US 20180153509A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2018/0153509 A1
Kremsl et al. (43) Pub. Date: Jun. 7, 2018

(54) **ULTRASOUND IMAGING WITH SMALL-ANGLE ADJUSTMENT**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventors: **Andreas Kremsl**, Wolfgang im Salzkammergut (AT); **Manuel Schoenauer**, Thalgau (AT); **Reinhold Bruestle**, Frankenburg am Hausruck (AT)

(21) Appl. No.: **15/370,961**

(22) Filed: **Dec. 6, 2016**

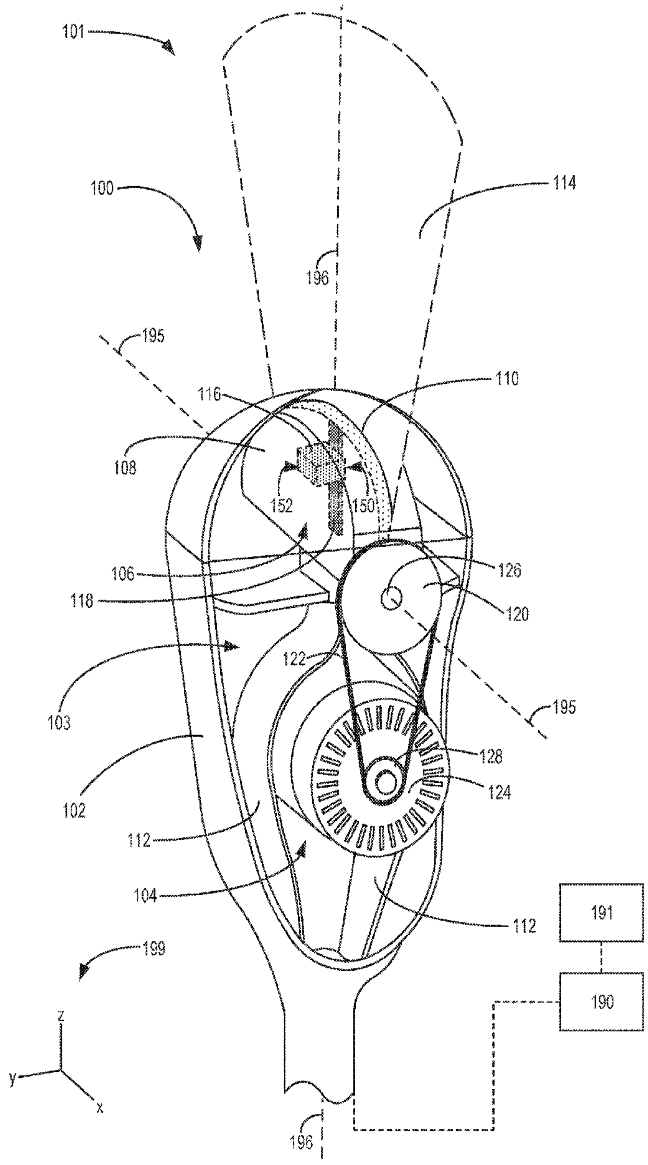
Publication Classification

(51) **Int. Cl.**
A61B 8/00 (2006.01)
G01S 7/52 (2006.01)
G01S 15/89 (2006.01)
A61B 8/14 (2006.01)

(52) **U.S. Cl.**
CPC ***A61B 8/4466*** (2013.01); ***G01S 7/52079*** (2013.01); ***G01S 15/8915*** (2013.01); ***A61B 8/469*** (2013.01); ***A61B 8/145*** (2013.01); ***A61B 8/54*** (2013.01); ***A61B 8/4494*** (2013.01)

(57) **ABSTRACT**

Methods and systems are provided for an ultrasound probe including a small-angle adjustment element. In one embodiment, the small-angle adjustment element includes a piezoelectric actuator configured to rotate a transducer array of the ultrasound probe in response to electrical signals transmitted to the piezoelectric actuator. In this way, an amount of angle spanned by the transducer array during a scan of a region of interest may be reduced, thereby increasing a precision of the ultrasound probe.



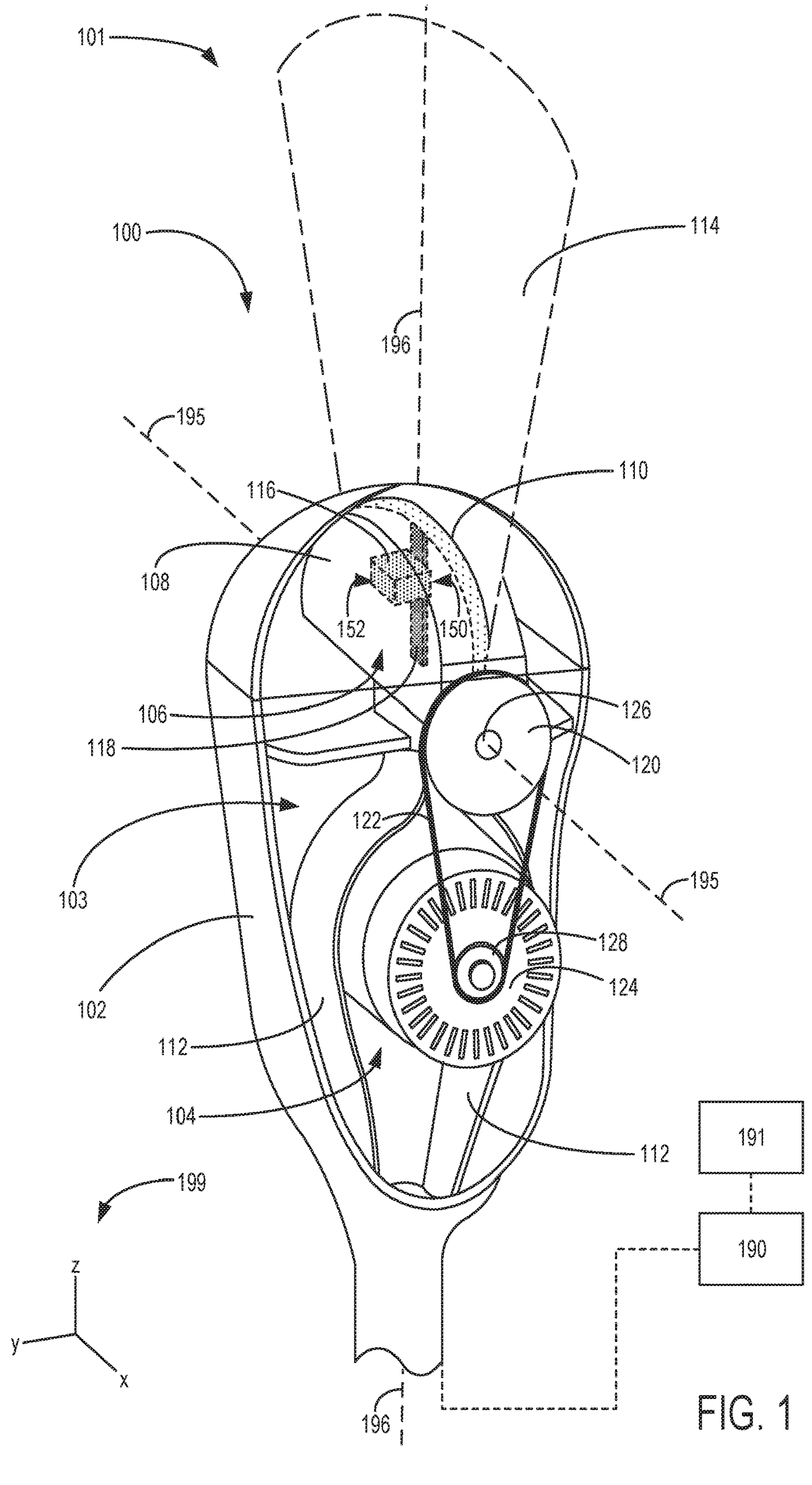

101
100
114
196
195
110
116
108
152
150
106
126
118
120
122
195
103
128
124
102
112
104
112
191
199
190
z
y
x
196

FIG. 1

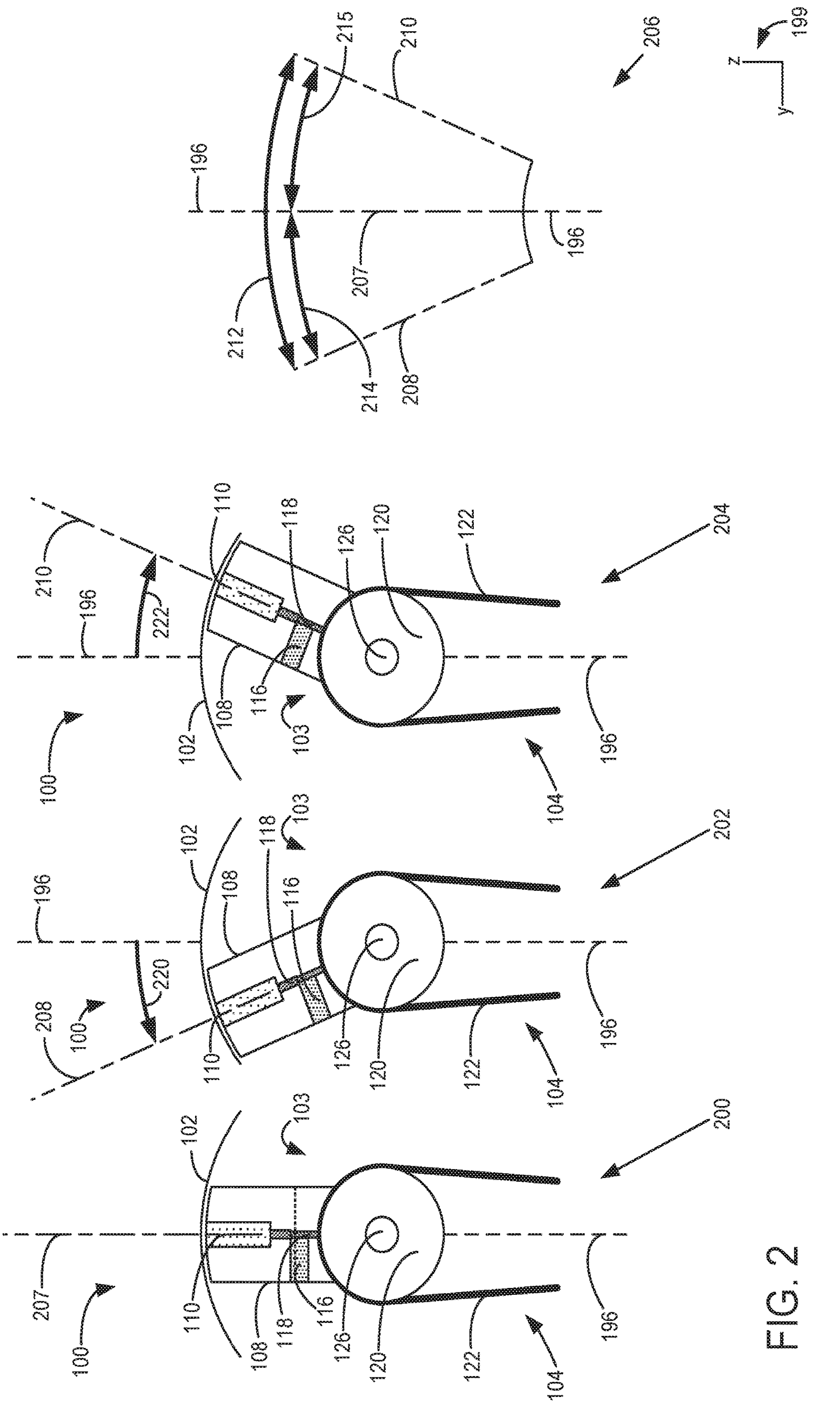

206
199
z
y
215
210
196
207
196
212
214
208
204
210
196
222
110
118
126
120
122
108
116
102
103
100
104
196
202
208
220
100
196
108
118
116
102
103
110
126
120
122
104
196
200
207
102
103
110
108
118
116
126
120
122
100
104
196

FIG. 2

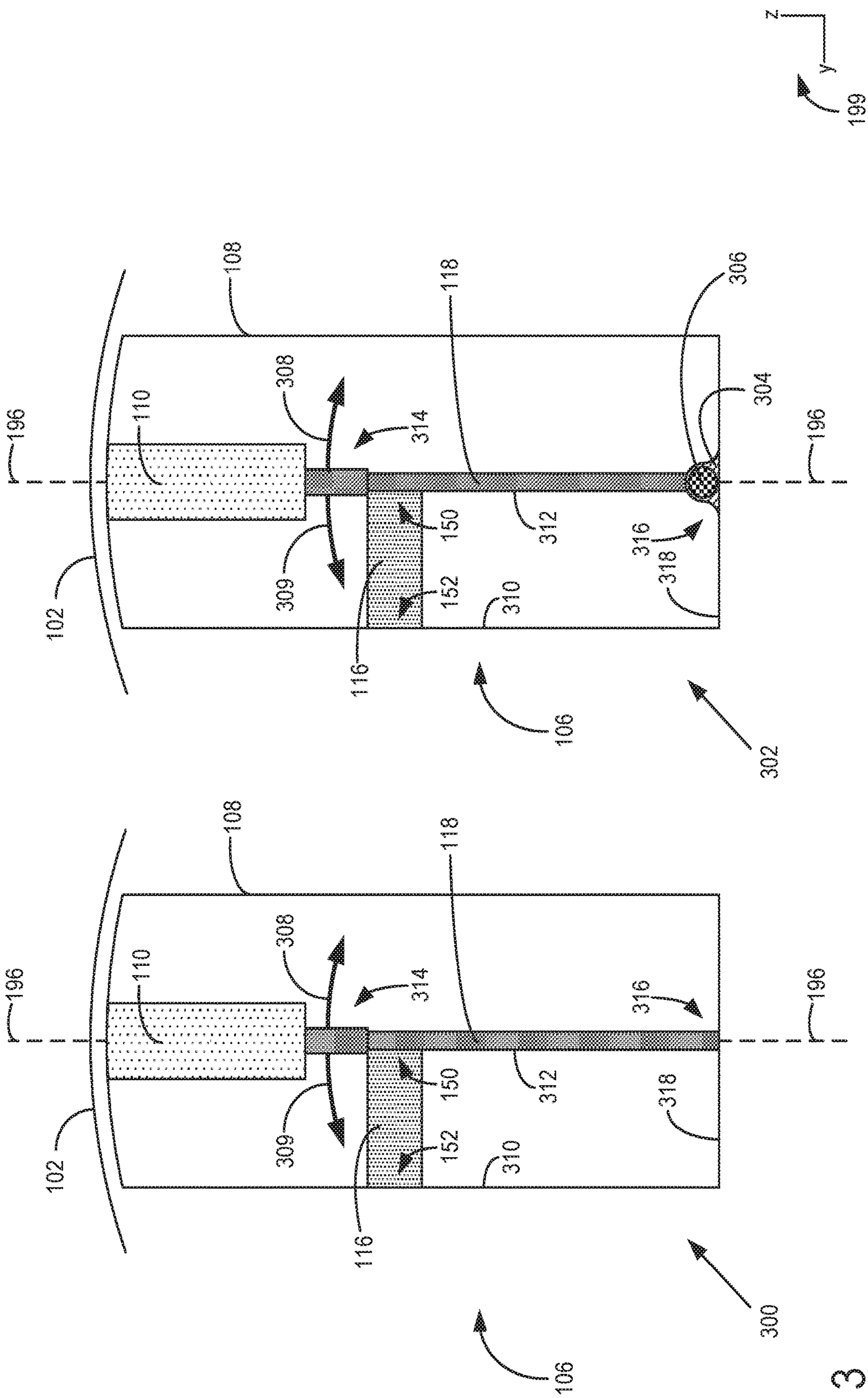

z
y
199
102
108
110
118
196
306
304
308
309
314
150
152
312
316
318
310
116
106
302
300

FIG. 3

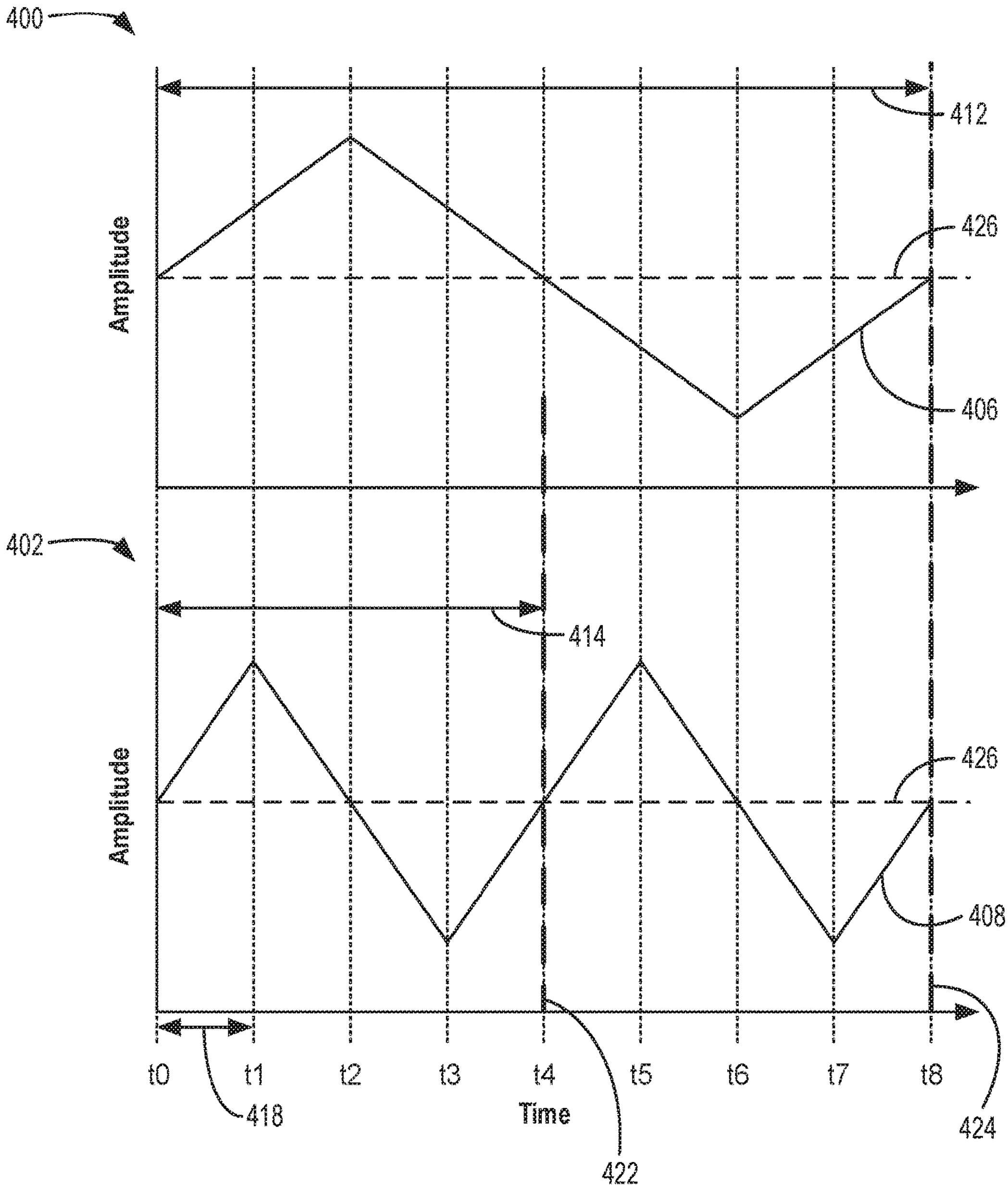
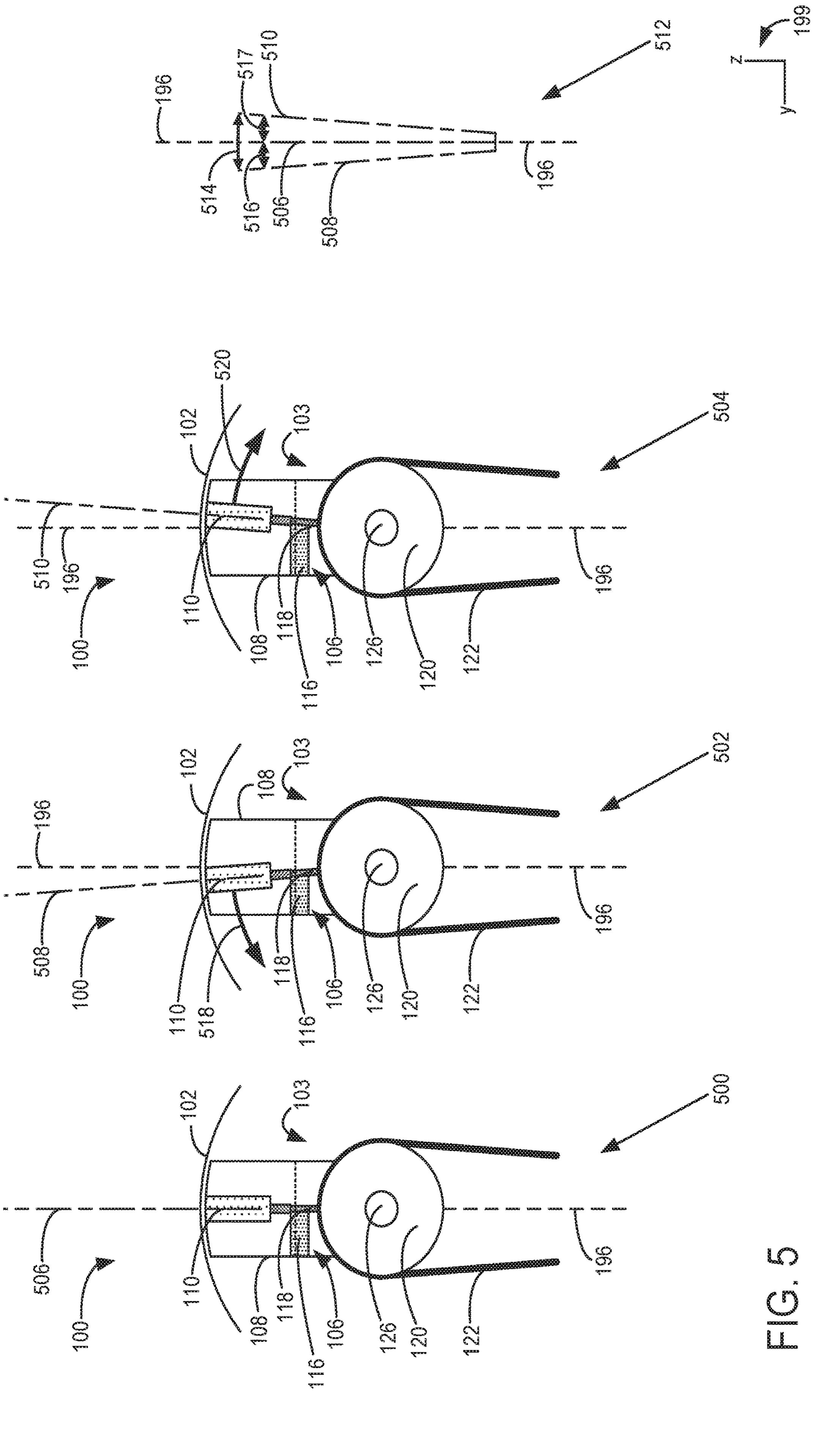

400
412
426
Amplitude
406
402
414
426
Amplitude
408
t0
t1
t2
t3
t4
t5
t6
t7
t8
Time
418
422
424

FIG. 4



199
z
y
512
510
517
196
514
516
506
508
196
520
102
103
504
510
196
100
110
108
118
116
106
126
120
122
196
502
102
108
103
196
508
100
110
518
118
116
106
126
120
122
196
500
102
103
506
100
110
108
118
116
106
126
120
122
196

FIG. 5

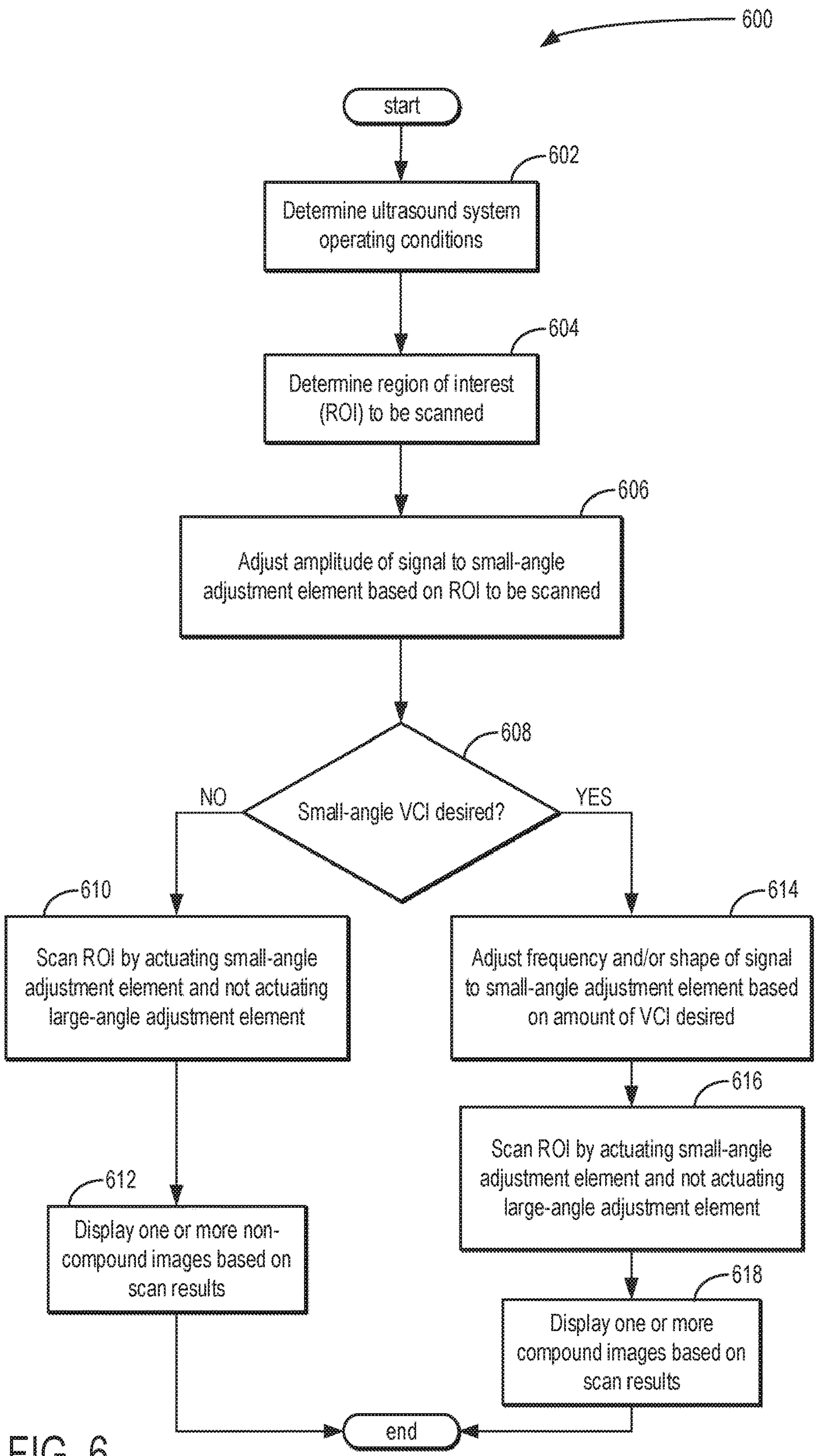

600
start
602
Determine ultrasound system operating conditions
604
Determine region of interest (ROI) to be scanned
606
Adjust amplitude of signal to small-angle adjustment element based on ROI to be scanned
608
Small-angle VCI desired?
NO
YES
610
Scan ROI by actuating small-angle adjustment element and not actuating large-angle adjustment element
614
Adjust frequency and/or shape of signal to small-angle adjustment element based on amount of VCI desired
616
Scan ROI by actuating small-angle adjustment element and not actuating large-angle adjustment element
612
Display one or more non-compound images based on scan results
618
Display one or more compound images based on scan results
end

FIG. 6

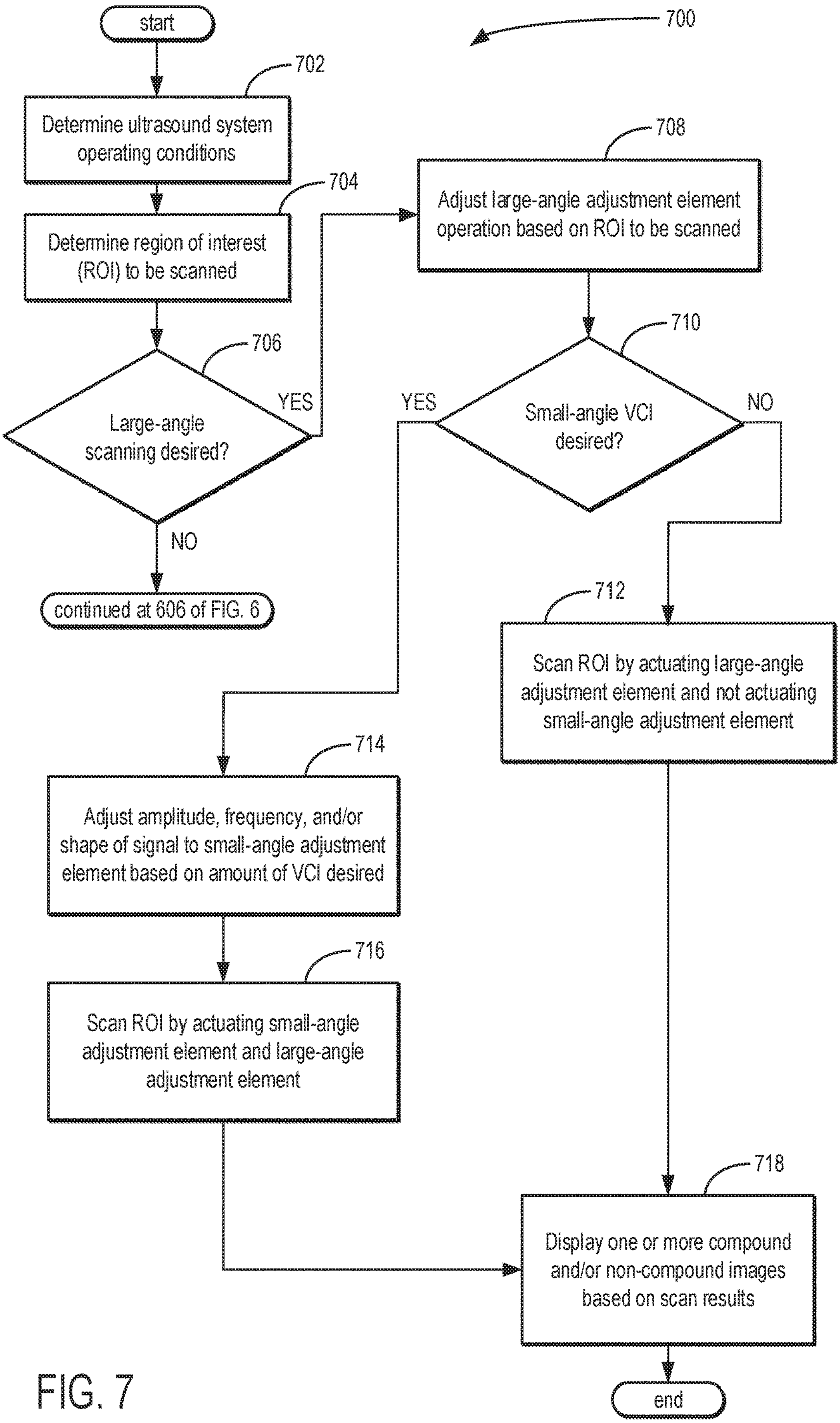

700
start
702
Determine ultrasound system operating conditions
704
Determine region of interest (ROI) to be scanned
706
Large-angle scanning desired?
YES
NO
continued at 606 of FIG. 6
708
Adjust large-angle adjustment element operation based on ROI to be scanned
710
Small-angle VCI desired?
YES
NO
712
Scan ROI by actuating large-angle adjustment element and not actuating small-angle adjustment element
714
Adjust amplitude, frequency, and/or shape of signal to small-angle adjustment element based on amount of VCI desired
716
Scan ROI by actuating small-angle adjustment element and large-angle adjustment element
718
Display one or more compound and/or non-compound images based on scan results
end

FIG. 7

ULTRASOUND IMAGING WITH SMALL-ANGLE ADJUSTMENT

FIELD

[0001] Embodiments of the subject matter disclosed herein relate to ultrasound imaging, and more particularly, to ultrasound probes.

BACKGROUND

[0002] An ultrasound imaging system may include an ultrasound probe configured to generate sound wave pulses and detect returning echoes within an object via an array of transducers. Such transducers typically include electromechanical elements capable of converting electrical energy into mechanical energy for transmission of ultrasonic wave pulses into patient tissue. Mechanical energy of reflected ultrasonic waves is then converted back into electrical energy when the reflected ultrasonic waves reach the transducers. The probe may be positioned by an operator of the system to scan a desired region of interest (e.g., a desired tissue or body region to be imaged), and echoes returning to the probe during the scan are processed into an image by a workstation or computational device of the system which may then display the image via a display device.

[0003] In some examples, the transducer array may be rotated by an actuator such as a stepper motor in order to acquire a sequence of images across a volume. The workstation or computational device may then compare images within the sequence to each other to produce a compound image with reduced acoustical artifacts in a process referred to as volume compound imaging (VCI).

[0004] However, an image sequence acquired via rotation of the transducer array by the stepper motor may span a large angle. As a result, a given image plane may span a relatively large amount of distance from adjacent image planes, thereby reducing an amount of acoustical artifact reduction provided by VCI and decreasing a scanning precision of the ultrasound probe. Therefore, a reduction in the distance between each image plane may increase a quality of images produced by the ultrasound system.

BRIEF DESCRIPTION

[0005] In one embodiment, an ultrasound probe comprises: a sensor housing; a piezoelectric actuator disposed within the sensor housing; and a transducer array coupled with the sensor housing, the transducer array rotatable relative to the sensor housing via energization of the piezoelectric actuator. In this way, the piezoelectric actuator may be energized to rotate the transducer array by a small angle, thereby increasing a scanning precision of the ultrasound probe.

[0006] It should be understood that the brief description above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0008] FIG. **1** shows a partial cross-sectional view of an ultrasound probe including a large-angle adjustment element and a small-angle adjustment element.

[0009] FIG. **2** shows the ultrasound probe in various partial cross-sectional views, with a transducer array of the probe rotated by the large-angle adjustment element.

[0010] FIG. **3** shows a first embodiment and a second embodiment of the small-angle adjustment element in cross-sectional views.

[0011] FIG. **4** shows various signal waveforms that may actuate the small-angle adjustment element.

[0012] FIG. **5** shows the ultrasound probe in various partial cross-sectional views, with a transducer array of the probe rotated by the small-angle adjustment element.

[0013] FIG. **6** shows an example method of acquiring images across a small angle by actuating the small-angle adjustment element of the ultrasound probe.

[0014] FIG. **7** shows an example method of acquiring images across a large angle by actuating the large-angle adjustment element of the ultrasound probe, and enhancing image acquisition by actuating the small-angle adjustment element.

DETAILED DESCRIPTION

[0015] The following description relates to various embodiments of ultrasound systems. In particular, systems and methods are provided for an ultrasound probe including a large-angle adjustment element and a small-angle adjustment element. An example of an ultrasound probe that may be used to acquire images with small-angle scans and/or large-angle scans is provided in FIG. **1**. In one example, the large-angle adjustment element may be a stepper motor used to rotate a sensor housing of the ultrasound probe to perform large-angle scans, as shown by FIG. **2**. The small-angle adjustment element may be a piezoelectric element coupled to a pivotable support, as shown by FIG. **3**. The piezoelectric element may be actuated by various signal waveforms, such as those shown by FIG. **4**, to rotate a transducer array within the sensor housing to perform small-angle scans, as shown by FIG. **5**. In one example, the small-angle adjustment element may be actuated to acquire images across a small angle as shown by the method of FIG. **6**. In another example, the small-angle adjustment element and large-angle adjustment element may be actuated together to acquire enhanced images across a large angle as shown by the method of FIG. **7**.

[0016] Various views of an ultrasound probe including a small-angle adjustment element and a large-angle adjustment element are shown by FIGS. **1-3** and FIG. **5**. Reference axes **199** are included by each of FIGS. **1-3** and FIG. **5** for comparison of the views shown.

[0017] FIG. **1** shows an ultrasound system **101** including an ultrasound probe **100** electrically coupled with a workstation **190**. The workstation **190** is configured to receive electrical signals from the ultrasound probe **100** and process the electrical signals into images to be displayed on display device **191** (e.g., a flat screen display). In one example, the display device may be a touch-sensitive display, also referred to as a touchscreen. An operator of the ultrasound system **101** may interact with the touchscreen to analyze the displayed image. In some examples, one or more additional user interface elements (e.g., mouse and keyboard) may be electrically coupled with the workstation **190** and configured such that an operator of the ultrasound system **101** may interact with (e.g., select, manipulate, etc.) images displayed by display device **191**.

[0018] In one example, the workstation **190** is a computer including a microprocessor unit, input/output ports, an electronic storage medium (such as a non-transitory read only memory chip) for storing executable programs, instructions, and calibration values, random access memory, keep alive memory, and a data bus. The workstation **190** receives signals from the ultrasound probe **100** via cables **112** electrically coupled to a transducer array **110**.

[0019] Ultrasound probe **100** includes a main housing **102** shown in cross-section by FIG. **2**. A large-angle adjustment element **104** is included within an interior **103** of the ultrasound probe **100**. In the examples shown by FIGS. **1-3** and FIG. **5**, the large-angle adjustment element **104** includes a stepper motor **124** configured to drive a first pulley **120** via belt **122**. In alternate embodiments, the large-angle adjustment element **104** may be a different type of actuator (e.g., a servomotor).

[0020] Stepper motor **124** includes a second pulley **128** rotatably coupled with the stepper motor **124**. The ultrasound probe **100** may be coupled to an electrical power source in order to drive components of the ultrasound probe **100** (e.g., stepper motor **124**, transducer array **110**, etc.). In one example, the electrical power source may be the workstation **190**, and the stepper motor **124** may be energized by the workstation **190** according to instructions stored in non-transitory memory of the workstation **190** (as described below with reference to FIGS. **6-7**). Energization of the stepper motor **124** may cause second pulley **128** to rotate, thereby driving belt **122** to rotate first pulley **120**. First pulley **120** is fixedly coupled with a sensor housing **108** within the main housing **102** by a fastener **126** (e.g., a bolt). In this configuration, as the first pulley **120** is rotated in a first direction by a first amount via the belt **122**, the sensor housing **108** is also rotated in the first direction by the first amount. Said another way, the first pulley **120** rotates around rotational axis **195** when driven by the stepper motor **124** via belt **122**, and the rotation of first pulley **120** results in a pivoting of the sensor housing **108** relative to the rotational axis **195** due to sensor housing **108** being directly coupled to first pulley **120** via fastener **126**.

[0021] The transducer array **110** of the ultrasound probe **100** includes a plurality of decoupled electric and acoustic modules. The transducer array **110** is typically used to transmit ultrasonic or acoustic waves towards an object (not shown in FIG. **1**). In response to transmitting the ultrasonic waves, the transducer array **110** may receive reflected or attenuated ultrasonic waves from the object. Further, these received ultrasonic waves are converted into electrical signals which are processed by the workstation **190** to obtain an ultrasonic image of the object. In one embodiment, the object may be a region of interest in a patient.

[0022] The transducer array **110** is coupled to the sensor housing **108** such that the transducer array **110** rotates (e.g., pivots) along with the sensor housing **108**. In other words, by rotating the sensor housing **108** via the stepper motor **124** as described above, the transducer array **110** is also rotated. In the example shown by FIG. **1**, the transducer array **110** is coupled to the sensor housing **108** via a shaft **118**. In one example, shaft **118** extends in a direction perpendicular with the rotational axis **195** and provides a rigid connection between transducer array **110** and the sensor housing **108**. Said another way, the shaft **118** may be directly coupled to the sensor housing **108** at an end opposite to an end coupled with the transducer array **110**. In this configuration, when the sensor housing **108** is pivoted around the rotational axis **195** by a first amount of angle, the transducer array **110** is also pivoted around the rotational axis **195** by the first amount of angle.

[0023] By rotating the transducer array **110** via the stepper motor **124**, an imaging plane **114** produced by the transducer array **110** is also rotated (e.g., pivoted). The imaging plane **114** shown by FIG. **1** represents a plane on which acoustic waves produced by the transducer array **110** travel when the transducer array **110** is energized by the workstation **190**. The acoustic waves may travel through an object (e.g., a region of interest on a patient) and reflect off of structures (e.g., tissues, blood vessels, etc.) internal to the object. The reflected waves may then return to the transducer array **110** along the imaging plane **114**, with the mechanical energy of the waves being converted into electrical signals by the transducer array **110**. The transducer array **110** then transmits the electrical signals to the workstation **190** via the cables **112**, where the workstation **190** processes the electrical signals to form an image on display device **191**. The acoustic waves transmitted along imaging plane **114** thereby characterize the image processed by the workstation **190** and shown on display device **191**. By rotating the imaging plane **114** via the stepper motor **124** as described above, the ultrasound probe **100** may gather images from a variety of angles without adjustment of a position of the ultrasound probe **100** (e.g., a position of the main housing **102**) by an operator of the ultrasound system **101**.

[0024] The shaft **118** is shown as part of a small-angle adjustment element **106**. The small-angle adjustment element **106** includes a piezoelectric actuator **116** directly coupled to (e.g., in face-sharing contact with) the shaft **118**. Piezoelectric actuator **116** is also electrically coupled with the electrical power source (e.g., workstation **190**) by one or more conductive wires within cable **112** (for example). The piezoelectric actuator **116** may be directly coupled with the shaft **118** at a first end **150**, and may be directly coupled with the sensor housing **108** at a second end **152**. Piezoelectric actuator **116** is configured to expand or contract in size in response to electrical signals transmitted to the piezoelectric actuator **116** by the workstation **190**.

[0025] For example, the workstation **190** may transmit an electrical signal to the piezoelectric actuator **116** resulting in a positive-valued voltage across the piezoelectric actuator **116**. As a result of the positive-valued voltage, the piezoelectric actuator **116** expands in a direction perpendicular to the shaft **118**. In other words, a length of the piezoelectric actuator **116** extending from the first end **150** coupled with the shaft **118** to the second end **152** coupled with the sensor housing **108** is increased by the positive-valued voltage. The piezoelectric actuator **116** thereby exerts a pressing force against the shaft **118** to pivot the shaft **118** and transducer array **110** relative to the sensor housing **108** in a first direction (as shown by FIG. **5** and described further below).

[0026] In another example, an electrical signal transmitted to the piezoelectric actuator **116** by the workstation **190** may result in a negative-valued voltage across the piezoelectric actuator **116**. As a result of the negative-valued voltage, a length of the piezoelectric actuator **116** extending between the first end **150** and second end **152** is decreased. The piezoelectric actuator **116** thereby exerts a pulling force against the shaft **118** to pivot the shaft **118** and transducer array **110** relative to the sensor housing **108** in a second direction opposite to the first direction (as shown by FIG. **5** and described below).

[0027] By configuring the ultrasound probe **100** according to the examples described above, the stepper motor **124** may rotate (e.g., pivot) the sensor housing **108** (and therefore, the transducer array **110** and imaging plane **114**) relative to the main housing **102** in order to perform relatively large-angle scans across a region of interest on a patient (for example). Additionally, the piezoelectric actuator **116** may be energized to pivot the transducer array **110** and imaging plane **114** relative to the sensor housing **108** in order to perform relatively small-angle scans across the region of interest. In some examples, the stepper motor **124** may be energized while the piezoelectric actuator **116** is not energized (e.g., in order to perform a large volumetric scan). In other examples, the piezoelectric actuator **116** may be energized while the stepper motor **124** is not energized (e.g., in order to enhance a scan using volume compound imaging). In yet other examples, both of the piezoelectric actuator **116** and stepper motor **124** may be energized (e.g., in order to perform a volumetric scan with volume compound imaging). Example scanning methods are described further below with reference to FIGS. **6-7**.

[0028] FIG. **2** shows views (e.g., first view **200**, second view **202**, and third view **204**) of the sensor housing **108** in various positions relative to the main housing **102**. Each of the first view **200**, second view **202**, and third view **204** show a portion of the ultrasound probe **100** in partial cross-section in order to illustrate a movement of the sensor housing **108** relative to the main housing **102**. As a result, some components included by the ultrasound probe **100** and shown by FIG. **1** are not shown by FIG. **2**. FIG. **2** additionally includes a fourth view **206**, with the fourth view **206** showing a positioning of a first imaging plane **207**, a second imaging plane **208**, and a third imaging plane **210** relative to each other. The first imaging plane **207** is produced by the transducer array **110** when the sensor housing **108** is in the position shown by the first view **200**, the second imaging plane **208** is produced by the transducer array **110** when the sensor housing **108** is in the position shown by the second view **202**, and the third imaging plane **210** is produced by the transducer array **110** when the sensor housing **108** is in the position shown by the third view **204**, as described below.

[0029] First view **200** shows an initial position of the sensor housing **108** in which the sensor housing **108** is not rotated relative to the main housing **102** (e.g., first imaging plane **207** produced by the transducer array **110** is aligned with the central axis **196**). The initial position of the sensor housing **108** shown by first view **200** may be referred to herein as a non-rotated position and/or reference position of the sensor housing **108**.

[0030] Second view **202** shows the sensor housing **108** rotated in a first direction **220** relative to the main housing **102**, such that the second imaging plane **208** is also rotated in the first direction **220** relative to the first imaging plane **207**. In other words, the second imaging plane **208** is at a first angle **214** relative to the central axis **196** and first imaging plane **207** as shown by fourth view **206** and described below. In one example, the sensor housing **108** may be rotated in the first direction **220** from the position shown by first view **200** to the position shown by second view **202** by the large-angle adjustment element **104** (e.g., via energization of the stepper motor **124** by the workstation **190**, both of which are shown by FIG. **1** and described above).

[0031] Third view **204** shows the sensor housing **108** rotated in a second direction **222** relative to the main housing **102**, such that the third imaging plane **210** is also rotated in the second direction **222** relative to the first imaging plane **207**. In other words, the third imaging plane **210** is at a second angle **215** relative to the central axis **196** and first imaging plane **207**. In one example, the sensor housing **108** may be rotated in the second direction **222** from the position shown by first view **200** to the position shown by third view **204** by the large-angle adjustment element **104** (e.g., via energization of the stepper motor **124** by the workstation **190**, both of which are shown by FIG. **1** and described above).

[0032] Fourth view **206** shows a relative arrangement of the first imaging plane **207**, second imaging plane **208**, third imaging plane **210**, and central axis **196**. As described above, second imaging plane **208** is angled relative to the first imaging plane **207** by a first angle **214**, and third imaging plane **210** is angled relative to the first imaging plane **207** by a second angle **215**. In one example, the first angle **214** and second angle **215** are a same amount of angle extending in opposite directions (e.g., first direction **220** and second direction **222**, respectively) from the central axis **196**.

[0033] During operation of the ultrasound probe **100**, the large-angle adjustment element **104** may be actuated by the workstation **190** (described below with reference to FIG. **7**) in order to perform a large-angle scan of a region of interest of an object (e.g., a patient). The large-angle scan may include images gathered by the ultrasound probe **100** along each of the first imaging plane **207**, second imaging plane **208**, and third imaging plane **210**. In other words, the large-angle scan may span an angle **212**, with the angle **212** extending between the second imaging plane **208** and third imaging plane **210**.

[0034] It should be noted that the large-angle scan spanning the angle **212** shown by FIG. **2** is one example of a large-angle scan. In other examples, the large-angle scan may span a different amount of angle than the angle **212** and may include a plurality of imaging planes different than those shown by FIG. **2**. In one example, the angle **212** may be 45 degrees, and the first angle **214** and second angle **215** may each be 22.5 degrees. In another example the angle **212** may be 50 degrees, and the number of imaging planes may be greater than 3. Additional examples of angle and number of imaging planes are also possible. However, in each example, the angle **212** of the large-angle scan is greater than an angle of a small-angle scan produced by actuation of the small-angle adjustment element **106** (shown by FIG. **1**), as described below with reference to FIGS. **3-5**.

[0035] FIG. **3** shows an enlarged view of the small-angle adjustment element **106** in a first view **300**, with an alternate embodiment of the small-angle adjustment element **106** shown by second view **302**. The small-angle adjustment element **106** includes the piezoelectric actuator **116** coupled between the sensor housing **108** and the shaft **118** as described above with reference to FIG. **1**. In particular, the second end **152** of the piezoelectric actuator **116** is coupled to an interior wall **310** of the sensor housing **108**, and the first end **150** of the piezoelectric actuator **116** is coupled to a first surface **312** of the shaft **118**, with the first surface **312** and interior wall **310** extending in a direction approximately parallel with each other when the piezoelectric actuator **116** is in a de-energized condition (e.g., not energized by workstation **190** shown by FIG. **1**). In this configuration, the piezoelectric actuator **116** extends between the interior wall **310** and the first surface **312** in a direction perpendicular with the interior wall **310**.

[0036] In the example shown by first view **300**, a first end **314** of the shaft **118** is coupled to the transducer array **110** and a second end **316** of the shaft **118** is coupled directly to a lower wall **318** of the sensor housing **108**. The lower wall **318** is joined with the interior wall **310** and extends in a direction perpendicular with the interior wall **310**. The second end **316** of the shaft **118** is permanently joined with (e.g., fused or welded to) the lower wall **318**. The first end **314** coupled with the transducer array **110** is pivotable relative to the second end **316** in a first direction **308** in response to a pressing force against the second end **316**, and the first end **314** is pivotable in a second direction **309** (opposite to the first direction **308**) in response to a pulling force against the second end **316**. Both of the pressing force and pulling force may be in directions approximately perpendicular with the direction of extension of shaft **118**.

[0037] In a second example shown by second view **302**, the second end **316** of the shaft **118** is instead coupled to a bearing **306** supported within a bearing housing **304**. The bearing housing **304** is coupled to the lower wall **318**, and the bearing **306** is shaped to rotate within the bearing housing **304** in response to a pivoting of the shaft **118**. For example, a pressing force may press against the first end **314** in order to pivot the shaft **118** relative to the bearing housing **304** in the first direction **308**. In another example, a pulling force may pull against the first end **314** to pivot the shaft **118** relative to the bearing housing **304** in the second direction **309**.

[0038] In one example (as described above and with reference to FIG. **1**), the pressing force and pulling force may result from an expansion or contraction of the piezoelectric actuator **116** when the piezoelectric actuator **116** is energized by the workstation **190** (shown by FIG. **1**). For example, the workstation **190** may transmit an electrical signal to the piezoelectric actuator **116** to apply a negative-valued voltage across the piezoelectric actuator **116**, thereby resulting in the first end **150** and second end **152** of the piezoelectric actuator **116** moving toward each other (e.g., shortening the piezoelectric actuator **116**). In another example, the workstation **190** may transmit an electrical signal to the piezoelectric actuator **116** to apply a positive-valued voltage across the piezoelectric actuator **116**, thereby resulting in the first end **150** and second end **152** of the piezoelectric actuator moving away from each other (e.g., lengthening the piezoelectric actuator **116**). Example signals that may be transmitted to the piezoelectric actuator **116** are shown by FIG. **4** and described below.

[0039] FIG. **4** shows two example electrical signals (e.g., pulses) that may be transmitted to piezoelectric actuator **116** (shown by FIGS. **1-3** and FIG. **5**). Specifically, first plot **400** shows a first signal **406** with a first wavelength **412** and second plot **402** shows a second signal **408** with a second wavelength **414**. In the example shown by FIG. **4**, second wavelength **414** has a length that is one-half an amount of a length of first wavelength **412**. Although the first signal **406** and second signal **408** are each shown as triangular waves, other wave shapes (e.g., sine waves, square waves, sawtooth waves, etc.) are possible. A threshold amplitude **426** is shown by each of the first plot **400** and second plot **402**. In one example, when an amplitude of a signal (e.g., first signal **406** and second signal **408**) is above the threshold amplitude **426**, the signal may result in a positive-valued voltage across the piezoelectric actuator, and when the amplitude of the signal is below the threshold amplitude **426**, the signal may result in a negative-valued voltage across the piezoelectric actuator.

[0040] Each of the times t**0** through t**8** shown by FIG. **4** correspond to times at which the transducer array **110** of the ultrasound probe **100** (shown by FIGS. **1-3** and FIG. **5**) may transmit electrical signals to the workstation **190** (e.g., times at which echoes from transmitted acoustic waves may be received). The workstation **190** may process the electrical signals to form an image (e.g., a frame) associated with each of the times t**0** through t**8**. For example, at time t**0**, the transducer array may receive echoes from a previously transmitted acoustic wave (e.g., prior to time t**0**) within an object (e.g., a patient). The mechanical energy of the echoes is converted into electrical energy by the transducer array, and the transducer array transmits the electrical energy to the workstation in the form of an electrical signal. The workstation then processes the electrical signal to form an image which may be displayed on a display device (e.g., display device **191** shown by FIG. **1**).

[0041] In the example shown by FIG. **4**, an amount of time **418** between time t**0** and time t**1** is a same amount of time as times between each adjacent time of t**0** through t**8**. In other words, the amount of time **418** between time t**0** and time t**1** is a same amount of time as an amount of time between t**1** and t**2**, between t**2** and t**3**, between t**3** and t**4**, etc. In one example, the amount of time **418** may correspond to an amount of time between transmission of acoustic waves from the transducer array and reception of echoes of the acoustic waves by the transducer array. An example of ultrasound probe operation in response to first signal **406** being transmitted to the ultrasound probe via the workstation is described below.

[0042] As shown by first plot **400**, the first wavelength **412** of the first signal **406** extends between time t**0** and time t**8**. Between time t**0** and time t**2**, the amplitude of the first signal **406** is above the threshold amplitude **426** and is increasing. The amplitude between time t**0** and time t**2** results in a positive-valued voltage across the piezoelectric actuator, thereby causing the piezoelectric actuator to increasingly expand. The expansion of the piezoelectric actuator results in a transducer array being rotated in a first direction relative to the sensor housing (e.g., as described above with reference to transducer array **110** and sensor housing **108** shown by FIGS. **1-3**, with the transducer array **110** rotated in the first direction **308** shown by FIG. **3**). At time t**2** the amplitude of the first signal **406** peaks. As a result, the piezoelectric actuator does not expand further and the transducer array does not rotate further in the first direction.

[0043] Between time t**2** and time t**4**, the amplitude of the first signal **406** is above the threshold amplitude **426** and is decreasing. As a result, a magnitude of the positive-valued voltage across the piezoelectric actuator decreases, and the piezoelectric actuator begins to contract relative to its fully expanded condition at time t2. The contraction of the piezoelectric actuator causes the transducer array **110** to rotate in a second direction (e.g., second direction **309** shown by FIG. **3**) opposite to the first direction.

[0044] At time t4 the amplitude of the first signal **406** decreases below the threshold amplitude **426**, and between time t4 and t6 the amplitude of the first signal **406** continues to decrease. The amplitude of the first signal **406** being below the threshold amplitude **426** results in a negative-valued voltage across the piezoelectric actuator, thereby causing the piezoelectric actuator to increasingly contract. The contraction of the piezoelectric actuator results in a continued rotation of the transducer array in the second direction as described above. At time t6 the amplitude of the first signal **406** is at a peak negative value. As a result, the piezoelectric actuator does not contract further and the transducer array does not rotate further in the second direction.

[0045] Between time t6 and time t8, the amplitude of the first signal **406** is below the threshold amplitude **426** and is increasing. As a result, the negative-valued voltage across the piezoelectric actuator becomes increasingly less negative-valued, and the piezoelectric actuator expands relative to its fully contracted condition (e.g., the condition of the piezoelectric actuator at time t6). The expansion of the piezoelectric actuator causes the transducer array to rotate in the first direction.

[0046] By rotating the transducer array in the first direction and second direction in response to the amplitude of the first signal **406** as described above, an angle of the transducer array relative to the sensor housing may be different at one or more or each of the times t0 through t8. For example, the transducer array may be at a first angle relative to the sensor housing at time t4, but may be angled toward the first direction (e.g., first direction **308** shown by FIG. **3**) at time t3, and may be angled toward the second direction (e.g., second direction **309** shown by FIG. **3**) at time t5. Imaging planes produced by the transducer array at each of the times t0 through t8 may be angled similarly to the example described above. With reference to the example described above, at time t4 the imaging plane produced by the transducer array is at the first angle, while at time t3 the imaging plane is angled toward the first direction relative to the first angle, and at time t5 the imaging plane is angled toward the second direction relative to the first angle. An example of a relative positioning of imaging planes is shown by FIG. **5** and described below.

[0047] In this way, as the transducer array receives echoes at each of the times t0 through t8 along the imaging planes as described above, the ultrasound probe transmits a series of electrical signals to the workstation and the workstation processes the electrical signals to form a plurality of images. Each image of the plurality of images is associated with one of the times t0 through t8. For example, the workstation may associate a first image of the plurality of images with echoes received at time t0, a second image of the plurality of images with echoes received at time t1, a third image of the plurality of images with echoes received at time t2, etc. In one example, the images may be associated by the workstation such that (for example) the first image associated with time t0 by the workstation is an image processed from echoes received along an imaging plane of the transducer array at time t0. In some examples (as described below with reference to FIGS. **6-7**) the workstation may compare at least two images of the plurality of images to each other in order to form a volume compound image for display on a display device (e.g., display device **191** shown by FIG. **1**). The volume compound image may have an increased clarity and/or contrast relative to the at least two images of the plurality of images.

[0048] Second signal **408** is shown as an example of a signal with an increased frequency relative to first signal **406**. Because the second wavelength **414** of second signal **408** is one-half the amount of length of first wavelength **412**, a rotation speed of the transducer array due to the expansion and contraction of the piezoelectric actuator (as described above with reference to the first signal **406**) is increased relative to the example described above. As a result, the transducer array may move over a region of interest more quickly when energized via the second signal **408** compared to the first signal **406**. However, due to the amount of time **418** between the reception of echoes by the ultrasound probe as described above, a number of images processed by the workstation for each wavelength of second signal **408** is reduced relative to a number of images processed by the workstation for each wavelength of first signal **406**.

[0049] For example, one wavelength of the first signal **406** (e.g., first wavelength **412**) spans the time between time t0 and time t8 (as indicated by dotted line **424** signifying an end of first wavelength **412**). As such, for the first wavelength of the first signal **406**, eight images (one for each of times t0 through t7) may be processed by the workstation, with the time t8 corresponding to an end of first wavelength **412** and a beginning of a next wavelength of first signal **406**. However, one wavelength of the second signal **408** (e.g., second wavelength **414**) spans the time between time t0 and time t4, for example (as indicated by dotted line **422** signifying an end of second wavelength **414**). As a result, four images (one for each of times t0 through t3) are associated with the second wavelength **414** of the second signal **408**, with the time t4 corresponding to an end of second wavelength **414** and a beginning of a next wavelength of second signal **408**. In one example, the number of images associated with each wavelength may contribute to a clarity and/or contrast of a volume compound image produced by the workstation for each wavelength (e.g., each scan of the region of interest via rotation of the transducer array). In other words, decreasing a wavelength of a signal transmitted to the piezoelectric actuator may increase a rotational speed of the transducer array in order to increase a scanning speed of the region of interest by the ultrasound probe, but may reduce a number of images gathered by the ultrasound probe during each scan. In one example, an operator of the ultrasound probe may interact with the workstation in order to set the wavelength of the electrical signal transmitted to the piezoelectric actuator in order to increase the scanning speed or increase the number of images gathered per scan. An example of scan is shown by FIG. **5** and described below.

[0050] FIG. **5** shows views (e.g., first view **500**, second view **502**, and third view **504**) of the transducer array **110** in various positions relative to the sensor housing **108**. Each of the first view **500**, second view **502**, and third view **504** show a portion of the ultrasound probe **100** in partial cross-section in order to illustrate a rotation (e.g., pivoting) of the transducer array **110** relative to the sensor housing **108**. As a result, some components included by the ultrasound probe **100** and shown by FIG. **1** are not shown by FIG.

5. FIG. **5** additionally includes a fourth view **512**, with the fourth view **512** showing a positioning of a first imaging plane **506**, a second imaging plane **508**, and a third imaging plane **510** relative to each other. The first imaging plane **506** is produced by the transducer array **110** when the transducer array **110** is in the position shown by the first view **500**, the second imaging plane **508** is produced by the transducer array **110** when the transducer array **110** is in the position shown by the second view **502**, and the third imaging plane **510** is produced by the transducer array **110** when the transducer array **110** is in the position shown by the third view **504**, as described below.

[0051] First view **500** shows an initial position of the transducer array **110** in which the transducer array **110** is not rotated relative to the sensor housing **108**. The initial position of the transducer array **110** shown by first view **500** may be referred to herein as a non-rotated position and/or reference position of the transducer array **110**. As described above, the small-angle adjustment element **106** may be energized by the workstation **190** (shown by FIG. **1**) in order to rotate the transducer array **110** relative to the sensor housing **108**. In the example described above with reference to FIGS. **1-4**, the piezoelectric actuator **116** of the small-angle adjustment element **106** may be energized by an electrical signal such as those described with reference to FIG. **4** in order to rotate transducer array **110** relative to sensor housing **108**.

[0052] Second view **502** shows the transducer array **110** rotated in a first direction **518** relative to the sensor housing **108**, such that the second imaging plane **508** is also rotated in the first direction **518** relative to the first imaging plane **506**. In other words, the second imaging plane **508** is at a first angle **516** relative to the first imaging plane **506** as shown by fourth view **512** and described below. In one example, the transducer array **110** may be rotated in the first direction **518** from the position shown by first view **500** to the position shown by second view **502** by the small-angle adjustment element **106** (e.g., via energization of the piezoelectric actuator **116** by the workstation **190**, both of which are shown by FIG. **1** and described above).

[0053] Third view **504** shows the transducer array **110** rotated in a second direction **520** relative to the sensor housing **108**, such that the third imaging plane **510** is also rotated in the second direction **520** relative to the first imaging plane **506**. In other words, the third imaging plane **510** is at a second angle **517** relative to the first imaging plane **506**. In one example, the transducer array **110** may be rotated in the second direction **520** from the position shown by first view **500** to the position shown by third view **504** by the small-angle adjustment element **106** (e.g., via energization of the piezoelectric actuator **116** by the workstation **190**, both of which are shown by FIG. **1** and described above).

[0054] Fourth view **512** shows a relative arrangement of the first imaging plane **506**, second imaging plane **508**, third imaging plane **510**, and central axis **196**. As described above, second imaging plane **508** is angled relative to the first imaging plane **506** by a first angle **516**, and third imaging plane **510** is angled relative to the first imaging plane **508** by a second angle **517**. In one example, the first angle **516** and second angle **517** are a same amount of angle extending in opposite directions (e.g., first direction **518** and second direction **520**, respectively) from the first imaging plane **506**.

[0055] During operation of the ultrasound probe **100**, the small-angle adjustment element **106** may be actuated by the workstation **190** (described below with reference to FIGS. **6-7**) in order to perform a small-angle scan of a region of interest of an object (e.g., a patient). In one example, the small-angle scan may include images gathered by the ultrasound probe **100** along each of the first imaging plane **506**, second imaging plane **508**, and third imaging plane **510**. In other words, the small-angle scan may span an angle **514**, with the angle **514** extending between the second imaging plane **506** and third imaging plane **510**.

[0056] It should be noted that the small-angle scan spanning the angle **514** shown by FIG. **5** is one example of a small-angle scan. In other examples, the small-angle scan may span a different amount of angle than the angle **514** and may include a plurality of imaging planes different than those shown by FIG. **5**. In one example, the angle **514** may be 5 degrees, and the first angle **516** and second angle **517** may each be 2.5 degrees. In another example the angle **514** may be 7 degrees, and the number of imaging planes may be greater than 3. Additional examples of angle and number of imaging planes are also possible. However, in each example, the angle **514** of the small-angle scan is much smaller (e.g., 5 degrees) relative to an angle of a large-angle scan (e.g., 45 degrees) produced by actuation of the large-angle adjustment element **104** (shown by FIGS. **1-2**), as described above with reference to FIG. **2**.

[0057] FIG. **6** shows an example operation of an ultrasound probe including a small-angle adjustment element, such as the ultrasound probe described in the examples above with reference to FIGS. **1-3** and FIG. **5**. The small-angle adjustment element may be configured to receive electrical signals from the workstation such as those shown by FIG. **4** and described above.

[0058] Instructions for carrying out method **600** shown by FIG. **6**, method **700** shown by FIG. **7**, and the rest of the methods included herein may be executed by a controller (e.g., workstation **190** shown by FIG. **1**) based on instructions stored on a memory of the controller and in conjunction with signals received from the ultrasound probe, such as the transducer array described above with reference to FIGS. **1-5**. The controller may employ actuators of the ultrasound probe to adjust ultrasound probe operation, according to the methods described below.

[0059] At **602**, the method includes determining ultrasound system operating conditions. In one example, determining ultrasound system operating conditions may include determining a position of the transducer array relative to the sensor housing, determining a position of the sensor housing relative to the main housing, determining electrical signals transmitted to the small-angle adjustment element, determining images stored in workstation memory and/or displayed on the display device, etc.

[0060] The method continues from **602** to **604** where the method includes determining a region of interest (ROI) to be scanned. In one example, an ROI may be a region of interest on a body of a patient (e.g., an abdomen of a patient). An operator of the ultrasound system (e.g., an ultrasound technician) may determine the ROI in order to position the ultrasound probe of the ultrasound system such that one or more scans of the region may be performed. In the example above, the ultrasound probe may be positioned against the abdomen in order to scan a region of the abdomen.

[0061] The method continues from **604** to **606** where the method includes adjusting an amplitude of a signal transmitted to the small-angle adjustment element based on the region of interest to be scanned. In one example, the amplitude of the signal may be increased in order to increase a rotation amount of the transducer array relative to the sensor housing (as described above with reference to FIG. **4**). By increasing the amplitude of the signal and the rotation amount of the sensor array, a larger amount of the region of interest may be scanned within a single scan. In another example, the amplitude of the signal may be decreased in order to decrease the rotation amount of the transducer array relative to the sensor housing. By decreasing the amplitude of the signal and the rotation amount of the sensor array, a narrower region may be scanned.

[0062] The method continues from **606** to **608** where the method includes determining whether small-angle volume compound imaging (VCI) is desired. For example, the operator of the system may determine that small-angle VCI is desired in order to increase a clarity and/or contrast of images of the region of interest. The workstation may compare and/or combine a first plurality of images formed during a single scan in order to produce one or more compound images, with an amount of the one or more compound images being less than an amount of the first plurality of images. The one or more compound images may have an increased clarity and/or contrast (e.g., reduction of acoustical artifacts) relative to the first plurality of images.

[0063] In another example, the operator of the system may determine that small-angle VCI is not desired. For example, the region of interest may be a region in which images produced by the ultrasound system typically do not include a high amount of acoustical artifacts, image noise, etc. As a result, the operator may determine that producing compound images via small-angle VCI is less desirable than acquiring non-compound images (e.g., images without VCI) at an increased rate.

[0064] If small-angle VCI is not desired at **608**, the method continues to **610** where the method includes scanning the ROI by actuating the small-angle adjustment element. For example, the small-angle adjustment element may be actuated via an electrical signal transmitted from the workstation to a piezoelectric element included by the small-angle adjustment element (e.g., piezoelectric actuator **116** described above with reference to FIG. **1**, FIG. **3**, etc.). In one example, the electrical signal may be similar to the signals shown by FIG. **4** and described above. In other words, the transducer array is rotated by actuation of the piezoelectric element (as described above with reference to FIGS. **3-5**). In this way, the ultrasound probe may perform a small-angle scan via energization of the piezoelectric element, as described above with reference to FIGS. **4-5**.

[0065] The method continues from **610** to **612** where the method includes displaying one or more non-compound images based on scan results. In some examples, images acquired during the small-angle scan described above with reference to **610** may be displayed by a display device electrically coupled with the workstation (e.g., display device **191** shown by FIG. **1**). For example, the workstation and display device may be configured to display each of the images acquired during the small-angle scan in an order in which they were acquired. In another example, the workstation and display device may be configured to display each of the images as a side-by-side comparison. In yet another example, the workstation and display device may be configured to display images associated with imaging planes chosen by the operator of the ultrasound system. The operator may select between display modes (e.g., the workstation and display device configurations described above) according to operator preference, and other display modes may be possible.

[0066] Returning to **608**, if the small-angle VCI is desired at **608**, the method continues to **614** where the method includes adjusting a frequency and/or a shape of the signal to the small-angle adjustment element based on an amount of VCI desired. For example, as described above with reference to FIG. **4**, a frequency of the electrical signal transmitted to the piezoelectric element may be decreased in order to increase a number of images acquired during a single small-angle scan. By increasing the number of images acquired, the workstation may compare and/or combine an increased number of images with each other in order to produce a compound image via VCI. The increased number of images thereby decreases an amount of acoustical artifacts, image noise, etc. included by the compound image.

[0067] In some examples, a shape of the waveform of the electric signal transmitted to the piezoelectric actuator may be adjusted in order to increase an amount of VCI along imaging planes selected by the operator of the ultrasound system. For example, an asymmetric waveform may be selected in order to acquire an increased number of images via imaging planes angled toward a first direction (e.g., first direction **518** shown by FIG. **5**) compared to a decreased number of images via imaging planes angled toward a second direction (e.g., second direction **520** shown by FIG. **5**). When the workstation compares and/or combines the images to form one or more compound images as described below, an averaging of the images may be weighted toward one or more regions of the scan in which a higher amount of VCI is desired. In other words, the operator of the ultrasound system may select a waveform configured to acquire a higher number of images in a first portion of the region of interest that typically has a high incidence of acoustical artifacts and/or image noise and a lower number of images in a second portion of the region of interest that typically has a low incidence of acoustical artifacts and/or image noise. In this way, a clarity and/or contrast of a compound image produced by the ultrasound system may be increased.

[0068] The method continues from **614** to **616** where the method includes scanning the ROI by actuating the small-angle adjustment element. As described above with reference to FIGS. **4-5**, the small-angle adjustment element may be actuated via an electrical signal transmitted from the workstation to the piezoelectric element included by the small-angle adjustment element (e.g., piezoelectric actuator **116** described above with reference to FIG. **1**, FIG. **3**, etc.). In one example, the electrical signal may be similar to the signals shown by FIG. **4** and described above. In other examples, the electrical signal may have a different type of waveform, such as the asymmetrical waveform described above. The transducer array may be rotated by actuation of the piezoelectric element as described above with reference to FIGS. **3-5**. In this way, the ultrasound probe may perform a small-angle scan via energization of the piezoelectric element, as described above with reference to FIGS. **4-5**. At least a portion of the images acquired during the small-angle scan may then be compared and/or combined by the workstation as described below with reference to **618**.

[0069] The method continues from **616** to **618** where the method includes displaying a compound image based on scan results. Scan results include the plurality of images acquired during the small-angle scan. In some examples, at least one compound image resulting from the small-angle scan described above with reference to **616** may be displayed by the display device electrically coupled with the workstation (e.g., display device **191** shown by FIG. **1**) at **618**. For example, the workstation and display device may be configured to display a compound image formed from one or more of the images acquired during the small-angle scan described above with reference to **616**. In other words, the workstation may compare one or more images from the small-angle scan to each other and apply an averaging algorithm (e.g., noise reduction algorithm) to combine the images into at least one compound image with reduced acoustical artifacts/aberrations. The at least one compound image may then be displayed by the display device. In some examples, each of the images acquired during the small-angle scan may be combined into a single compound image, and the single compound image may be displayed by the display device. In other examples, a first amount of images from the small-angle scan may be combined into a first compound image, and a second amount of images from the small-angle scan may be combined into a second compound image, and both of the first compound image and second compound image may be displayed by the display device. For example, the workstation and display device may be configured to display multiple compound images associated with different imaging planes chosen by the operator of the ultrasound system.

[0070] FIG. **7** shows another example operation of an ultrasound probe including a small-angle adjustment element and a large-angle adjustment element, such as the ultrasound probe described in the examples above with reference to FIGS. **1-3** and FIG. **5**. The small-angle adjustment element may be configured to receive electrical signals from the workstation such as those shown by FIG. **4** and described above.

[0071] At **702**, the method includes determining ultrasound probe operating conditions. As described above with reference to **602** of method **600** shown by FIG. **6**, determining ultrasound system operating conditions may include determining a position of the transducer array relative to the sensor housing, determining a position of the sensor housing relative to the main housing, determining electrical signals transmitted to the small-angle adjustment element and/or large-angle adjustment element, determining images stored in workstation memory and/or displayed on the display device, etc.

[0072] The method continues from **702** to **704** where the method includes determining a region of interest (ROI) to be scanned. As described above with reference to **604** of method **600** shown by FIG. **6**, in one example an ROI may be a region of interest on a body of a patient (e.g., an abdomen of a patient). An operator of the ultrasound system (e.g., an ultrasound technician) may determine the ROI in order to position the ultrasound probe of the ultrasound system such that one or more scans of the region may be performed. In the example above, the ultrasound probe may be positioned against the abdomen in order to scan a region of the abdomen.

[0073] The method continues from **704** to **706** where the method includes determining whether large-angle scanning is desired. For example, the operator of the ultrasound system may determine that large-angle scanning is desired in order to acquire images of an object to be scanned (e.g., a patient) over an increased volume (e.g., an increased amount of angle relative to a central axis of the ultrasound probe, as described above with reference to FIG. **2**). In one example, the operator may desire a scanning angle of 45 degrees, as shown by FIG. **2** and described above, in order to locate a particular feature (e.g., a muscle, organ, etc.) within the region of interest.

[0074] If large-angle volumetric scanning is not desired at **706**, the method continues to **606** of method **600** shown by FIG. **6** and described above, in order to perform a small-angle volumetric scanning.

[0075] If large-angle volumetric scanning is desired at **706**, the method continues to **708** where the method includes adjusting large-angle adjustment element operation based on the ROI to be scanned. In one example, adjusting large-angle adjustment element operation may include adjusting a number and/or polarity of electrical pulses transmitted to a stepper motor (e.g., stepper motor **124** shown by FIG. **1** and described above) during a single scan. For example, the stepper motor may be configured to rotate a pulley (e.g., second pulley **128** shown by FIG. **1**) by one increment (e.g., one "step") in response to an electrical pulse transmitted to the stepper motor from the workstation. The polarity of the electrical pulse may result in a positive-valued current or a negative-valued current through terminals of the stepper motor, with the positive-valued current resulting in the stepper motor rotating the pulley by one step in a first direction, and the negative-valued current resulting in the stepper motor rotating the pulley by one step in a second direction opposite to the first direction.

[0076] As described above with reference to FIG. **1**, rotation of the pulley results in a rotation of the sensor housing relative to the main housing (e.g., in the example of FIG. **1**, rotation of second pulley **128** causes the first pulley **120** to rotate due to a movement of belt **122**, with first pulley **120** coupled to the sensor housing **108**). In this way, each electrical pulse transmitted to the stepper motor corresponds to an amount of rotation of the sensor housing relative to the main housing. By adjusting the number of electrical pulses (e.g., increasing or decreasing the number of pulses) transmitted to the stepper motor during a single large-angle scan, a number of steps rotated by the stepper motor may be increased or decreased accordingly, thereby increasing or decreasing an amount of angle through which the sensor housing is rotated relative to the main housing during the large-angle scan. In other words, adjusting the operation of the large-angle adjustment element as described above increases or decreases an angle over the large-angle scan is performed, such that a greater amount of the region of interest may be included within the large-angle scan.

[0077] The method continues from **708** to **710** where the method includes determining whether small-angle volume compound imaging (VCI) is desired. For example, the operator of the ultrasound system may determine that small-angle VCI is desired in order to increase a clarity and/or contrast of images acquired through the region of interest during a large-angle scan. For example, during a large-angle scan (e.g., a scan spanning an angle of 45 degrees, for example, and performed via actuation of the large-angle adjustment element as described below), a first plurality of images may be acquired along a first plurality of imaging planes. Small-angle VCI may produce a second plurality of images along a second plurality of imaging planes during the large-angle scan via actuation of the small-angle adjustment element in combination with actuation of the large-angle adjustment element as described below with reference to **716**. A portion of the second plurality of images may be compared and/or combined with a portion of the first plurality of images in order to produce a plurality of compound images associated with the first plurality of imaging planes and with increased clarity and/or contrast relative to the first plurality of images. Further examples are described below.

[0078] In another example, the operator of the system may determine that small-angle VCI is not desired. For example, the region of interest may be a region in which images produced by the ultrasound system typically do not include a high amount of acoustical artifacts, image noise, etc. As a result, the operator may determine that producing compound images via small-angle VCI is less desirable than acquiring non-compound images (e.g., images without VCI) at an increased rate.

[0079] If small-angle VCI is not desired at **710**, the method continues to **712** where the method includes scanning the ROI by actuating the large-angle adjustment element and not actuating the small-angle adjustment element. In other words, a plurality of electrical pulses may be transmitted to the stepper motor in order to drive the stepper motor and rotate the sensor housing relative to the main housing through a large scan angle (e.g., 45 degrees, 50 degrees, etc.). As the sensor housing rotates relative to the main housing, the transducer array may transmit acoustic waves through the region of interest and receive echoes as described above with reference to FIG. **1** and FIG. **4**. In this way, images associated with a plurality of imaging planes may be transmitted from the ultrasound probe to the workstation.

[0080] The method continues from **712** to **718** where the method includes displaying a compound and/or non-compound image based on scan results. In one example, each of the non-compound images acquired during the large-angle scan at **712** may be displayed by the display device in an order in which they were acquired. In another example, one or more of the non-compound images acquired during the large-angle scan may be displayed side-by-side. In yet another example, a plurality of the non-compound images may be compared and/or combined in order to form at least one compound image for display on the display device.

[0081] Returning to **710**, if small-angle VCI is desired at **710**, the method continues to **714** where the method includes adjusting a frequency and/or a shape of a signal to the small-angle adjustment element based on an amount of VCI desired. For example (and as described above with reference to **606** and **614** of method **600** shown by FIG. **6**), adjusting an amplitude of an electrical signal transmitted to the piezoelectric actuator of the small-angle adjustment element may increase or decrease an amount of angle spanned during a small-angle scan (e.g., may increase or decrease a rotation of the transducer array relative to the sensor housing during the small-angle scan). In another example, adjusting a frequency and/or shape of the electrical signal may increase or decrease an amount of images acquired during a small-angle scan. For example, as described above with reference to FIG. **4**, decreasing a frequency of the electrical signal may increase an amount of images acquired during a small-angle scan via actuation of the piezoelectric actuator.

[0082] The method continues from **714** to **716** where the method includes scanning the ROI by actuating both of the small-angle adjustment element and the large-angle adjustment element. For example, the large-angle adjustment element may be actuated to rotate the sensor housing relative to the main housing through a relatively large angle (e.g., 45 degrees, in one example) to perform a large-angle scan, thereby acquiring a first plurality of images associated with a first plurality of imaging planes. During the large-angle scan, the small-angle adjustment element may be actuated to rotate the transducer array relative to the sensor housing to acquire a second plurality of images. In one example, the second plurality of images may be associated with a second plurality of imaging planes different from the first plurality of imaging planes. For example, each imaging plane of the first plurality of imaging planes may be positioned between two adjacent imaging planes of the second plurality of imaging planes, such that the two adjacent imaging planes of the second plurality of imaging planes are at a relatively small angle (±2.5 degrees, for example) relative to the imaging plane of the first plurality of imaging planes. In this way, by actuating the small-angle adjustment element in combination with the large-angle adjustment element, an increased amount of images may be acquired for each step of the stepper motor.

[0083] The method continues from **716** to **718** where the method includes displaying a compound and/or a non-compound image based on scan results. In one example, each of the non-compound images acquired during the large-angle scan at **716** (e.g., the first plurality of images referenced by **716**) may be compared and/or combined with the non-compound images acquired during at least one small-angle scan at **716** (e.g., the second plurality of images referenced by **716**) in order to form a plurality of compound images. The plurality of compound images may be associated with the same plurality of imaging planes as the first plurality of images. In other words, the plurality of compound images may be similar to the first plurality of images (e.g., associated with the same imaging planes) and may have an increased clarity and/or contrast relative to the first plurality of images due to additional details provided by the second plurality of images. The compound images may then be displayed by the display device in an order in which they were acquired. In another example, one or more of the compound images may be displayed side-by-side by the display device.

[0084] A technical effect of the disclosure is to increase a scanning precision of an ultrasound probe by including a small-angle adjustment element configured to rotate a transducer array of the ultrasound probe relative to a sensor housing, as described above with reference to FIGS. **1-7**. In one example, the small-angle adjustment element includes a piezoelectric actuator. The piezoelectric actuator may be selectively energized in order to adjust an amount of rotation of the transducer array relative to the sensor housing. An angle of an imaging plane produced by the transducer array may be adjusted in this way by a much smaller amount (e.g., 5 degrees) relative to an adjustment to the angle produced by rotating the sensor housing via actuation of a large-angle adjustment element (e.g., 45 degrees). In this way, an amount of angle between imaging planes may be reduced, and an amount of acoustical artifacts, image noise, etc. included within a resulting compound image formed by one or more of the non-compound images may be increased.

[0085] Another technical effect of the disclosure is to actuate the small-angle adjustment element and large-angle adjustment element together or separately in order to adjust the number and/or types of images displayed on a display device according to operator preference. For example, the operator may increase a number of images acquired during a small-angle scan in order to increase a clarity and/or contrast of one or more compound images produced from the images acquired during the small-angle scan. In another example, the operator may actuate the small-angle adjustment element during a large-angle scan in order to increase a clarity and/or contrast of images acquired during the large-angle scan. In this way, a quality of images produced by the ultrasound probe may be increased for a wide range of applications.

[0086] In one embodiment, an ultrasound probe includes: a sensor housing; a piezoelectric actuator disposed within the sensor housing; and a transducer array coupled with the sensor housing, the transducer array rotatable relative to the sensor housing via energization of the piezoelectric actuator. In a first example of the ultrasound probe, the ultrasound probe includes a shaft disposed within the sensor housing, the shaft coupled to the piezoelectric actuator and the transducer array. A second example of the ultrasound probe optionally includes the first example, and further includes wherein a first end of the piezoelectric actuator is coupled to the sensor housing and a second end of the piezoelectric actuator is coupled to the shaft. A third example of the ultrasound probe optionally includes one or both of the first and second examples, and further includes wherein a first end of the shaft is directly coupled to a bottom surface of the sensor housing and a second end of the shaft is coupled to the transducer array. A fourth example of the ultrasound probe optionally includes one or more or each of the first through third examples, and further includes a bearing rotatably coupled to a bearing housing and disposed within the bearing housing, the bearing housing coupled to a bottom surface of the sensor housing, and wherein a first end of the shaft is coupled to the bearing and a second end of the shaft is coupled to the transducer array. A fifth example of the ultrasound probe optionally includes one or more or each of the first through fourth examples, and further includes: a main housing, the sensor housing disposed in an interior of the main housing; a stepper motor and a plurality of pulleys disposed within the interior of the main housing, the plurality of pulleys coupled via a belt and rotatable via actuation of the stepper motor, with a first pulley of the plurality of pulleys coupled to the sensor housing and configured to rotate the sensor housing relative to the main housing.

[0087] In one embodiment, a method includes: transmitting a first electrical signal to a piezoelectric actuator of an ultrasound probe; and responsive to the first electrical signal, rotating a transducer array of the ultrasound probe by a first rotational angle by expanding or contracting the piezoelectric actuator. In a first example of the method, expanding the piezoelectric actuator rotates the transducer array in a first direction, and contracting the piezoelectric actuator rotates the transducer array in a second direction opposite to the first direction. A second example of the method optionally includes the first example, and further includes adjusting a frequency of the first electrical signal in order to adjust a rotational speed of the transducer array. A third example of the method optionally includes one or both of the first and second examples, and further includes wherein increasing the frequency increases the rotational speed, and decreasing the frequency decreases the rotational speed. A fourth example of the method optionally includes one or more or each of the first through third examples, and further includes adjusting an amplitude of the first electrical signal in order to adjust the first rotational angle of the transducer array. A fifth example of the method optionally includes or more or each of the first through fourth examples, and further includes wherein increasing the amplitude increases the first rotational angle, and decreasing the amplitude decreases the first rotational angle. A sixth example of the method optionally includes or more or each of the first through fifth examples, and further includes wherein adjusting the amplitude of the first electrical signal in order to adjust the first rotational angle of the transducer array includes increasing or decreasing the first rotational angle by a positive amount less than five degrees. A seventh example of the method optionally includes or more or each of the first through sixth examples, and further includes wherein expanding the piezoelectric actuator occurs responsive to a positive-valued voltage of the first electrical signal, and wherein contracting the piezoelectric actuator occurs responsive to a negative-valued voltage of the first electrical signal. An eighth example of the method optionally includes or more or each of the first through seventh examples, and further includes actuating a stepper motor of the ultrasound probe via a second electrical signal transmitted to the stepper motor, wherein actuating the stepper motor rotates a sensor housing including the transducer array by a second rotational angle, and wherein the second rotational angle is greater than the first rotational angle.

[0088] In another embodiment, an ultrasound probe includes: a main housing including a central axis; a stepper motor and a sensor housing disposed within an interior of the main housing, the sensor housing pivotable relative to the central axis via energization of the stepper motor; a transducer array pivotally coupled to the sensor housing via a shaft disposed within the sensor housing; and a piezoelectric actuator coupled to an interior wall of the sensor housing and the shaft, the transducer array being pivotable relative to the sensor housing via energization of the piezoelectric actuator. In a first example of the ultrasound probe, the ultrasound probe includes a controller electrically coupled with the ultrasound probe and including instructions stored in non-transitory memory to adjust a first electrical signal sent to the piezoelectric actuator and a second electrical signal sent to the stepper motor in response to input from an operator of the ultrasound probe. A second example of the ultrasound probe optionally includes the first example, and further includes wherein the sensor housing is not pivotable relative to the main housing via energization of the piezoelectric actuator, and wherein the transducer array is not pivotable relative to the sensor housing via energization of the stepper motor. A third example of the ultrasound probe optionally includes one or both of the first and second examples, and further includes wherein the stepper motor is configured to pivot the sensor housing by a first amount and the piezoelectric actuator is configured to pivot the transducer array by a second amount, with the second amount being less than the first amount relative to the central axis. A fourth example of the ultrasound probe optionally includes one or more or each of the first through third examples, and further includes wherein the sensor housing pivots along a rotational axis arranged perpendicular with the central axis.

[0089] As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to "one embodiment" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising," "including," or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property. The terms "including" and "in which" are used as the plain-language equivalents of the respective terms "comprising" and "wherein." Moreover, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements or a particular positional order on their objects.

[0090] This written description uses examples to disclose the invention, including the best mode, and also to enable a person of ordinary skill in the relevant art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

1. An ultrasound probe comprising:
a sensor housing;
a piezoelectric actuator disposed within the sensor housing; and
a transducer array coupled with the sensor housing, the transducer array rotatable relative to the sensor housing via energization of the piezoelectric actuator.

2. The ultrasound probe of claim **1**, further comprising a shaft disposed within the sensor housing, the shaft coupled to the piezoelectric actuator and the transducer array.

3. The ultrasound probe of claim **2**, wherein a first end of the piezoelectric actuator is coupled to the sensor housing and a second end of the piezoelectric actuator is coupled to the shaft.

4. The ultrasound probe of claim **3**, wherein a first end of the shaft is directly coupled to a bottom surface of the sensor housing and a second end of the shaft is coupled to the transducer array.

5. The ultrasound probe of claim **3**, further comprising a bearing rotatably coupled to a bearing housing and disposed within the bearing housing, the bearing housing coupled to a bottom surface of the sensor housing, and wherein a first end of the shaft is coupled to the bearing and a second end of the shaft is coupled to the transducer array.

6. The ultrasound probe of claim **1**, further comprising:
a main housing, the sensor housing disposed in an interior of the main housing;
a stepper motor and a plurality of pulleys disposed within the interior of the main housing, the plurality of pulleys coupled via a belt and rotatable via actuation of the stepper motor, with a first pulley of the plurality of pulleys coupled to the sensor housing and configured to rotate the sensor housing relative to the main housing.

7. A method comprising:
transmitting a first electrical signal to a piezoelectric actuator of an ultrasound probe; and
responsive to the first electrical signal, rotating a transducer array of the ultrasound probe by a first rotational angle by expanding or contracting the piezoelectric actuator.

8. The method of claim **7**, wherein expanding the piezoelectric actuator rotates the transducer array in a first direction, and contracting the piezoelectric actuator rotates the transducer array in a second direction opposite to the first direction.

9. The method of claim **7**, further comprising adjusting a frequency of the first electrical signal in order to adjust a rotational speed of the transducer array.

10. The method of claim **9**, wherein increasing the frequency increases the rotational speed, and decreasing the frequency decreases the rotational speed.

11. The method of claim **7**, further comprising adjusting an amplitude of the first electrical signal in order to adjust the first rotational angle of the transducer array.

12. The method of claim **11**, wherein increasing the amplitude increases the first rotational angle, and decreasing the amplitude decreases the first rotational angle.

13. The method of claim **12**, wherein adjusting the amplitude of the first electrical signal in order to adjust the first rotational angle of the transducer array includes increasing or decreasing the first rotational angle by a positive amount less than five degrees.

14. The method of claim **7**, wherein expanding the piezoelectric actuator occurs responsive to a positive-valued voltage of the first electrical signal, and wherein contracting the piezoelectric actuator occurs responsive to a negative-valued voltage of the first electrical signal.

15. The method of claim **7**, further comprising actuating a stepper motor of the ultrasound probe via a second electrical signal transmitted to the stepper motor, wherein actuating the stepper motor rotates a sensor housing including the transducer array by a second rotational angle, and wherein the second rotational angle is greater than the first rotational angle.

16. An ultrasound probe comprising:
a main housing including a central axis;
a stepper motor and a sensor housing disposed within an interior of the main housing, the sensor housing pivotable relative to the central axis via energization of the stepper motor;
a transducer array pivotally coupled to the sensor housing via a shaft disposed within the sensor housing; and
a piezoelectric actuator coupled to an interior wall of the sensor housing and the shaft, the transducer array being pivotable relative to the sensor housing via energization of the piezoelectric actuator.

17. The ultrasound probe of claim **16**, further comprising a controller electrically coupled with the ultrasound probe and including instructions stored in non-transitory memory to adjust a first electrical signal sent to the piezoelectric actuator and a second electrical signal sent to the stepper motor in response to input from an operator of the ultrasound probe.

18. The ultrasound probe of claim **16**, wherein the sensor housing is not pivotable relative to the main housing via energization of the piezoelectric actuator, and wherein the transducer array is not pivotable relative to the sensor housing via energization of the stepper motor.

19. The ultrasound probe of claim **16**, wherein the stepper motor is configured to pivot the sensor housing by a first amount and the piezoelectric actuator is configured to pivot the transducer array by a second amount, with the second amount being less than the first amount relative to the central axis.

20. The ultrasound probe of claim **19**, wherein the sensor housing pivots along a rotational axis arranged perpendicular with the central axis.

* * * * *

patsnap

专利名称(译)	超声成像与小角度调整		
公开(公告)号	US20180153509A1	公开(公告)日	2018-06-07
申请号	US15/370961	申请日	2016-12-06
[标]申请(专利权)人(译)	通用电气公司		
申请(专利权)人(译)	通用电气公司		
当前申请(专利权)人(译)	通用电气公司		
[标]发明人	KREMSL ANDREAS SCHOENAUER MANUEL BRUESTLE REINHOLD		
发明人	KREMSL, ANDREAS SCHOENAUER, MANUEL BRUESTLE, REINHOLD		
IPC分类号	A61B8/00 G01S7/52 G01S15/89 A61B8/14		
CPC分类号	A61B8/4466 G01S7/52079 G01S15/8915 A61B8/469 A61B8/145 A61B8/54 A61B8/4494 G01S7/52085 G01S15/894		
外部链接	Espacenet USPTO		

摘要(译)

提供了用于包括小角度调节元件的超声波探头的方法和系统。在一个实施例中，小角度调节元件包括压电致动器，该压电致动器构造成响应于传输到压电致动器的电信号而旋转超声探头的换能器阵列。以这种方式，可以减少在感兴趣区域的扫描期间由换能器阵列跨越的角度量，由此增加超声波探头的精确度。