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(54) **ULTRASOUND IMAGE PROCESSING METHOD AND ULTRASOUND IMAGING APPARATUS THEREOF**

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(57) **ABSTRACT**

Provided is an ultrasound imaging apparatus. The ultrasound imaging apparatus includes a data acquiring unit transmitting an ultrasound signal to a region of interest (ROI) of an object and then receiving an ultrasound echo signal reflected from the ROI of the object, and a control unit calculating a shear modulus of at least one point in the ROI and a strain of the at least one point, based on the received ultrasound echo signal, and calculating a stress applied to the at least one point by using the shear modulus and the strain.

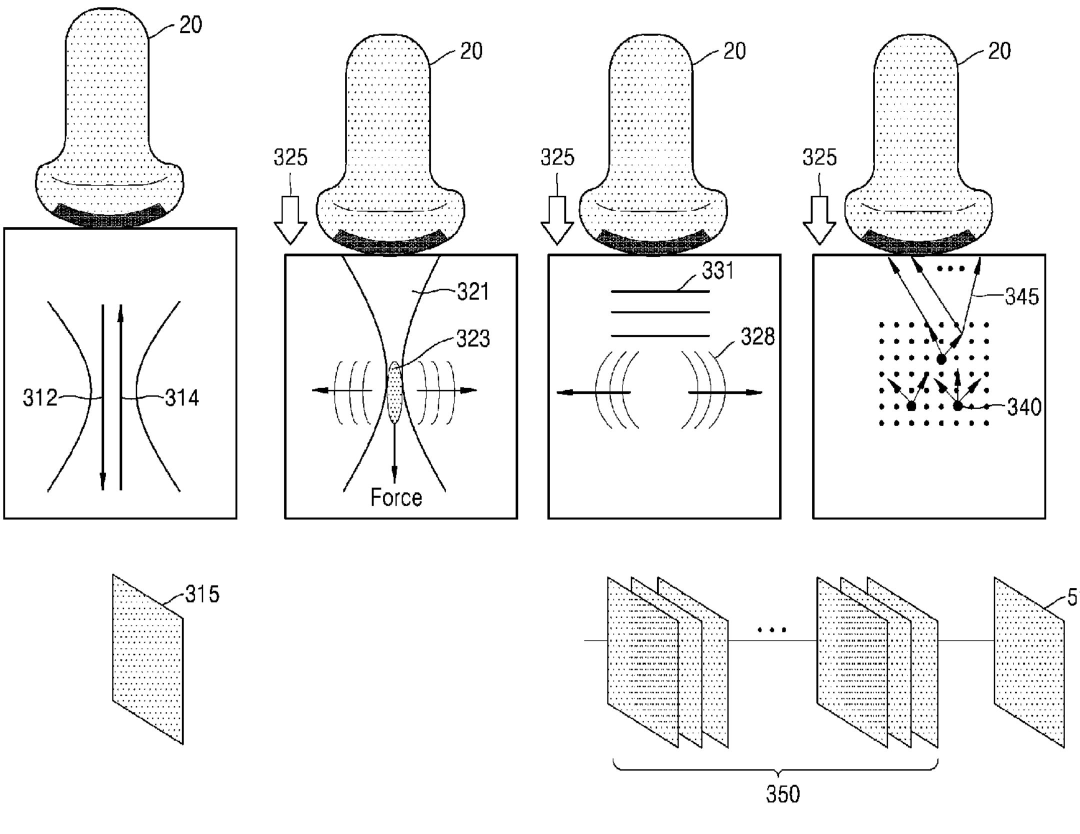


FIG. 1

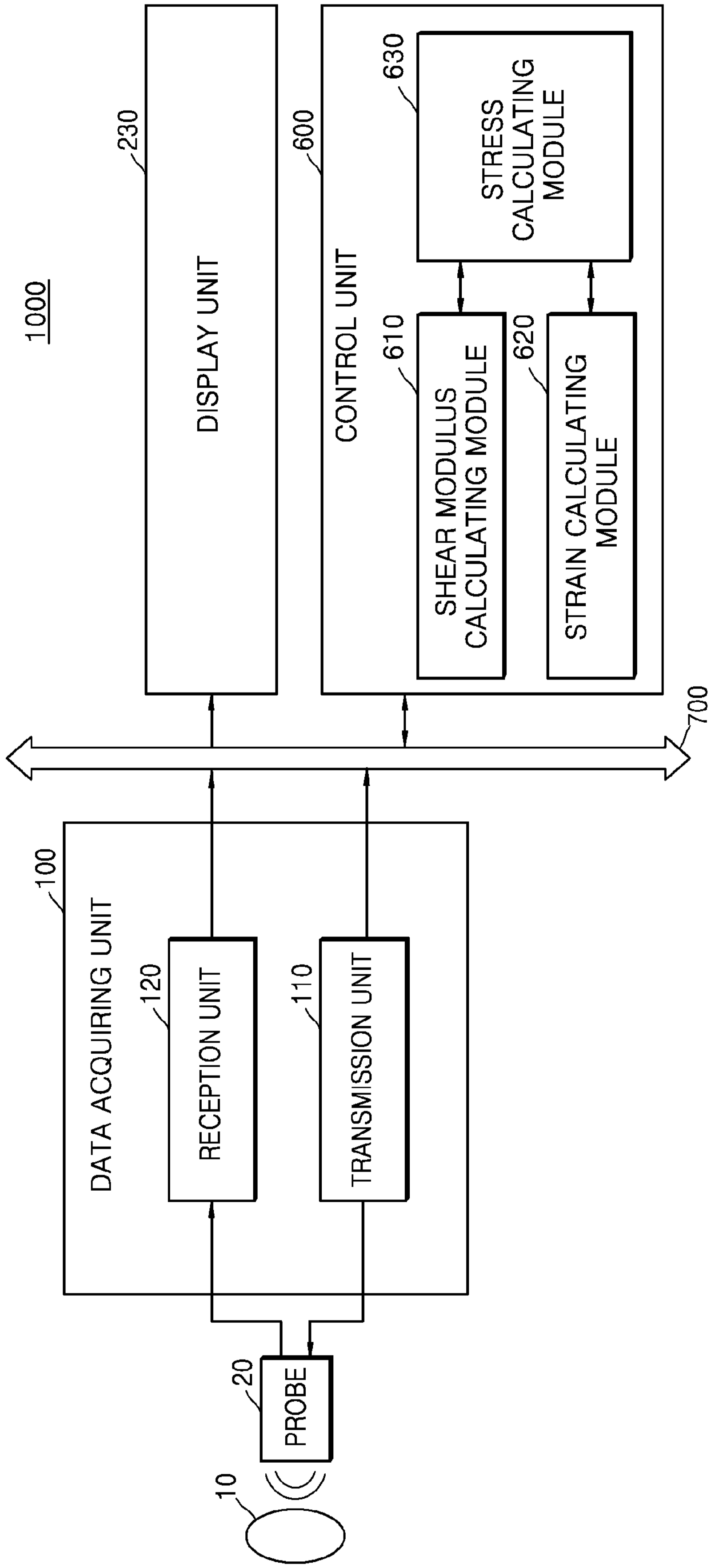

1000
10
20
PROBE
100
DATA ACQUIRING UNIT
120
RECEPTION UNIT
110
TRANSMISSION UNIT
700
230
DISPLAY UNIT
600
CONTROL UNIT
610
SHEAR MODULUS CALCULATING MODULE
620
STRAIN CALCULATING MODULE
630
STRESS CALCULATING MODULE

FIG. 2

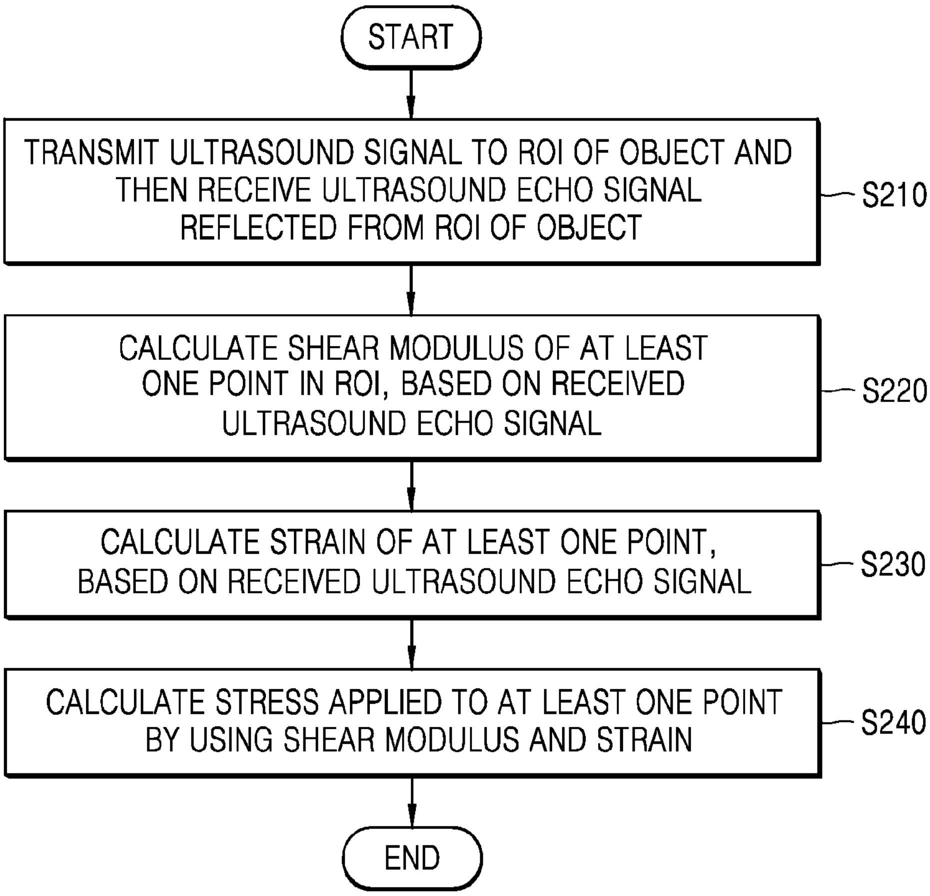

START
TRANSMIT ULTRASOUND SIGNAL TO ROI OF OBJECT AND THEN RECEIVE ULTRASOUND ECHO SIGNAL REFLECTED FROM ROI OF OBJECT
S210
CALCULATE SHEAR MODULUS OF AT LEAST ONE POINT IN ROI, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S220
CALCULATE STRAIN OF AT LEAST ONE POINT, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S230
CALCULATE STRESS APPLIED TO AT LEAST ONE POINT BY USING SHEAR MODULUS AND STRAIN
S240
END

FIG. 3

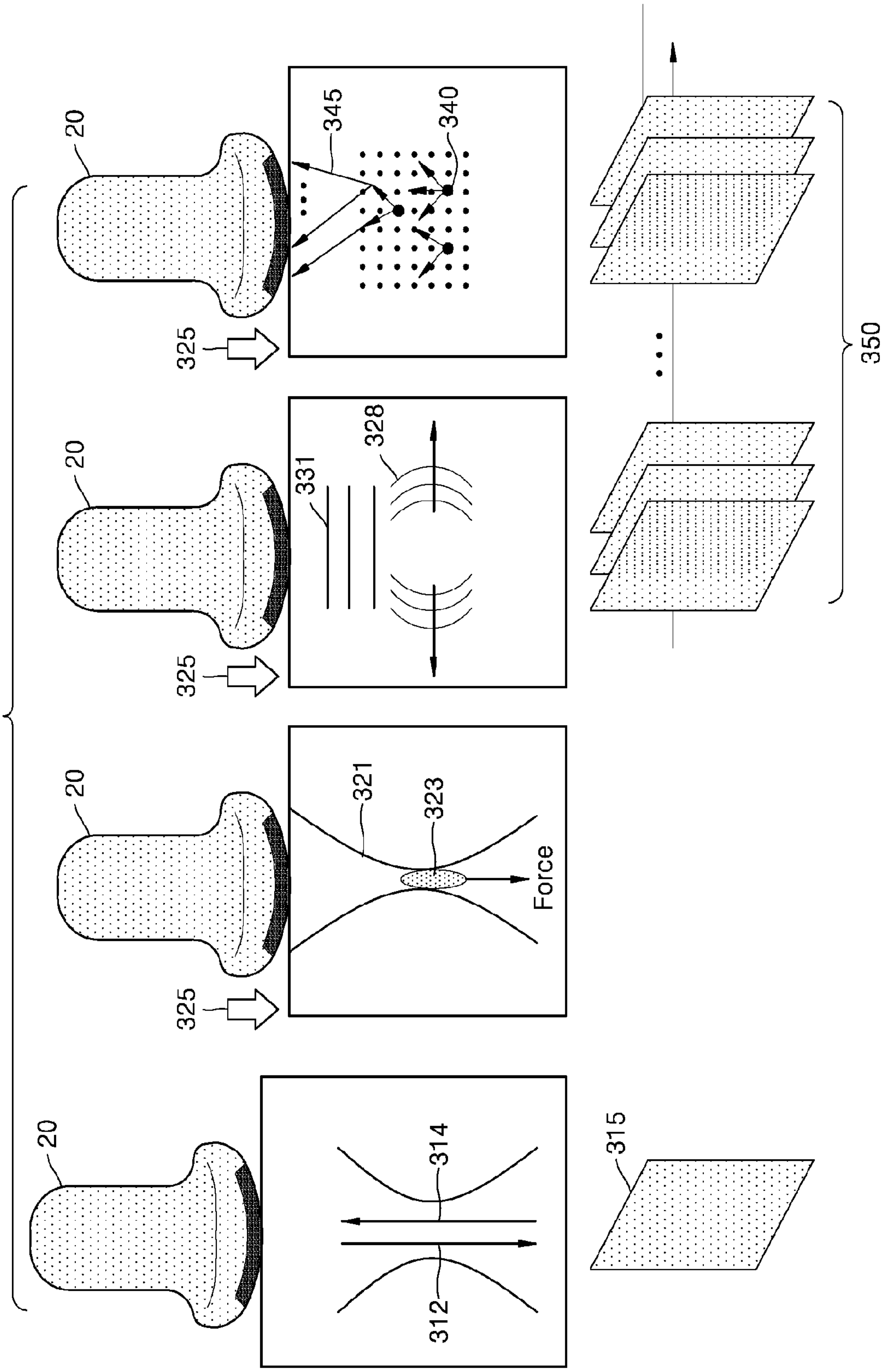


FIG. 4

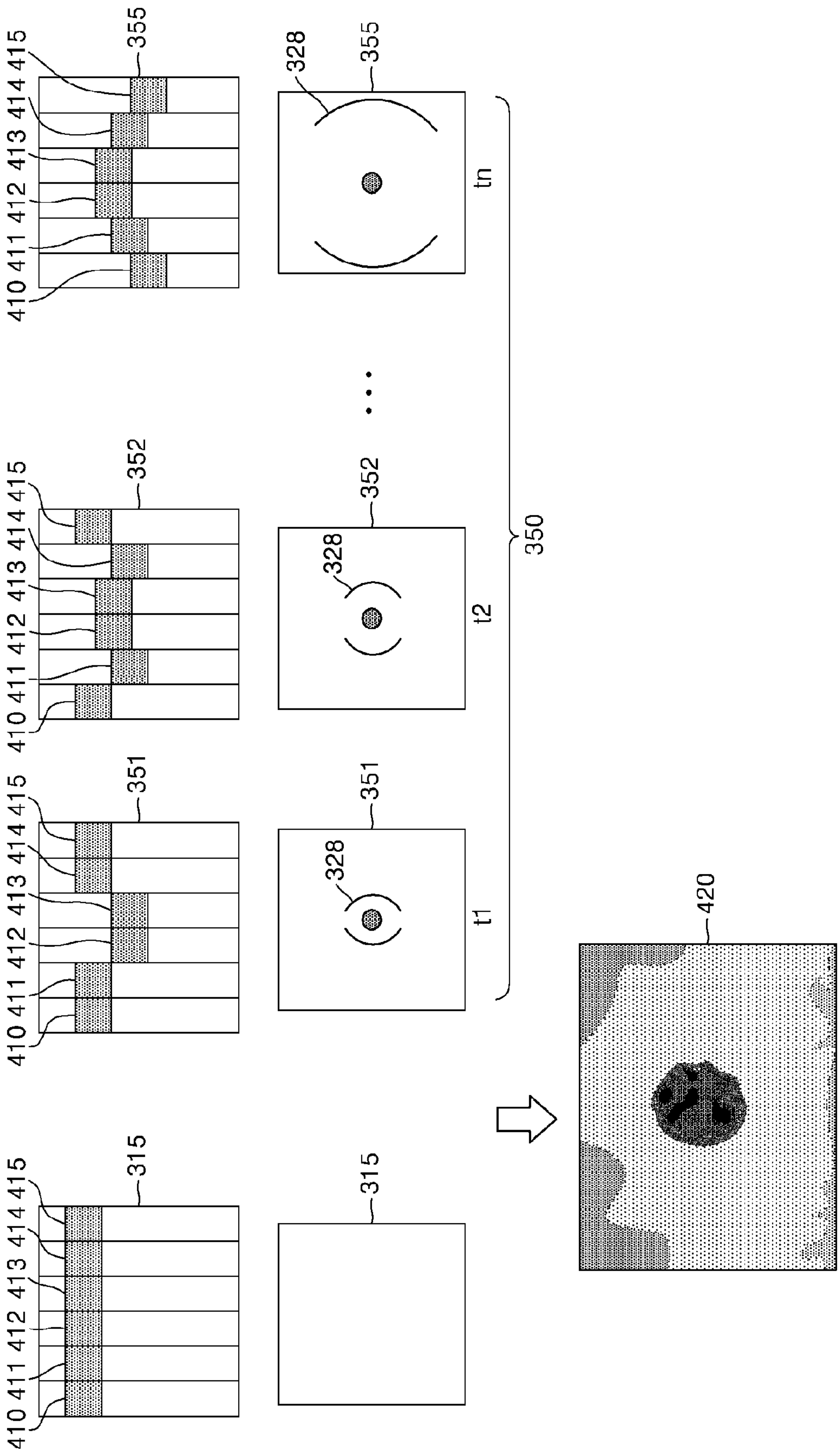


FIG. 5

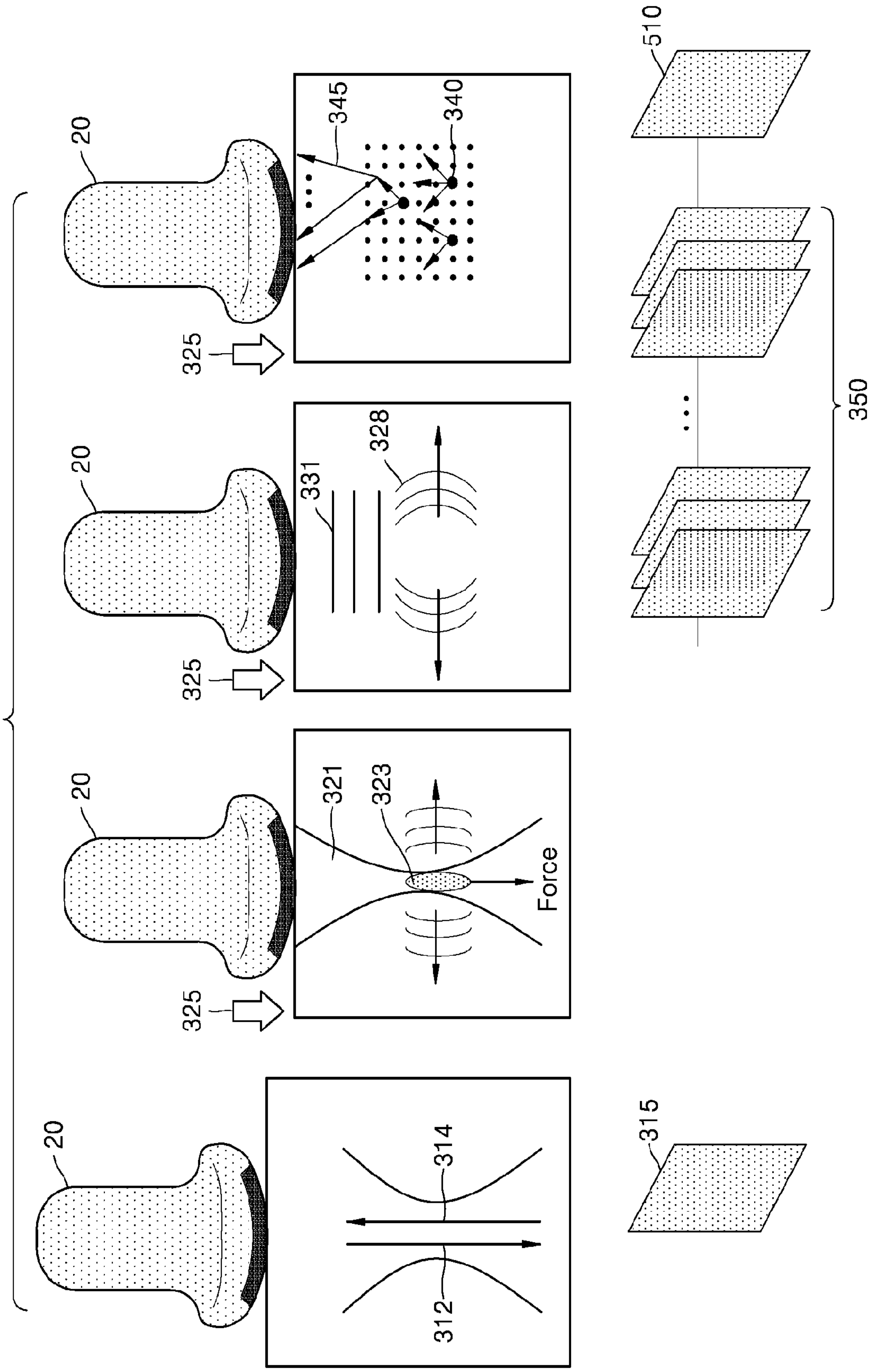

20
20
20
20
325
325
325
345
340
331
328
321
323
Force
314
312
315
510
350

FIG. 6A

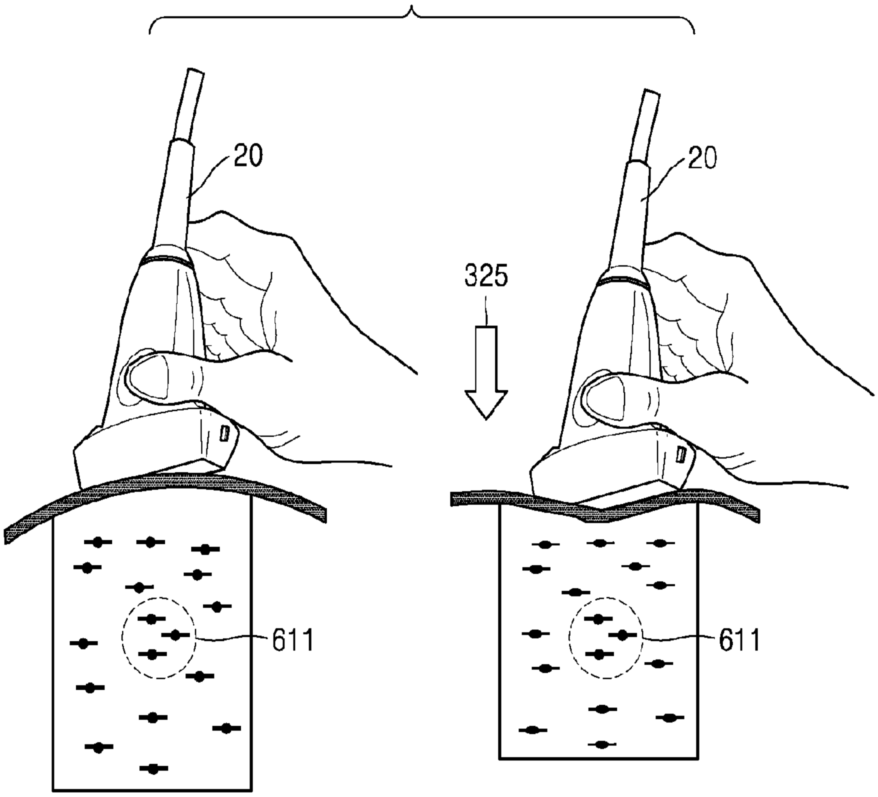


FIG. 6B

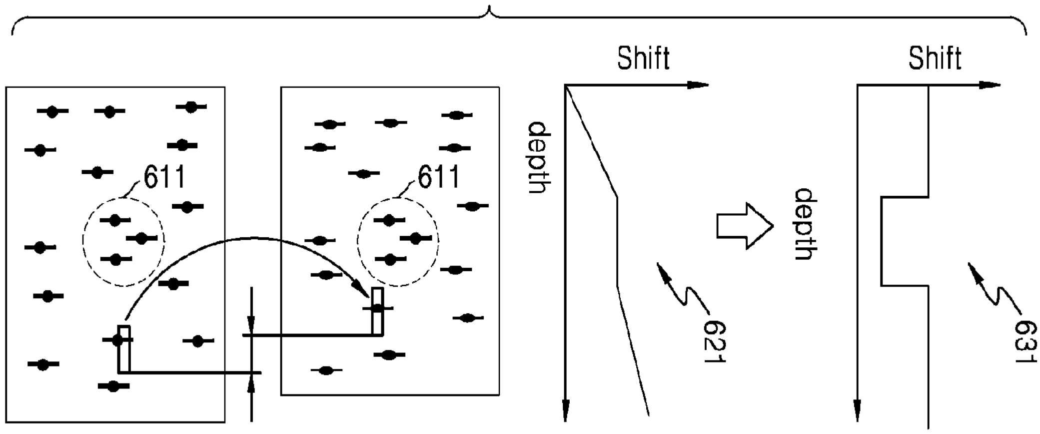


FIG. 7

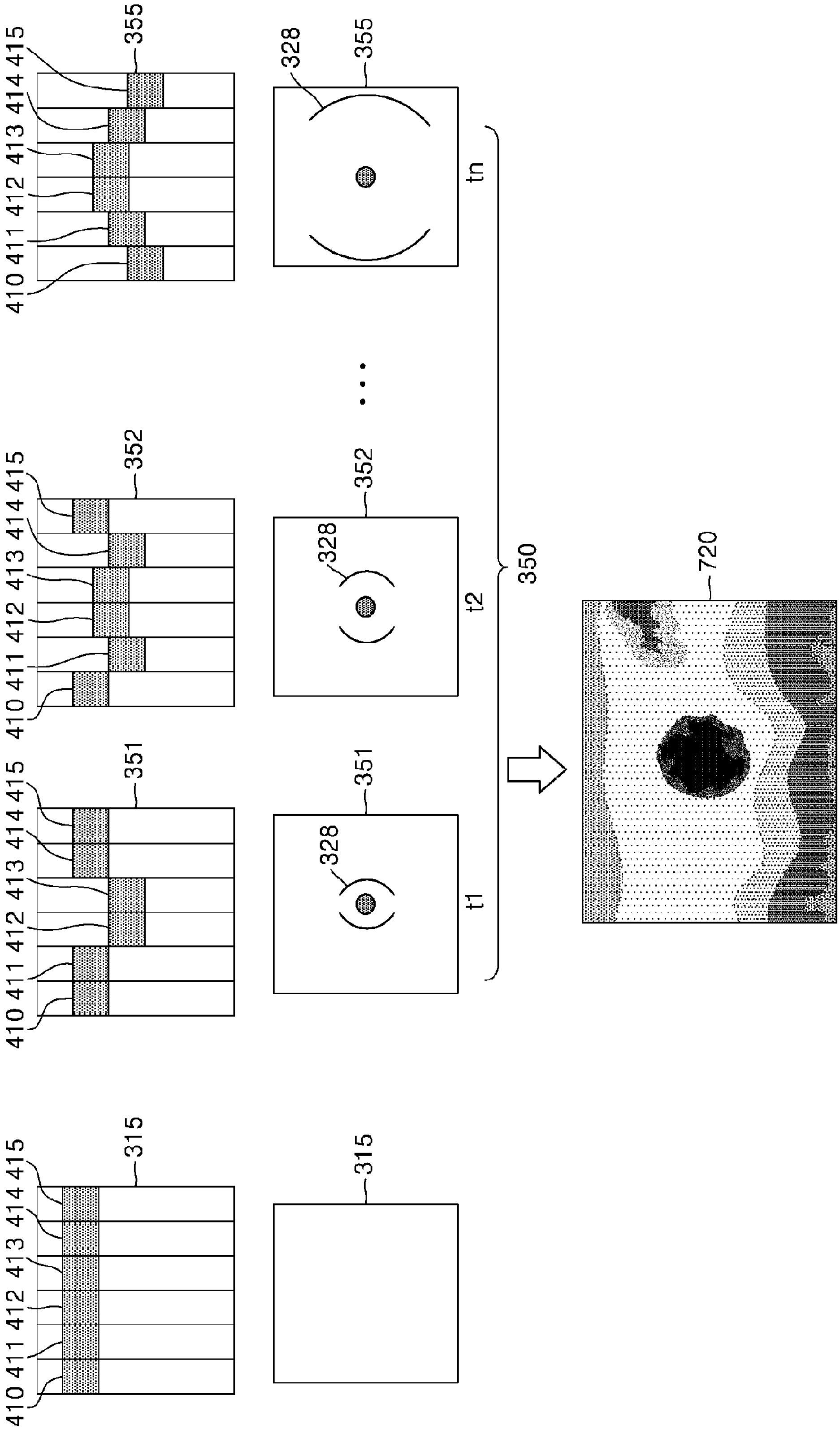


FIG. 8

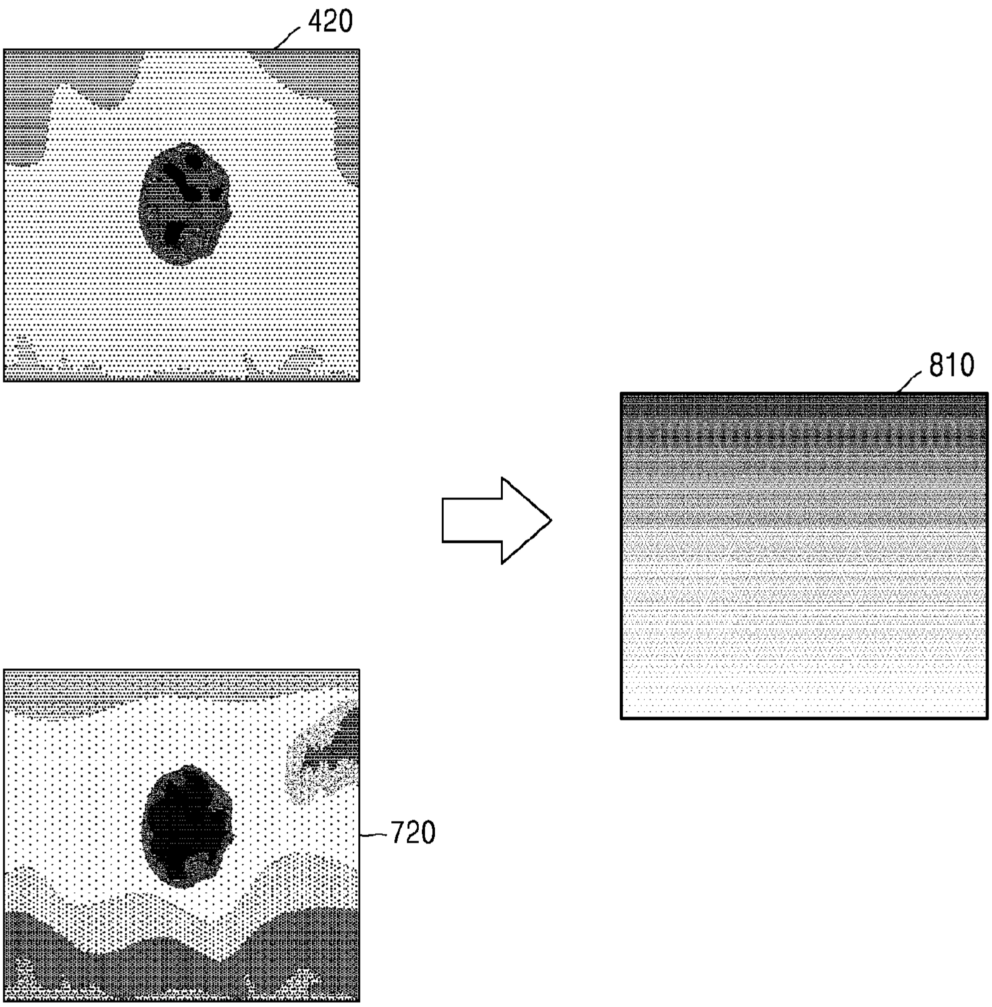


FIG. 9

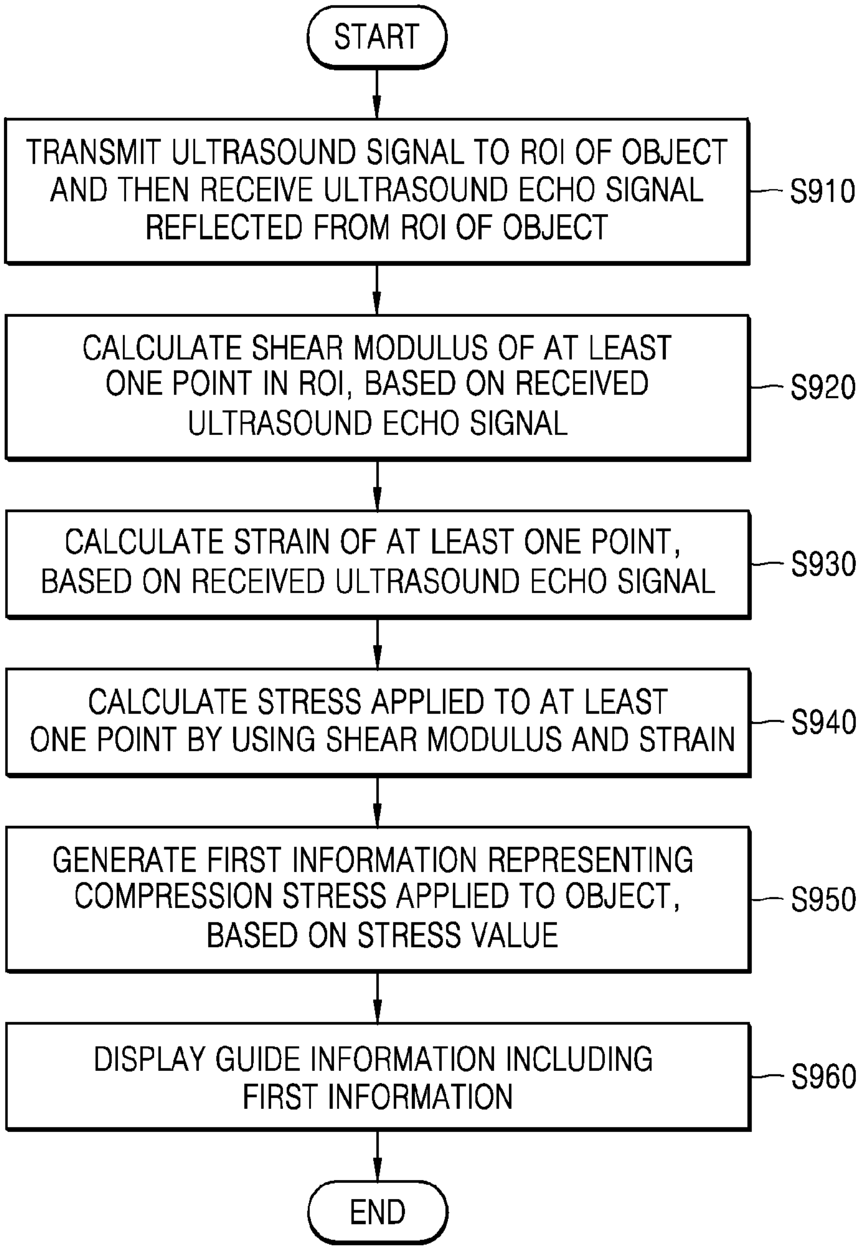

START
TRANSMIT ULTRASOUND SIGNAL TO ROI OF OBJECT AND THEN RECEIVE ULTRASOUND ECHO SIGNAL REFLECTED FROM ROI OF OBJECT
S910
CALCULATE SHEAR MODULUS OF AT LEAST ONE POINT IN ROI, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S920
CALCULATE STRAIN OF AT LEAST ONE POINT, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S930
CALCULATE STRESS APPLIED TO AT LEAST ONE POINT BY USING SHEAR MODULUS AND STRAIN
S940
GENERATE FIRST INFORMATION REPRESENTING COMPRESSION STRESS APPLIED TO OBJECT, BASED ON STRESS VALUE
S950
DISPLAY GUIDE INFORMATION INCLUDING FIRST INFORMATION
S960
END

FIG. 10

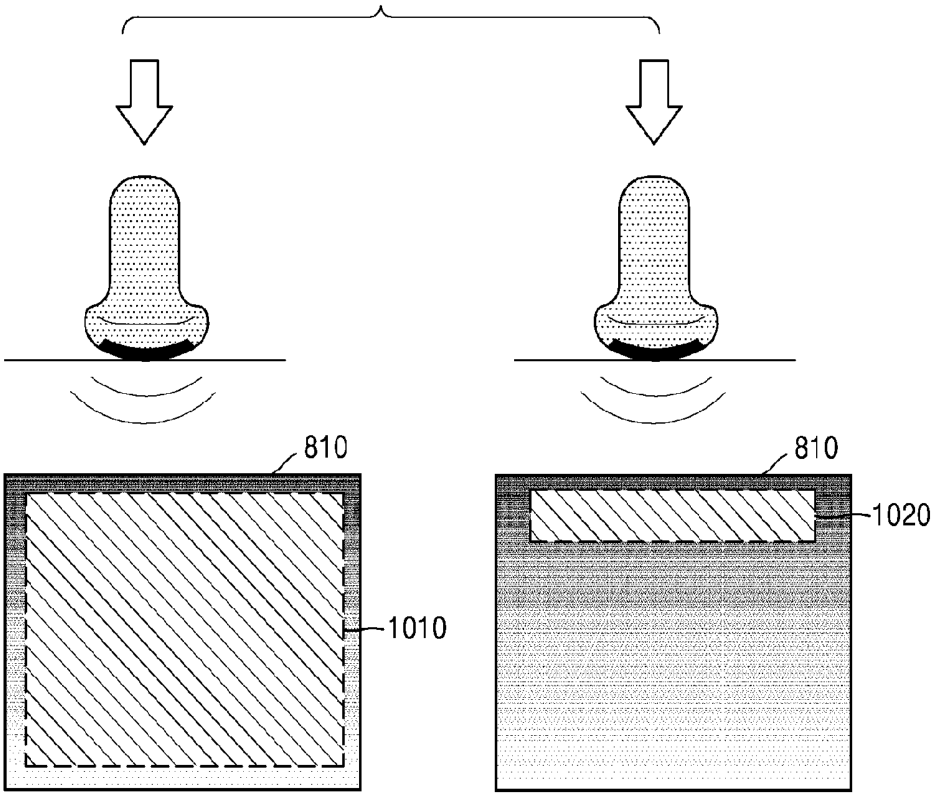


FIG. 11

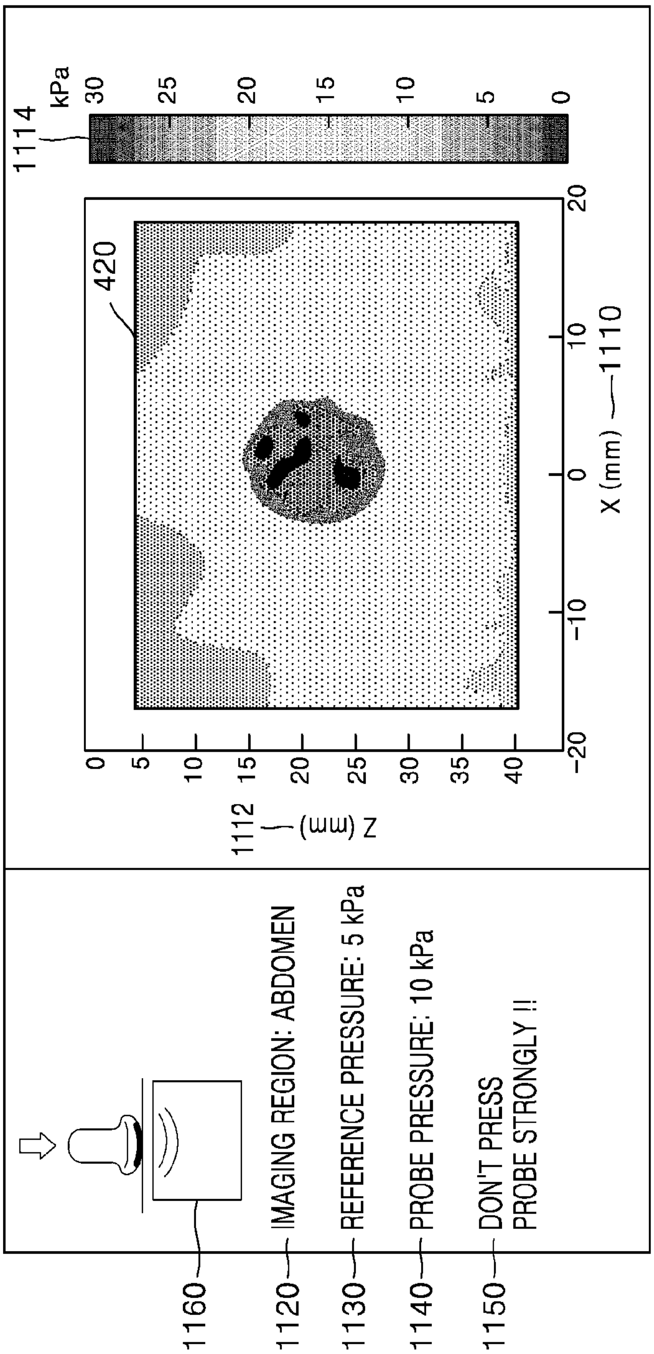

1160
1120 IMAGING REGION: ABDOMEN
1130 REFERENCE PRESSURE: 5 kPa
1140 PROBE PRESSURE: 10 kPa
1150 DON'T PRESS PROBE STRONGLY !!
1112 Z (mm)
0 5 10 15 20 25 30 35 40
−20 −10 0 10 20
X (mm) 1110
420
1114
kPa
30 25 20 15 10 5 0

FIG. 12

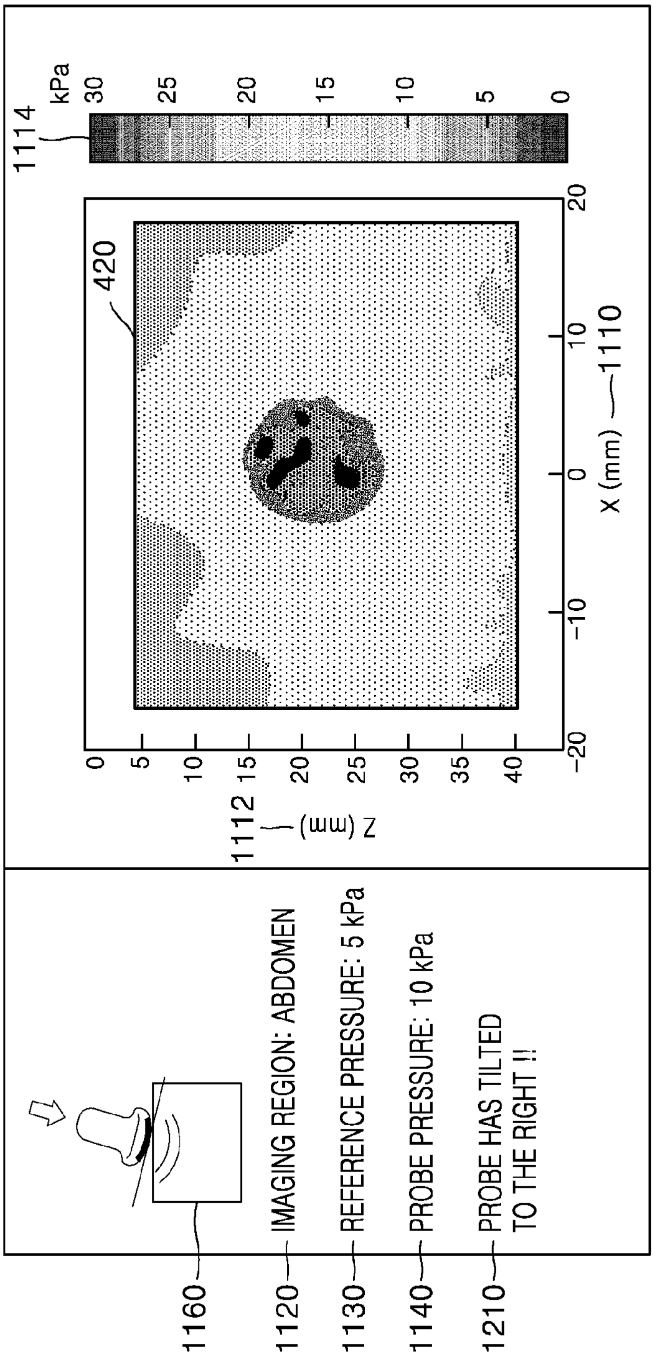

1114
kPa
30
25
20
15
10
5
0
420
1110
1112
Z (mm)
X (mm)
0
5
10
15
20
25
30
35
40
−20
−10
0
10
20
1160
1120
IMAGING REGION: ABDOMEN
1130
REFERENCE PRESSURE: 5 kPa
1140
PROBE PRESSURE: 10 kPa
1210
PROBE HAS TILTED
TO THE RIGHT !!

FIG. 13

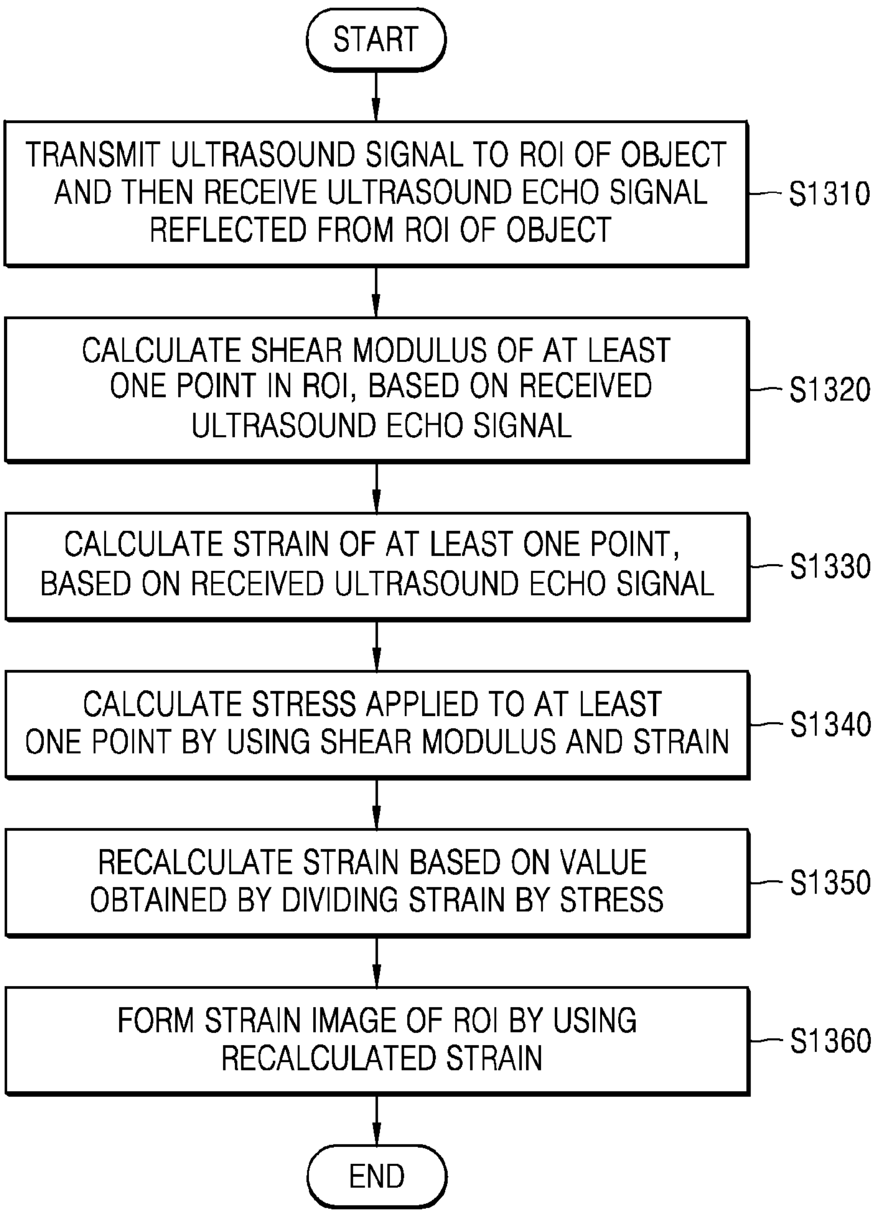

START
TRANSMIT ULTRASOUND SIGNAL TO ROI OF OBJECT AND THEN RECEIVE ULTRASOUND ECHO SIGNAL REFLECTED FROM ROI OF OBJECT
S1310
CALCULATE SHEAR MODULUS OF AT LEAST ONE POINT IN ROI, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S1320
CALCULATE STRAIN OF AT LEAST ONE POINT, BASED ON RECEIVED ULTRASOUND ECHO SIGNAL
S1330
CALCULATE STRESS APPLIED TO AT LEAST ONE POINT BY USING SHEAR MODULUS AND STRAIN
S1340
RECALCULATE STRAIN BASED ON VALUE OBTAINED BY DIVIDING STRAIN BY STRESS
S1350
FORM STRAIN IMAGE OF ROI BY USING RECALCULATED STRAIN
S1360
END

FIG. 14

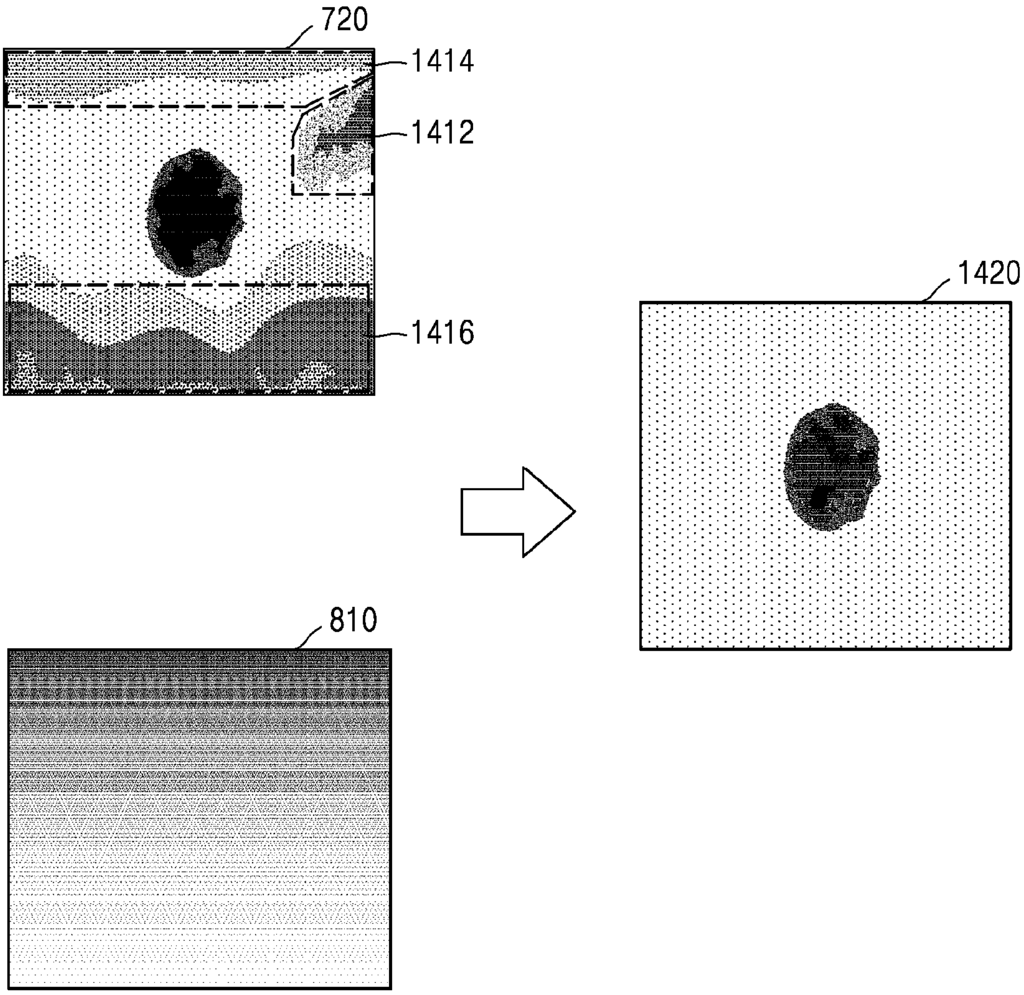


FIG. 15

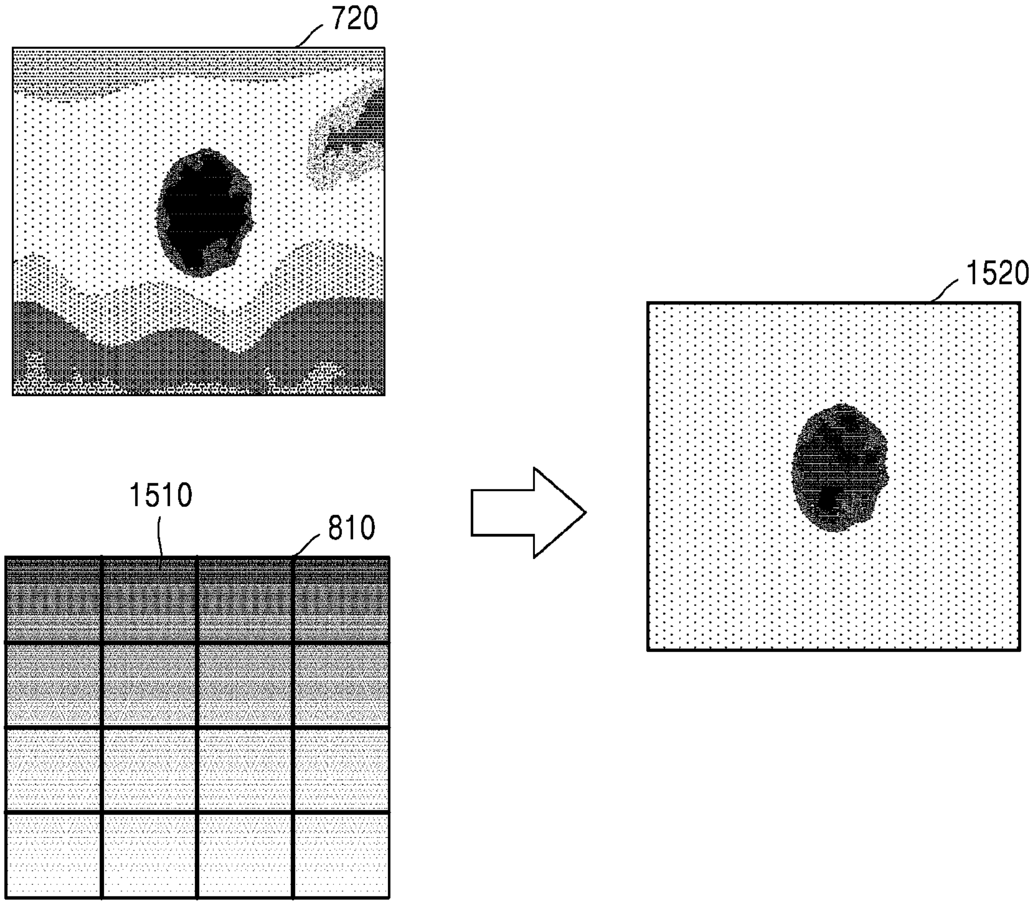


FIG. 16A

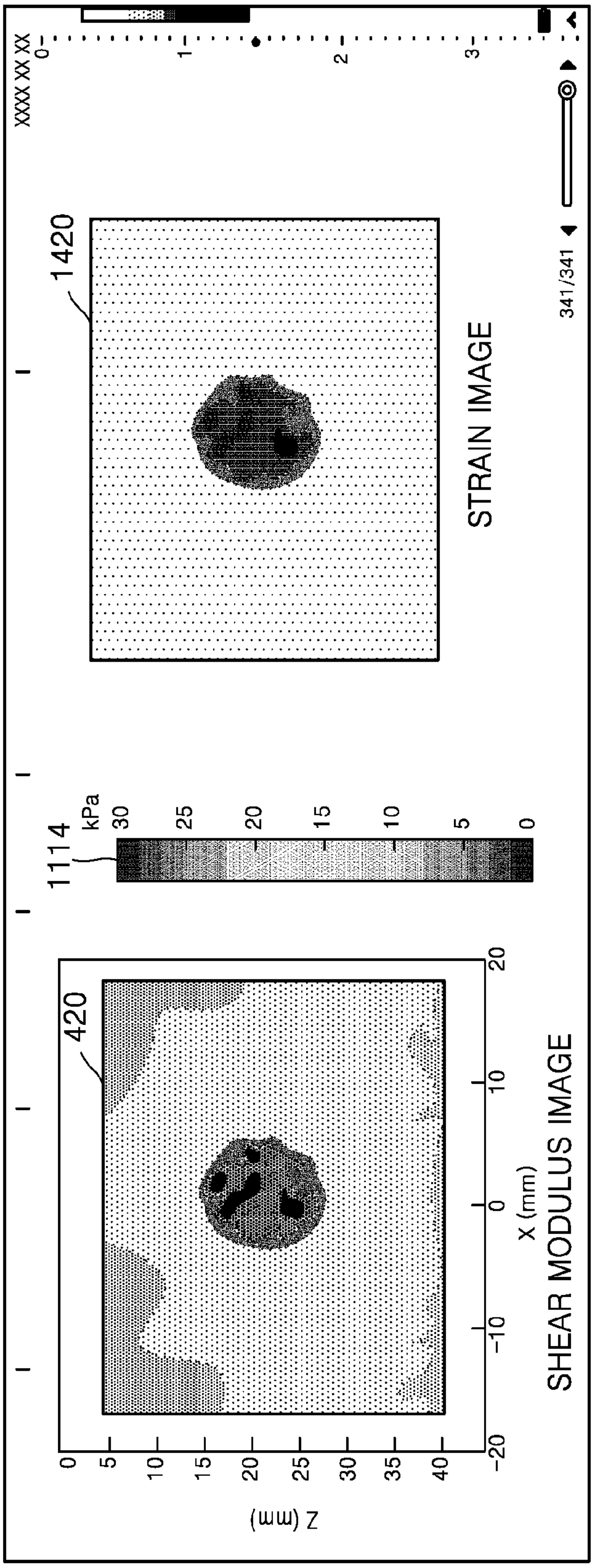

XXXX XX XX
1420
STRAIN IMAGE
341/341
1114
kPa
30
25
20
15
10
5
0
420
SHEAR MODULUS IMAGE
X (mm)
Z (mm)

FIG. 16B

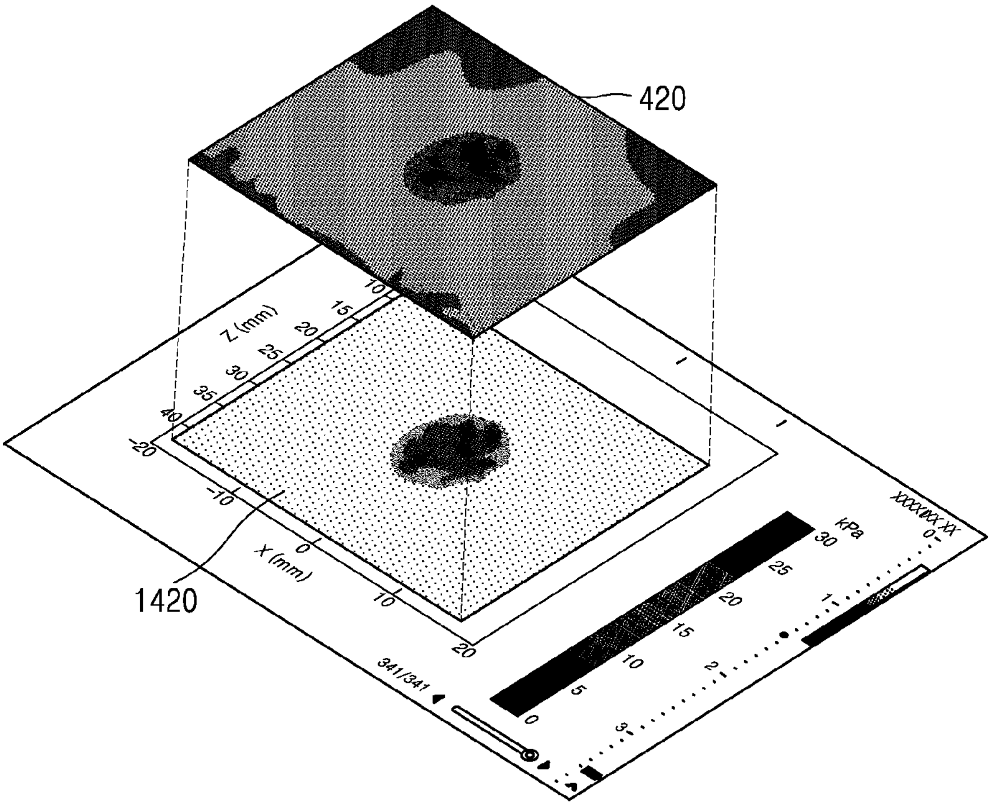
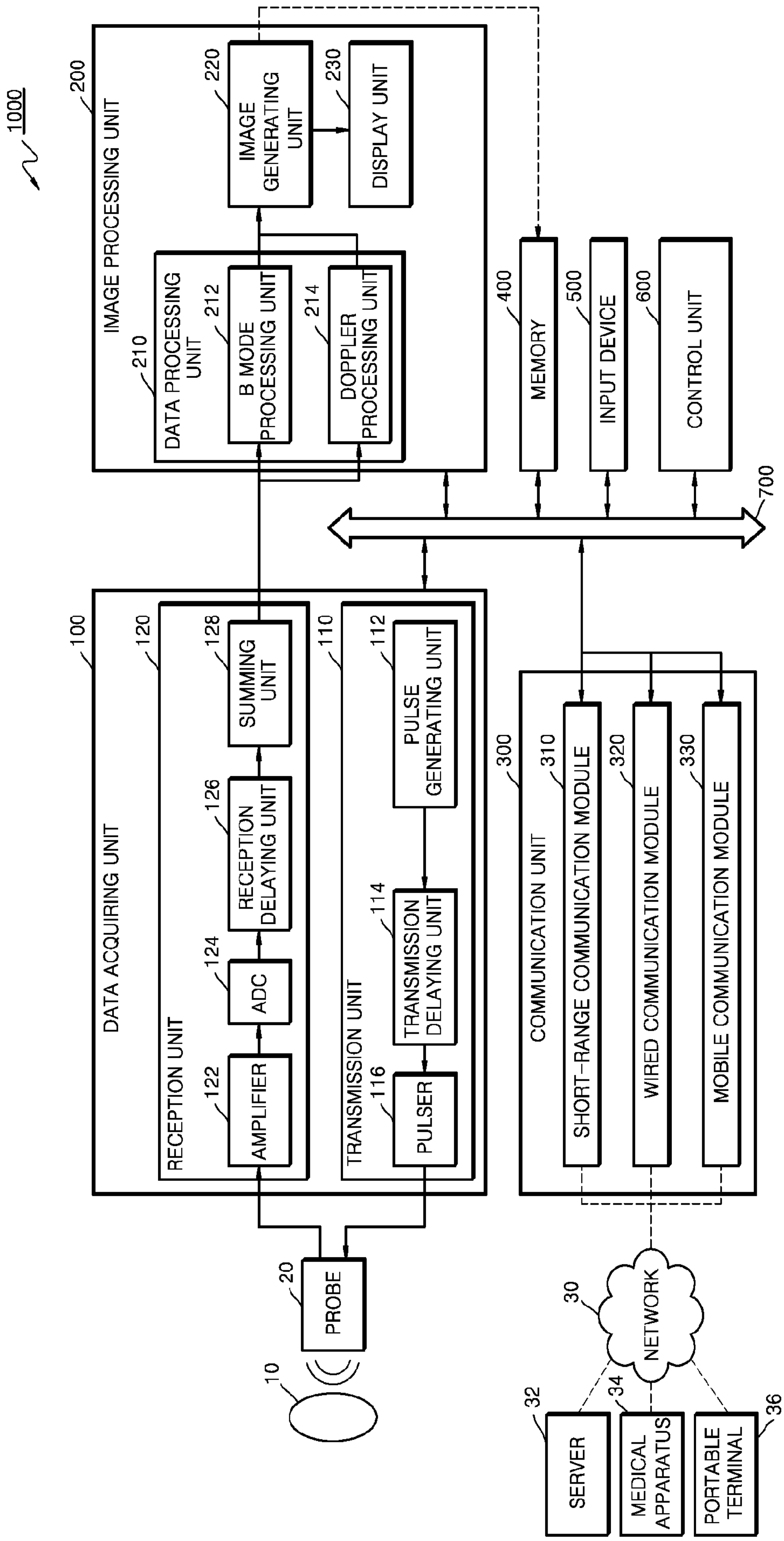


FIG. 17


1000
200
IMAGE PROCESSING UNIT
210
DATA PROCESSING UNIT
212
B MODE PROCESSING UNIT
214
DOPPLER PROCESSING UNIT
220
IMAGE GENERATING UNIT
230
DISPLAY UNIT
400
MEMORY
500
INPUT DEVICE
600
CONTROL UNIT
700
100
DATA ACQUIRING UNIT
120
RECEPTION UNIT
122
AMPLIFIER
124
ADC
126
RECEPTION DELAYING UNIT
128
SUMMING UNIT
110
TRANSMISSION UNIT
112
PULSE GENERATING UNIT
114
TRANSMISSION DELAYING UNIT
116
PULSER
300
COMMUNICATION UNIT
310
SHORT-RANGE COMMUNICATION MODULE
320
WIRED COMMUNICATION MODULE
330
MOBILE COMMUNICATION MODULE
10
20
PROBE
30
NETWORK
32
SERVER
34
MEDICAL APPARATUS
36
PORTABLE TERMINAL

ULTRASOUND IMAGE PROCESSING METHOD AND ULTRASOUND IMAGING APPARATUS THEREOF

TECHNICAL FIELD

[0001] One or more exemplary embodiments relate to methods of measuring a stress applied to a tissue and generating an elasticity image based on the measured stress, and ultrasound imaging apparatuses thereof.

BACKGROUND

[0002] An ultrasound imaging apparatus irradiates ultrasound signals generated by transducers of a probe to an object and receives echo signals reflected from the object, thereby obtaining images regarding the interior of the object (e.g., tomography of soft tissues or blood flow). In particular, an ultrasound imaging apparatus may be used for medical purposes including observation of the interior of an object, detection of foreign substances, and diagnosis of damage. The ultrasound imaging apparatus may display information regarding an object in real time. Furthermore, unlike the use of X-rays, use of the ultrasound imaging apparatus is very safe as it does not involve any radioactive exposure. Therefore, the ultrasound imaging apparatus is widely used together with other types of imaging apparatuses such as computer tomography (CT) scanners, magnetic resonance imaging (MRI) apparatuses, and nuclear medical diagnosis apparatuses.

[0003] A tumor generated in a soft tissue such as a breast or a prostate is harder than its surroundings. Since a tumor tissue is harder than a surrounding tissue, a diagnosing doctor may diagnose the presence/absence of a tumor by directly pressing a tissue.

[0004] The ultrasound imaging apparatus may replace palpation. For example, the ultrasound imaging apparatus may transmit an ultrasound signal to a tissue and calculate the hardness of the tissue based on an ultrasound echo signal received from the tissue.

SUMMARY

[0005] One or more exemplary embodiments include methods of measuring a stress applied to a tissue and generating an elasticity image based on the measured stress, and ultrasound imaging apparatuses thereof.

[0006] Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented exemplary embodiments.

[0007] One or more exemplary embodiments include methods of generating an elasticity image more accurately.

BRIEF DESCRIPTION OF DRAWINGS

[0008] These and/or other aspects will become apparent and more readily appreciated from the following description of exemplary embodiments, taken in conjunction with the accompanying drawings in which:

[0009] FIG. **1** is a block diagram illustrating a configuration of an ultrasound imaging apparatus according to an exemplary embodiment;

[0010] FIG. **2** is a flowchart illustrating a method of calculating, by an ultrasound imaging apparatus, a stress applied to at least one point in a region of interest (ROI), according to an exemplary embodiment;

[0011] FIG. **3** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a shear modulus of at least one point in an ROI, according to an exemplary embodiment;

[0012] FIG. **4** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a shear modulus of an ROI, based on a propagation velocity of a shear wave in the ROI, according to an exemplary embodiment;

[0013] FIG. **5** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a strain of an ROI, according to an exemplary embodiment;

[0014] FIGS. **6***a* and **6***b* are diagrams illustrating a strain of a tissue generated by a force applied manually through a probe of an ultrasound imaging apparatus, according to an exemplary embodiment;

[0015] FIG. **7** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a strain generated by a force applied manually through a probe, according to an exemplary embodiment;

[0016] FIG. **8** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a stress of an ROI, based on a shear modulus and a strain, according to an exemplary embodiment;

[0017] FIG. **9** is a flowchart illustrating a method of guiding, by an ultrasound imaging apparatus, an operation of a user pressing a probe, according to an exemplary embodiment;

[0018] FIG. **10** is a diagram illustrating a method of calculating, by an ultrasound imaging apparatus, a force of a user applied to an object through a probe, according to an exemplary embodiment;

[0019] FIG. **11** is a diagram illustrating a method of guiding, by an ultrasound imaging apparatus, an operation of a user pressing a probe when capturing a shear modulus image, according to an exemplary embodiment;

[0020] FIG. **12** is a diagram illustrating a method of guiding, by an ultrasound imaging apparatus, an operation of a user pressing a probe when capturing a shear modulus image, according to an exemplary embodiment;

[0021] FIG. **13** is a flowchart illustrating a method of recalculating, by an ultrasound imaging apparatus, a strain by using a stress, according to an exemplary embodiment;

[0022] FIG. **14** is a diagram illustrating a method of recalculating, by an ultrasound imaging apparatus, a strain by using a stress, according to an exemplary embodiment;

[0023] FIG. **15** is a diagram illustrating a method of recalculating, by an ultrasound imaging apparatus, a strain by using a stress, according to another exemplary embodiment;

[0024] FIGS. **16***a* and **16***b* are diagrams illustrating a method of displaying, by an ultrasound imaging apparatus, a shear modulus image and a strain image, according to an exemplary embodiment; and

[0025] FIG. **17** is a block diagram illustrating a configuration of an ultrasound imaging apparatus according to an exemplary embodiment.

DETAILED DESCRIPTION

[0026] According to one or more exemplary embodiments, an ultrasound imaging apparatus includes: a data acquirer configured to transmit at least one ultrasound signal to a region of interest (ROI) of an object and then to receive at least one ultrasound echo signal reflected from the ROI of the object; and a controller configured to calculate a shear modulus which corresponds to at least one point in the ROI and a strain which corresponds to the at least one point, based on the received at least one ultrasound echo signal, and to calculate a stress applied to the at least one point by using the calculated shear modulus and the calculated strain.

[0027] The controller may be further configured to generate first information which represents a compression stress applied to the object, based on the calculated stress, and the ultrasound imaging apparatus may further include a display device configured to display a user interface screen which includes the first information under a control of the controller.

[0028] The controller may be further configured to recalculate the strain based on a value which is obtainable by dividing the calculated strain by the calculated stress, and to form a strain image of the ROI by using the recalculated strain.

[0029] The controller may be further configured divide the ROI into at least one region, to calculate an average stress which corresponds to each of the at least one region, and to recalculate the strain based on a value which is obtainable by dividing the calculated strain by the calculated average stress.

[0030] The controller may be further configured to determine a value which is proportional to a product of the calculated shear modulus and the calculated strain as the stress.

[0031] The controller may be further configured to acquire a shear modulus map of the ROI by using the calculated shear modulus which corresponds to the at least one point, to acquire a strain imaging map of the ROI by using the calculated strain which corresponds to the at least one point, and to calculate the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

[0032] The at least one ultrasound signal may include a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via an ultrasound probe, and the at least one ultrasound echo signal may include a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

[0033] The controller may include a shear modulus calculating module configured to calculate a time-dependent displacement of the at least one point, based on the third ultrasound echo signal, and to calculate the shear modulus which corresponds to the at least one point by using the calculated time-dependent displacement.

[0034] The controller may include a strain calculating module configured to acquire reference image data which relates to the ROI by using the first ultrasound echo signal, to calculate a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal, and to calculate the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

[0035] The controller may be further configured to generate a shear modulus image of the ROI by using the shear modulus which corresponds to the at least one point and to generate a strain image of the ROI by using the strain which corresponds to the at least one point, and the ultrasound imaging apparatus may further include a display device configured to display the generated shear modulus image and the generated strain image simultaneously on a screen.

[0036] According to one or more exemplary embodiments, an ultrasound image processing method includes: transmitting at least one ultrasound signal to a region of interest (ROI) of an object and then receiving at least one ultrasound echo signal reflected from the ROI of the object; calculating a shear modulus which corresponds to at least one point in the ROI, based on the at least one received ultrasound echo signal; calculating a strain which corresponds to the at least one point, based on the at least one received ultrasound echo signal; and calculating a stress applied to the at least one point by using the calculated shear modulus and the calculated strain.

[0037] The ultrasound image processing method may further include: generating first information which represents a compression stress applied to the object, based on the calculated stress; and displaying a user interface screen which includes the first information.

[0038] The ultrasound image processing method may further include: recalculating the strain based on a value which is obtainable by dividing the calculated strain by the calculated stress; and forming a strain image of the ROI by using the recalculated strain.

[0039] The recalculating the strain may include dividing the ROI into at least one region, calculating an average stress which corresponds to each of the at least one region, and recalculating the strain based on a value which is obtainable by dividing the calculated strain by the calculated average stress.

[0040] The calculating the stress applied to the at least one point by using the calculated shear modulus and the calculated strain may include determining a value which is proportional to a product of the calculated shear modulus and the calculated strain as the stress.

[0041] The calculating the stress applied to the at least one point by using the calculated shear modulus and the calculated strain may include acquiring a shear modulus map of the ROI by using the calculated shear modulus which corresponds to the at least one point, acquiring a strain imaging map of the ROI by using the calculated strain which corresponds to the at least one point, and calculating the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

[0042] The at least one ultrasound signal may include a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via an ultrasound probe, and the at least one ultrasound echo signal may include a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

[0043] The calculating the shear modulus which corresponds to the at least one point may include: calculating a time-dependent displacement of the at least one point, based on the third ultrasound echo signal; and calculating the shear modulus which corresponds to the at least one point by using the calculated time-dependent displacement.

[0044] The calculating the strain which corresponds to the at least one point may include: acquiring reference image data which relates to the ROI by using the first ultrasound echo signal; calculating a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal; and calculating the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

[0045] The ultrasound image processing method may further include: generating a shear modulus image of the ROI by using the calculated shear modulus which corresponds to the at least one point; generating a strain image of the ROI by using the calculated strain which corresponds to the at least one point; and displaying the generated shear modulus image and the generated strain image simultaneously on a screen.

[0046] According to one or more exemplary embodiments, an ultrasound imaging apparatus includes: an ultrasound probe configured to transmit at least one ultrasound signal toward a region of interest (ROI) of an object and to receive at least one ultrasound echo signal reflected from the ROI of the object; a probe controller configured to control the ultrasound probe to transmit the at least one ultrasound signal and to receive the at least one ultrasound echo signal as an output from the ultrasound probe; a signal processor configured to use the received at least one ultrasound echo signal to determine a shear modulus which corresponds to at least one point in the ROI and to determine a strain which corresponds to the at least one point, and to calculate a stress applied to the at least one point by using the determined shear modulus and the determined strain; and a display configured to display information which is obtained from the received at least one ultrasound echo signal.

[0047] The signal processor may be further configured to adjust the strain based on a value which is obtainable by dividing the determined strain by the calculated stress, and to form a strain image of the ROI by using the adjusted strain.

[0048] The signal processor may be further configured to divide the ROI into at least one region, to calculate an average stress which corresponds to each of the at least one region, and to adjust the strain based on a value which is obtainable by dividing the determined strain by the calculated average stress.

[0049] The signal processor may be further configured to acquire a shear modulus map of the ROI by using the determined shear modulus which corresponds to the at least one point, to acquire a strain imaging map of the ROI by using the determined strain which corresponds to the at least one point, and to calculate the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

[0050] The at least one ultrasound signal may include a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via the ultrasound probe, and the at least one ultrasound echo signal may include a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

[0051] The signal processor may include a shear modulus calculating module configured to calculate a time-dependent displacement of the at least one point, based on the third ultrasound echo signal, and to determine the shear modulus which corresponds to the at least one point by using the calculated time-dependent displacement.

[0052] The signal processor may include a strain calculating module configured to acquire reference image data which relates to the ROI by using the first ultrasound echo signal, to calculate a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal, and to determine the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

[0053] According to one or more exemplary embodiments, an ultrasound image processing method includes: controlling an ultrasound probe to transmit at least one ultrasound signal toward a region of interest (ROI) of an object and to receive at least one ultrasound echo signal reflected from the ROI of the object; using the received at least one ultrasound echo signal to determine a shear modulus which corresponds to at least one point in the ROI and to determine a strain which corresponds to the at least one point; calculating a stress applied to the at least one point by using the determined shear modulus and the determined strain; and displaying information which is obtained from the received at least one ultrasound echo signal.

[0054] The ultrasound image processing method may further include: adjusting the strain based on a value which is obtainable by dividing the determined strain by the calculated stress; and forming a strain image of the ROI by using the adjusted strain.

[0055] The adjusting the strain may include dividing the ROI into at least one region, calculating an average stress of each of the at least one region, and adjusting the strain based on a value which is obtainable by dividing the determined strain by the calculated average stress.

[0056] The calculating the stress may include acquiring a shear modulus map of the ROI by using the determined shear modulus which corresponds to the at least one point, acquiring a strain imaging map of the ROI by using the determined strain which corresponds to the at least one point, and calculating the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

[0057] The at least one ultrasound signal may include a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via the ultrasound probe, and the at least one ultrasound echo signal may include a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

[0058] The determining the shear modulus which corresponds to the at least one point may include: calculating a time-dependent displacement of the at least one point, based on the third ultrasound echo signal; and using the calculated time-dependent displacement to determine the shear modulus which corresponds to the at least one point.

[0059] The calculating the strain which corresponds to the at least one point may include: acquiring reference image data which corresponds to the ROI by using the first ultrasound echo signal; calculating a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal; and determining the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

[0060] This application is a national stage entry of International Application No. PCT/KR2015/000006, filed on Jan. 2, 2015, in accordance with the Patent Cooperation Treaty (PCT). In addition, this application claims priority from Korean Patent Application No. 10-2014-0128281, filed on Sep. 25, 2014, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference in its entirety.

[0061] Reference will now be made in detail to exemplary embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the present exemplary embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the exemplary embodiments are merely described below, by referring to the figures, to explain aspects of the present description. As used herein, expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0062] The terms used in the specification will be briefly described, and the exemplary embodiments will be described in detail.

[0063] The terms used in this specification are those general terms currently widely used in the art in consideration of functions in regard to the exemplary embodiments, but the terms may vary according to the intention of those of ordinary skill in the art, precedents, or new technology in the art. Also, specified terms may be selected by the applicant, and in this case, the detailed meaning thereof will be described in the detailed description of the exemplary embodiments. Thus, the terms used in the specification should be understood not as simple names but based on the meaning of the terms and the overall description of the exemplary embodiments.

[0064] When something "comprises" or "includes" a component, another component may be further included unless specified otherwise. Also, the terms "units" and "modules" used herein refer to units that perform at least one function or operation, and the units may be implemented as hardware or software or a combination of hardware and software.

[0065] Throughout the specification, an "ultrasound image" refers to an image of an object, which is acquired by using ultrasonic waves. Also, an "object" may include a person or an animal, or a part of a person or an animal. For example, the object may include organs such as a liver, a heart, a womb, a brain, a breast, and an abdomen, or a blood vessel. Also, the object may include a phantom. The phantom may refer to a material having a volume that is approximately the intensity and effective atomic number of a living thing, and may include a spherical phantom having a property similar to a human body.

[0066] Also, a "user" may be, but is not limited to, a medical expert, such as a doctor, a nurse, a medical laboratory technologist, or a medial image expert, or a technician who repairs a medical apparatus.

[0067] Hereinafter, exemplary embodiments will be described in detail with reference to the accompanying drawings so that those of ordinary skill in the art may easily implement the exemplary embodiments. However, the exemplary embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. In addition, portions irrelevant to the description of the exemplary embodiments will be omitted in the drawings for a clear description of the exemplary embodiments, and like reference numerals will denote like elements throughout the specification.

[0068] FIG. **1** is a block diagram illustrating a configuration of an ultrasound imaging apparatus **1000** according to an exemplary embodiment.

[0069] Referring to FIG. **1**, the ultrasound imaging apparatus **1000** may include a display unit (also referred to herein as a "display device" and/or as a "display") **230**, a control unit (also referred to herein as a "controller") **600**, and a data acquiring unit (also referred to herein as a "data acquirer") **100**. The display unit **230**, the control unit **600**, and the data acquiring unit **100** may be connected to one another via buses **700**. Also, the ultrasound imaging apparatus **1000** may further include a probe (or ultrasound probe) **20** in addition to the display unit **230**, the control unit **600**, and the data acquiring unit **100**.

[0070] The probe **20** may transmit at least one ultrasound signal to an object **10** according to a driving signal applied from the data acquiring unit **100** and receive at least one echo signal reflected from the object **10**. The probe **20** may include a plurality of transducers, and the plurality of transducers may oscillate according to an electrical signal transmitted thereto and generate an ultrasonic wave, that is, acoustic energy. Also, the probe **20** may be connected to a main body of the ultrasound imaging apparatus **1000** by wire or wirelessly. According to exemplary embodiments, the ultrasound imaging apparatus **1000** may include a plurality of probes **20**.

[0071] The data acquiring unit **100** may include a transmission unit (also referred to herein as a "transmitter") **110** and a reception unit (also referred to herein as a "receiver") **120**. The transmission unit **110** may supply a driving signal to the probe **20**. The reception unit **120** may generate ultrasound data by processing the echo signal received from the probe **20**.

[0072] In general, the control unit **600** may control overall operations of the ultrasound imaging apparatus **1000**. For example, the control unit **600** may control the data acquiring unit **100** and the display unit **230**.

[0073] The control unit **600** may include a shear modulus calculating module **610**, a strain calculating module **620**, and a stress calculating module **630**.

[0074] The shear modulus calculating module **610** may calculate a shear modulus of a region of interest (ROI) of the object **10**, based on the ultrasound data generated by the data acquiring unit **100**. The shear modulus may refer to a modulus that represents an elasticity of an object with respect to one face of the object.

[0075] The strain calculating module **620** may calculate a strain generated by a force applied to the ROI of the object **10**, based on the ultrasound data generated by the data acquiring unit **100**. The strain may refer to a variation of an object per unit length.

[0076] Also, the stress calculating module **630** may calculate a stress applied to the ROI of the object **10**, based on the shear modulus calculated by the shear modulus calculating module **610** and the strain calculated by the strain calculating module **620**. For example, the stress calculating module **630** may calculate a value, which is proportional to a product of the shear modulus and the strain, as the stress.

[0077] Also, the strain calculating module **620** may recalculate the strain of the ROI of the object **10**, based on the calculated stress. For example, the strain calculating module

620 may recalculate a value, which is proportional to a value obtained by dividing the precalculated strain by the calculated stress, as the strain.

[0078] The display unit **230** may generate an ultrasound image by scan-converting the ultrasound data generated by the data acquiring unit **100** and display the ultrasound image.

[0079] Also, the display unit **230** may display a strain image of the ROI of the object **10** generated based on the strain calculated by the strain calculating module **620**. In this case, together with the strain image, the display unit **230** may display the force applied to the ROI of the object **10** by the probe **20**. Also, the display unit **230** may display a shear modulus image of the ROI of the object **10** generated based on the shear modulus calculated by the shear modulus calculating module **610**.

[0080] Also, the display unit **230** may display the shear modulus image and the strain image simultaneously on a screen. Also, the display unit **230** may display the shear modulus image and the strain image in a superimposed manner.

[0081] FIG. **2** is a flowchart illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a stress applied to at least one point in the ROI, according to an exemplary embodiment.

[0082] Referring to FIG. **2**, in operation S**210**, the ultrasound imaging apparatus **1000** may transmit an ultrasound signal to the ROI of the object **10** and then receive an ultrasound echo signal reflected from the ROI of the object **10**.

[0083] The at least one ultrasound signal may include a first ultrasound signal used to generate a reference image and a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI. Also, the ultrasound signal may include a third ultrasound signal used to calculate a displacement of at least one point in the ROI, which is generated by the acoustic force and a pressure applied through the probe **20**.

[0084] The at least one ultrasound echo signal may include a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object **10**.

[0085] In operation S**220**, the ultrasound imaging apparatus **1000** may calculate a shear modulus of the at least one point in the ROI, based on the received ultrasound echo signal.

[0086] The ultrasound imaging apparatus **1000** may calculate the shear modulus of the ROI, based on a displacement of a tissue generated by the acoustic force.

[0087] For example, the ultrasound imaging apparatus **1000** may calculate a time-dependent displacement of the at least one point, based on the third ultrasound echo signal and calculate the shear modulus of the at least one point by using the time-dependent displacement.

[0088] In operation S**230**, the ultrasound imaging apparatus **1000** may calculate a strain of the at least one point, based on the received ultrasound echo signal.

[0089] The ultrasound imaging apparatus **1000** may acquire reference image data of the ROI by using the first ultrasound echo signal, calculate a displacement of the at least one point in the ROI, which is generated by a pressure applied through the probe **20**, based on the reference image data and the third ultrasound echo signal, and calculate the strain of the at least one point in the ROI by differentiating the calculated displacement.

[0090] In operation S**240**, the ultrasound imaging apparatus **1000** may calculate a stress applied to the at least one point by using the shear modulus and the strain.

[0091] The ultrasound imaging apparatus **1000** may calculate a value, which is proportional to the product of the shear modulus and the strain, as the stress.

[0092] Also, the ultrasound imaging apparatus **1000** may acquire a shear modulus map of the ROI by using the shear modulus of the at least one point, acquire a strain imaging map of the ROI by using the strain of the at least one point, and calculate the stress of the ROI, based on the shear modulus map and the strain imaging map.

[0093] FIG. **3** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a shear modulus of at least one point in the ROI, according to an exemplary embodiment.

[0094] Referring to FIG. **3**, the control unit **600** may generate a shear modulus image of the ROI. The shear modulus image may be an image that represents a stiffness of the tissue, based on a shear modulus of the tissue located in the ROI.

[0095] The data acquiring unit **100** may transmit a first ultrasound signal **312** to the ROI through the probe **20** and receive a first ultrasound echo signal **314** corresponding to the first ultrasound signal **312** from the ROI.

[0096] As the first ultrasound echo signal **314** is received, the control unit **600** may generate a reference image **315** of the ROI, based on the first ultrasound echo signal **314**. The reference image **315** may be an image that represents a position of the tissue before a force is applied to the ROI. The reference image **315** may be a B mode image or an M mode image of the ROI.

[0097] After receiving the first ultrasound echo signal **314**, the data acquiring unit **100** may transmit a second ultrasound signal **321** of a focusing point **323** in the ROI through the probe **20**. The second ultrasound signal **321** may be a focused ultrasonic pulse.

[0098] When a strong focused ultrasonic pulse **321** is transmitted to the focusing point **323** in the ROI, a transverse wave **328** may be generated in the tissue located in the ROI. For example, the strong focused ultrasonic pulse **321** may push the tissue in the direction of an ultrasonic pulse (i.e., axial direction). An axial movement of the tissue located at the focusing point **323** may cause an adjacent tissue to move in the same direction (axial direction). As the tissue adjacent to the focusing point **323** moves in the same direction, the movement may again propagate to a tissue adjacent to the moved tissue. In this case, the force of the ultrasonic wave causing the tissue to move may be referred to as an acoustic force.

[0099] As the movement propagates to the adjacent tissue, the acoustic force applied to the focusing point **323** may generate a wave in a direction perpendicular to the direction of the ultrasonic pulse (i.e., lateral direction) with the focusing point **323** being a point of origin. The transverse wave **328** propagating in the direction perpendicular to the direction of the ultrasonic pulse may be referred to as a shear wave.

[0100] The propagation velocity of the shear wave **328** may be determined according to any of the stiffness, Young's modulus, and/or shear modulus of the tissue.

[0101] For example, the propagation velocity of the shear wave **328** may change by about 1 m/s to about 10 m/s according to the stiffness of the tissue. Also, the propagation velocity of the shear wave **328** in the tissue may increase as the stiffness of the tissue increases.

[0102] Also, the propagation velocity of the shear wave **328** in the tissue may have a relationship with the stiffness of the tissue as expressed by Equation 1 below.

$$G=\rho\cdot C^2 \quad \text{Equation 1}$$

[0103] In Equation 1, G may denote the stiffness of the tissue, ρ may denote the density of the tissue, and C may denote the propagation velocity of the shear wave **328**. The density "ρ" of the tissue may be regarded as a constant value in the ROI and may be mostly a known value. Accordingly, the stiffness of the tissue may be detected by measuring the propagation velocity of the shear wave **328** propagating in the tissue.

[0104] The shear wave **328** may be detected by measuring the displacement of the tissue in the direction of the ultrasonic pulse (i.e., axial direction). The displacement of the tissue may refer to a movement distance of the tissue in the axial direction with respect to the reference image **315**. Also, the propagation velocity of the shear wave **328** at a partial tissue in the ROI may be calculated based on a time point at which the displacement of the partial tissue and the displacement of a tissue adjacent to the partial tissue are at their maximum.

[0105] Referring to FIG. **3**, in order to calculate the displacement of the tissue generated by the acoustic force, the data acquiring unit **100** may transmit a third ultrasound signal **331** to the ROI. In this case, in order to more accurately measure the propagation velocity of the shear wave **328**, the data acquiring unit **100** may transmit a plane wave as the third ultrasound signal **331**. When a plane wave is transmitted as the third ultrasound signal **331**, the ultrasound imaging apparatus **1000** may image the shear wave **328** at a rate of thousands of frames per second.

[0106] After the third ultrasonic pulse **331** is transmitted to the tissue, the third ultrasonic pulse **331** may be scattered by a scatter **340** located at the tissue in the ROI. The third ultrasonic pulse **331** scattered by the scatter **340** may return to the probe **20**. In this case, the third ultrasonic pulse **331** scattered by the scatter **340** may be referred to as a third ultrasonic echo pulse **345**.

[0107] As the third ultrasonic echo pulse **345** is received, the control unit **600** may generate ultrasound images of the ROI, based on the third ultrasonic echo pulse **345**. An image including the shear wave **328**, from among the ultrasound images generated based on the third ultrasonic echo pulse **345**, may be referred to as a shear wave image **350**. When a plane wave is transmitted as the third ultrasound signal **331**, the control unit **600** may generate the shear wave image **350** at a rate of thousands of frames per second.

[0108] The shear wave image **350** may represent the displacement of the tissue in the ROI. The control unit **600** may calculate the propagation velocity of the shear wave **328** by using the displacement of the tissue in the ROI.

[0109] FIG. **4** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a shear modulus of the ROI, based on a propagation velocity of a shear wave in the ROI, according to an exemplary embodiment.

[0110] The shear modulus calculating module **610** may calculate a shear modulus of the ROI, based on the displacement of the tissue generated by the acoustic force.

[0111] For example, the shear modulus calculating module **610** may detect a moved position of a first partial tissue (e.g., one of **410** to **415**) in the reference image **315** from each shear wave image **351**, based on a cross-correlation method. Based on the detected position, the shear modulus calculating module **610** may calculate an axial displacement of the first partial tissue (e.g., one of **410** to **415**). Based on the calculated displacement, the shear modulus calculating module **610** may detect a time point at which the displacement of the first partial tissue is at its maximum. The shear modulus calculating module **610** may determine the time point at which the displacement of the first partial tissue is at its maximum as a time point at which the shear wave **328** has reached the first partial tissue.

[0112] Referring to FIG. **4**, the ultrasound data constituting a first image **351** from among a plurality of shear wave images **350** is received at a time point "t1", and the displacements of two partial tissues **412** and **413** adjacent to the focusing point may be at their maximum in the first image **351**. Accordingly, the shear modulus calculating module **610** may determine that the shear wave **328** has reached the two partial tissues **412** and **413** at the time point "t1". Also, the shear modulus calculating module **610** may detect the position of the shear wave **328** and the time point the shear wave **328** has arrived with respect to the plurality of shear wave images **350** in the same manner, and may calculate the velocity of the shear wave **328** at the at least one point in the ROI, based on the position of the shear wave **328** and the time point the shear wave **328** has arrived.

[0113] As the velocity of the shear wave **328** at the at least one point in the ROI is calculated, the shear modulus calculating module **610** may calculate a shear modulus of a point, at which the velocity of the shear wave **328** has been calculated, by substituting the density of the ROI and the velocity of the shear wave **328** into Equation 1.

[0114] As the shear modulus of the at least one point in the ROI is calculated, the control unit **600** may generate a shear modulus map representing the shear modulus of each point in the ROI.

[0115] Also, the control unit **600** may generate a shear modulus image **420** by mapping the shear modulus map with different colors according to the values of the shear modulus. For example, the ultrasound imaging apparatus **1000** may map with bluer color as the shear modulus is lower and map with redder color as the shear modulus is higher. Also, the control unit **600** may generate a shear modulus image **420** by mapping the shear modulus map with different brightness or chroma according to the values of the shear modulus. For example, the control unit **600** may map with lower brightness or chroma as the shear modulus is lower and map with higher brightness or chroma as the shear modulus is higher.

[0116] FIG. **5** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a strain of the ROI, according to an exemplary embodiment.

[0117] After the first ultrasound echo signal **314** for the reference image **315** is received, the user may manually apply a force **325** to the object **10** through the probe **20** intentionally or unintentionally. Accordingly, the tissue in the ROI may be modified by the force **325** applied manually through the probe **20**.

[0118] Referring to FIG. **5**, the strain calculating module **620** may calculate a strain of the ROI, based on the reference image **315** and an image not including the shear wave **328**, from among the ultrasound images generated based on the third ultrasonic echo pulse **345**.

[0119] An image **510** generated after a reference time, from among the ultrasound images generated based on the third ultrasonic echo pulse **345**, may be an image that does not include the shear wave **328** generated by the acoustic force. The image **510** generated after the reference time, from among the ultrasound images generated based on the third ultrasonic echo pulse **345**, may be referred to as a strain sample image **510**. The reference time may be preset based on the lateral width of the ROI and the density of the tissue in the ROI.

[0120] FIGS. **6***a* and **6***b* are diagrams illustrating a strain of a tissue generated by a force applied manually through the probe **20** of the ultrasound imaging apparatus **1000**, according to an exemplary embodiment.

[0121] Referring to FIG. **6***a*, the user may manually apply a force **325** to the ROI, in which a tumor tissue is located, through the probe **20**.

[0122] Referring to FIG. **6***b*, the control unit **600** may image the ROI before the force **325** is applied thereto and image the ROI after the force **325** is applied thereto. The strain calculating module **620** may calculate a strain of the ROI by comparing an image of the ROI captured before the force **325** is applied thereto and an image of the ROI captured after the force **325** is applied thereto.

[0123] A stiff tumor tissue **611** has a small displacement generated by the force **325**. On the other hand, a relatively soft tissue has a large displacement generated by the force **325** because it may be easily compressed by the same force **325**.

[0124] Thus, the strain calculating module **620** may calculate a strain of the at least one point in the ROI by calculating a displacement per unit length with respect to the at least one point in the ROI.

[0125] A strain "ϵ" may refer to a displacement per unit length. Also, the strain "ϵ" may be expressed as Equation 2 below.

$$\varepsilon = \frac{\Delta L}{L} \quad \text{Equation 2}$$

[0126] In Equation 2, ϵ may denote the strain, L may denote the length of the tissue, and ΔL may denote the displacement of the tissue.

[0127] Also,

$$\frac{\Delta L}{L}$$

may change with respect to the strain of the partial tissue as expressed in Equation 3 below.

$$\alpha=\partial u_z/\partial z \quad \text{Equation 3}$$

[0128] =

[0129] In Equation 3, u_z may denote the displacement in a z-axis direction. Thus, the strain may refer to a spatial derivative with respect to the displacement.

[0130] Referring to FIG. **6***b*, the strain calculating module **620** may calculate a depth-dependent displacement **621** of the tissue with respect to the ROI by comparing an—ultrasound image captured before the force **325** is applied and an ultrasound image captured after the force **325** is applied.

[0131] As the depth-dependent displacement **621** of the tissue is calculated, the strain calculating module **620** may calculate a depth-dependent strain **631** of the tissue by differentiating the depth-dependent displacement **621** of the tissue in a depth direction.

[0132] FIG. **7** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a strain generated by a force applied manually through the probe **20**, according to an exemplary embodiment.

[0133] Referring to FIG. **7**, the strain calculating module **620** may calculate a strain of the at least one point in the ROI, based on the reference image **315** and the strain sample image **510**.

[0134] The strain calculating module **620** may calculate the displacement of the tissue generated by a force applied manually through the probe **20**.

[0135] For example, the strain calculating module **620** may detect the position of the partial tissue **412** in the reference image **315** from the strain sample image **510**, based on a cross-correlation method. The strain calculating module **620** may calculate a displacement **710** of the partial tissue **412** in a force application direction, based on the detected position of the partial tissue **412**. Also, the strain calculating module **620** may calculate the displacements of a plurality of partial tissues in the ROI in the force application direction.

[0136] The strain calculating module **620** may calculate a strain of the at least one point in the ROI by differentiating the calculated displacements of the plurality of partial tissues in the force application direction.

[0137] As the strain of the at least one point in the ROI is calculated, the control unit **600** may generate a strain map representing the strain of each point in the ROI.

[0138] Also, the control unit **600** may generate a strain image **720** by mapping the strain map with different colors according to the values of the strain. Also, the control unit **600** may generate a strain image **720** by mapping the strain map with different brightness or chroma according to the values of the strain.

[0139] FIG. **8** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a stress of the ROI, based on a shear modulus and a strain, according to an exemplary embodiment.

[0140] Referring to FIG. **8**, the stress calculating module **630** may calculate a stress of the at least one point in the ROI, based on the strain and the elastic modulus of the at least one point in the ROI.

[0141] Also, the relationship between the stress and the strain may be expressed as Equation 4 below.

$$\sigma=E\cdot\epsilon \quad \text{Equation 4}$$

[0142] In Equation 4, σ may denote the stress, E may denote the elastic modulus, and ϵ may denote the strain. Also, the stress "σ" may refer to a force per area.

[0143] Also, the relationship between the elastic modulus and the shear modulus may be expressed as Equation 5 below.

$$E=3G \quad \text{Equation 5}$$

[0144] In Equation 5, E may denote the elastic modulus and G may denote the shear modulus.

[0145] Thus, the stress may be expressed as Equation 6 below.

$$\sigma=3G\cdot\epsilon= \quad \text{Equation 6}$$

[0146] The stress calculating module **630** may calculate a stress applied to the at least one point in the ROI by calculating a product of the shear modulus and the strain of the at least one point in the ROI and tripling the product.

[0147] Also, the stress calculating module **630** may calculate a stress applied to each point in the ROI by calculating a product of the shear modulus and the strain of each point in the ROI and tripling the product, based on the shear modulus map and the strain map.

[0148] As the stress applied to the at least one point in the ROI is calculated, the control unit **600** may generate a stress map **810** representing the stress of each point in the ROI.

[0149] FIG. **9** is a flowchart illustrating a method of guiding, by the ultrasound imaging apparatus **1000**, an operation of the user pressing the probe **20**, according to an exemplary embodiment.

[0150] Referring to FIG. **9**, in operation S**910**, the ultrasound imaging apparatus **1000** may transmit an ultrasound signal to the ROI of the object **10** and then receive an ultrasound echo signal reflected from the ROI of the object **10**. In operation S**920**, the ultrasound imaging apparatus **1000** may calculate a shear modulus of the at least one point in the ROI, based on the received ultrasound echo signal. In operation S**930**, the ultrasound imaging apparatus **1000** may calculate a strain of the at least one point, based on the received ultrasound echo signal. In operation S**940**, the ultrasound imaging apparatus **1000** may calculate a stress applied to the at least one point by using the shear modulus and the strain. Operations S**910** to S**940** may correspond to operations S**210** to S**240** illustrated in FIG. **2**.

[0151] In operation S**950**, the ultrasound imaging apparatus **1000** may generate first information representing a compression stress applied to the object **10**, based on the stress.

[0152] The first information representing the compression stress applied to the object **10** may include information about a force of the user applied to the object **10**.

[0153] The ultrasound imaging apparatus **1000** may calculate the force of the user applied to the object **10**, based on the stress of the at least one point in the ROI.

[0154] In operation S**960**, the ultrasound imaging apparatus **1000** may display guide information including the first information.

[0155] The ultrasound imaging apparatus **1000** may display the information about the force of the user applied to the object **10**, together with the shear modulus image.

[0156] FIG. **10** is a diagram illustrating a method of calculating, by the ultrasound imaging apparatus **1000**, a force of the user applied to the object **10** through the probe **20**, according to an exemplary embodiment.

[0157] Referring to FIG. **10**, the control unit **600** may calculate the force of the user applied to the object **10**, based on the stress of the at least one point in the ROI.

[0158] The control unit **600** may calculate an average value of the stress on an entire ROI **1010** and determine the calculated average value as the force of the user applied to the object **10**.

[0159] Also, the control unit **600** may calculate an average value of the stress on a region **1020** in the ROI, which is located within a predetermined distance from the surface of the object **10**, and determine the calculated average value as the force of the user applied to the object **10**.

[0160] Also, the control unit **600** may calculate an average value of the stress on a region in the ROI, which is located within a predetermined distance from the probe **20**, and determine the calculated average value as the force of the user applied to the object **10**.

[0161] FIG. **11** is a diagram illustrating a method of guiding, by the ultrasound imaging apparatus **1000**, an operation of the user pressing the probe **20** when capturing a shear modulus image, according to an exemplary embodiment.

[0162] Referring to FIG. **11**, the display unit **230** of the ultrasound imaging apparatus **1000** may display guide information about a force of the user pressing the probe **20** when capturing a shear modulus image.

[0163] The stiffness of the tissue may be changed when the user presses the probe **20** with a pressure that is lower or higher than a reference pressure, when capturing a shear modulus image. A shear modulus image, which is captured when the stiffness of the tissue changes, may fail to quantitatively represent the original stiffness of the tissue.

[0164] The display unit **230** may guide the reference pressure to be applied through the probe **20**, by displaying the guide information about the force of the user pressing the probe **20**.

[0165] The display unit **230** may display the shear modulus image together with coordinate axes **1110** and **1112** representing the position of the at least one point in the ROI. Also, the display unit **230** may display the shear modulus image together with an image **1114** representing the value of the shear modulus corresponding to each color.

[0166] Also, the display unit **230** may display a region **1120** of the ROI of which the shear modulus has been calculated, a reference pressure **1130** with respect to the region **1120** of the ROI, a pressure **1140** of the probe **20** calculated based on the stress of the ROI, and a guidance text **1150** for guiding the force of the user pressing the probe **20**.

[0167] The region **1120** of the ROI may be set by the user. Also, the reference pressure **1130** may be preset in the ultrasound imaging apparatus **1000**, corresponding to a region of a human body.

[0168] FIG. **12** is a diagram illustrating a method of guiding, by the ultrasound imaging apparatus **1000**, an operation of the user pressing the probe **20** when capturing a shear modulus image, according to an exemplary embodiment.

[0169] Referring to FIG. **12**, the display unit **230** may display guide information about the direction of the force of the user pressing the probe **20** when capturing a shear modulus image.

[0170] When capturing a shear modulus image, the user may tilt the probe **20** back and forth or right and left. When the probe **20** is tilted back and forth or right and left, the forces applied to partial regions in the ROI may be different from each other.

[0171] The display unit **230** may display information **1210** about the direction of the force of the user pressing the probe **20**. For example, when the probe **20** is tilted to the right, the display unit **230** may display text **1210** representing the tilt direction and the current shape of the probe **20**.

[0172] FIG. **13** is a flowchart illustrating a method of recalculating, by the ultrasound imaging apparatus **1000**, a strain by using a stress, according to an exemplary embodiment.

[0173] Referring to FIG. **13**, in operation S**1310**, the ultrasound imaging apparatus **1000** may transmit an ultrasound signal to the ROI of the object **10** and then receive an ultrasound echo signal reflected from the ROI of the object **10**. In operation S**1320**, the ultrasound imaging apparatus **1000** may calculate a shear modulus of at least one point in the ROI, based on the received ultrasound echo signal. In operation S**1330**, the ultrasound imaging apparatus **1000** may calculate a strain of the at least one point, based on the received ultrasound echo signal. In operation S**1340**, the ultrasound imaging apparatus **1000** may calculate a stress applied to the at least one point by using the shear modulus and the strain.

Operations **S1310** to **S1340** may correspond to operations **S210** to **S240** illustrated in FIG. **2**.

[0174] In operation **S1350**, the ultrasound imaging apparatus **1000** may recalculate the strain, based on a value obtained by dividing the strain by the stress.

[0175] The ultrasound imaging apparatus **1000** may recalculate a value, which is obtained by dividing the strain of a first point in the ROI by the stress of the first point, as the strain of the first point.

[0176] Also, the ultrasound imaging apparatus **1000** may divide the ROI into at least one region, calculate an average stress of each of the at least one region, and recalculate the strain by dividing the strain of a first point in the ROI by the average stress of a region including the first point.

[0177] In operation **S1360**, the ultrasound imaging apparatus **1000** may form a strain image of the ROI by using the recalculated strain.

[0178] FIG. **14** is a diagram illustrating a method of recalculating, by the ultrasound imaging apparatus **1000**, a strain by using a stress, according to an exemplary embodiment.

[0179] Referring to FIG. **14**, the strain calculating module **620** may recalculate a strain of the ROI by using a calculated stress of each point in the ROI.

[0180] Referring to Equation 4, the strain of the tissue may increase as the stress applied to the tissue increases. Also, under the same stress, if the first tissue has a higher stiffness or a higher shear modulus than the second tissue, the first tissue may have a higher strain than the second tissue. Thus, assuming that the same stress is applied to the ROI, the strain of the tissue may refer to the stiffness of the tissue.

[0181] Assuming that the same stress is applied to the ROI, the strain image may be an image that is represented by measuring the stiffness of the ROI. However, the force applied to the probe **10** by the probe **20** may not uniformly act on the entire ROI. For example, the force applied by the probe **20** may greatly act on the tissue that is adjacent to the probe **20**, and the force applied by the probe **20** may slightly act on the tissue that is distant from the probe **20**. Also, the probe **20** may be obliquely pressed onto the object **10**. Thus, the stiffness of the tissue represented in the strain image may be different from the original stiffness of the tissue.

[0182] Artifacts **1412** to **1416**, which are generated because the force does not uniformly act on the entire ROI, may be observed in the strain image. The artifacts **1412** to **1416** may indicate that a general tissue having a low stiffness unlike a tumor is displayed differently from surrounding tissues since an excessive stress is applied to the general tissue.

[0183] The strain calculating module **620** may remove the artifacts by compensating for a non-uniform stress applied to the ROI by using the calculated stress. For example, the strain calculating module **620** may recalculate a value, which is obtained by dividing the strain of the first point in the ROI by the stress of the first point, as the strain of the first point.

[0184] The strain calculating module **620** may recalculate a strain map of the ROI by recalculating the strain of each point in the ROI. As the strain map of the ROI is recalculated, the control unit **600** may generate a strain image **1420**, based on the recalculated strain map.

[0185] Also, the display unit **230** may display the strain image **1420** generated based on the strain calculated as a quantitative value.

[0186] FIG. **15** is a diagram illustrating a method of recalculating, by the ultrasound imaging apparatus **1000**, a strain by using a stress, according to another exemplary embodiment.

[0187] Referring to FIG. **15**, the strain calculating module **620** may calculate an average stress of a plurality of partial regions and recalculate the strain of the partial region, based on the calculated average stress.

[0188] The stress does not change abruptly according to distance. Thus, the stresses applied to the adjacent tissues in the ROI may be regarded as being substantially identical to each other.

[0189] Accordingly, the control unit **600** may divide the ROI into a plurality of partial regions **1510** and calculate an average stress of the partial region **1510**, based on the stress of each point in the partial region **1510**. As the average stress of the partial region **1510** is calculated, the strain calculating module **620** may divide the strain of each point in the partial region **1510** by the average stress and recalculate the resulting value of the division as the strain of each point in the ROI. As the strain of each point in the ROI is recalculated, the control unit **600** may recalculate a strain map of the ROI and may generate a strain image **1520** based on the recalculated strain map of the ROI.

[0190] FIGS. **16***a* and **16***b* are diagrams illustrating a method of displaying, by the ultrasound imaging apparatus **1000**, a shear modulus image and a strain image, according to an exemplary embodiment.

[0191] Referring to FIG. **16***a*, the display unit **230** may display the shear modulus image **420** and the strain image **1420** together.

[0192] The control unit **600** may acquire the shear modulus image **420** of the ROI by using the shear modulus of the at least one point in the ROI. Also, the control unit **600** may acquire the strain image **1420** of the ROI by using the strain of the at least one point in the ROI. Also, the display unit **230** may display the shear modulus image **420** and the strain image **1420** simultaneously on a screen.

[0193] Also, the display unit **230** may display the shear modulus image **420** and the strain image **1420** together with the B mode image, the M mode image, or the Doppler image.

[0194] Referring to FIG. **16***b*, the display unit **230** may display the shear modulus image **420** and the strain image **1420** in a superimposed manner.

[0195] For example, the display unit **230** may display the strain image **1420** and the shear modulus image **420** in a superimposed manner. In this case, the shear modulus image **420** may be displayed semitransparently so that the strain image **1420** may be projected through the shear modulus image **420**.

[0196] Also, the display unit **230** may display the shear modulus image **420** and display the strain image **1420** on the shear modulus image **420** in a superimposed manner so that the shear modulus image **420** may be projected through the strain image **1420**.

[0197] FIG. **17** is a block diagram illustrating a configuration of an ultrasound imaging apparatus **1000** according to an exemplary embodiment.

[0198] Referring to FIG. **17**, the ultrasound imaging apparatus **1000** may include a data acquiring unit **100**, a display unit **230**, and a control unit **600** and may further include an image processing unit (also referred to herein as an "image processor") **200**, a communication unit (also referred to herein as a "communicator") **300**, a memory **400**, and an input device **500**, where the components stated above may be connected to one another via buses **700**.

[0199] The ultrasound imaging apparatus **1000** may be embodied not only as a cart type ultrasound imaging apparatus, but also as a portable ultrasound imaging apparatus. Examples of the portable ultrasound imaging apparatus may include a picture archiving and communication system (PACS) viewer, a smart phone, a laptop computer, a personal digital assistant (PDA), and a tablet personal computer (PC); however, exemplary embodiments are not limited thereto.

[0200] A probe **20** transmits an ultrasound signal to an object **10** according to a driving signal applied from the data acquiring unit **100** and receives an echo signal reflected from the object **10**. The probe **20** includes a plurality of transducers, and the plurality of transducers oscillate according to an electrical signal transmitted thereto and generate an ultrasonic wave, that is, acoustic energy. Also, the probe **20** may be connected to a main body of the ultrasound imaging apparatus **1000** by wire or wirelessly. According to exemplary embodiments, the ultrasound imaging apparatus **1000** may include a plurality of probes **20**.

[0201] A transmission unit **110** supplies a driving signal to the probe **20** and includes a pulse generating unit (also referred to herein as a "pulse generator") **112**, a transmission delaying unit (also referred to herein as a "transmission delayer") **114**, and a pulser **116**. The pulse generating unit **112** generates pulses for forming transmission ultrasonic waves according to a predetermined pulse repetition frequency (PRF), and the transmission delaying unit **114** applies a delay time for determining transmission directionality to the pulses. The pulses to which a delay time is applied correspond to a plurality of piezoelectric vibrators included in the probe **20**, respectively. The pulser **116** applies a driving signal (or a driving pulse) to the probe **20** at a timing corresponding to each pulse to which a delay time is applied.

[0202] A reception unit **120** generates ultrasound data by processing echo signals received from the probe **20** and may include an amplifier **122**, an analog-digital converter (ADC) **124**, a reception delaying unit (also referred to herein as a "reception delayer") **126**, and a summing unit (also referred to herein as a "summer") **128**. The amplifier **122** amplifies echo signals in each channel, and the ADC **124** analog-digital converts the amplified echo signals. The reception delaying unit **126** applies delay times for determining reception directionality to the digital-converted echo signals, and the summing unit **128** generates ultrasound data by summing the echo signals processed by the reception delaying unit **126**. Also, according to exemplary embodiments, the reception unit **120** may not include the amplifier **122**. In other words, when the sensitivity of the probe **20** or the capability to process bits by the ADC **124** is enhanced, the amplifier **122** may be omitted.

[0203] The image processing unit **200** generates an ultrasound image by scan-converting ultrasound data generated by the data acquiring unit **100** and displays the ultrasound image. The ultrasound image may include not only a gray-scale image obtained by scanning the object **10** in an amplitude (A) mode, a brightness (B) mode, and a motion (M) mode, but also a Doppler image representing a motion of the object **10** by using a Doppler effect. The Doppler image may include a bloodstream Doppler image (also referred to as a color Doppler image) representing a flow of blood, a tissue Doppler image representing a motion of a tissue, and a spectral Doppler image representing a movement speed of the object **10** in a waveform.

[0204] A B mode processing unit **212** extracts B mode components from ultrasound data and processes the B mode components. An image generating unit **220** may generate an ultrasound image representing signal intensities as brightness, based on the B mode components extracted by the B mode processing unit **212**.

[0205] Likewise, a Doppler processing unit **214** may extract Doppler components from ultrasound data, and the image generating unit **220** may generate a Doppler image representing a motion of the object **10** as colors or waveforms, based on the extracted Doppler components.

[0206] The image generating unit **220** according to an exemplary embodiment may generate a three-dimensional (3D) ultrasound image through volume-rendering of volume data and may also generate an elasticity image that visualizes the deformation of the object **10** due to a pressure. In addition, the image generating unit **220** may display various additional information in an ultrasound image by using texts and graphics. The generated ultrasound image may be stored in the memory **400**.

[0207] The display unit **230** displays the generated ultrasound image. The display unit **230** may display not only an ultrasound image, but also various information processed by the ultrasound imaging apparatus **1000** on a screen via a graphic user interface (GUI). The ultrasound imaging apparatus **1000** may include two or more display units **230** according to exemplary embodiments.

[0208] The communication unit **300** is connected by wire or wirelessly to a network **30** to communicate with an external device or a server. The communication unit **300** may exchange data with a hospital server or other medical apparatuses in a hospital connected through a Picture Archiving and Communication System (PACS). Also, the communication unit **300** may perform data communication according to the Digital Imaging and Communications in Medicine (DICOM) standard.

[0209] The communication unit **300** may transmit and receive data related to diagnosis of the object **10**, e.g., an ultrasound image, ultrasound data, and Doppler data of the object **10**, via the network **30** and may also transmit and receive medical images obtained by other medical apparatuses, e.g., a computer tomography (CT) image, a magnetic resonance imaging (MRI) image, and an X-ray image. In addition, the communication unit **300** may receive information related to a diagnosis history or treatment schedule of a patient from a server and use the information to diagnose the object **10**. In addition, the communication unit **300** may perform data communication not only with a server or a medical apparatus in a hospital, but also with a portable terminal of a doctor or a patient.

[0210] The communication unit **300** may be connected by wire or wirelessly to the network **30** to exchange data with a server **32**, a medical apparatus **34**, or a portable terminal **36**. The communication unit **300** may include one or more components that enable communication with external devices, and may include, for example, a short-range communication module **310**, a wired communication module **320**, and a mobile communication module **330**.

[0211] The short-range communication module **310** refers to a module for short-range communication within a predetermined distance. Examples of short-range communication techniques according to an exemplary embodiment may include wireless LAN, Wi-Fi, Bluetooth, Zigbee, Wi-Fi Direct (WFD), ultra wideband (UWB), infrared data association (IrDA), Bluetooth Low Energy (BLE), and near field communication (NFC); however, exemplary embodiments are not limited thereto.

[0212] The wired communication module **320** refers to a module for communication using electrical signals or optical signals. Examples of wired communication techniques according to an exemplary embodiment may include a twisted pair cable, a coaxial cable, an optical fiber cable, and an Ethernet cable.

[0213] The mobile communication module **330** transmits and receives wireless signals to and from at least one of a base station, an external terminal, and a server on a mobile communication network. Herein, the wireless signals may include voice call signals, video call signals, or various types of data for transmission and reception of text/multimedia messages.

[0214] The memory **400** stores various data processed by the ultrasound imaging apparatus **1000**. For example, the memory **400** may store medical data related to diagnosis of the object **10**, such as ultrasound data and ultrasound images that are input or output and may also store algorithms or programs to be executed in the ultrasound imaging apparatus **1000**.

[0215] The memory **400** may be embodied as any of various storage media such as a flash memory, a hard disk drive, and an electrically erasable programmable read-only memory (EEPROM). Also, the ultrasound imaging apparatus **1000** may utilize web storage or a cloud server that functions as the memory **400** online.

[0216] The input device **500** refers to a unit via which a user inputs data for controlling the ultrasound imaging apparatus **1000**. The input device **500** may include hardware components, such as a keypad, a mouse, a touch panel, a touch screen, a track ball, and a jog switch. However, exemplary embodiments are not limited thereto, and the input device **50** may further include various other input units, such as an electrocardiogram measuring module, a respiration measuring module, a voice recognition sensor, a gesture recognition sensor, a fingerprint recognition sensor, an iris recognition sensor, a depth sensor, and a distance sensor.

[0217] The control unit **600** may control overall operations of the ultrasound imaging apparatus **1000**. In other words, the control unit **600** may control operations among the probe **20**, the data acquiring unit **100**, the image processing unit **200**, the communication unit **300**, the memory **400**, and the input device **500**.

[0218] All or some of the probe **20**, the data acquiring unit **100**, the image processing unit **200**, the communication unit **300**, the memory **400**, the input device **500**, and the control unit **600** may be operated by software modules. However, exemplary embodiments are not limited thereto, and some of the components stated above may be operated by hardware modules. Also, at least one of the data acquiring unit **100**, the image processing unit **200**, and the communication unit **300** may be included in the control unit **600**; however, exemplary embodiments are not limited thereto.

[0219] The exemplary embodiments may also be implemented in the form of a computer-readable recording medium including instructions executable by a computer, such as a program module executed by a computer. The computer-readable recording medium may be any available medium accessible by computers, examples of which may include a volatile recording medium, a nonvolatile recording medium, a removable recording medium, and an unremovable recording medium. Also, examples of the computer-readable recording medium may include a computer storage medium and a communication medium. Examples of the computer storage medium may include a volatile storage medium, a nonvolatile storage medium, a removable storage medium, and an unremovable storage medium that are implemented by any method or technology for storing information such as computer-readable instructions, data structures, program modules, or other data. Examples of the communication medium may include any information transmission medium including computer-readable instructions, data structures, program modules, other data of modulated data signals, or other transmission mechanisms.

[0220] The foregoing is illustrative of exemplary embodiments and is not to be construed as limiting thereof. Although the exemplary embodiments have been described above, those of ordinary skill in the art will readily appreciate that various modifications are possible in the exemplary embodiments without materially departing from the concepts and features of the exemplary embodiments. Therefore, it is to be understood that the exemplary embodiments described above should be considered in a descriptive sense only and not for purposes of limitation. For example, elements described as being combined may also be implemented in a distributed manner, and elements described as being distributed may also be implemented in a combined manner.

[0221] Therefore, the scope of the inventive concept is defined not by the detailed description of the exemplary embodiments but by the appended claims, and all modifications or differences within the scope should be construed as being included in the inventive concept.

[0222] In addition, other exemplary embodiments may also be implemented through computer-readable code/instructions in/on a medium, e.g., a transitory or non-transitory computer-readable medium, to control at least one processing element to implement any of the above-described exemplary embodiments. The medium may correspond to any medium/media permitting the storage and/or transmission of the computer-readable code.

[0223] The computer-readable code may be recorded/transferred on a medium in a variety of ways, with examples of the medium including recording media, such as magnetic storage media (e.g., ROM, floppy disks, hard disks, etc.) and optical recording media (e.g., CD-ROMs, or DVDs), and transmission media such as Internet transmission media. Thus, the medium may be such a defined and measurable structure including or carrying a signal or information, such as a device carrying a bitstream according to one or more exemplary embodiments. The media may also be a distributed network, so that the computer-readable code is stored/transferred and executed in a distributed fashion. Furthermore, the processing element could include a processor or a computer processor, and processing elements may be distributed and/or included in a single device.

[0224] It should be understood that the exemplary embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each exemplary embodiment should typically be considered as available for other similar features or aspects in other exemplary embodiments.

[0225] While one or more exemplary embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the inventive concept as defined by the following claims.

1. An ultrasound imaging apparatus comprising:

a data acquirer configured to transmit at least one ultrasound signal to a region of interest (ROI) of an object and to receive at least one ultrasound echo signal reflected from the ROI of the object; and

a controller configured to calculate a shear modulus which corresponds to at least one point in the ROI and a strain which corresponds to the at least one point, based on the received at least one ultrasound echo signal, and to calculate a stress applied to the at least one point by using the calculated shear modulus and the calculated strain.

2. The ultrasound imaging apparatus of claim **1**, wherein

the controller is further configured to generate first information which represents a compression stress applied to the object, based on the calculated stress, and

the ultrasound imaging apparatus further comprises a display device configured to display a user interface screen which includes the first information under a control of the controller.

3. The ultrasound imaging apparatus of claim **1**, wherein the controller is further configured to recalculate the strain based on a value which is obtainable by dividing the calculated strain by the calculated stress, and to form a strain image of the ROI by using the recalculated strain.

4. The ultrasound imaging apparatus of claim **3**, wherein the controller is further configured to divide the ROI into at least one region, to calculate an average stress which corresponds to each of the at least one region, and to recalculate the strain based on a value which is obtainable by dividing the calculated strain by the calculated average stress.

5. The ultrasound imaging apparatus of claim **1**, wherein the controller is further configured to calculate the stress by determining a value which is proportional to a product of the calculated shear modulus and the calculated strain as the stress.

6. The ultrasound imaging apparatus of claim **1**, wherein the control unit controller is further configured to acquire a shear modulus map of the ROI by using the calculated shear modulus which corresponds to the at least one point, to acquire a strain imaging map of the ROI by using the calculated strain which corresponds to the at least one point, and to calculate the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

7. The ultrasound imaging apparatus of claim **1**, wherein

the at least one ultrasound signal comprises a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via an ultrasound probe, and

the at least one ultrasound echo signal comprises a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

8. The ultrasound imaging apparatus of claim **7**, wherein the controller comprises a shear modulus calculating module configured to calculate a time-dependent displacement of the at least one point, based on the third ultrasound echo signal, and to calculate the shear modulus which corresponds to the at least one point by using the calculated time-dependent displacement.

9. The ultrasound imaging apparatus of claim **7**, wherein the controller comprises a strain calculating module configured to acquire reference image data which relates to the ROI by using the first ultrasound echo signal, to calculate a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal, and to calculate the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

10. The ultrasound imaging apparatus of claim **1**, wherein

the controller is further configured to generate a shear modulus image of the ROI by using the shear modulus which corresponds to the at least one point and to generate a strain image of the ROI by using the strain which corresponds to the at least one point, and the ultrasound imaging apparatus further comprises a display device configured to display the generated shear modulus image and the generated strain image simultaneously on a screen.

11. An ultrasound image processing method comprising:

transmitting at least one ultrasound signal to a region of interest (ROI) of an object and then receiving at least one ultrasound echo signal reflected from the ROI of the object;

calculating a shear modulus which corresponds to at least one point in the ROI, based on the at least one received ultrasound echo signal;

calculating a strain which corresponds to the at least one point, based on the at least one received ultrasound echo signal; and

calculating a stress applied to the at least one point by using the calculated shear modulus and the calculated strain.

12. The ultrasound image processing method of claim **11**, further comprising:

generating first information which represents a compression stress applied to the object, based on the calculated stress; and

displaying a user interface screen which includes the first information.

13. The ultrasound image processing method of claim **11**, further comprising:

recalculating the strain; based on a value which is obtainable by dividing the calculated strain by the calculated stress; and

forming a strain image of the ROI by using the recalculated strain.

14. The ultrasound image processing method of claim **13**, wherein the recalculating the strain comprises dividing the ROI into at least one region, calculating an average stress of each of the at least one region, and recalculating the strain based on a value which is obtainable by dividing the calculated strain by the calculated average stress.

15. The ultrasound image processing method of claim **11**, wherein the calculating the stress applied to the at least one point by using the calculated shear modulus and the calculated strain comprises determining a value which is proportional to a product of the calculated shear modulus and the calculated strain as the stress.

16. The ultrasound image processing method of claim **11**, wherein the calculating the stress applied to the at least one point by using the calculated shear modulus and the calculated strain comprises acquiring a shear modulus map of the ROI by using the calculated shear modulus which corresponds to the at least one point, acquiring a strain imaging map of the ROI by using the calculated strain which corresponds to the at least one point, and calculating the stress which corresponds to the ROI based on the acquired shear modulus map and the acquired strain imaging map.

17. The ultrasound image processing method of claim **11**, wherein the at least one ultrasound signal comprises a first ultrasound signal used to generate a reference image, a second ultrasound signal that is a focused ultrasonic pulse used to apply an acoustic force to the ROI, and a third ultrasound signal used to calculate a displacement of the at least one point in the ROI, which is generated by the acoustic force and a pressure applied via an ultrasound probe, and

the at least one ultrasound echo signal comprises a first ultrasound echo signal which corresponds to the first ultrasound signal and a third ultrasound echo signal which corresponds to the third ultrasound signal, which are reflected from the ROI of the object.

18. The ultrasound image processing method of claim **17**, wherein the calculating the shear modulus which corresponds to the at least one point comprises:

calculating a time-dependent displacement of the at least one point, based on the third ultrasound echo signal; and

calculating the shear modulus which corresponds to the at least one point by using the calculated time-dependent displacement.

19. The ultrasound image processing method of claim **17**, wherein the calculating the strain which corresponds to the at least one point comprises:

acquiring reference image data which corresponds to the ROI by using the first ultrasound echo signal;

calculating a displacement of the at least one point in the ROI based on the acquired reference image data and the third ultrasound echo signal; and

calculating the strain which corresponds to the at least one point in the ROI by differentiating the calculated displacement.

20. The ultrasound image processing method of claim **11**, further comprising:

generating a shear modulus image of the ROI by using the calculated shear modulus which corresponds to the at least one point;

generating a strain image of the ROI by using the calculated strain which corresponds to the at least one point; and

displaying the generated shear modulus image and the generated strain image simultaneously on a screen.

* * * * *

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专利名称(译)	超声图像处理方法及其超声成像设备		
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摘要(译)

提供一种超声成像设备。超声成像设备包括：数据获取单元，将超声信号发送到对象的感兴趣区域（ROI），然后接收从对象的ROI反射的超声回波信号;以及控制单元，至少计算剪切模量基于接收的超声回波信号，ROI中的一个点和至少一个点的应变，并通过使用剪切模量和应变计算施加到至少一个点的应力。