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(54) **IMAGE FORMING METHOD AND APPARATUS, AND ULTRASONIC IMAGING APPARATUS**

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(57)   **ABSTRACT**

In forming an image without clutters indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, the variance T of the velocity of the echo source is evaluated based on the Doppler shift, and the signal strength of the image is adjusted depending on the value of variance.

FIG. 1

FIG. 2

6

604   602

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                ┌──────────────┐      ┌──────────────┐
                │ TRANSMIS-    │      │ TRANSMIS-    │
                │ SION BEAM    │◄─────│ SION TIM-    │
                │ FORMER       │      │ ING GENER-   │
                │              │      │ ATION UNIT   │
                └──────────────┘      └──────────────┘
606                    │
┌──────────────┐       │
│ TRANSMIT/    │◄──────┘
│ RECEIVE      │
│ SWITCHING    │               610
│ UNIT         │
└──────────────┘      ┌──────────────┐
        │             │ RECEPTION    │
        └────────────►│ BEAM         │──────────►
                      │ FORMER       │
                      └──────────────┘
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FIG. 6

10

102   104

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┌──────────────┐      ┌──────────────┐
│ LOGARITHMIC  │      │ ENVELOPE     │
│ AMPLIFYING   │─────►│ DETECT       │──────►
│ UNIT         │      │ UNIT         │
└──────────────┘      └──────────────┘
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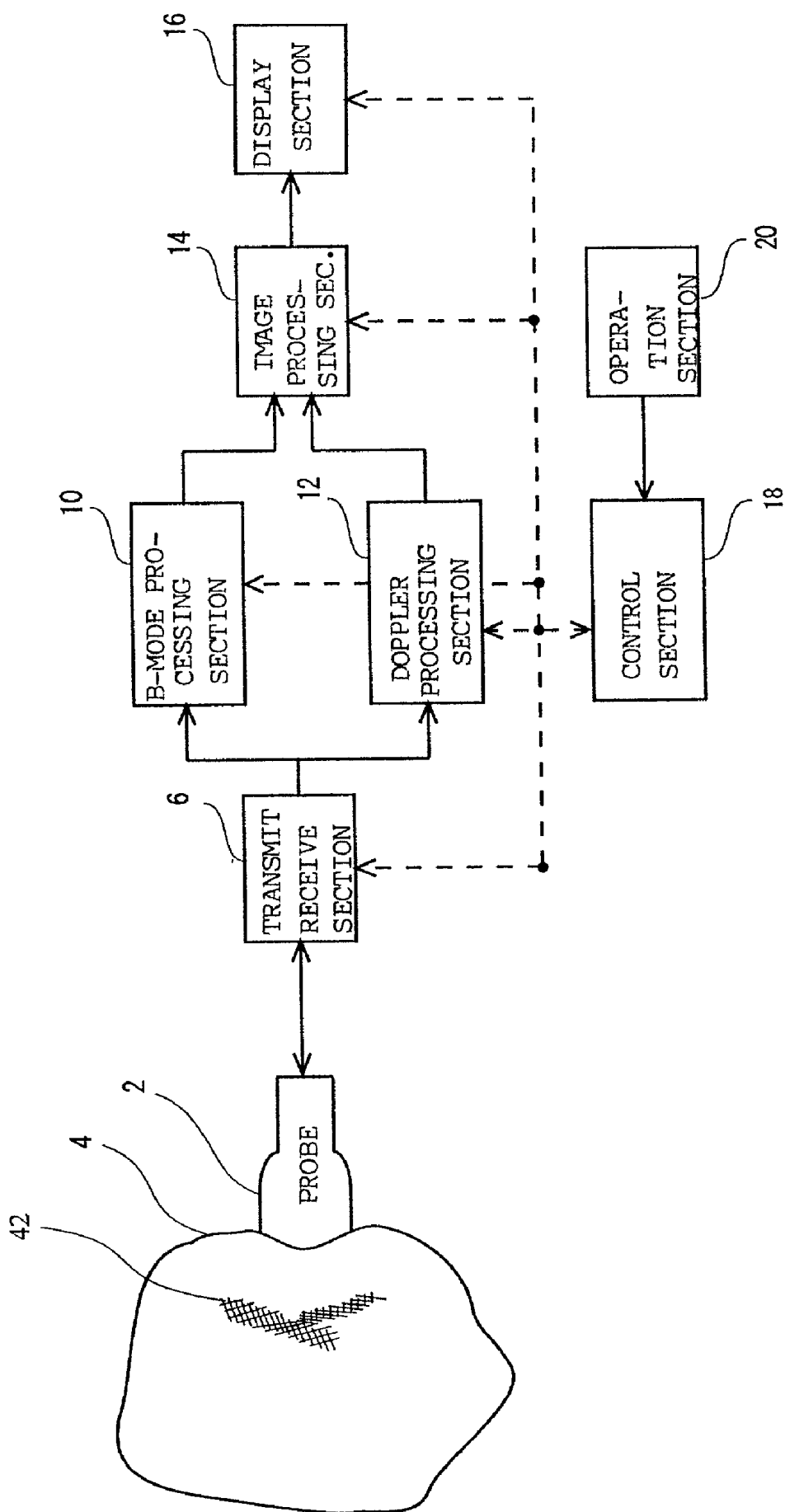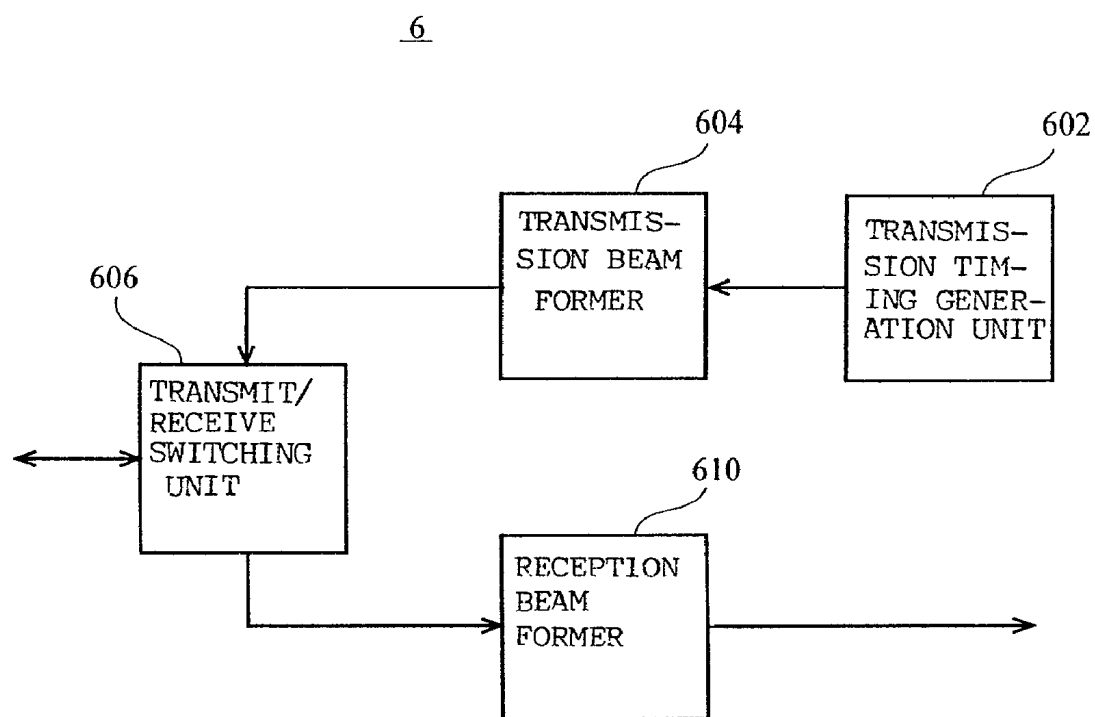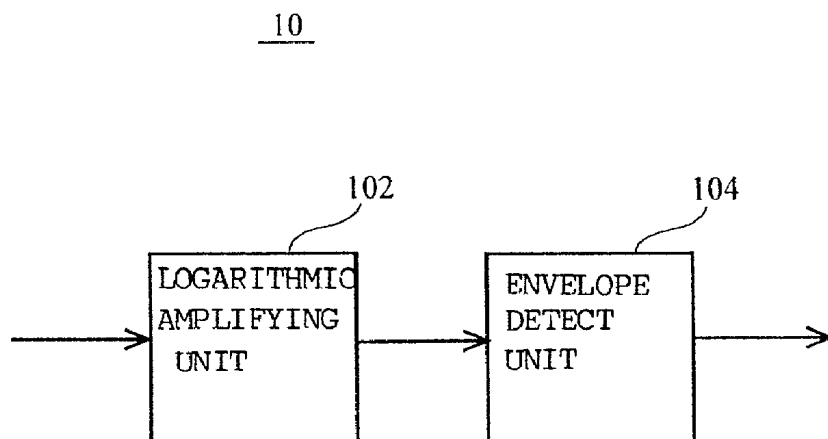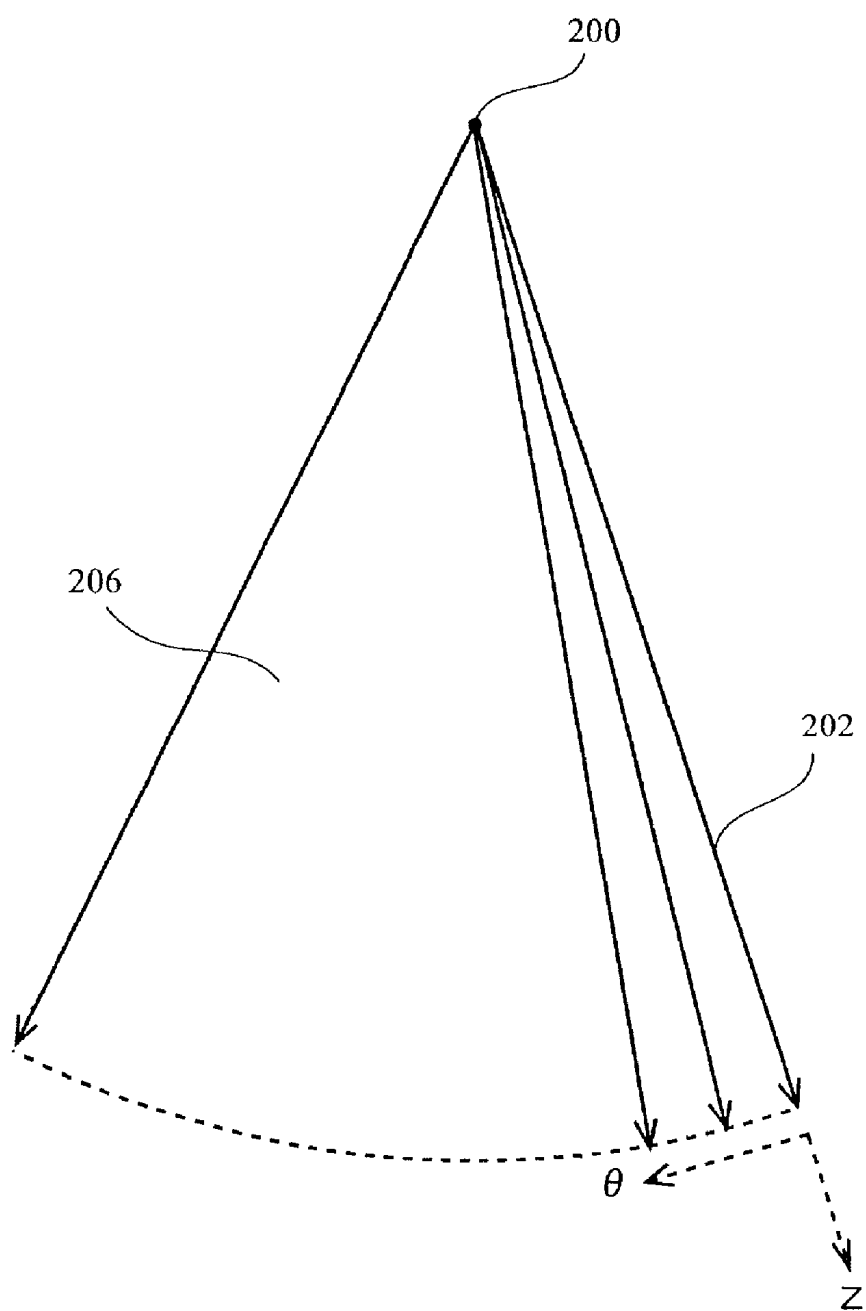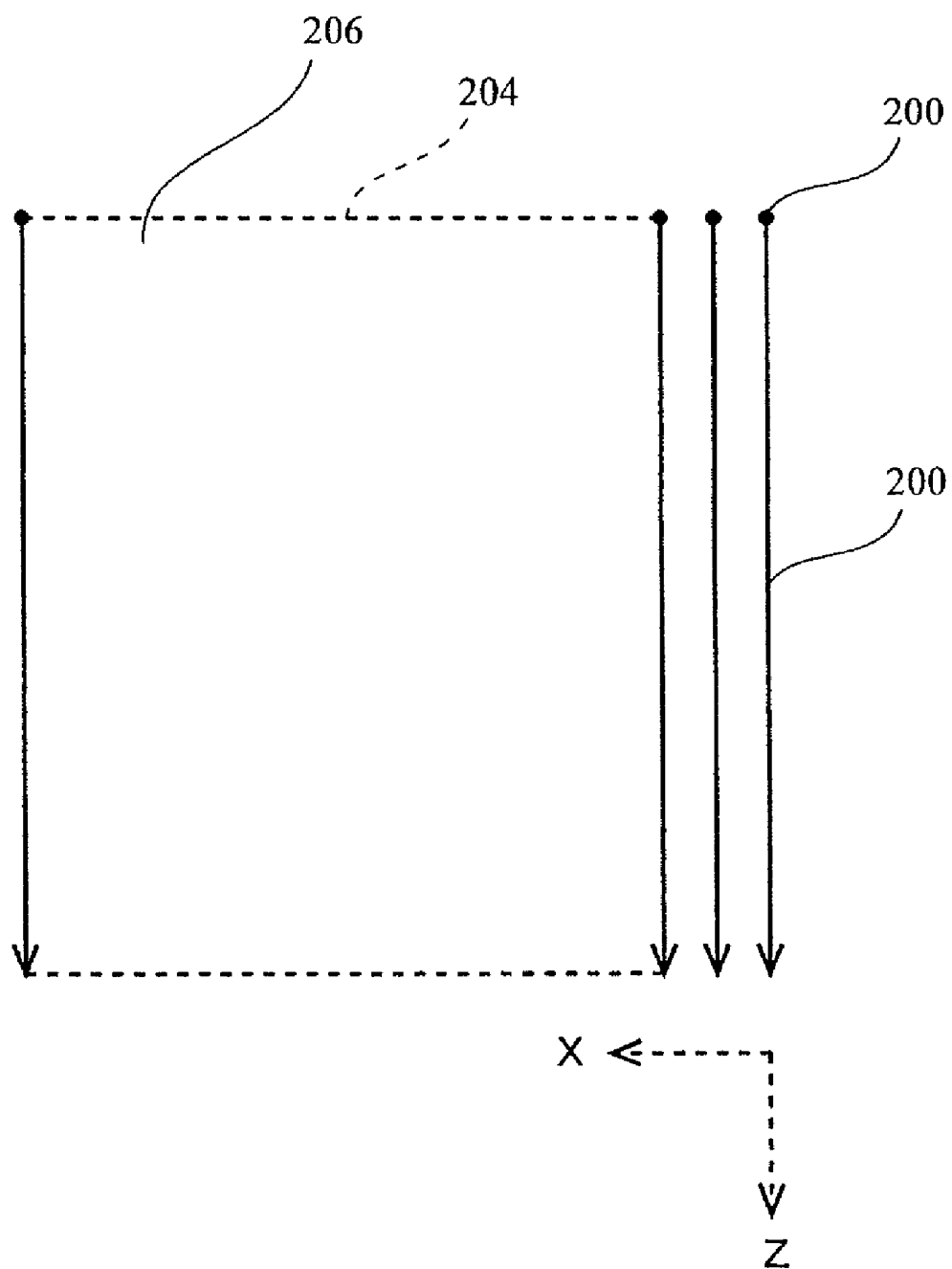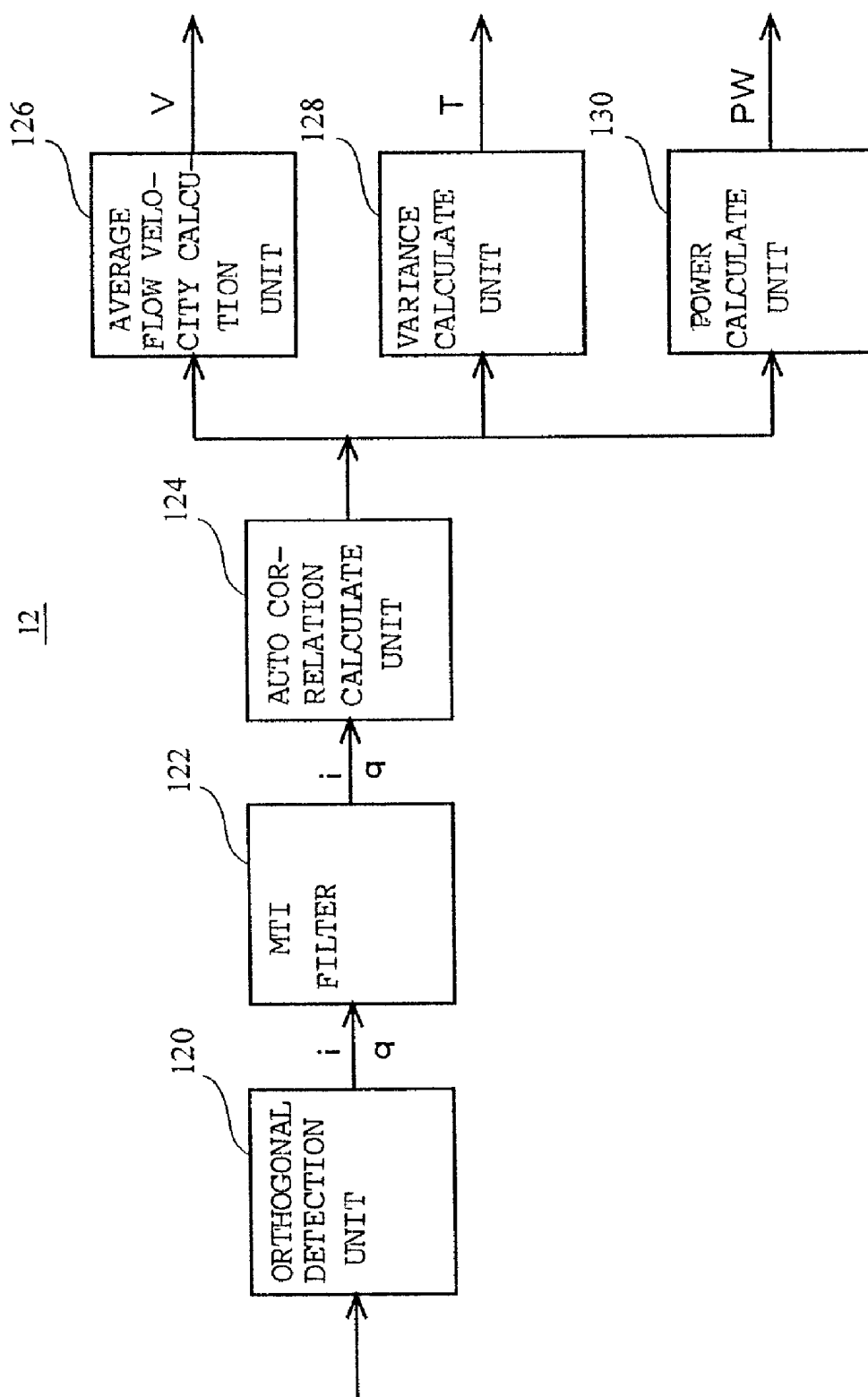
FIG. 3

FIG. 4

206

204

200

200

X

Z

FIG. 5

FIG. 7

FIG. 8
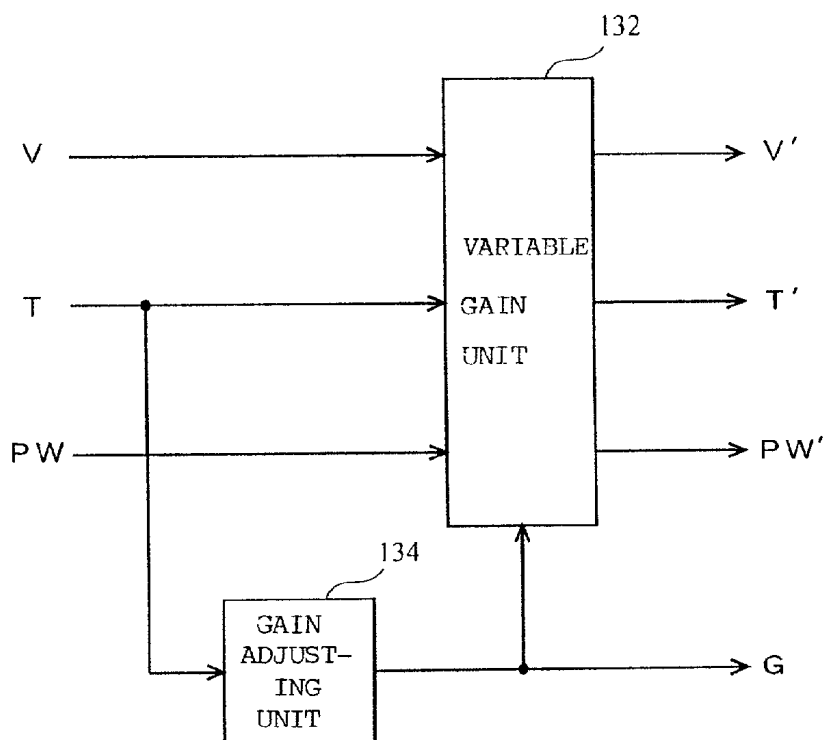

FIG. 9

FIG.10

FIG.11

FIG.12

Gain

1.0

0

TH1

TH2

Variance

Power decreases

FIG.13

14

142

INPUT
DATA
MEMORY

144

DIGITAL
SCAN
CONVERTER

146

IMAGE
MEMORY

(10), (12)

(16)

140

148

PROCESSOR

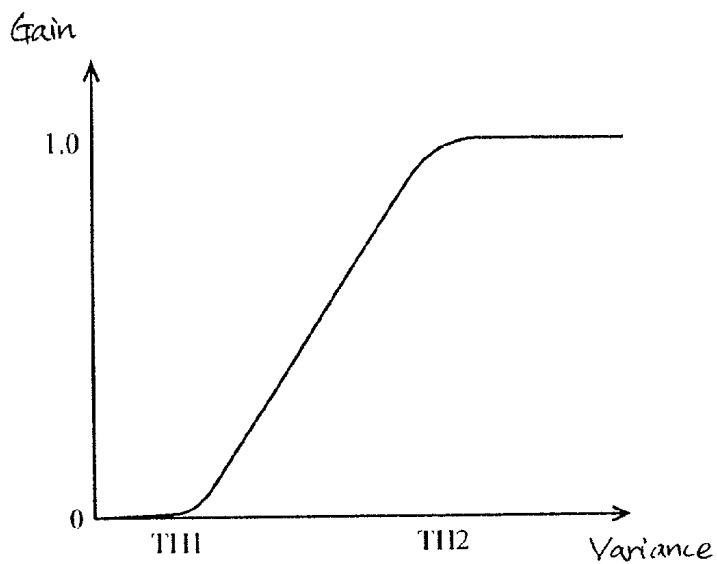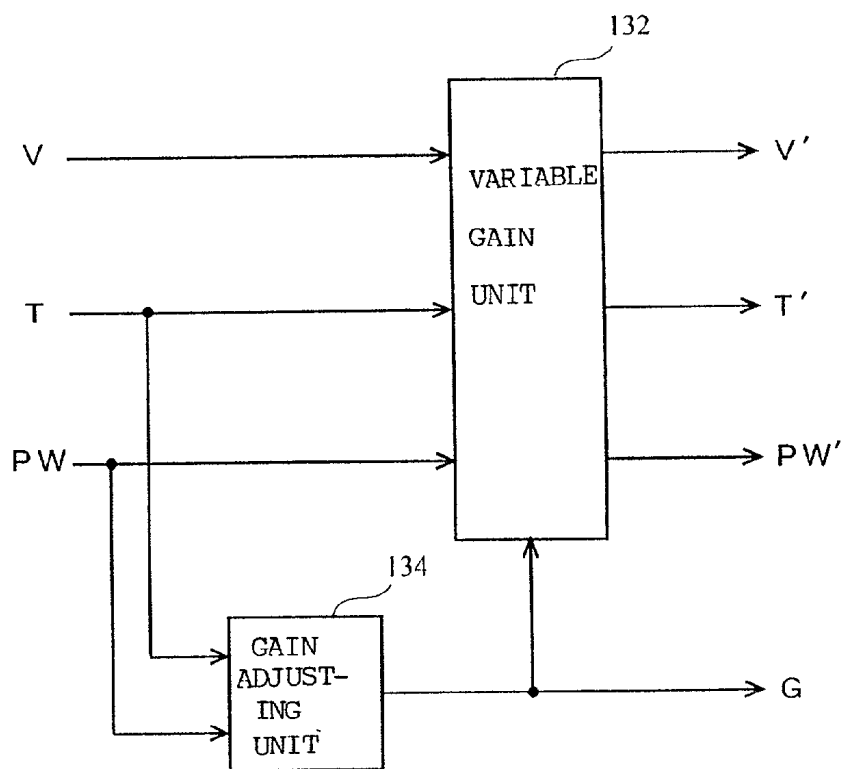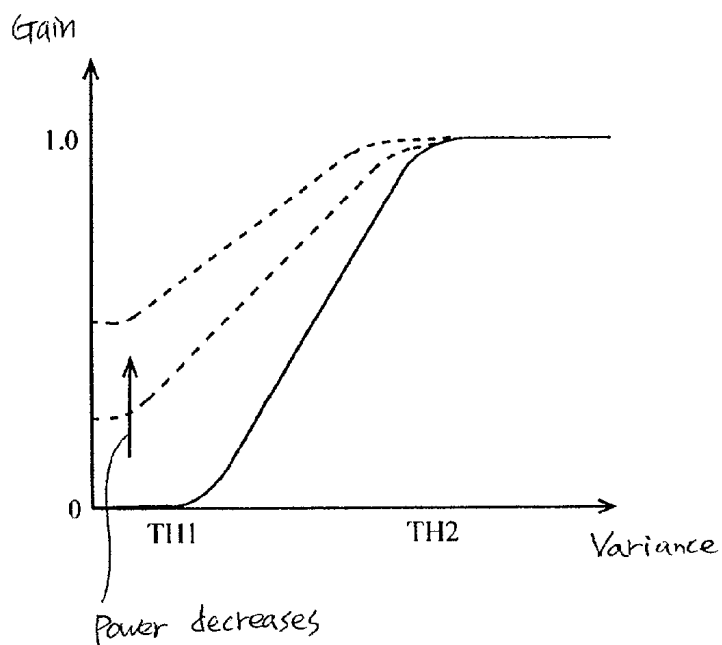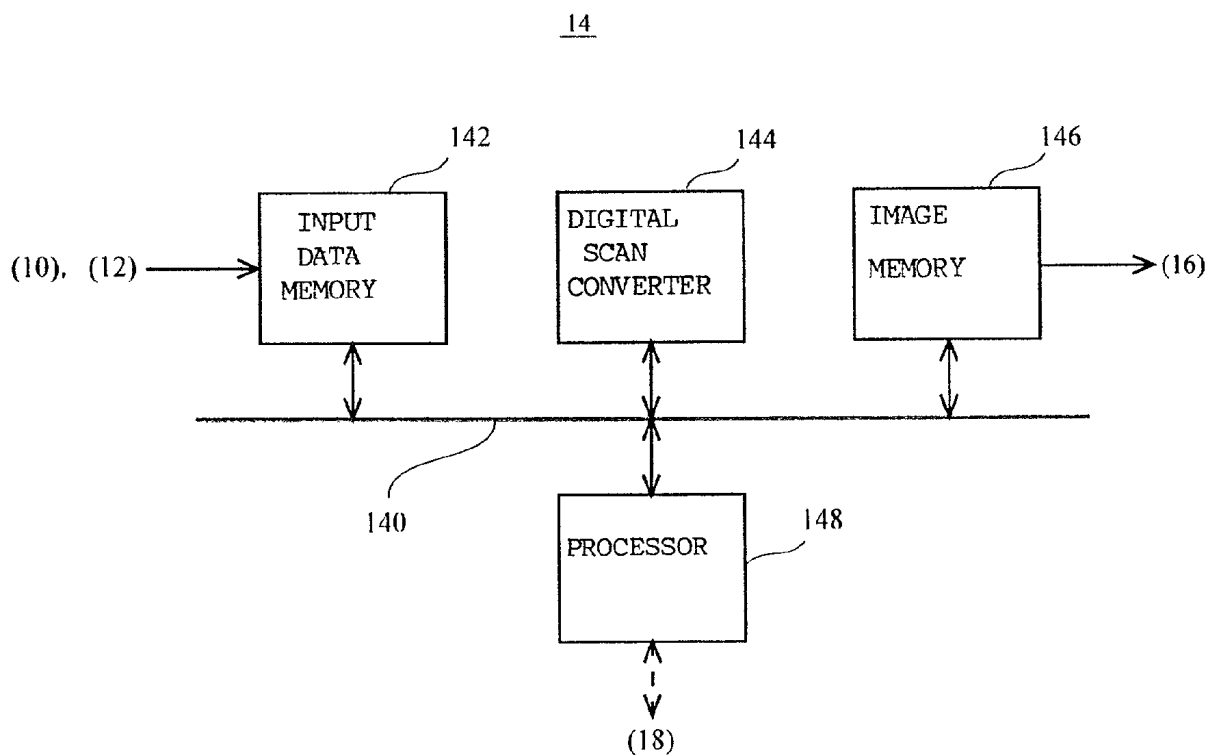(18)

IMAGE FORMING METHOD AND APPARATUS, AND ULTRASONIC IMAGING APPARATUS

BACKGROUND OF THE INVENTION

[0001]   The present invention relates to an image forming method and apparatus and a ultrasonic imaging apparatus, and particularly to an image forming method and apparatus for forming an image of a dynamic state based on the Doppler shift of a ultrasonic echo, and to a ultrasonic imaging apparatus which is equipped with the image forming apparatus.

[0002]   Ultrasonic imaging of a dynamic state of the blood flow is based on the use of the Doppler shift of a ultrasonic echo created by small particles, such as red blood cells, included in blood. The produced image is displayed as a color Doppler image.

[0003]   If it is needed to raise the magnitude of echo for the blood portion, a ultrasonic contrast agent is put in blood. The ultrasonic contrast agent is a liquid including numerous fine bubbles having a diameter of around several μm. Such contrast agent, in which fine bubbles produce an echo including the harmonics of the transmitted ultrasonic wave, is called harmonic contrast agent.

[0004]   Due to the Doppler shift of a ultrasonic echo of body tissues in motion, Doppler signals which are unrelated to blood, i.e., clutters, emerge. A ultrasonic echo of body tissues further includes harmonic components due to the nonlinearity of ultrasonic transmission, and therefore clutters also emerge in the harmonic region.

[0005]   Clutters attributable to body tissues are featured to have a large power and a small velocity as compared with blood-caused signals, and this fact is utilized to separate clutters from blood-caused signals thereby to diminish the clutters. However, this scheme is not sufficient to remove clutters completely.

SUMMARY OF THE INVENTION

[0006]   It is an object of the present invention is to accomplish an image forming method and apparatus capable of producing an image of dynamic state without clutters and a ultrasonic imaging apparatus which is equipped with the image forming apparatus.

[0007]   Before describing a means of solving the problem, the characteristics of a ultrasonic echo which a harmonic contrast agent produces will be explained. The harmonic contrast agent is featured to have its Doppler shift exhibiting the LOC (Loss of Correlation) phenomenon, besides the creation of a harmonic echo of the transmitted ultrasonic wave.

[0008]   The velocity evaluated based on the Doppler shift having the LOC phenomenon has an extremely large variance, and it can be distinguished clearly from clutters which are generally small in variance. The present invention utilizes such characteristics of the Doppler shift of the harmonic contrast agent.

[0009]   (1) The invention at a first viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, and adjusting the signal strength of the image depending on the value of variance.

[0010]   The invention at this viewpoint is designed to adjust the signal strength of the image depending on the value of the variance of velocity of the echo source, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0011]   (2) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, and minimizing the signal strength of the image when the variance is smaller than a predetermined value.

[0012]   The invention at this viewpoint is designed to minimize the signal strength of the image when the variance of the velocity of the echo source is smaller than a predetermined value, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image.

[0013]   (3) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, and multiplying a gain, which is given as a function of the variance, to the signal strength of the image.

[0014]   The invention at this viewpoint is designed to multiply a gain, which is given as a function of the variance, to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0015]   (4) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, evaluating the power of a signal having the Doppler shift, and multiplying a gain, which is given as a function of the variance and power, to the signal strength of the image.

[0016]   The invention at this viewpoint is designed to multiply a gain, which is given as a function of the variance and power to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0017] (5) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method of any one of the items (1) through (4), which is characterized in that the dynamic state is the velocity.

[0018] The invention at this viewpoint is capable of producing a velocity image which is rid of clutters.

[0019] (6) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method of any one of the items (1) through (4), which is characterized in that the dynamic state is the variance of velocity.

[0020] The invention at this viewpoint is capable of producing a variance image which is rid of clutters.

[0021] (7) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method of any one of the items (1) through (4), which is characterized in that the dynamic state is the combination of the velocity and variance.

[0022] The invention at this viewpoint is capable of producing a velocity/variance combination image which is rid of clutters.

[0023] (8) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method of any one of the items (1) through (4), which is characterized in that the dynamic state is the power of a signal having the Doppler shift.

[0024] The invention at this viewpoint is capable of producing a power image which is rid of clutters.

[0025] (9) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method of any one of the items (1) through (4), which is characterized in that the dynamic state is the combination of the power of a signal having the Doppler shift and the variance of velocity.

[0026] The invention at this viewpoint is capable of producing a power/variance combination image which is rid of clutters.

[0027] (10) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, and forming the image based on a signal which is given as a function of the variance.

[0028] The invention at this viewpoint is designed to form an image based on a signal which is given as a function of the variance, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0029] (11) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming method which forms an image indicative of a dynamic state of an echo source containing a harmonic

contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by evaluating the variance of the velocity of the echo source based on the Doppler shift, evaluating the power of a signal having the Doppler shift, and forming the image based on a signal which is given as a function of the variance and power.

[0030] The invention at this viewpoint is designed to form an image based on a signal which is given as a function of the variance and power, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0031] (12) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which adjusts the signal strength of the image depending on the value of variance.

[0032] The invention at this viewpoint is designed so that the signal strength adjusting means adjusts the signal strength of the image depending on the value of the variance of velocity of the echo source, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0033] (13) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which minimizes the signal strength of the image when the variance is smaller than a predetermined value.

[0034] The present invention at this viewpoint is designed so that the signal strength adjusting means minimizes the signal strength of the image when the variance of the velocity of the echo source is smaller than a predetermined value, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image.

[0035] (14) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which multiplies a gain, which is given as a function of the variance, to the signal strength of the image.

[0036] The invention at this viewpoint is designed so that the signal strength adjusting means multiplies a gain, which is given as a function of the variance, to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0037] (15) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, a power calculation means which evaluates the power of a signal having the Doppler shift, and a signal strength adjusting means which multiplies a gain, which is given as a function of the variance and power, to the signal strength of the image.

[0038] The invention at this viewpoint is designed so that the signal strength adjusting means multiplies a gain, which is given as a function of the variance and power, to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0039] (16) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus of any one of the items (12) through (15), which is characterized in that the dynamic state is the velocity.

[0040] The invention at this viewpoint is capable of producing a velocity image which is rid of clutters.

[0041] (17) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus of any one of the items (12) through (15), which is characterized in that the dynamic state is the variance of velocity.

[0042] The invention at this viewpoint is capable of producing a velocity image which is rid of clutters.

[0043] (18) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus of any one of the items (12) through (15), which is characterized in that the dynamic state is the combination of the velocity and variance.

[0044] The invention at this viewpoint is capable of producing a velocity/variance combination image which is rid of clutters.

[0045] (19) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus of any one of the items (12) through (15), which is characterized in that the dynamic state is the power of a signal having the Doppler shift.

[0046] The invention at this viewpoint is capable of producing a power image which is rid of clutters.

[0047] (20) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus of any one of the items (13) through (16), which is characterized in that the dynamic state is the combination of the power of a signal having the Doppler shift and the variance of velocity.

[0048] The invention at this viewpoint is capable of producing a power/variance combination image which is rid of clutters.

[0049] (21) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and an image forming means which forms the image based on a signal which is given as a function of the variance.

[0050] The invention at this viewpoint is designed so that the image forming means forms an image based on a signal which is given as a function of the variance, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0051] (22) The invention at other viewpoint intending to solve the above-mentioned problem resides in an image forming apparatus which forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, a power calculation means which evaluates the power of a signal having the Doppler shift, and an image forming means which forms the image based on a signal which is given as a function of the variance and power.

[0052] The invention at this viewpoint is designed so that the image forming means forms an image based on a signal which is given as a function of the variance and power, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0053] (23) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which adjusts the signal strength of the image depending on the value of variance.

[0054] The invention at this viewpoint is designed so that the signal strength adjusting means adjusts the signal strength of the image depending on the value of the variance of velocity of the echo source, and in consequence it is

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possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0055]   (24) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which minimizes the signal strength of the image when the variance is smaller than a predetermined value.

[0056]   The invention at this viewpoint is designed so that the signal strength adjusting means minimizes the signal strength of the image when the variance is smaller than a predetermined value, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image.

[0057]   (25) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and a signal strength adjusting means which multiplies a gain, which is given as a function of the variance, to the signal strength of the image.

[0058]   The invention at this viewpoint is designed so that the signal strength adjusting means multiplies a gain, which is given as a function of the variance, to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0059]   (26) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, a power calculation means which evaluates the power of a signal having the Doppler shift, and a signal strength adjusting means which multiplies a gain, which is given as a function of the variance and power, to the signal strength of the image.

[0060]   The invention at this viewpoint is designed so that the signal strength adjusting means multiplies a gain, which is given as a function of the variance and power, to the signal strength of the image, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is

also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0061]   (27) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus of any one of the items (23) through (26), which is characterized in that the dynamic state is the velocity.

[0062]   The invention at this viewpoint is capable of producing a velocity image which is rid of clutters.

[0063]   (28) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus of any one of the items (23) through (26), which is characterized in that the dynamic state is the variance of velocity.

[0064]   The invention at this viewpoint is capable of producing a variance image which is rid of clutters.

[0065]   (29) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus of any one of the items (23) through (26), which is characterized in that the dynamic state is the combination of the velocity and variance.

[0066]   The invention at this viewpoint is capable of producing a velocity/variance combination image which is rid of clutters.

[0067]   (30) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus of any one of the items (23) through (26), which is characterized in that the dynamic state is the power of a signal having the Doppler shift.

[0068]   The invention at this viewpoint is capable of producing a power image which is rid of clutters.

[0069]   (31) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus of any one of the items (23) through (26), which is characterized in that the dynamic state is the combination of the power of a signal having the Doppler shift and the variance of velocity.

[0070]   The invention at this viewpoint is capable of producing a power/variance combination image which is rid of clutters.

[0071]   (32) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, and an image forming means which forms the image based on a signal which is given as a function of the variance.

[0072]   The invention at this viewpoint is designed so that the image forming means forms an image based on a signal which is given as a function of the variance, and in consequence it is possible to prevent clutter elements which are

generally small in variance from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance.

[0073] (33) The invention at other viewpoint intending to solve the above-mentioned problem resides in a ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, and is characterized by comprising a variance calculation means which evaluates the variance of the velocity of the echo source based on the Doppler shift, a power calculation means which evaluates the power of a signal having the Doppler shift, and an image forming means which forms the image based on a signal which is given as a function of the variance and power.

[0074] The invention at this viewpoint is designed so that the image forming means forms an image based on a signal which is given as a function of the variance and power, and in consequence it is possible to prevent clutter elements which are generally small in variance and large in power from appearing in the image. It is also possible to emphasize the dynamic state image of the harmonic contrast agent which is generally large in variance and small in power.

[0075] Therefore, the present invention can accomplish an image forming method and apparatus capable of producing a dynamic state image without clutters and a ultrasonic imaging apparatus which is equipped with the image forming apparatus.

[0076] Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as illustrated in the accompanying invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0077] FIG. 1 is a block diagram of an apparatus which is an example of embodiment of this invention.

[0078] FIG. 2 is a block diagram of the transmit/receive section of the apparatus shown in FIG. 1.

[0079] FIG. 3 is a schematic diagram of sonic beam scanning by the apparatus shown in FIG. 1.

[0080] FIG. 4 is a schematic diagram of sonic beam scanning by the apparatus shown in FIG. 1.

[0081] FIG. 5 is a schematic diagram of sonic beam scanning by the apparatus shown in FIG. 1.

[0082] FIG. 6 is a block diagram of the B-mode processing section of the apparatus shown in FIG. 1.

[0083] FIG. 7 is a block diagram of the doppler processing section of the apparatus shown in FIG. 1.

[0084] FIG. 8 is a block diagram of part of the doppler processing section of the apparatus shown in FIG. 1.

[0085] FIG. 9 is a graph showing the gain adjustment characteristics of the apparatus shown in FIG. 8.

[0086] FIG. 10 is a graph showing the gain adjustment characteristics of the apparatus shown in FIG. 8.

[0087] FIG. 11 is a block diagram of part of the doppler processing section of the apparatus shown in FIG. 1.

[0088] FIG. 12 is a graph showing the gain adjustment characteristics of the apparatus shown in FIG. 11.

[0089] FIG. 13 is a block diagram of the image processing section of the apparatus shown in FIG. 1.

DETAILED DESCRIPTION OF THE
INVENTION

[0090] Embodiments of the present invention will be explained in detail with reference to the drawings. FIG. 1 shows by block diagram a ultrasonic imaging apparatus, which is an example of embodiment of this invention. The arrangement of this apparatus shows an example of embodiment the inventive apparatus. The operation of this apparatus shows an example of embodiment of the inventive method.

[0091] As shown in FIG. 1, this apparatus includes a ultrasonic probe 2. The ultrasonic probe 2 includes an array of a number of ultrasonic transducers (not shown). Each ultrasonic transducer is formed of a piezoelectric material, e.g., PZT (titanium (Ti) acid zirconium (Zr) acid) ceramics.

[0092] The ultrasonic probe 2 is used by the operator to come in contact with a subject 4. The subject 4 has in advance the injection of a ultrasonic contrast agent 42 by intravenous injection or the like. A harmonic contrast agent is used for the ultrasonic contrast agent 42.

[0093] The ultrasonic probe 2 is connected to a transmit/receive section 6. The transmit/receive section 6 supplies a drive signal to the ultrasonic probe 2, which then transmits a ultrasonic wave. The transmit/receive section 6 gets an echo signal which is received by the ultrasonic probe 2.

[0094] FIG. 2 shows by block diagram the transmit/receive section 6. As shown in the figure, the transmit/receive section 6 includes a transmission timing generation unit 602. The transmission timing generation unit 602 generates a transmission timing signal periodically and puts the signal into a transmission beamformer 604. The transmission timing signal has its period controlled by a control section 18 which will be explained later.

[0095] The transmission beamformer 604, which implements the beamforming for transmission, produces a beamforming signal for making a ultrasonic beam of a prescribed azimuth based on the transmission timing signal. The beamforming signal consists of a number of drive signals having time differences which correspond to the azimuths. Beamforming is controlled by the control section 18 which will be explained later. The transmission beamformer 604 puts the transmission beamforming signal into a transmit/receive switching unit 606.

[0096] The transmit/receive switching unit 606 puts the beamforming signal into the ultrasonic transducer array. The ultrasonic transducers which constitute transmission apertures generate ultrasonic waves having phase differences which correspond to the time differences of the drive signals. Based on the wavefront composition of these ultrasonic waves, a ultrasonic beam along the line of a certain azimuth is made.

[0097] The transmit/receive switching unit 606 is connected to a reception beamformer 610. The transmit/receive switching unit 606 puts the echo signals, which have been received by reception apertures of the ultrasonic transducer

array into the reception beamformer **610**. The reception beamformer **610**, which implements the beamforming for reception in correspondence to the transmission sonic beam, makes time differences among received echoes to adjust their phases and subsequently sums the echoes to form an echo reception signal along the sonic beam of a certain azimuth. The beamforming of reception is controlled by the control section **18** which will be explained later.

[0098] Transmission of ultrasonic beam takes place repetitively at a certain time interval in response to the transmission timing signal generated by the transmission timing generation unit **602**. In synchronism with the beam transmission, the transmission beamformer **604** and reception beamformer **610** alter the azimuth of sonic beam at a certain step. In consequence, the sonic beam scans the inside of the subject **4** in succession. The transmit/receive section **6** having this arrangement performs the scanning as shown in **FIG. 3** for example. Specifically, it scans a two-dimensional sectoral region **206** along the direction of θ with a sonic beam **202** extending in the z direction from a radiation point **200**, thereby performing the so-called sector scanning.

[0099] In case the transmission and reception apertures are formed as part of the ultrasonic transducer array, the apertures are moved in succession along the array, thereby implementing the scanning as shown in **FIG. 4** for example. Specifically, the sonic beam **202** which extends in the z direction from the radiation point **200** is moved along a locus **204** of straight line to scan a two-dimensional rectangular region **206** in the x direction, thereby performing the so-called linear scanning.

[0100] In case the ultrasonic transducer array is a so-called convex array in which the ultrasonic transducer array is arranged along an arc which is advanced toward the ultrasonic transmission direction, it is obviously possible based on sonic beam scanning similar to linear scanning to scan a two-dimensional sectoral region **206** along the θ direction by moving the radiation point **200** of the sonic beam **202** along an circular arc locus **204** as shown in **FIG. 5** for example, thereby performing the so-called convex scanning.

[0101] The transmit/receive section **6** is connected to a B-mode processing section **10** and doppler processing section **12**. The echo reception signal of each sonic beam released by the transmit/receive section **6** is put into the B-mode processing section **10** and doppler processing section **12**.

[0102] The B-mode processing section **10** functions to produce B-mode image data. The B-mode processing section **10** includes a logarithmic amplify unit **102** and an envelope detect unit **104** as shown in **FIG. 6**. The B-mode processing section **10** implements with its envelope detect unit **104** the logarithmic amplification for the echo reception signal and implements with its envelope detect unit **104** the envelope detection for the amplified signal thereby to produce a signal indicative of the strength of echo at each reflection point on the sonic beams, i.e., A-scope signal, and produce B-mode image data by sampling the amplitude of the A-scope signal as a value of luminous intensity.

[0103] The doppler processing section **12** functions to produce doppler image data. The doppler image data includes flow velocity data, variance data and power data which will be explained later.

[0104] The doppler processing section **12** has an orthogonal detection unit **120**, an MTI (Moving Target Identification) filter **122**, an autocorrelation calculation unit **124**, an average flow velocity calculation unit **126**, a variance calculation unit **128** and a power calculation unit **130**, as shown in **FIG. 7**.

[0105] The doppler processing section **12** implements with the orthogonal detection unit **120** the orthogonal detection for the echo reception signal, and implements with the MTI filter **122** the MTI process to evaluate the Doppler shift of the echo signal. It further implements with the autocorrelation calculation unit **124** the autocorrelation calculation for the output signal of the MTI filter **122**, evaluates the average of flow velocity V from the autocorrelation result with its flow velocity calculation unit **126**, evaluates with the variance calculation unit **128** the variance T of the flow velocity from the result of autocorrelation calculation, and evaluates with the power calculation unit **130** the power PW of the doppler signal from the result of autocorrelation calculation. The average of flow velocity will be called simply flow velocity, the variance of velocity will be called simply variance, and the power of doppler signal will be called simply power.

[0106] The variance calculation unit **128** is an example of embodiment of the inventive variance calculation means. The power calculation unit **130** is an example of embodiment of the inventive power calculation means.

[0107] The doppler processing section **12** produces data of each sonic beam indicative of the flow velocity V, variance T and power PW of the echo source in motion in the subject **4**. The data indicates the flow velocity, variance and power of each pixel on the sonic beam. The flow velocity represents the component in the sonic beam direction, with the directivity of coming toward or going away from the ultrasonic probe **2** being distinguished.

[0108] The doppler processing section **12** further includes a variable gain unit **132** as shown in **FIG. 8**. The variable gain unit **132** multiplies a variable gain to the flow velocity V, variance T and power PW, and delivers the resulting flow velocity V', variance T' and power PW' to the next stage.

[0109] The variable gain unit **132** has its gain adjusted by a gain adjusting unit **134**. The gain adjusting unit **134**, which receives the variance T as input signal, adjusts the gain of the variable gain unit **132** in accordance with the value of input signal. The section made up of the variable gain unit **132** and gain adjusting unit **134** is an example of embodiment of the inventive signal strength adjusting means.

[0110] Adjustment of gain of the variable gain unit **132** by the gain adjusting unit **134** is to have gain 1 or gain 0 depending on as to whether the variance is greater than or smaller than a certain threshold value TH, respectively, as shown in **FIG. 9** for example.

[0111] In consequence, when the variance exceeds the threshold value TH, gain 1 is applied to the flow velocity V, variance T and power PW, and the input signals of the variable gain unit **132** are sent intact to the next stage. Otherwise, when the variance is smaller than the threshold value TH, gain 0 is applied to the input signals, and the signals to be sent to the next stage are all nullified. This gain adjustment is carried out for each pixel.

[0112] The threshold value TH is determined depending on the variance value caused by the LOC phenomenon of the harmonic contrast agent. The determined threshold value TH is sufficiently greater than the variance of velocity of moving body tissues. Accordingly, based on the above-mentioned gain adjustment for the variable gain unit **132**, the apparent flow velocity, variance and power caused by the motion of body tissues are not sent to the next stage. Namely, the signals are sent to the next stage while being rid of clutters.

[0113] A region with a variance greater than the threshold value TH may be given a gain greater than 1, so that the flow velocity V, variance T and power PW indicative of the dynamic states of the harmonic contrast agent are emphasized.

[0114] Gain adjustment by the gain adjusting unit **134** may be continuous as a function of the variance as shown in **FIG. 10**, instead of the bi-level fashion described above. Specifically, the gain adjusting unit **134** provides gain 0 for a region with a variance smaller than threshold value TH1, provides gain 1 for a region with a variance greater than threshold value TH2, and varies the gain continuously from 0 to 1 for variance values between the threshold values TH1 and TH2.

[0115] The threshold value TH1 is determined to be slightly greater than the variance of clutters. The threshold value TH2 is determined to be slightly smaller than the variance of the harmonic contrast agent. Based on this gain adjustment scheme, it is possible to multiply a gain which depends on the variance value to the signals to be sent to the next stage for portions, e.g., blood flow, which do not contain the harmonic contrast agent.

[0116] The gain value G of the gain adjusting unit **134** having the characteristics shown in **FIG. 9** or **FIG. 10** becomes an input signal to the next stage in addition to the adjusted flow velocity V', variance T' and power PW'. The gain value G is produced for each pixel of each sonic beam. The gain value G is included in the doppler image data. The gain value G is an example of embodiment of this invention of the signal which is given as a function of the variance.

[0117] The gain adjusting unit **134** may be designed to receive the power PW as another input signal as shown in **FIG. 11**, so that it adjusts the gain of the variable gain unit **132** in terms of a function of the variance and power.

[0118] In this case, a region equal to or below the threshold value TH2 has its gain increased in inverse proportion to the power. Based on this adjustment scheme, it becomes possible to make a sufficiently small gain for clutters which are generally small in variance and large in power, while multiply an appropriate gain to the signals derived from a blood flow which does not contain the harmonic contrast agent and send the resulting signals to the next stage.

[0119] A region of the threshold value from TH1 to TH2 may be given a gain properly. A region above the threshold value TH2 may be given a gain greater than 1, so that the flow velocity V, variance T and power PW indicative of the dynamic states of the harmonic contrast agent are emphasized.

[0120] The gain value G of the gain adjusting unit **134** having the characteristics shown in **FIG. 12** becomes an input signal to the next stage in addition to the adjusted flow velocity V', variance T' and power PW'. The gain value G is produced for each pixel of each sonic beam. The gain value G is included in the doppler image data. The gain value G is an example of embodiment of this invention of the signal which is given as a function of the variance and power.

[0121] The B-mode processing section **10** and doppler processing section **12** are connected to an image processing section **14**. The image processing section **14** forms a B-mode image and a doppler image based on the data provided by the B-mode processing section **10** and doppler processing section **12**, respectively. The image processing section **14** is an example of embodiment of the inventive image forming means.

[0122] The image processing section **14** includes an input data memory **142**, a digital scan converter **144**, an image memory **146** and a processor **148** which are connected together by a bus **140** as shown in **FIG. 13**.

[0123] B-mode image data and doppler image data provided by the B-mode processing section **10** and doppler processing section **12** for each sonic beam are stored in the input data memory **142**. The data in the input data memory **142** is rendered the scan conversion by the digital scan converter **144** and stored in the image memory **146**. The processor **148** implements certain processings for the data in the input data memory **142** and image memory **146**.

[0124] The image processing section **14** is connected with a display section **16**. The display section **16** is supplied with the image signal from the image processing section **14**, so that it displays a picture based on the signal. The display section **16** is a graphic display unit which is capable of displaying a color picture.

[0125] The foregoing transmit/receive section **6**, B-mode processing section **10**, doppler processing section **12**, image processing section **14** and display section **16** are connected with the control section **18**. The control section **18** controls these sections by supplying the control signals to them. The control section **18** has inputs of various information signals from the controlled sections. The B-mode operation and doppler mode operation take place under control of the control section **18**.

[0126] The control section **18** is connected with an operation section **20**. The operation section **20** is operated by the operator to enter commands and information to the control section **18**. The operation section **20** is an operation panel which is equipped with a keyboard, pointing device and other operation devices.

[0127] The operation of this apparatus will be explained. The operator brings the ultrasonic probe **2** to come in contact with an intended portion of the subject **4**, and operates the operation section **20** to carry out the imaging operation which covers both the B mode and doppler mode for example. B-mode imaging and doppler-mode imaging take place on a time slice basis under control of the control section **18**. Specifically, for example, scannings for the B mode and doppler mode take place at such a proportion as one B-mode scanning in every certain number of doppler-mode scanning.

[0128] In the B mode, the transmit/receive section **6** operates on the ultrasonic probe **2** to scan the inside of subject **4** and receive the echo of each sonic beam. The B-mode processing section **10** amplifies with its logarithmic

amplify unit **102** the echo reception signal provided by the transmit/receive section **6** and implements the envelope detection with its envelope detect unit **104** to produce the A-scope signal, thereby producing B-mode image data for each sonic beam based on the signal.

[0129] The image processing section **14** stores the B-mode image data of each sonic beam into the input data memory **142**. In consequence, a sonic beam data space for the B-mode image data is formed in the input data memory **142**.

[0130] In the doppler mode, the transmit/receive section **6** operates on the ultrasonic probe **2** to scan the inside of the subject **4** and receive the echo of each sonic beam. In this operation, a number of times of ultrasonic wave transmission and reception take place for each sonic beam.

[0131] The doppler processing section **12** implements with its orthogonal detection unit **120** the orthogonal detection for the echo reception signal, implements the MTI process with its MTI filter **122**, and evaluates the autocorrelation with its autocorrelation calculation unit **124**. It further evaluates the flow velocity V from the autocorrelation result with its flow velocity calculation unit **126**, evaluates the variance T with its variance calculation unit **128**, and evaluates the power PW with its power calculation unit **130**. These calculated values become data indicative of the flow velocity, variance and power of the echo source of each pixel and each sonic beam.

[0132] These data yield the flow velocity V', variance T' and power PW' by being fed through the variable gain unit **132**, which also provide the gain value G. The flow velocity V', variance T', power PW' and gain value G' are put into the image processing section **14** as doppler image data.

[0133] The image processing section **14** stores doppler image data of each pixel and each sonic beam provided by the doppler processing section **12** into the input data memory **142**. In consequence, a sonic beam data space for each doppler image data is formed in the input data memory **142**.

[0134] The processor **148** implements with its digital scan converter **144** the scan conversion for the B-mode image data and doppler image data in the input data memory **142**, and writes the resulting data into the image memory **146**.

[0135] In this case, the doppler image data is written as flow velocity distribution image data which is the combination of the flow velocity V' and variance T', power doppler image data with variance which is the power-doppler image data using the power PW' or the combination of the power PW' and variance T', the variance image data using the variance T', and the gain image data using the gain value G.

[0136] The processor **148** writes the B-mode image data and each doppler image data into separate areas. The display section **16** displays a picture which is based on the B-mode image data and each doppler image data.

[0137] The B-mode image becomes a tomographic image of the body tissues on the sonic beam scanning plane. Among the color doppler images, the flow velocity distribution image becomes an image indicative of a two-dimensional distribution of flow velocities of the echo source. This image has different colors for different flow directions, has

different luminous intensities for different flow velocities, and intensifies certain colors thereby to vary the purity of display colors for different variances.

[0138] The power doppler image becomes an image indicative of a two-dimensional distribution of the power of the doppler signal. This image reveals the presence of echo sources in motion. The luminous intensity in display color of the image corresponds to the power. With the variance being combined to it, certain colors are intensified thereby to vary the purity of display colors for different variances.

[0139] The variance image becomes an image indicative of a two-dimensional distribution of variance values. This image also reveals the presence of echo sources in motion. The luminous intensity in display color corresponds to the value of variance.

[0140] The gain image becomes an image indicative of a two-dimensional distribution of gains of pixels. It also reveals the presence of echo sources in motion. The luminous intensity in display color corresponds to the value of gain. In case the gain characteristics shown in **FIG. 9** is used, the presence of echo sources in motion is revealed in terms of a bi-level image. In case the gain characteristics shown in **FIG. 10** or **FIG. 11** is used, the echo sources are revealed in terms of a tone image with saturation.

[0141] Every color doppler image is displayed by being rid of clutters and emphasized for the image of harmonic contrast agent **42** based on the gain adjustment shown in **FIG. 9**, **FIG. 10** or **FIG. 12**. In consequence, the observer can know the state of doping of the harmonic contrast agent **42** in the subject **4**.

[0142] The observer can know the presence of an arterial blood flow in a doped portion at an early phase of contrast agent injection. The observer can know the presence of a pylic blood flow for example in a doped portion at a mid phase of contrast agent injection. The observer can know the presence of a venous blood flow in a doped portion at a late phase of contrast agent injection.

[0143] With these images being displayed in an overlap fashion on a B-mode image on the display section **16**, it is possible to observe a color doppler image which reveals clearly the positional relation with body tissues.

[0144] Many widely different embodiments of the invention may be configured without departing from the spirit and the scope of the present invention is not limited to the specific embodiments described in the specification, except as defined in the appended claims.

   1. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

    evaluating the variance of the velocity of said echo source based on the Doppler shift; and

    adjusting the signal strength of the image depending on the value of variance.

   2. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

evaluating the variance of the velocity of said echo source based on the Doppler shift; and

minimizing the signal strength of the image when the variance is smaller than a predetermined value.

3. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

evaluating the variance of the velocity of said echo source based on the Doppler shift; and

multiplying a gain, which is given as a function of the variance, to the signal strength of the image.

4. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

evaluating the variance of the velocity of said echo source based on the Doppler shift;

evaluating the power of a signal having the Doppler shift; and

multiplying a gain, which is given as a function of the variance and power, to the signal strength of the image.

5. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

evaluating the variance of the velocity of said echo source based on the Doppler shift; and

forming the image based on a signal which is given as a function of the variance.

6. An image forming method of forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising the steps of:

evaluating the variance of the velocity of said echo source based on the Doppler shift;

evaluating the power of a signal having the Doppler shift; and

forming the image based on a signal which is given as a function of the variance and power.

7. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

signal strength adjusting means for adjusting the signal strength of the image depending on the value of variance.

8. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

signal strength adjusting means for minimizing the signal strength of the image when the variance is smaller than a predetermined value.

9. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

signal strength adjusting means for multiplying a gain, which is given as a function of the variance, to the signal strength of the image.

10. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift;

power calculation means for evaluating the power of a signal having the Doppler shift; and

signal strength adjusting means for multiplying a gain, which is given as a function of the variance and power, to the signal strength of the image.

11. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

image forming means for forming the image based on a signal which is given as a function of the variance.

12. An image forming apparatus for forming an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of a ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift;

power calculation means for evaluating the power of a signal having the Doppler shift; and

image forming means for forming the image based on a signal which is given as a function of the variance and power.

13. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

signal strength adjusting means for adjusting the signal strength of the image depending on the value of variance.

14. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

signal strength adjusting means for minimizing the signal strength of the image when the variance is smaller than a predetermined value.

15. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift;

signal strength adjusting means for multiplying a gain, which is given as a function of the variance, to the signal strength of the image.

16. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift;

power calculation means for evaluating the power of a signal having the Doppler shift; and

signal strength adjusting means for multiplying a gain, which is given as a function of the variance and said power, to the signal strength of the image.

17. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift; and

image forming means for forming the image based on a signal which is given as a function of the variance.

18. A ultrasonic imaging apparatus which transmits a ultrasonic wave, receives an echo thereof, and forms an image indicative of a dynamic state of an echo source containing a harmonic contrast agent based on the Doppler shift of the ultrasonic echo, comprising:

variance calculation means for evaluating the variance of the velocity of said echo source based on the Doppler shift;

power calculation means which evaluates the power of a signal having the Doppler shift; and

image forming means for forming the image based on a signal which is given as a function of the variance and power.

* * * * *

专利名称(译)	图像形成方法和设备，以及超声成像设备		
公开(公告)号	US20010025143A1	公开(公告)日	2001-09-27
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[标]申请(专利权)人(译)	铃木 洋一		
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当前申请(专利权)人(译)	铃木洋一		
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发明人	SUZUKI, YOICHI		
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摘要(译)

在基于超声回波的多普勒频移形成没有表示包含谐波造影剂的回波源的动态的杂波的图像时，基于多普勒频移评估回波源的速度的方差T，并且根据方差值调整图像的信号强度。