance with the data step width determined according to the image display range of the display device **4**. Accordingly, the B-mode image data generation unit **341** generates B-mode image data. A B-mode image is a grayscale image where the values of R (red), G (green), and B (blue), which are variables when the RGB color system is adopted as the color space, are made equal.

[0066] The B-mode image data generation unit **341** performs coordinate conversion on the reception data for B-mode for rearrangement so as to spatially represent scanning ranges correctly, and then performs interpolation between the reception data for B-mode. Accordingly, the B-mode image data generation unit **341** bridges gaps between the reception data for B-mode, and generates B-mode image data. The B-mode image data generation unit **341** outputs the generated B-mode image data to the feature image data generation unit **342**.

[0067] The feature image data generation unit **342** superimposes visual information related to the feature(s) calculated by the feature calculation unit **333** on each pixel of an image of the B-mode image data, and accordingly generates feature image data. The feature image data generation unit **342** assigns visual information corresponding to the feature (s) of a frequency spectrum calculated from, for example, one amplification data group F_j (j=1, 2, . . . , K) illustrated in FIG. **4** to a pixel region corresponding to the data amount of the amplification data group F_j. The feature image data generation unit **342** associates hue as the visual information with any of, for example, the above-mentioned slope, intercept, and midband fit to generate feature image data. The feature image data generation unit **342** may associate hue with one of two features selected from the slope, intercept, and midband fit, and associate contrast with the other, to generate feature image data. Examples of the visual information on the feature(s) include variables of a color space forming a predetermined color system such as saturation, luminance value, R (red), G (green), and B (blue), in addition to hue and contrast (brightness).

[0068] The control unit **36** is realized by a Central Processing Unit (CPU) having a computation and control function, various arithmetic circuits, and the like. The control unit **36** reads information retained and stored in the storage unit **37** from the storage unit **37**, executes various computation processes related to a method for operating the ultrasound observation apparatus **3**, and accordingly integrally controls the ultrasound observation apparatus **3**. The control unit **36** may share a common CPU and the like with the signal processing unit **32** and the computing unit **33**.

[0069] The storage unit **37** includes the divided region information storage unit **371** that stores information on the divided regions, a spectrum information storage unit **372** that stores information on the frequency spectra calculated by the frequency analysis unit **332** together with the reception depths and the receiving directions, a feature information storage unit **373** that stores information on the features calculated by the feature calculation unit **333** and the corrected features corrected by the feature correction unit **335**, and an attenuation factor information storage unit **374** that stores information on an optimum attenuation factor set for each divided region by the attenuation factor setting unit **334** and a cumulative attenuation factor of each sampling point calculated by the feature correction unit **335**.

[0070] In addition to the above information, the storage unit **37** stores, for example, information necessary for the amplification process (the relationship between the amplification factor and the reception depth illustrated in FIG. **2**), information necessary for the amplification correction process (the relationship between the attenuation factor and the reception depth illustrated in FIG. **3**), information necessary for the attenuation correction process (refer to equation (1)), and information on a window function (such as Hamming, Hanning, or Blackman) necessary for the frequency analysis process.

[0071] Moreover, the storage unit **37** stores various programs including an operation program for executing the method for operating the ultrasound observation apparatus **3**. The operation program can also be recorded in computer-readable recording media such as hard disks, flash memories, CD-ROMs, DVD-ROMs, and flexible disks to be put into general circulation. The above-mentioned various programs can also be acquired by being downloaded via communication networks. The communication networks here are realized by, for example, an existing public network, Local Area Network (LAN), and Wide Area Network (WAN) irrespective of wired or wireless.

[0072] The storage unit **37** having the above configuration is realized by, for example, a Read Only Memory (ROM) in which various programs and the like are preinstalled, and a Random Access Memory (RAM) in which computational parameters, data, and the like of various processes are stored.

[0073] FIG. **9** is a flowchart illustrating an overview of a process that is performed by the ultrasound observation apparatus **3** having the above configuration. Specifically, FIG. **9** is a flowchart illustrating an overview of a process after the ultrasound observation apparatus **3** receives an echo signal from the ultrasound endoscope **2**. The process that is performed by the ultrasound observation apparatus **3** is described hereinafter with reference to FIG. **9**. First, the ultrasound observation apparatus **3** receives, from the ultrasound endoscope **2**, an echo signal as a measurement result of the observation target by the ultrasound transducer **21** (Step **S1**).

[0074] The signal amplification unit **311**, which has received the echo signal from the ultrasound transducer **21**, amplifies the echo signal (Step **S2**). The signal amplification unit **311** performs an amplification (the STC correction) on the echo signal based on, for example, the relationship between the amplification factor and the reception depth illustrated in FIG. **2**.

[0075] Next, the B-mode image data generation unit **341** generates B-mode image data using the echo signal amplified by the signal amplification unit **311**, and outputs the B-mode image data to the display device **4** (Step **S3**). The display device **4**, which has received the B-mode image data, displays a B-mode image corresponding to the B-mode image data.

[0076] The amplification correction unit **331** performs amplification correction on the RF data output from the transmitting and receiving unit **31** such that the amplification factor is constant irrespective of the reception depth (Step **S4**). The amplification correction unit **331** performs amplification correction based on, for example, the relationship between the amplification factor and the reception depth illustrated in FIG. **3**.

[0077] The frequency analysis unit **332** then performs a frequency analysis by the FFT on the RF data of each sound ray after amplification correction to calculate frequency spectra for all sample data groups, and stores them in the spectrum information storage unit **372** (Step **S5**). FIG. **10** is a flowchart illustrating an overview of the process that is performed by the frequency analysis unit **332** in Step S**5**. The details of the frequency analysis process are described hereinafter with reference to the flowchart illustrated in FIG. **10**.

[0078] First, the frequency analysis unit **332** sets a counter k that identifies a sound ray targeted for analysis to k_0 (Step S**21**).

[0079] Next, the frequency analysis unit **332** sets an initial value $Z^{(k)}_0$ of a data position (corresponding to the reception depth) $Z^{(k)}$ representing a series of data groups (sample data groups) generated for FFT computation (Step S**22**). For example, FIG. **4** illustrates the case where the position of the eighth data of the sound ray SR_k is set as an initial value $Z^{(k)}_0$ as described above.

[0080] Next, the frequency analysis unit **332** acquires the sample data groups (Step S**23**), and applies a window function stored in the storage unit **37** to the acquired sample data groups (Step S**24**). The window function is applied to the sample data groups in this manner and accordingly, it is possible to avoid the sample data groups from becoming discontinuous at their boundaries and prevent the occurrence of an artifact.

[0081] Next, the frequency analysis unit **332** determines whether or not the sample data group at the data position $Z^{(k)}$ is a normal data group (Step S**25**). As described with reference to FIG. **4**, the sample data group needs to include the number of pieces of data being a power of 2. The number of pieces of data of a normal sample data group shall be 2^n (n is a positive integer) below. In the embodiment, the data position $Z^{(k)}$ is set to be located as close to the center of a sample data group to which $Z^{(k)}$ belongs as possible. Specifically, since the number of pieces of data of a sample data group is 2^n, $Z^{(k)}$ is set at the $2^n/2$ ($=2^{n-1}$)-th position close to the center of the sample data group. In this case, that the sample data group is normal indicates that there are $2^{n-1}-1$ (=N) pieces of data on the shallower side than the data position $Z^{(k)}$, and there are 2^{n-1} (=M) pieces of data on the deeper side than the data position $Z^{(k)}$. In the case of FIG. **4**, the sample data group F_j (j=1, 2, . . . , K−1) is normal. FIG. **4** illustrates a case where n=4 (N=7, M=8).

[0082] If the sample data group at the data position $Z^{(k)}$ is normal as the result of the determination in Step S**25** (Step S**25**: Yes), the frequency analysis unit **332** proceeds to Step S**27** described below.

[0083] If the sample data group at the data position $Z^{(k)}$ is not normal as the result of the determination in Step S**25** (Step S**25**: No), the frequency analysis unit **332** generates a normal sample data group by inserting zero data covering the shortfall (Step S**26**). The sample data group determined to be not normal in Step S**25** (for example, the sample data group F_K of FIG. **4**) is applied a window function before being added zero data. Hence, even if zero data is inserted into the sample data group, the discontinuity of data does not occur. After Step S**26**, the frequency analysis unit **332** proceeds to Step S**27** described below.

[0084] In Step S**27**, the frequency analysis unit **332** performs the FFT computation using a sample data group to obtain a frequency spectrum being the amplitude-frequency distribution (Step S**27**).

[0085] Next, the frequency analysis unit **332** changes the data position $Z^{(k)}$ by a step width D (Step S**28**). The step width D is stored in the storage unit **37** in advance. FIG. **4** illustrates a case where D=15. The step width D is desired to agree with the data step width that is used when the B-mode image data generation unit **341** generates B-mode image data. However, if the amount of computation in the frequency analysis unit **332** is desired to be reduced, a larger value than the data step width may be set as the step width D.

[0086] The frequency analysis unit **332** then determines whether or not the data position $Z^{(k)}$ is larger than a maximum value $Z^{(k)}_{max}$ of the sound ray SR_k (Step S**29**). If the data position $Z^{(k)}$ is larger than the maximum value $Z^{(k)}_{max}$ (Step S**29**: Yes), the frequency analysis unit **332** increments the counter k by one (Step S**30**). This indicates a shift of the processing to the adjacent sound ray. On the other hand, if the data position $Z^{(k)}$ is equal to or less than the maximum value $Z^{(k)}_{max}$ (Step S**29**: No), the frequency analysis unit **332** returns to Step S**23**.

[0087] After Step S**30**, the frequency analysis unit **332** determines whether or not the counter k is larger than the maximum value k_{max} (Step S**31**). If the counter k is larger than k_{max} (Step S**31**: Yes), the frequency analysis unit **332** ends a series of the frequency analysis process steps. On the other hand, if the counter k is equal to or less than k_{max} (Step S**31**: No), the frequency analysis unit **332** returns to Step S**22**. The maximum value k_{max} is a value that a user such as an operator has input through the input unit **35**, or a value that is preset in the storage unit **37**.

[0088] In this manner, the frequency analysis unit **332** performs FFT computation multiple times on each of ($k_{max}-k_0+1$) sound rays within an analysis target region. The frequency spectra obtained as the result of the FFT computation, together with the reception depths and the receiving directions, are stored in the spectrum information storage unit **372**.

[0089] In the above explanation, the frequency analysis unit **332** performs the frequency analysis process on all the regions that have received the ultrasound signal. However, the input unit **35** may accept setting and input of a partial region divided by a specific depth width and sound ray width, and the frequency analysis process may be performed on only the set partial region.

[0090] Subsequent to the frequency analysis process of Step S**5** described above, the feature calculation unit **333** calculates features of a frequency spectrum at a sampling point included in each divided region (Step S**6**). Specifically, the feature calculation unit **333** performs a regression analysis on a frequency spectrum in a predetermined frequency band to approximate the frequency spectrum by a linear expression $I=a_0f+b_0$, and calculates the slope a_0, the intercept b_0, and the midband fit c_0 as the features. For example, the straight line L_{10} illustrated in FIG. **5** is a regression line obtained by approximating the frequency spectrum C_1 in the frequency band U by the feature calculation unit **333** through a regression analysis.

[0091] The attenuation factor setting unit **334** then sets, as a predetermined initial value α_0, the value of the attenuation factor candidate value α that is applied upon the performance of attenuation correction described below (Step S**7**). It is preferable that the initial value α_0 should be stored in the attenuation factor information storage unit **374** in advance.

[0092] Next, the attenuation factor setting unit **334** performs attenuation correction on the features obtained by approximating each frequency spectrum by the feature calculation unit **333**, using α as the attenuation factor candidate value, to calculate preliminarily corrected features, and stores the preliminarily corrected features together with the attenuation factor candidate value α in the feature information storage unit **373** (Step S**8**). The straight line L_1 illustrated in FIG. **7** is an example of a straight line obtained by the attenuation factor setting unit **334** performing the attenuation correction process.

[0093] In Step S**8**, the attenuation factor setting unit **334** does the calculations by substituting the data position $Z=(f_{sp}/2v_s)Dn$ obtained using data arrangement of a sound ray of an ultrasound signal into the reception depth z in the above-mentioned equations (2) and (4). f_{sp} is the sampling frequency of data, v_s is the velocity of sound, D is the data step width, and n is the number of data steps from the first data of the sound ray up to the data position of an amplification data group as a process target. For example, assuming that the data sampling frequency f_{sp} is 50 MHz; the velocity of sound v_s is 1530 m/sec; and the step width D is 15 by adopting the data arrangement illustrated in FIG. **4**, z=0.2295 n(mm).

[0094] The attenuation factor setting unit **334** calculates the variance in a representative preliminarily corrected feature among the plurality of preliminarily corrected features obtained by performing attenuation correction on each frequency spectrum by the attenuation factor setting unit **334**, associates the variance with the attenuation factor candidate value α, and stores the variance in the feature information storage unit **373** (Step S**9**). For example, if the preliminarily corrected features are the slope a and the midband fit c, the attenuation factor setting unit **334** calculates the variance of one of the preliminarily corrected features a and c as described above. It is preferable in Step S**9** that, the variance of the preliminarily corrected feature a in each divided region be applied if the preliminarily corrected feature a is used to generate a feature image, and the variance of the preliminarily corrected feature c in each divided region be applied if the preliminarily corrected feature c is used to generate a feature image

[0095] The attenuation factor setting unit **334** then increments the value of the attenuation factor candidate value α by $\Delta\alpha$ (Step S**10**), and compares the magnitudes of the incremented attenuation factor candidate value α and a predetermined maximum value α_{max} (Step S**11**). If the attenuation factor candidate value α is larger than the maximum value α_{max} as the result of the comparison in Step S**11** (Step S**11**: Yes), the ultrasound observation apparatus **3** proceeds to Step S**12**. On the other hand, if the attenuation factor candidate value α is equal to or less than the maximum value α_{max} as the result of the comparison in Step S**11** (Step S**11**: No), the ultrasound observation apparatus **3** returns to Step S**8**.

[0096] In Step S**12**, the attenuation factor setting unit **334** refers to the variance in the preliminarily corrected feature of each attenuation factor candidate value stored in the feature information storage unit **373**, for each divided region, and sets an attenuation factor candidate value having a minimum variance as the optimum attenuation factor in the divided region (Step S**12**).

[0097] FIG. **11** is a diagram illustrating an overview of a process that is performed by the attenuation factor setting unit **334**. FIG. **11** is a diagram illustrating an example of the relationship between the attenuation factor candidate value α and a variance $S(\alpha)$, where $\alpha_0=0$ (dB/cm/MHz), $\alpha_{max}=1.0$ (dB/cm/MHz), and $\Delta\alpha=0.2$ (dB/cm/MHz). In the case illustrated in FIG. **11**, the variance takes a minimum value $S(\alpha)_{min}$ when the attenuation factor candidate value α is 0.2 (dB/cm/MHz). Therefore, in the case illustrated in FIG. **11**, the attenuation factor setting unit **334** sets $\alpha=0.2$ (dB/cm/MHz) as the optimum attenuation factor.

[0098] The feature correction unit **335** then uses the optimum attenuation factor set for each divided region by the attenuation factor setting unit **334** to calculate a cumulative attenuation factor at a sampling point (Step S**13**). For example, the cumulative attenuation factor $\gamma_{IJ}(h)$ at the sampling point $S_{IJ}(h)$ in the divided region P_{IJ} illustrated in FIG. **6** is expressed by equation (7).

[0099] Next, the feature correction unit **335** performs attenuation correction on the features using the cumulative attenuation factor to calculate corrected features (Step S**14**). For example, the corrected features $a_{IJ}(h)$, $b_{IJ}(h)$, and $c_{IJ}(h)$ of the slope a_0, the intercept b_0, and the midband fit c_0 at the sampling point $S_{IJ}(h)$ in the divided region P_{IJ} illustrated in FIG. **6** are calculated using equations (9) to (11), respectively.

[0100] The feature image data generation unit **342** superimposes visual information (for example, hue) associated with the corrected feature calculated in Step S**14** on each pixel in the B-mode image data generated by the B-mode image data generation unit **341** to generate feature image data (Step S**15**). The feature image data generation unit **342** transmits the generated feature image data to the display device **4**. The display device **4**, which has received the feature image data, displays a feature image corresponding to the received feature image data.

[0101] After Step S**15**, the ultrasound observation apparatus **3** ends a series of the processing steps. The ultrasound observation apparatus **3** repeatedly and periodically executes the processing of Steps S**1** to S**15**.

[0102] According to the embodiment of the present invention described above, preliminarily corrected features of a frequency spectrum in accordance with a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics from each other are calculated in each divided region obtained by dividing an ultrasound image into a plurality of regions. Based on the calculation result, an optimum attenuation factor for an observation target is set for each divided region from the plurality of attenuation factor candidate values. An optimum attenuation factor of a divided region present between the surface of the ultrasound transducer and a sampling point is used to calculate a cumulative attenuation factor per unit frequency at the sampling point. The cumulative attenuation factor is used to perform attenuation correction on features, and thereby corrected features are calculated. Hence, even if the observation target has nonuniform attenuation factors, the corrected features that take the nonuniformity into account can be calculated. Therefore, according to the present invention, it becomes possible to accurately identify the tissue characteristics of the observation target having nonuniform attenuation factors.

[0103] Moreover, according to the embodiment, by calculating a sum of an optimum attenuation factor of each divided region present between a surface position of the ultrasound transducer and a sampling point, the optimum attenuation factor being multiplied by a weight indicating a round-trip distance in the depth direction in the divided region, the cumulative attenuation factor at the sampling point is calculated. Accordingly, it is possible to appropriately set an attenuation factor in the middle between the surface of the ultrasound transducer and the sampling point.

[0104] Up to this point, the mode for carrying out the present invention has been described. However, the present invention is not intended to be limited only to the above-mentioned embodiment. For example, the method for setting divided regions of an ultrasound image is not limited to the one illustrated in FIG. **6**. FIG. **12** is a diagram illustrating another example of the setting of divided regions in an ultrasound image. FIG. **12** illustrates a case where an ultrasound image **201** is divided into 30 divided regions Q_{ij} (i=1 to 5, j=1 to 6). Regions at the same depth, that is, regions having a common value in j among the divided regions Q_{ij} all have the same area. On the other hand, regions at different depths among the divided regions Q_{ij} are increased in height H_j (j=1 to 6) ($H_1<H_2< \ldots <H_6$) as the depth from a surface position **202** of the ultrasound transducer **21** is increased. Generally, ultrasound attenuation is increased with increasing depth. Accordingly, the area of a divided region distant from the ultrasound transducer **21** is increased to enable an improvement in S/N ratio in the distance.

[0105] In this case, the cumulative attenuation factor $\gamma_{IJ}(h)$ at the sampling point $S_{IJ}(h)$ whose distance from a boundary on a side close to the ultrasound transducer **21** is h ($0<h\leq H_J$) in the divided region Q_{IJ} ($1\leq I\leq i_{max}$, $1\leq J\leq j_{max}$; I and j are constants) is expressed as

$$\gamma_{IJ}(h)=[\Sigma_{j=1,2, \ldots ,J-1}(2H_j\cdot\alpha(Q_{IJ}))]+2h\cdot\alpha(Q_{IJ}) \quad (12).$$

[0106] Equation (12) is different from equation (7) in that the length H_j in the direction of depth in the divided region Q_{Ij} of the first term on the right-hand side is dependent on the region.

[0107] Moreover, the method for the setting of an optimum attenuation factor that is performed by the attenuation factor setting unit **334** is not limited to the above-mentioned method. FIG. **13** is a diagram illustrating an overview of another method for the setting of an optimum attenuation factor that is performed by the attenuation factor setting unit **334**. FIG. **13** illustrates an example of the relationship between the attenuation factor candidate value α and the variance S(α), where $\alpha_0=0$ (dB/cm/MHz), $\alpha_{max}=1.0$ (dB/cm/MHz), and $\Delta\alpha=0.2$ (dB/cm/MHz). All the values of the variance S(α) for the attenuation factor candidate values α=0, 0.2, 0.4, 0.6, 0.8, and 1.0 (all in dB/cm/MHz) are respectively the same as those in FIG. **11**. In this case, the feature calculation unit **333** performs a regression analysis before the attenuation factor setting unit **334** sets an optimum attenuation factor. Accordingly, a curve R that interpolates the values of the variance S(α) for the attenuation factor candidate value α is calculated. The attenuation factor setting unit **334** then calculates a minimum value $S'(\alpha)_{min}$ when 0 (dB/cm/MHz)≤α≤1.0 (dB/cm/MHz) for the curve R and sets a value α' of its attenuation factor candidate value as the optimum attenuation factor. Therefore, in the case illustrated in FIG. **13**, the optimum attenuation factor α' is a value between 0 (dB/cm/MHz) and 0.2 (dB/cm/MHz).

[0108] Moreover, the attenuation factor setting unit **334** may calculate an equivalent optimum attenuation factor value corresponding to an optimum attenuation factor in all frames of the ultrasound image, and set, as the optimum attenuation factor, the mean, median, or mode of a predetermined number of equivalent optimum attenuation factor values including an equivalent optimum attenuation factor value of the latest frame. In this case, the number of changes in optimum attenuation factor is reduced as compared to a case of setting an optimum attenuation factor for each frame, so that the value can be stabilized.

[0109] Moreover, the attenuation factor setting unit **334** may set an optimum attenuation factor in predetermined frame intervals of the ultrasound image. Consequently, the amount of computation can be significantly reduced. In this case, it is simply required to use an optimum attenuation factor value that was set last until the next optimum attenuation factor is set.

[0110] Moreover, it may be configured such that the input unit **35** can accept the input of a change in the setting of the initial value α_0 of the attenuation factor candidate value.

[0111] Moreover, it is also possible to apply any of, for example, the standard deviation, the difference between the maximum value and the minimum value of a feature in a population, and the half width of the distribution of features, as the quantity that gives statistical dispersion. A case where the inverse of a variance is applied as the quantity that gives statistical dispersion is also conceivable. In this case, however, it is needless to say that an attenuation factor candidate value having a maximum value is the optimum attenuation factor.

[0112] Moreover, it is also possible that the attenuation factor setting unit **334** calculates the statistical dispersion of a plurality of kinds of preliminarily corrected features, and set, as the optimum attenuation factor, an attenuation factor candidate value having minimal statistical dispersion.

[0113] Moreover, the attenuation factor setting unit **334** may calculate a preliminarily corrected feature by performing attenuation correction on a frequency spectrum with a plurality of attenuation factor candidate values, and performing a regression analysis on the frequency spectrum after attenuation correction.

[0114] Moreover, an application to an ultrasound probe, other than an ultrasound endoscope, is also possible. For example, a slim ultrasound miniature probe without an optical system may be applied as the ultrasound probe. The ultrasound miniature probe is generally used to be inserted into the biliary tract, bile duct, pancreatic duct, trachea, bronchus, urethra, or ureter and observe its surrounding organ (such as the pancreas, lung, prostate, bladder, or lymph node). Moreover, an external ultrasound probe that applies ultrasound from the body surface of a subject may be applied as the ultrasound probe. The external ultrasound probe is generally used to observe an abdominal organ (the liver, gallbladder, or bladder), the breast (especially, the mammary gland), and the thyroid.

[0115] According to some embodiments, a preliminarily corrected feature of a frequency spectrum in accordance with a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics is calculated in each of divided regions obtained by dividing an ultrasound image into a plurality of regions. An optimum attenuation factor for an observation target is set for each of the divided regions among the plurality of attenuation factor candidate values based on the calculation result. An optimum attenuation factor of a divided region present between a surface of an ultrasound transducer and a sampling point is used to calculate a cumulative attenuation factor per unit frequency at the sampling point. Attenuation correction is performed on a feature using the cumulative attenuation factor to calculate a corrected feature. Hence, even if attenuation factors of the observation target are nonuniform, the corrected feature can be calculated in view of the non-uniformity. Therefore, according to some embodiments, it is possible to accurately identify tissue characteristics of the observation target with the nonuniform attenuation factors.

[0116] In this manner, the present invention can include various embodiments within the range that does not depart from the technical idea described in the claims.

[0117] As described above, an ultrasound observation apparatus, a method for operating the ultrasound observation apparatus, and a computer-readable recording medium according to some embodiments are useful for accurately identifying tissue characteristics of an observation target having nonuniform attenuation factors.

[0118] Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. An ultrasound observation apparatus for generating an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target, the ultrasound observation apparatus comprising:

a frequency analysis unit configured to analyze a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal;

a feature calculation unit configured to calculate features of the plurality of frequency spectra;

an attenuation factor setting unit configured to use each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby to calculate a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and to set an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and

a feature correction unit configured to calculate a cumulative attenuation factor per unit frequency at a sampling point, using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions by the attenuation factor setting unit, and to perform attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

2. The ultrasound observation apparatus according to claim **1**, wherein the feature correction unit is configured to calculate a sum of the optimum attenuation factor of each of the divided regions present between the surface of the ultrasound transducer and the sampling point, the optimum attenuation factor being multiplied by a weight indicating a round-trip distance in a depth direction in each of the divided regions, to calculate the cumulative attenuation factor at the sampling point.

3. The ultrasound observation apparatus according to claim **1**, wherein, in two of the divided regions which are adjacent along a depth direction, one of the two divided regions located more distant from the ultrasound transducer has a length in the depth direction equal to or more than a length in the depth direction of the other of the two divided regions located closer to the ultrasound transducer.

4. The ultrasound observation apparatus according to claim **1**, wherein the attenuation factor setting unit is configured to calculate a statistical dispersion of the preliminarily corrected feature for each of the attenuation factor candidate values, and set an attenuation factor candidate value having a minimal statistical dispersion as the optimum attenuation factor.

5. The ultrasound observation apparatus according to claim **1**, further comprising a feature image data generation unit configured to generate feature image data for showing information on the corrected feature together with the ultrasound image.

6. The ultrasound observation apparatus according to claim **1**, wherein the feature calculation unit is configured to approximate each of the frequency spectra by an n-th order polynomial (n is a positive integer) to calculate the features.

7. The ultrasound observation apparatus according to claim **6**, wherein

the feature calculation unit is configured to approximate a predetermined frequency band in the frequency spectrum by a linear expression to calculate the features that are one or more of an intercept of the linear expression, a slope of the linear expression, and a midband fit as a value of the linear expression at an intermediate frequency in the frequency band, and that include one of the slope and the midband fit, and

the attenuation factor setting unit is configured to set the optimum attenuation factor based on the one of the slope and the midband fit.

8. The ultrasound observation apparatus according to claim **7**, wherein

the attenuation factor setting unit is configured to set the optimum attenuation factor based on the slope when the slope is the features, and set the optimum attenuation factor based on the midband fit when the midband fit is the features.

9. A method for operating an ultrasound observation apparatus, the ultrasound observation apparatus being configured to generate an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target, the method comprising:

by a frequency analysis unit, analyzing a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal;

by a feature calculation unit, calculating features of the plurality of frequency spectra;

by an attenuation factor setting unit, using each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby calculating a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and setting an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and

by a feature correction unit, calculating a cumulative attenuation factor per unit frequency at a sampling point by using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions, and performing attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

10. A non-transitory computer-readable recording medium with an executable program stored thereon, the program causing an ultrasound observation apparatus that is configured to generate an ultrasound image based on an ultrasound signal acquired by an ultrasound probe, the ultrasound probe having an ultrasound transducer configured to transmit ultrasound to an observation target and receive the ultrasound reflected from the observation target, to execute:

by a frequency analysis unit, analyzing a frequency of the ultrasound signal to calculate a plurality of frequency spectra in accordance with reception depths and receiving directions of the ultrasound signal;

by a feature calculation unit, calculating features of the plurality of frequency spectra;

by an attenuation factor setting unit, using each of a plurality of attenuation factor candidate values per unit length and per unit frequency that give different attenuation characteristics when the ultrasound propagates through the observation target, in each of divided regions obtained by dividing the ultrasound image into a plurality of regions, to perform attenuation correction on the features of the frequency spectra for removing an influence of the ultrasound, and thereby calculating a preliminarily corrected feature of each of the frequency spectra for each of the attenuation factor candidate values, and setting an optimum attenuation factor for the observation target among the plurality of attenuation factor candidate values based on a calculation result; and

by a feature correction unit, calculating a cumulative attenuation factor per unit frequency at a sampling point by using an optimum attenuation factor of a divided region present between a surface of the ultrasound transducer and the sampling point among optimum attenuation factors set respectively for the divided regions, and performing attenuation correction on the features using the cumulative attenuation factor to calculate a corrected feature.

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专利名称(译)	超声波观察装置，超声波观察装置的操作方法以及计算机可读取的记录介质		
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摘要(译)

超声波观测装置包括：计算单元，其计算通过分析超声波信号的频率而获得的频谱的特征;设置单元，在通过划分超声图像而获得的每个划分区域中，使用给出不同衰减特性的每单位长度和每单位频率的每个衰减因子候选值，对所述频谱的特征执行衰减校正，以消除从而针对每个衰减因子候选值计算每个频谱的预先校正的特征，并且在衰减因子候选值中设置最佳衰减因子;以及校正单元，使用存在于超声波换能器的表面和所述采样点之间的分割区域的最佳衰减因子，计算采样点处的每单位频率的累积衰减因子，并使用累积衰减因子。