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(54) **MULTIPLE FREQUENCY SCANNING USING AN ULTRASOUND PROBE**

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A61B 8/00	(2006.01)

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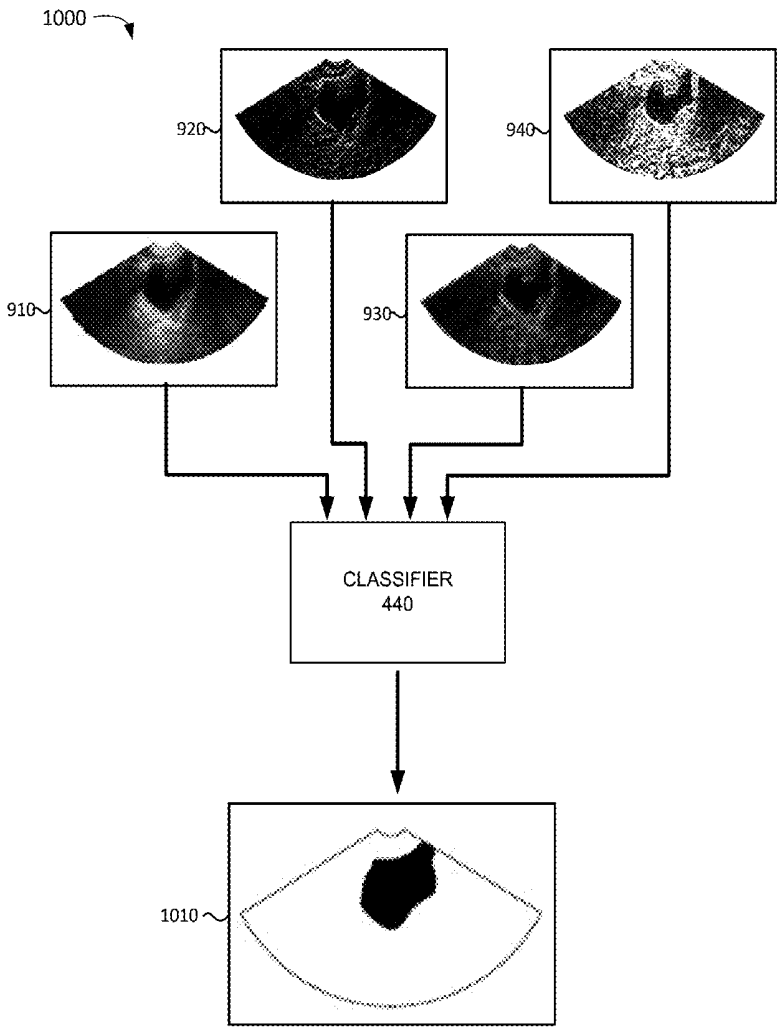
(57) **ABSTRACT**

A system may include an ultrasound probe and a controller unit configured to communicate with the ultrasound probe. The controller unit may be further configured to transmit ultrasound signals using the ultrasound probe toward an area of interest in a patient's body, wherein the ultrasound signals include a fundamental frequency signal and at least one harmonic frequency signal; receive echo signals from the area of interest based on the transmitted ultrasound signals; obtain a fundamental frequency echo signal and at least one harmonic frequency echo signal from the received echo signals; and generate a visual representation of the area of interest based on the obtained fundamental frequency echo signal and the obtained at least one harmonic frequency echo signal.



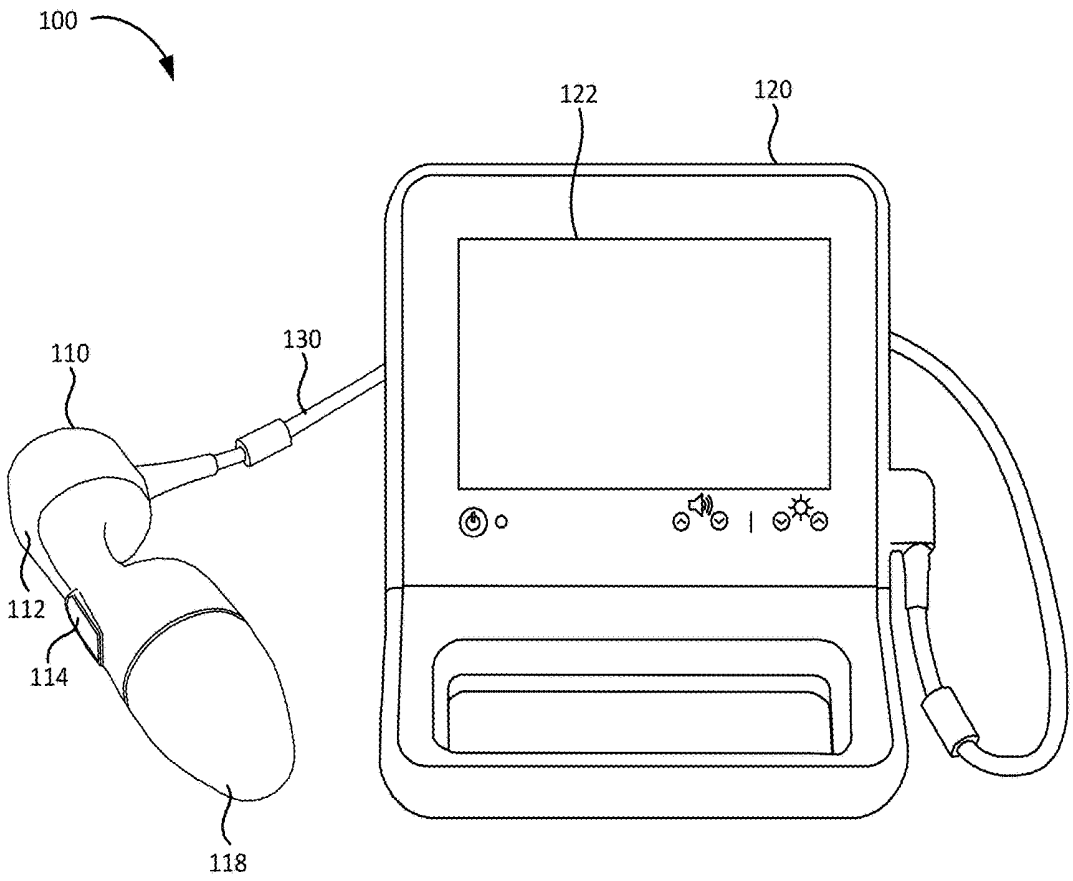


FIG. 1A

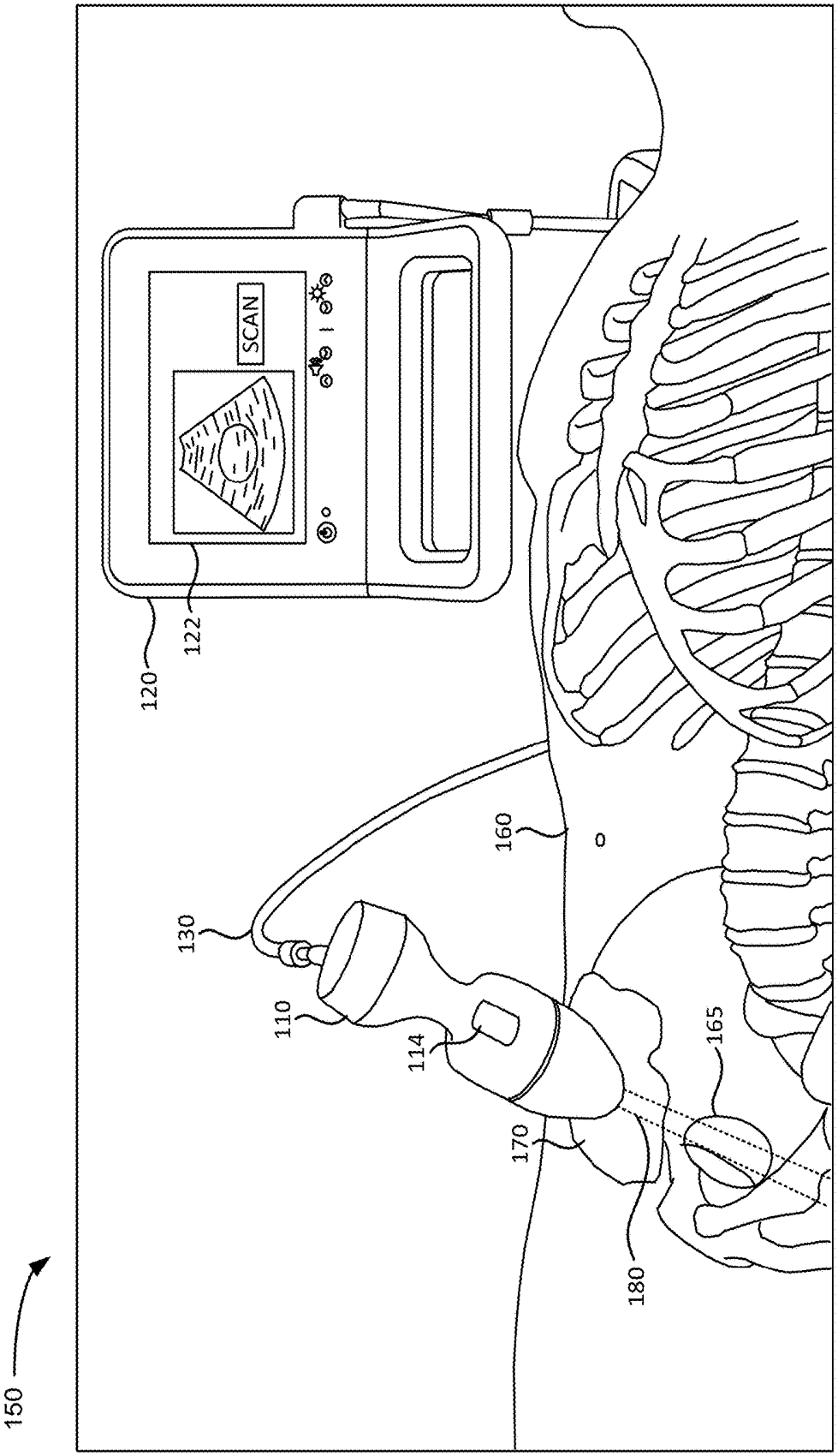


FIG. 1B

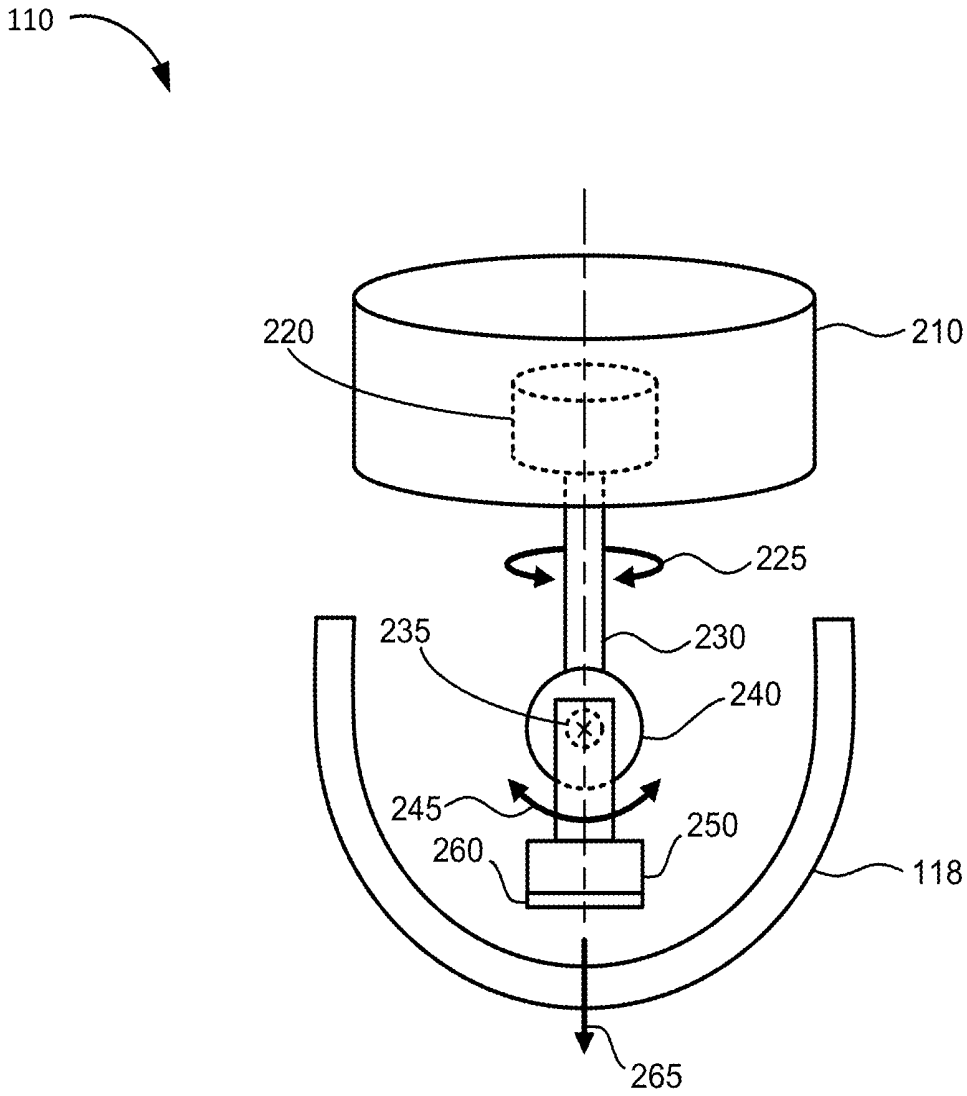


FIG. 2A

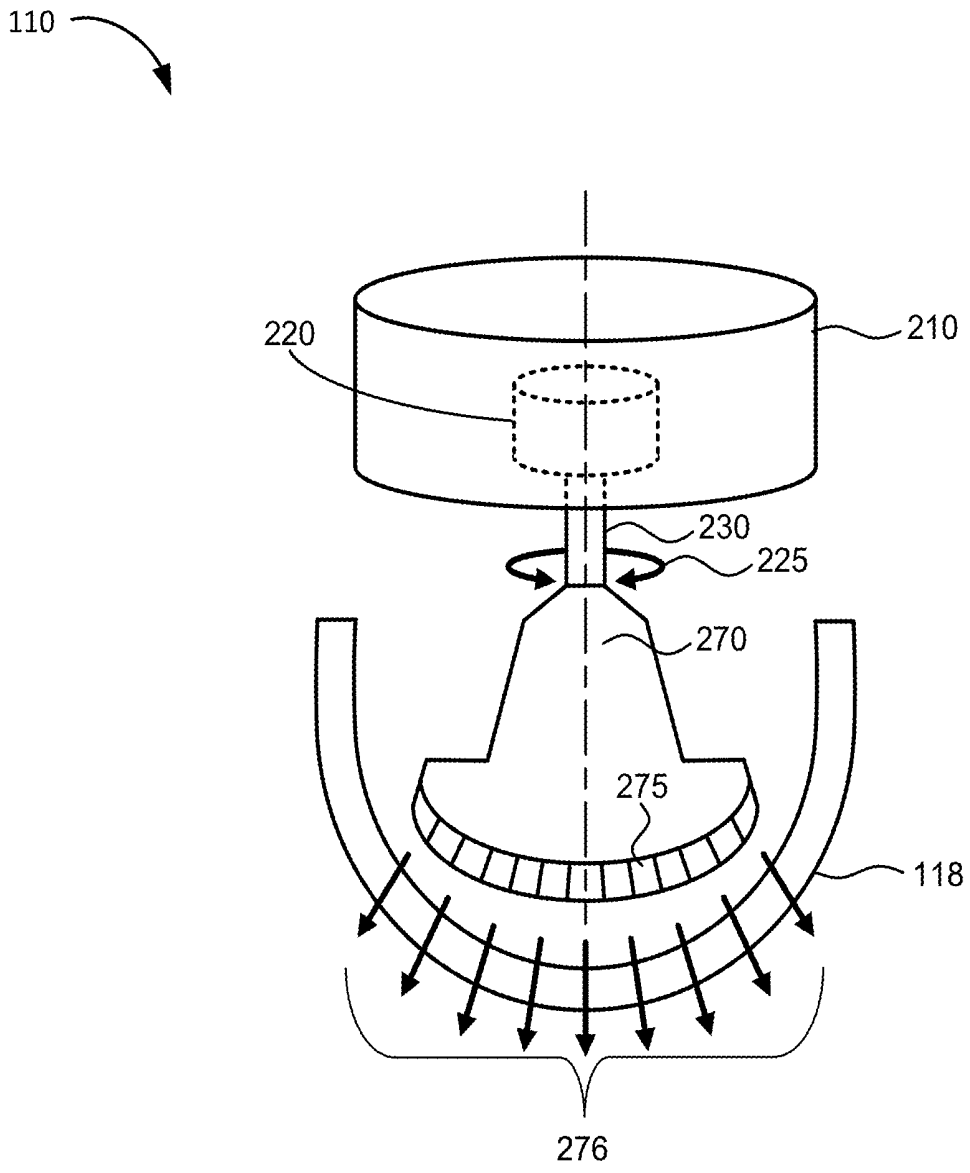


FIG. 2B

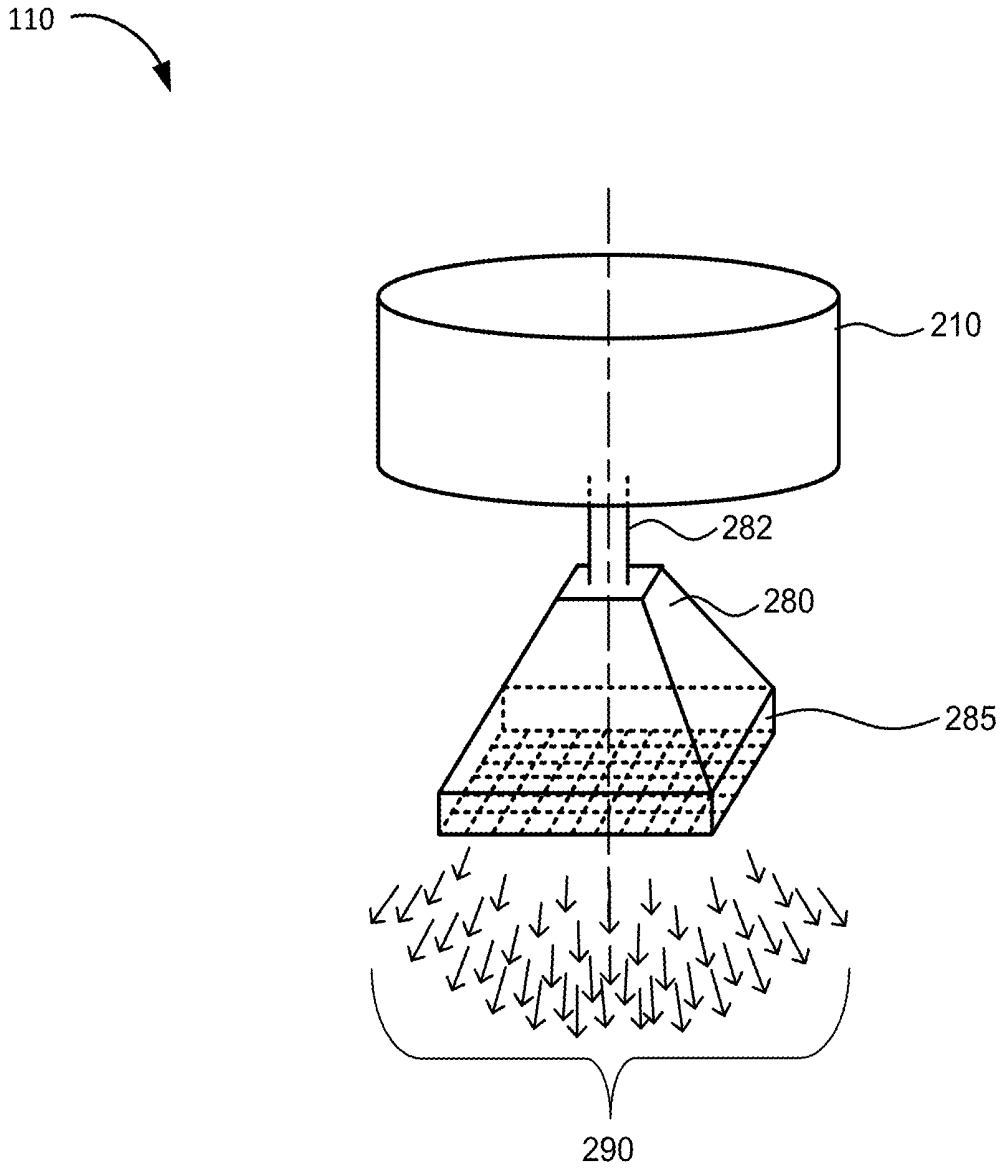


FIG. 2C

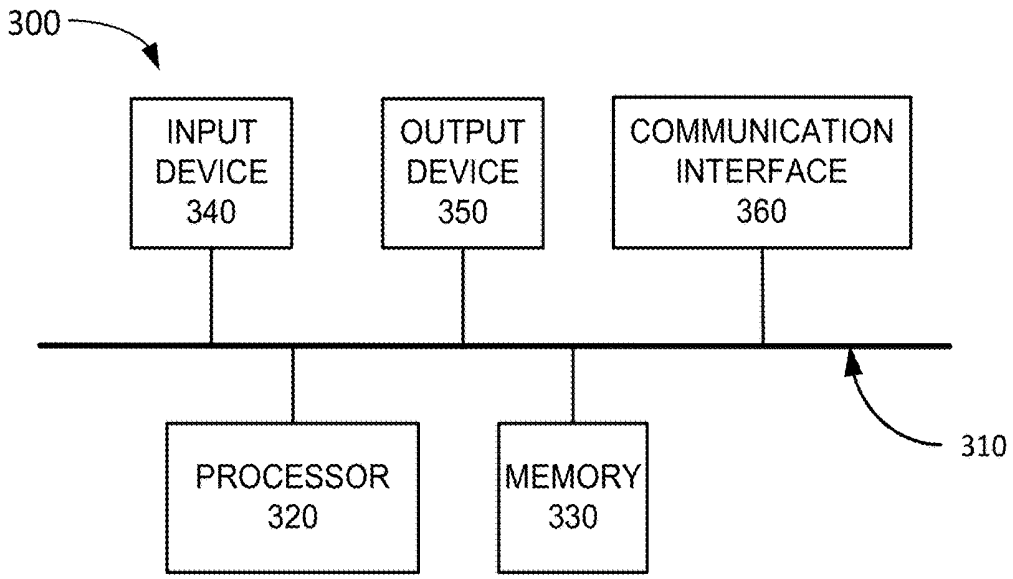

300
INPUT DEVICE 340
OUTPUT DEVICE 350
COMMUNICATION INTERFACE 360
310
PROCESSOR 320
MEMORY 330

FIG. 3

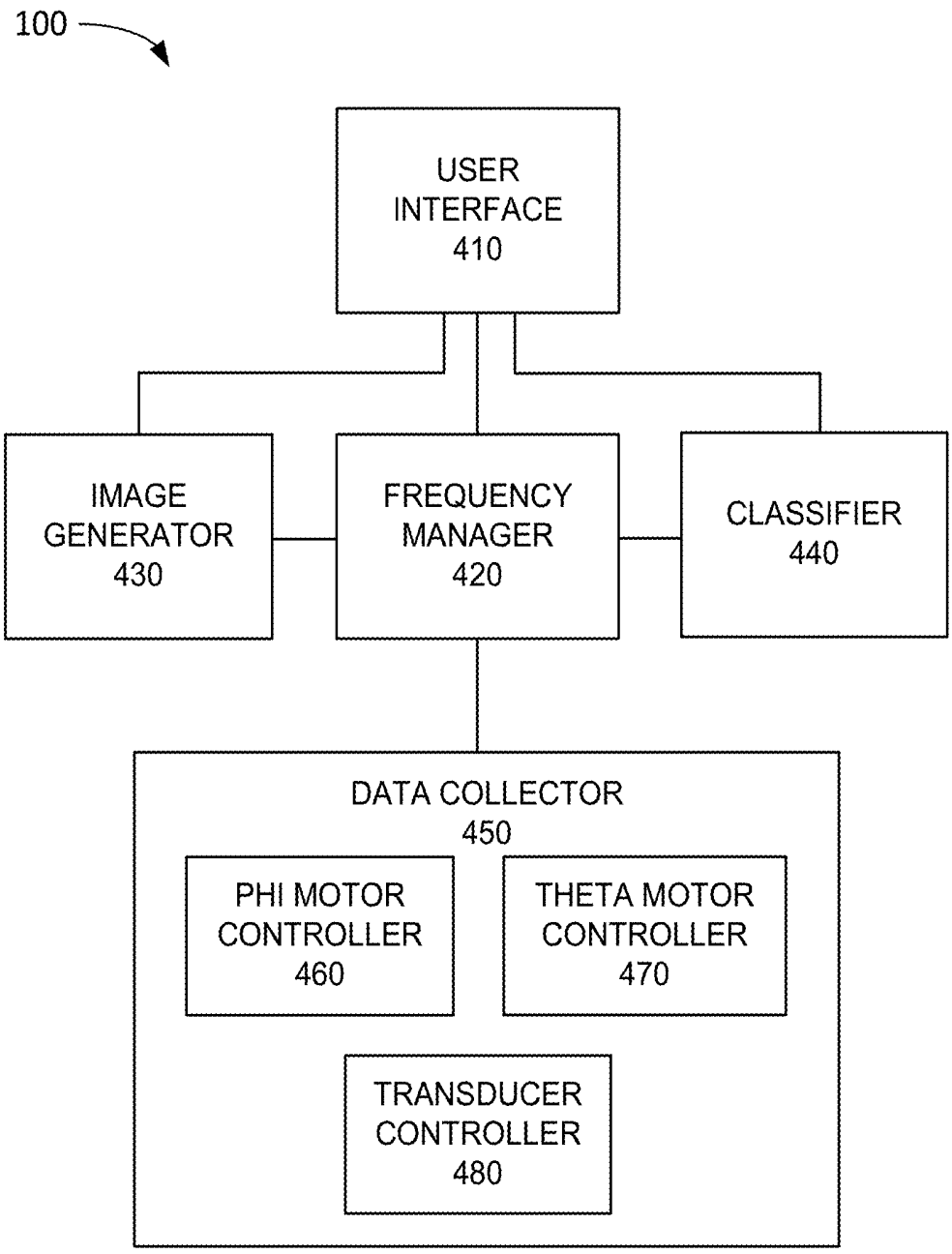

100
USER INTERFACE 410
IMAGE GENERATOR 430
FREQUENCY MANAGER 420
CLASSIFIER 440
DATA COLLECTOR 450
PHI MOTOR CONTROLLER 460
THETA MOTOR CONTROLLER 470
TRANSDUCER CONTROLLER 480

FIG. 4

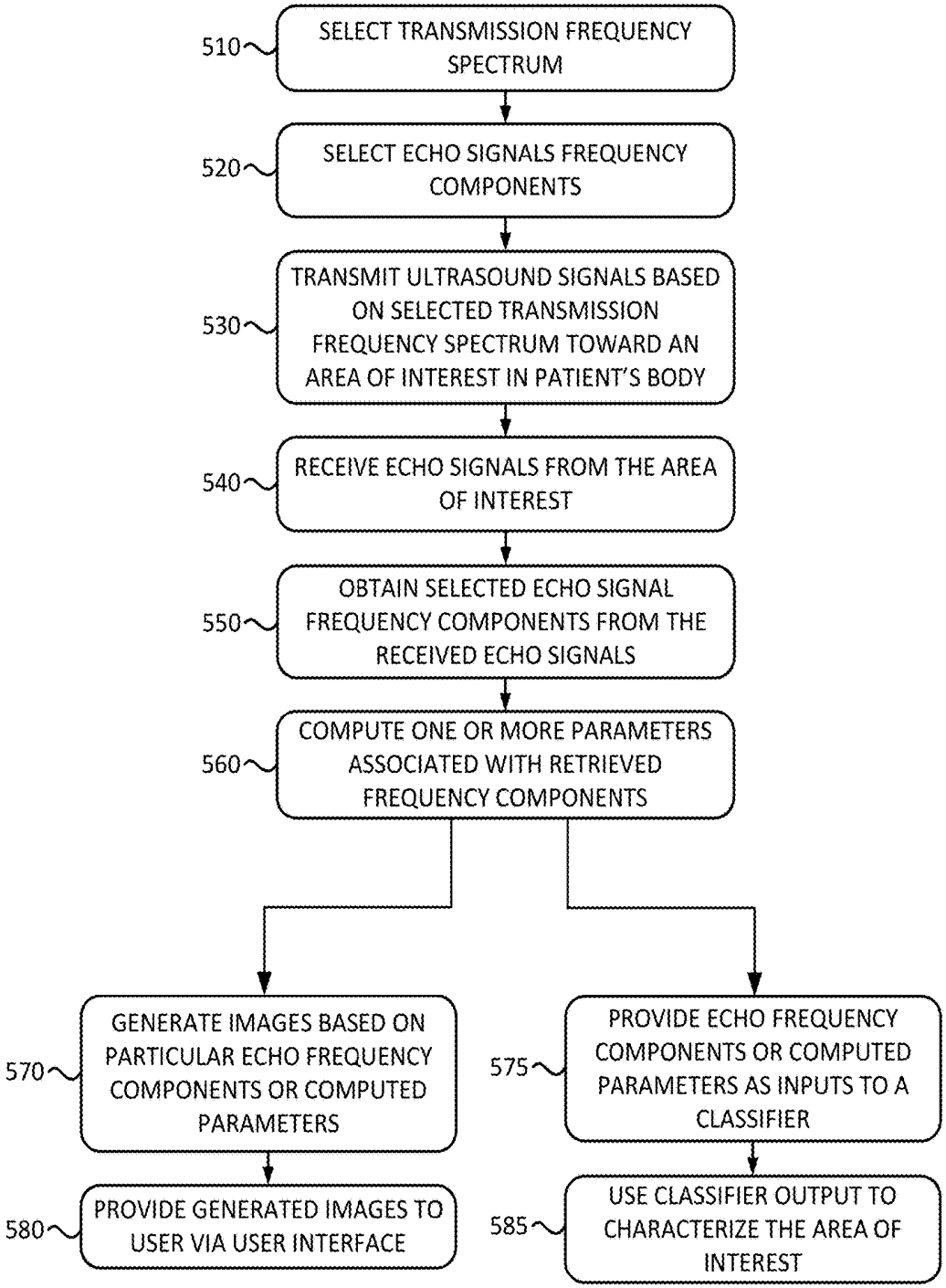

510
SELECT TRANSMISSION FREQUENCY SPECTRUM
520
SELECT ECHO SIGNALS FREQUENCY COMPONENTS
530
TRANSMIT ULTRASOUND SIGNALS BASED ON SELECTED TRANSMISSION FREQUENCY SPECTRUM TOWARD AN AREA OF INTEREST IN PATIENT'S BODY
540
RECEIVE ECHO SIGNALS FROM THE AREA OF INTEREST
550
OBTAIN SELECTED ECHO SIGNAL FREQUENCY COMPONENTS FROM THE RECEIVED ECHO SIGNALS
560
COMPUTE ONE OR MORE PARAMETERS ASSOCIATED WITH RETRIEVED FREQUENCY COMPONENTS
570
GENERATE IMAGES BASED ON PARTICULAR ECHO FREQUENCY COMPONENTS OR COMPUTED PARAMETERS
580
PROVIDE GENERATED IMAGES TO USER VIA USER INTERFACE
575
PROVIDE ECHO FREQUENCY COMPONENTS OR COMPUTED PARAMETERS AS INPUTS TO A CLASSIFIER
585
USE CLASSIFIER OUTPUT TO CHARACTERIZE THE AREA OF INTEREST

FIG. 5

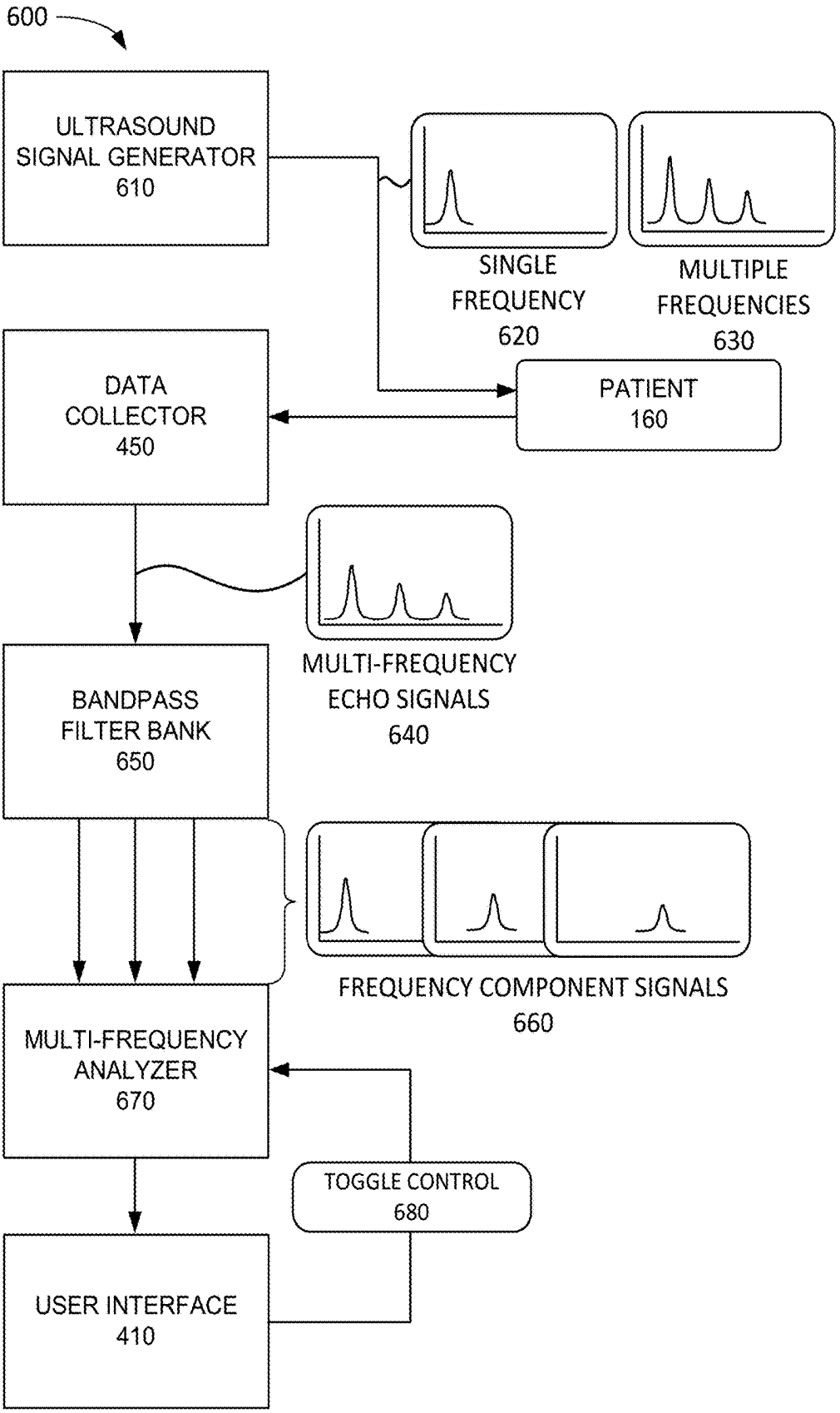

600
ULTRASOUND SIGNAL GENERATOR 610
SINGLE FREQUENCY 620
MULTIPLE FREQUENCIES 630
DATA COLLECTOR 450
PATIENT 160
MULTI-FREQUENCY ECHO SIGNALS 640
BANDPASS FILTER BANK 650
FREQUENCY COMPONENT SIGNALS 660
MULTI-FREQUENCY ANALYZER 670
TOGGLE CONTROL 680
USER INTERFACE 410

FIG. 6

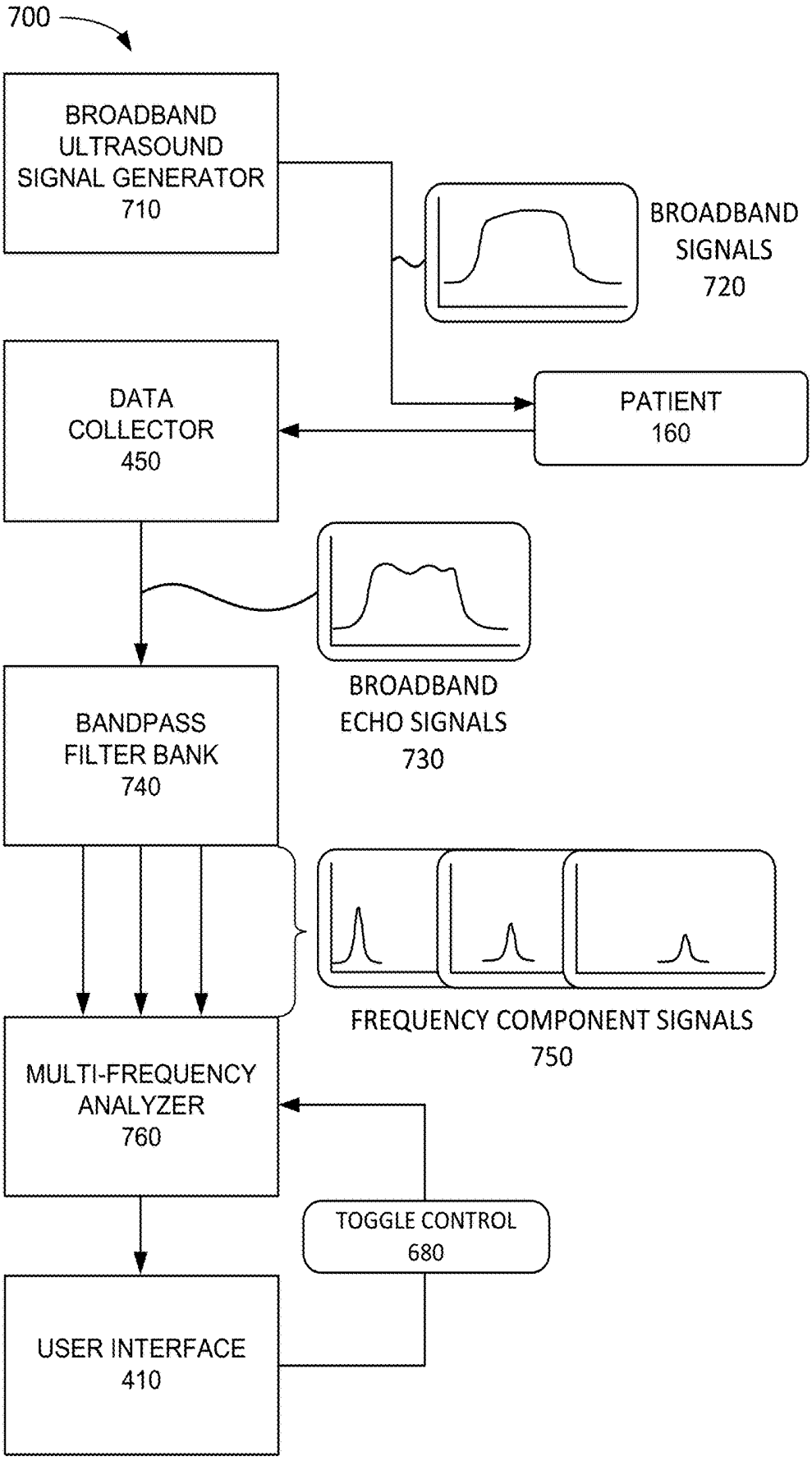

700
BROADBAND ULTRASOUND SIGNAL GENERATOR 710
BROADBAND SIGNALS 720
DATA COLLECTOR 450
PATIENT 160
BROADBAND ECHO SIGNALS 730
BANDPASS FILTER BANK 740
FREQUENCY COMPONENT SIGNALS 750
MULTI-FREQUENCY ANALYZER 760
TOGGLE CONTROL 680
USER INTERFACE 410

FIG. 7

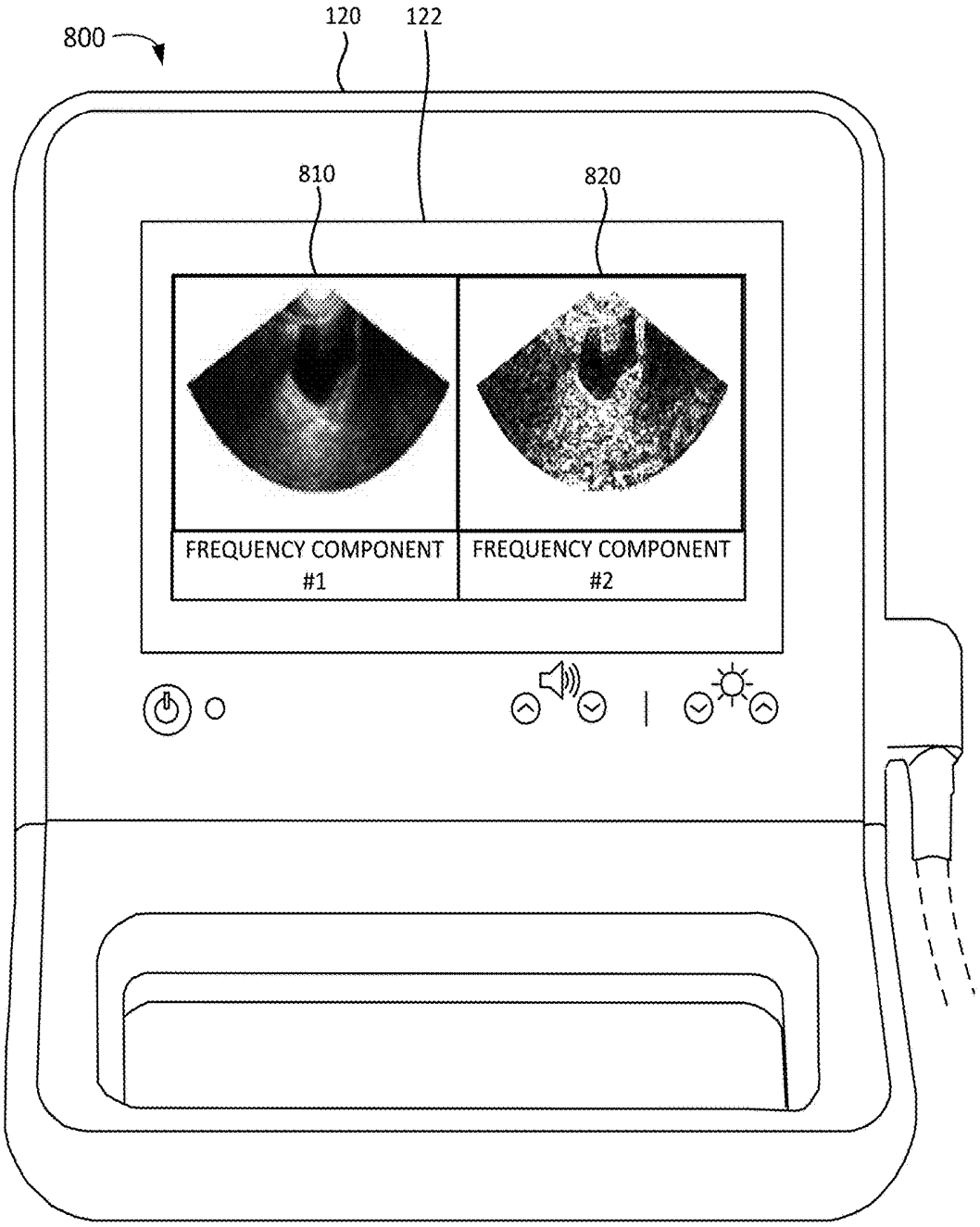

800
120
122
810
820
FREQUENCY COMPONENT #1
FREQUENCY COMPONENT #2

FIG. 8

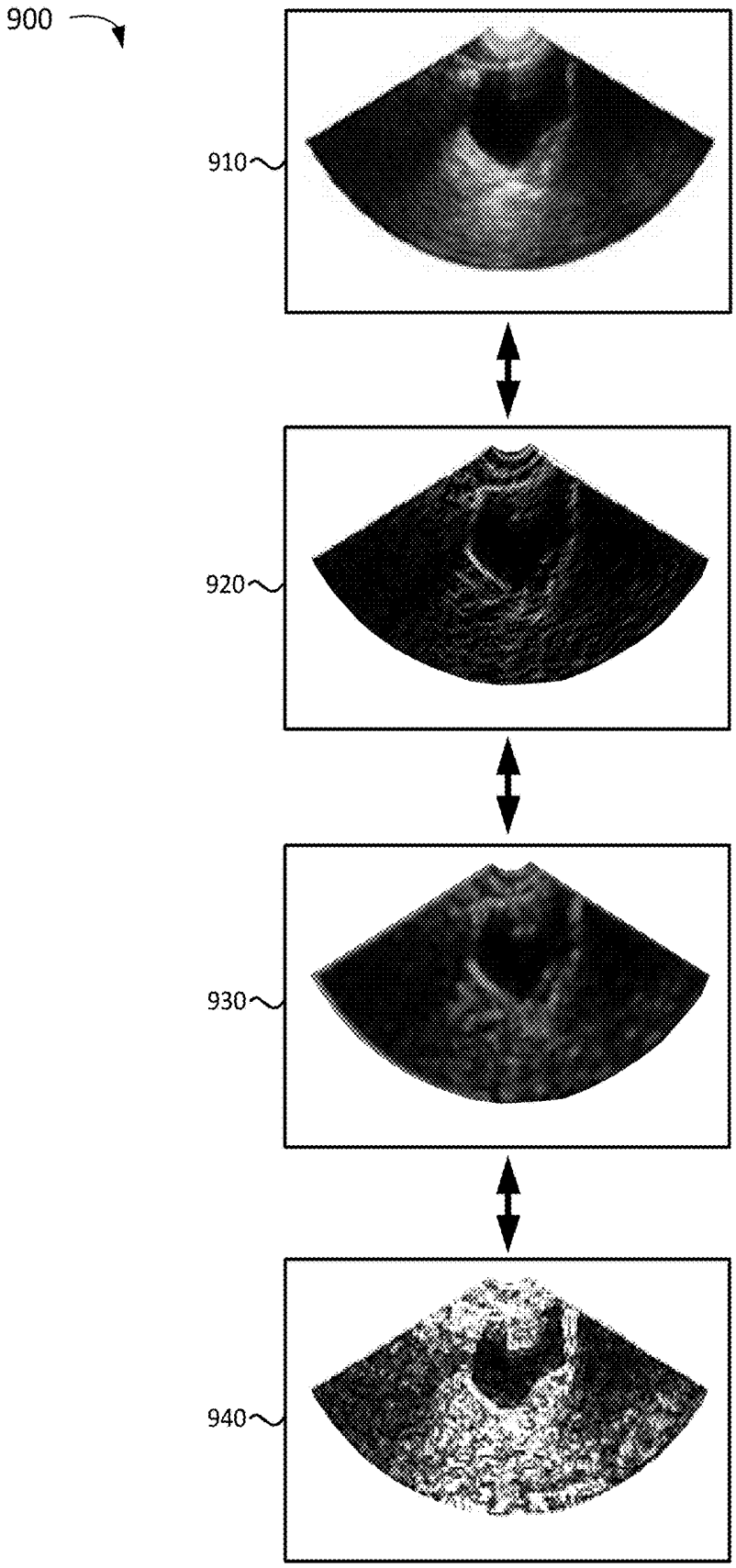


FIG. 9

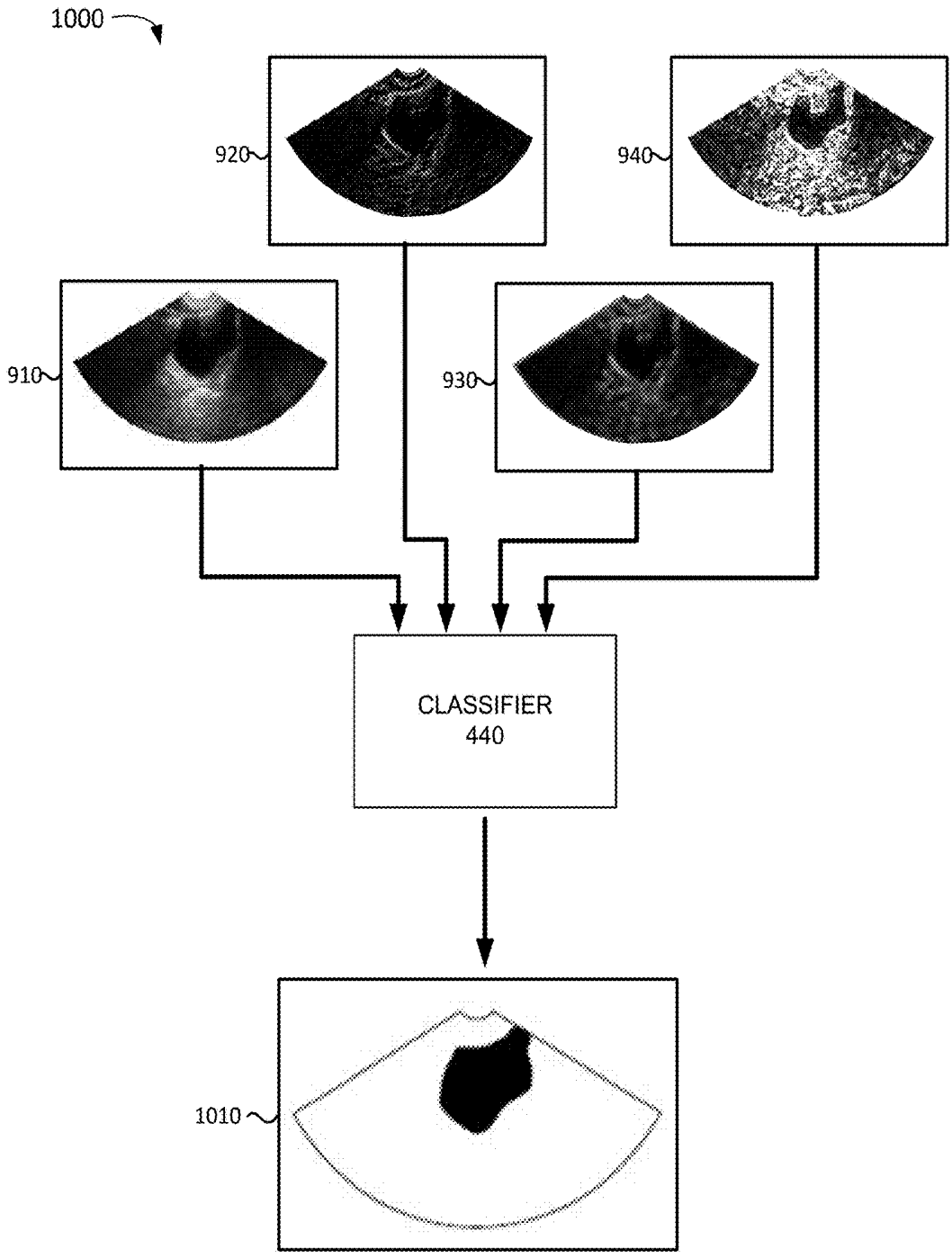


FIG. 10

MULTIPLE FREQUENCY SCANNING USING AN ULTRASOUND PROBE

PRIORITY INFORMATION

[0001] This patent application claims benefit of priority to U.S. Provisional Application No. 62/644,773, entitled "MULTIPLE FREQUENCY SCANNING USING AN ULTRASOUND PROBE" and filed on Mar. 19, 2018, which is hereby incorporated herein by reference in its entirety.

BACKGROUND INFORMATION

[0002] An ultrasound probe may generate ultrasound signals using a transducer, such as, for example, a piezoelectric transducer or a capacitive transducer, which converts electrical signals into ultrasound energy and which converts ultrasound echoes back into electrical signals. Ultrasound probes are typically used to identify a target organ or other structures in the body and/or determine features associated with the target organ/structure, such as the size of the organ/structure or the volume of fluid in the organ. Different types of ultrasound signals may generate different types of echo signals from particular structures in the body. Therefore, different types of ultrasound signals may be used to identify different structures in the body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1**A is a diagram illustrating an exemplary ultrasound system according to an implementation described herein;

[0004] FIG. **1**B is a diagram illustrating an exemplary environment for the ultrasound system of FIG. **1**A according to an implementation described herein;

[0005] FIG. **2**A is a diagram of a first exemplary ultrasound probe according to an implementation described herein;

[0006] FIG. **2**B is a diagram of a second exemplary ultrasound probe according to an implementation described herein;

[0007] FIG. **2**C is a diagram of a third exemplary ultrasound probe according to an implementation described herein;

[0008] FIG. **3** is a diagram illustrating exemplary components of the controller unit of FIG. **1**A;

[0009] FIG. **4** is a diagram illustrating exemplary functional components of the system of FIG. **1**A;

[0010] FIG. **5** is a flowchart of a process for multiple frequency ultrasound scanning according to an implementation described herein;

[0011] FIG. **6** is a diagram of a first exemplary multiple frequency ultrasound scanning implementation;

[0012] FIG. **7** is a diagram of a second exemplary multiple frequency ultrasound scanning implementation;

[0013] FIG. **8** is a diagram of a first user interface according to an implementation described herein;

[0014] FIG. **9** is a diagram of a second user interface according to an implementation described herein; and

[0015] FIG. **10** is a diagram of a third user interface according to an implementation described herein.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0016] The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements.

[0017] An ultrasound probe may transmit a pulse at a particular frequency, such a pulse at 2.5 megahertz (MHz), 5.0 MHz, and/or another frequency, toward an area of interest in a patient's body. The ultrasound signals may echo (i.e., reflect) off tissues in the area of interest and echo signals may be received by the ultrasound probe and processed to generate images and/or characterize the area of interest. As a result of non-linear propagation through bodily tissues, the echo signals may include echo signals at the fundamental frequency and echo signals at one or more harmonic frequencies of the fundamental frequency. The harmonic frequency signals may be used to characterize the area of interest by, for example, determining a boundary of a body structure, identifying an area that includes fluid, distinguish one body organ from another body organ, etc.

[0018] For example, body tissue may respond differently to ultrasound pulses than fluid with respect to nonlinear propagation. Nonlinear propagation may result in generation of harmonic frequencies components and the extent of generation of harmonic frequencies may be used, for example, to identify a type of body tissue in a particular region of the area of interest. One parameter used to determine the importance of nonlinear or dissipative behavior (e.g., attenuation) is the Goldberg number. The Goldberg number is a dimensionless number defined as the ratio between the absorption length l_a (the inverse of the absorption coefficient) and shock length l_s which is a measure of the length at which a waveform would shock (i.e., move faster than the local wave propagation speed) if no absorption is present. The Goldberg number F may expressed as:

$$\Gamma = \frac{l_a}{l_s} = \frac{k\beta M}{\alpha} \qquad \text{Eq. (1)}$$

where k corresponds to the wave number, β corresponds to the acoustic Mach number, M corresponds to the acoustic nonlinearity parameter, and a corresponds to the absorption coefficient. However, the harmonic frequency components in the echo signals may not always be of sufficiently high amplitude to satisfactorily characterize the area of interest.

[0019] Implementations described herein relate to multiple frequency scanning using an ultrasound probe. An ultrasound system may be configured to control an ultrasound transducer to transmit ultrasound signals at multiple frequencies. For example, the ultrasound system may transmit ultrasound signals at a fundamental frequency and at one or more harmonic frequencies of the fundamental frequency. When the ultrasound transducer transmits multiple frequencies that include harmonic frequencies in addition to a fundamental frequency, measures of nonlinearity such as the Goldberg number may not be the distinguishing factor between different structures, such as tissues and fluid, because the harmonic frequency components of the echo signals may not be generated by nonlinear propagation through the structures in the area of interest in the patient's body. Nevertheless, different harmonic frequency components of the echo signals may provide information relating

to frequency-dependent attenuation. Furthermore, because harmonic frequency signals are being transmitted by the ultrasound transducer, rather than being generated by non-linear propagation in the body structures, the frequency-dependent attenuation may be measured more clearly due to the higher amplitude of the harmonic frequency components in the echo signals.

[0020] The ultrasound system may be configured to transmit ultrasound signals, which include a fundamental frequency signal and at least one harmonic frequency, using an ultrasound probe toward an area of interest in a patient's body; receive echo signals from the area of interest based on the transmitted ultrasound signals; obtain a fundamental frequency echo signal and at least one harmonic frequency echo signal from the received echo signals; and generate a visual representation of the area of interest based on the obtained fundamental frequency echo signal and the obtained at least one harmonic frequency echo signal.

[0021] In some implementations, multiple frequencies may be transmitted in a multi-frequency manner (e.g., simultaneously), such as, for example, transmitting an ultrasound pulse that includes a 2.5 MHz component and a 5.0 MHz component. In other implementations, multiple frequencies may be transmitted in a variable-frequency manner (e.g., sequentially or alternately), such as, for example, transmitting 2.5 MHz and 5.0 MHz pulses alternately. In yet other implementation, multiple frequencies may be transmitted both simultaneously and sequentially, such as, for example, alternating transmitting 1 and 2 MHz pulses together, and transmitting 4 and 6 MHz pulses together.

[0022] In yet other implementations, the ultrasound system may be configured to control the ultrasound probe to transmit and/or receive broadband ultrasound signals. For example, an ultrasound transducer may transmit a broadband pulse that covers the range from 2 MHz to 4 MHz and receives returned echoes in a range from 2 MHz to 4 MHz, returned echoes in a range from 2 MHz to 8 MHz, and/or returned echoes in a different range. One or more bandpass filters may be applied to the received broadband echoes to retrieve echo signals at particular frequencies. For example, in some implementations, a Short-Time Fourier Transform (STFT) operation, a Wavelet Decomposition (WD), a Wavelet Packet Decomposition (WPD) operation, and/or another type of signal processing operation may be used to retrieve frequency component echo signals from a signal of returned echoes. As an example, a 128-tap STFT unit may be configured to function as a filter bank that generates echo signal components at 128 different frequencies.

[0023] In yet other implementations, the ultrasound system may be configured to control the ultrasound probe to transmit and/or receive harmonic frequencies that are not integer multiples of the fundamental frequency. For example, rather than transmitting an ultrasound pulse at a 2 MHz fundamental frequency and harmonic frequencies at 4, 6, or 8 MHz, the ultrasound transducer may be controlled to transmit an ultrasound pulse at a 2 MHz fundamental frequency and ultrasound pulses at one or more non-integer harmonic frequencies, such as, for example, at 3 MHz, 5 MHz, and/or another non-integer harmonic frequency. Furthermore, one or more bandpass filters may be used to retrieve echo signals at one or more non-integer harmonic frequencies from returned echo signals based on the transmitted ultrasound pulses.

[0024] In some implementations, the harmonic frequency components retrieved from the returned echo signals may be used to generate an ultrasound image. As an example, an ultrasound image may be generated in which brightness/shade of a particular pixel represents the amplitude of a particular harmonic frequency echo signal at the location represented by the particular pixel. As another example, one or more parameters may be computed relating the fundamental frequency echo signal and a harmonic frequency echo signal, relating a first harmonic frequency echo signal and a second harmonic frequency echo signal, relating three or more frequency components, etc., and an ultrasound image may be generated based on the computed one or more parameters, in which the brightness/shade of a particular pixel represents a computed parameter at the location represented by the particular pixel. The computed parameters may include a power ratio (e.g., an attenuation ratio), attenuation coefficient, a probability value (e.g., indicating a likelihood of a pixel corresponding to a particular type of tissue, fluid, etc.), and/or another type of parameter. Thus, the ultrasound system may generate a series of ultrasound images for different harmonic frequency echo signals and/or different computed parameters, such as power ratios.

[0025] Furthermore, the ultrasound system may combine two or more of the generated ultrasound images. For example, the ultrasound system may generate a color map that assigns a particular color to a particular harmonic frequency echo signal and/or computed parameter, such as a power ratio. The brightness/shade of the assigned color at a particular pixel may correspond to the value of the particular harmonic frequency echo signal and/or computed parameter associated with the assigned color at the location represented by the particular pixel and multiple harmonic frequency echo signals and/or computed parameters may be displayed on the image using multiple colors.

[0026] Additionally or alternatively, the harmonic frequency components retrieved from the returned echo signals, and/or the computed parameters, may be used to characterize the area of interest by providing the harmonic frequency components and/or the computed parameter values as inputs into a classifier. The classifier may be trained to use the harmonic frequency components and/or the computed parameter values to distinguish between a first target and a second target in the area of interest (e.g., distinguish between a first body structure and a second body structure, etc.), to identify an area that includes a target in the area of interest (e.g., identify an area that includes fluid, etc.), or identify a target boundary in the area of interest (e.g., identify a tissue boundary, etc.), to identify a particular tissue and/or body structure, to identify a medical instrument (e.g., a catheter, needle, a cannula, etc.), to identify an ultrasound artifact, and/or to otherwise characterize the area of interest.

[0027] In some implementations, the generated ultrasound images may correspond to B-mode ultrasound images. In other implementations, other types of ultrasound images may be generated, such as probability mode (P-mode) ultrasound images. A P-mode ultrasound image may correspond to an ultrasound image (e.g., a B-mode ultrasound image, etc.) in which each particular pixel is mapped to a probability indicating whether that particular pixel is within or part of a target organ/structure. As another example, the generated ultrasound images may include Doppler mode ultrasound images (e.g., Power Doppler, Continuous Wave

Doppler, Pulsed Wave Doppler, etc.), motion mode (M-mode) ultrasound images, and/or any other type of imaging modality that uses ultrasound data.

[0028] Furthermore, in other implementations, the harmonic frequency echo signal ultrasound images may be used for additional types of processing. As an example, the harmonic frequency echo signal ultrasound images may be used in connection with positioning a needle guide for needle insertion (e.g., to obtain a biopsy sample, etc.); to measure the volume of an area of interest (e.g., bladder volume measurement, prostate volume measurement, uterus volume measurement, aorta volume measurement, etc.); and/or to perform other types of processing.

[0029] FIG. **1**A is a diagram illustrating an exemplary ultrasound system **100** according to an implementation described herein. As shown in FIG. **1**A, ultrasound system **100** may include an ultrasound probe **110**, a base unit **120**, and a cable **130**.

[0030] Ultrasound probe **110** may house one or more ultrasound transducers configured to generate ultrasound energy at a particular frequency and/or pulse repetition rate and to receive reflected ultrasound energy (e.g., ultrasound echoes) and convert the reflected ultrasound energy into electrical signals. For example, in some implementations, ultrasound probe **110** may be configured to transmit ultrasound signals in a range that extends from approximately about two megahertz (MHz) to approximately 10 or more MHz (e.g., 18 MHz). In other implementations, ultrasound probe **110** may be configured to transmit ultrasound signals in a different range. Furthermore, ultrasound probe **110** may house one or more motors for controlling the movement of the ultrasound transducer.

[0031] Ultrasound probe **110** may include a handle **112**, a trigger **114**, and a dome **118** (also referred to as a "nose"). A user (e.g., a medical practitioner, etc.) may hold ultrasound probe **110** via handle **112** and press trigger **114** to activate one or more ultrasound transceivers and transducers located in dome **118** to transmit ultrasound signals toward a patient's area of interest (e.g., a particular body organ, a body joint, a blood vessel, etc.). For example, probe **110** may be positioned on a pelvic area of a patient and over the patient's bladder.

[0032] Handle **112** enables a user to move probe **110** relative to a patient's area of interest. Activation of trigger **114** initiates an ultrasound scan of a selected anatomical portion while dome **118** is in contact with a surface portion of a patient's body when the patient's area of interest is scanned. Dome **118** may enclose one or more ultrasound transducers and may be formed from a material that provides an appropriate acoustical impedance match to the anatomical portion and/or permits ultrasound energy to be properly focused as it is projected into the anatomical portion. Dome **118** may also include transceiver circuitry that includes a transmitter and a receiver to transmit and receive ultrasound signals. Probe **110** may communicate with base unit **120** via a wired connection, such as via cable **130**. In other implementations, probe **110** may communicate with base unit **120** via a wireless connection (e.g., Bluetooth, WiFi, etc.).

[0033] Base unit **120** may house and include one or more processors or processing logic configured to process reflected ultrasound energy that is received by probe **110** to produce an image of the scanned anatomical region. Furthermore, base unit **120** may include display **122** to enable a user to view images from an ultrasound scan, and/or to enable operational interaction with respect to the user during operation of probe **110**. For example, display **122** may include an output display/screen, such as a liquid crystal display (LCD), light emitting diode (LED) based display, touchscreen, and/or another type of display that provides text and/or image data to a user.

[0034] For example, display **122** may provide instructions for positioning probe **110** relative to a selected anatomical portion of a patient. Alternatively, ultrasound probe **110** may include a small display (e.g., in handle **112**) that provides instructions for positioning ultrasound probe **110**. Display **122** may also display two-dimensional or three-dimensional images of the selected anatomical region. In some implementations, display **122** may include a graphical user interface (GUI) that allows the user to select various features associated with an ultrasound scan. For example, display **122** may include selection items (e.g., buttons, dropdown menu items, checkboxes, etc.) to select particular transmission frequencies. As an example, the selection items may enable the user to select a particular fundamental frequency, one or more integer harmonic frequencies, and/or one or more non-integer harmonic frequencies. As another example, the selection items may enable the user to select a broadband transmission signal.

[0035] Furthermore, display **122** may include selection items to select one or more harmonic frequency echo signals that are to be extracted from returned echo signals and/or to select one or more parameters (e.g., power/attenuation ratios, etc.) that are to be computed based on the returned echo signals. Moreover, display **122** may include selection items to select to use a classifier and to select a particular characterization to be performed by the classifier (e.g., organ identification, fluid detection, tissue boundary detection, etc.).

[0036] Additionally, display **122** may include selection items to select particular types of ultrasound images to be obtained, such as B-mode images, P-mode images, Doppler ultrasound images, harmonic mode images, M-mode images, and/or other types of ultrasound images. Moreover, display **122** may include selection items to select an aiming mode for probe **110** and/or to initiate a three-dimensional (3D) scan after probe **110** has been successfully positioned with respect to the patient's area of interest.

[0037] FIG. **1**B is a diagram illustrating an exemplary environment **150** for ultrasound system **100** according to an implementation described herein. Environment **150** illustrates the operation of ultrasound system **100** with respect to a patient **160**. As shown in FIG. **1**B, patient **160** may be positioned so that a patient's area of interest may be scanned. For example, assume the area of interest corresponds to the patient's bladder **165**. To scan bladder **165**, ultrasound probe **110** may be positioned against a surface portion of patient **160** that is proximate to the anatomical portion to be scanned. The user may apply acoustic gel **170** (or gel pads) to the skin of patient **160** over the area of bladder **165** to provide an acoustical impedance match when dome **118** is placed against the skin.

[0038] The user may select an aiming mode via base unit **120** (e.g., by selecting an aiming mode button, menu item, etc., on display **122**, by speaking a voice command, etc.). Alternatively, an aiming mode may be selected automatically when base unit **120** detects motion of ultrasound probe **110** or ultrasound probe **110** contacts acoustic gel **170** or the skin of patient **160** (e.g., via an accelerometer and/or gyro-

scope inside ultrasound probe **110**). Ultrasound probe **110** may transmit ultrasound signals **180** through bladder **165** and may receive reflected ultrasound signals. The reflected ultrasound signals may be processed into images that are displayed on display **122**.

[0039] Although FIGS. **1**A and **1**B show exemplary components of ultrasound system **100**, in other implementations, ultrasound system **100** may include fewer components, different components, additional components, or differently arranged components than depicted in FIGS. **1**A and **1**B. Additionally or alternatively, one or more components of ultrasound system **100** may perform one or more tasks described as being performed by one or more other components of ultrasound system **100**.

[0040] For example, in other embodiments, ultrasound probe **110** may correspond to a self-contained device that includes a microprocessor housed within ultrasound probe **110**, configured to operably control the one or more ultrasound transducers, and to process the reflected ultrasound energy to generate ultrasound images. Accordingly, a display on ultrasound probe **110** may be used to display the generated images and/or to view other information associated with the operation of ultrasound probe **110**. In yet other implementations, ultrasound probe **110** may be coupled to a general-purpose computer, such as a laptop, tablet, and/or a desktop computer (via a wired or wireless connection) that includes software that at least partially controls the operation of ultrasound probe **110** and/or that includes software to process information received from ultrasound probe **110** to generate ultrasound images.

[0041] FIG. **2**A is a diagram of a first exemplary implementation of ultrasound probe **110** according to an implementation described herein. As shown in FIG. **2**A, ultrasound probe **110** may include a single transducer element coupled to two rotational motors. In this implementation, ultrasound probe **110** may include a base **210** connected to dome **118**, a theta motor **220**, a spindle **230**, a phi motor **240**, and a transducer bucket **250** with a transducer **260**. Theta motor **220**, phi motor **240**, and/or transducer **260** may include wired or wireless electrical connections that electrically connect theta motor **220**, phi motor **240**, and/or transducer **260** to base unit **120** via cable **130** (not shown in FIG. **2**A).

[0042] Base **210** may house theta motor **220** and provide structural support to ultrasound probe **110**. Base **210** may connect to dome **118** and may form a seal with dome **118** to protect the components of ultrasound probe **110** from the external environment. Theta motor **220** may rotate spindle **230** with respect to base **210** in a longitudinal direction with respect to transducer **260**, by rotating around a vertical axis referred to herein as a theta (**8**) rotational plane **225**. Spindle **230** may terminate in a shaft **235** and phi motor **240** may be mounted onto shaft **235**. Phi motor **240** may rotate around an axis orthogonal to the theta rotational plane **225** around a horizontal axis referred to herein as a phi (**4**)) rotational plane **245**. Transducer bucket **250** may be mounted to phi motor **240** and may move with phi motor **240**.

[0043] Transducer **260** may be mounted to transducer bucket **250**. Transducer **260** may include a piezoelectric transducer, a capacitive transducer, and/or another type of ultrasound transducer. Transducer **260**, along with transceiver circuitry associated with transducer **260**, may convert electrical signals to ultrasound signals at a particular ultrasound frequency or range of ultrasound frequencies, may receive reflected ultrasound signals (e.g., echoes, etc.), and may convert the received ultrasound signals to electrical signals. As an example, transducer **260** may include a set of transducers, each of which is configured to generate an ultrasound pulse at a particular frequency. As another example, transducer **260** may include a broadband ultrasound transducer. Transducer **260** may transmit and receive ultrasound signals in a signal direction **265** that is substantially perpendicular to the surface of transducer **260**.

[0044] Signal direction **265** may be controlled by the movement of phi motor **240** and the orientation of phi motor may be controlled by theta motor **220**. For example, phi motor **240** may rotate back and forth across an angle that is less than 180 degrees to generate ultrasound image data for a particular plane and theta motor **220** may rotate to particular positions to obtain ultrasound image data for different planes.

[0045] In an aiming mode, theta motor **220** may remain stationary while phi motor **240** rotates back and forth to obtain ultrasound image data for a particular aiming plane. In the aiming mode, theta motor **220** may move back and forth between multiple aiming planes and phi motor **240** may rotate back and forth to obtain ultrasound image data. As an example, theta motor **220** may move between two orthogonal planes while the aiming mode is selected. As another example, theta motor **220** may sequentially rotate through three planes offset by 120 degrees to each other during the aiming mode.

[0046] In a 3D scan mode, theta motor **220** may cycle through a set of planes one or more times to obtain a full 3D scan of an area of interest. In each particular plane of the set of planes, phi motor **240** may rotate to obtain ultrasound image data for the particular plane. The movement of theta motor **220** and phi motor **240** may be interlaced in the 3D scan motor. For example, the movement of phi motor **240** in a first direction may be followed by a movement of theta motor **220** from a first plane to a second plane, followed by the movement of phi motor **240** in a second direction opposite to the first direction, followed by movement of theta motor **220** from the second plane to a third plane, etc. Such interlaced movement may enable ultrasound probe **110** to obtain smooth continuous volume scanning as well as improving the rate at which the scan data is obtained.

[0047] FIG. **2**B is a diagram of a second exemplary implementation of ultrasound probe **110** according to an implementation described herein. As shown in FIG. **2**B, ultrasound probe **110** may include a one-dimensional (1D) array of transducer elements coupled to a rotation motor. In this implementation, ultrasound probe **110** may include a base **210** connected to dome **118**, a theta motor **220**, a spindle **230**, and a transducer bucket **270** with a 1D transducer array **275**. Theta motor **220** and/or 1D transducer array **275** may include wired or wireless electrical connections that electrically connect theta motor **220** and/or 1D transducer array **275** to base unit **120** via cable **130** (not shown in FIG. **2**B).

[0048] Base **210** may house theta motor **220** and provide structural support to ultrasound probe **110**. Base **210** may connect to dome **118** and may form a seal with dome **118** to protect the components of ultrasound probe **110** from the external environment. Theta motor **220** may rotate spindle **230** with respect to base **210** in longitudinal direction with respect to 1D transducer array **275** by rotating around theta rotational plane **225**. Spindle **230** may terminate in trans-

ducer bucket **270**. 1D transducer array **275** may be mounted to transducer bucket **270**. 1D transducer array **275** may include a curved 1D array of piezoelectric transducers, capacitive transducers, and/or other types of ultrasound transducers. 1D transducer array **275** may convert electrical signals to ultrasound signals at a particular ultrasound frequency or range of ultrasound frequencies, may receive reflected ultrasound signals (e.g., echoes, etc.), and may convert the received ultrasound signals to electrical signals. Each element of 1D transducer array **275** may transmit and receive ultrasound signals in a particular direction of a set of directions, illustrated as item **276** in FIG. **2**B. Thus, together, the elements of 1D transducer array **275** may generate ultrasound image data for a particular plane.

[0049] In an aiming mode, theta motor **220** may remain stationary while 1D transducer array **275** obtains B-mode image data for a particular aiming plane. In the aiming mode, theta motor **220** may move back and forth between multiple aiming planes and 1D transducer array **275** may obtain ultrasound image data in each aiming plane. As an example, theta motor **220** may move between two orthogonal planes while aiming mode is selected. As another example, theta motor **220** may sequentially rotate through three planes located 120 degrees apart from each other. In a 3D scan mode, theta motor **220** may cycle through a set of planes one or more times to obtain a full 3D scan of an area of interest. In each particular plane of the set of planes, 1D transducer array **275** may obtain ultrasound image data for the particular plane.

[0050] FIG. **2**C is a diagram of a third exemplary ultrasound probe **110** according to an implementation described herein. As shown in FIG. **2**C, ultrasound probe **110** may include a two-dimensional (2D) array of transducer elements. In this implementation, ultrasound probe **110** may include a base **210**, a spindle **230**, and a transducer bucket **280** with a 2D transducer array **285**. 2D transducer array **285** may include wired or wireless electrical connections that electrically connects 2D transducer array **285** to base unit **120** via cable **130** (not shown in FIG. **2**C).

[0051] Base **210** may provide structural support to ultrasound probe **110** and secure spindle **230**. Spindle **282** may terminate in transducer bucket **280**. 2D transducer array **285** may be mounted to transducer bucket **280**. 2D transducer array **285** may include a 2D array of piezoelectric transducers, capacitive transducers, and/or other types of ultrasound transducers. 2D transducer array **285** may convert electrical signals to ultrasound signals at a particular ultrasound frequency or range of ultrasound frequencies, may receive reflected ultrasound signals (e.g., echoes, etc.), and may convert the received ultrasound signals to electrical signals. Each element of 2D transducer array **285** may transmit and receive ultrasound signals in a particular direction of a set of directions, illustrated as item **290** in FIG. **2**C. Thus, together, the elements of 2D transducer array **285** may generate ultrasound image data for multiple planes to generate a 3D ultrasound scan. In other words, 2D transducer array **285** may be controlled to tilt or direct an ultrasound beam/signal electronically in a particular direction.

[0052] In an aiming mode, 2D transducer array **285** may obtain ultrasound image data for one or more selected aiming planes. For a particular selected aiming plane, a subset of transducer elements from 2D transducer array **285** may be selected to generate an ultrasound image for the particular selected aiming plane. A particular plane may be scanned by using one or more rows of transducer elements in 2D transducer array **285**. The number of rows may change dynamically depending on the target depth and the elevational focus may be electronically controlled by applying a timing delay between rows. As an example, two subsets of transducers may be selected for two orthogonal planes and may alternate between obtaining ultrasound images of the two orthogonal planes. Alternatively, the ultrasound images for the two orthogonal planes may be obtained substantially simultaneously. As another example, 2D transducer array **285** may cycle through three planes located 120 degrees apart from each other and three subsets of transducer elements from 2D transducer array **285** may obtain the ultrasound images for the three planes. In a 3D scan mode, 2D transducer array **285** may cycle through subsets of transducer elements one or more times to obtain a full 3D scan of an area of interest. Alternatively, multiple subsets of transducer elements, or even all of the transducer elements, of 2D transducer array **285** may be activated substantially simultaneously to obtain a full 3D scan of the area of interest.

[0053] Although FIGS. **2**A, **2**B, and **2**C show exemplary components of ultrasound probe **110**, in other implementations, ultrasound probe **110** may include fewer components, different components, additional components, or differently arranged components than depicted in FIGS. **2**A, **2**B, and **2**C. Additionally or alternatively, one or more components of ultrasound probe **110** may perform one or more tasks described as being performed by one or more other components of ultrasound probe **110**.

[0054] FIG. **3** is a diagram illustrating example components of a device **300** according to an implementation described herein. Ultrasound probe **110** and/or base unit **120** may each include one or more devices **300**. As shown in FIG. **3**, device **300** may include a bus **310**, a processor **320**, a memory **330**, an input device **340**, an output device **350**, and a communication interface **360**.

[0055] Bus **310** may include a path that permits communication among the components of device **300**. Processor **320** may include any type of single-core processor, multi-core processor, microprocessor, latch-based processor, and/or processing logic (or families of processors, microprocessors, and/or processing logics) that interprets and executes instructions. In other embodiments, processor **320** may include an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), and/or another type of integrated circuit or processing logic.

[0056] Memory **330** may include any type of dynamic storage device that may store information and/or instructions, for execution by processor **320**, and/or any type of non-volatile storage device that may store information for use by processor **320**. For example, memory **330** may include a random access memory (RAM) or another type of dynamic storage device, a read-only memory (ROM) device or another type of static storage device, a content addressable memory (CAM), a magnetic and/or optical recording memory device and its corresponding drive (e.g., a hard disk drive, optical drive, etc.), and/or a removable form of memory, such as a flash memory.

[0057] Input device **340** may allow an operator to input information into device **300**. Input device **340** may include, for example, a keyboard, a mouse, a pen, a microphone, a remote control, an audio capture device, an image and/or video capture device, a touch-screen display, and/or another

type of input device. In some embodiments, device **300** may be managed remotely and may not include input device **340**. In other words, device **300** may be "headless" and may not include a keyboard, for example.

[0058] Output device **350** may output information to an operator of device **300**. Output device **350** may include a display, a printer, a speaker, and/or another type of output device. For example, device **300** may include a display, which may include a liquid-crystal display (LCD) for displaying content to the customer. In some embodiments, device **300** may be managed remotely and may not include output device **350**. In other words, device **300** may be "headless" and may not include a display, for example.

[0059] Communication interface **360** may include a transceiver that enables device **300** to communicate with other devices and/or systems via wireless communications (e.g., radio frequency, infrared, and/or visual optics, etc.), wired communications (e.g., conductive wire, twisted pair cable, coaxial cable, transmission line, fiber optic cable, and/or waveguide, etc.), or a combination of wireless and wired communications. Communication interface **360** may include a transmitter that converts baseband signals to radio frequency (RF) signals and/or a receiver that converts RF signals to baseband signals. Communication interface **360** may be coupled to an antenna for transmitting and receiving RF signals.

[0060] Communication interface **360** may include a logical component that includes input and/or output ports, input and/or output systems, and/or other input and output components that facilitate the transmission of data to other devices. For example, communication interface **360** may include a network interface card (e.g., Ethernet card) for wired communications and/or a wireless network interface (e.g., a WiFi) card for wireless communications. Communication interface **360** may also include a universal serial bus (USB) port for communications over a cable, a Bluetooth™ wireless interface, a radio-frequency identification (RFID) interface, a near-field communications (NFC) wireless interface, and/or any other type of interface that converts data from one form to another form.

[0061] As will be described in detail below, device **300** may perform certain operations relating to multi-frequency scanning using an ultrasound probe. Device **300** may perform these operations in response to processor **320** executing software instructions contained in a computer-readable medium, such as memory **330**. A computer-readable medium may be defined as a non-transitory memory device. A memory device may be implemented within a single physical memory device or spread across multiple physical memory devices. The software instructions may be read into memory **330** from another computer-readable medium or from another device. The software instructions contained in memory **330** may cause processor **320** to perform processes described herein. Alternatively, hardwired circuitry may be used in place of, or in combination with, software instructions to implement processes described herein. Thus, implementations described herein are not limited to any specific combination of hardware circuitry and software.

[0062] Although FIG. **3** shows exemplary components of device **300**, in other implementations, device **300** may include fewer components, different components, additional components, or differently arranged components than depicted in FIG. **3**. Additionally or alternatively, one or more components of device **300** may perform one or more tasks described as being performed by one or more other components of device **300**.

[0063] FIG. **4** is a diagram illustrating exemplary functional components of ultrasound system **100**. The functional components of ultrasound system **100** may be implemented in ultrasound probe **110**, base unit **120**, and/or another device/system, for example, via processor **320** executing instructions from memory **330**. Alternatively, some or all of the functional components of ultrasound system **100** may be implemented via hard-wired circuitry. As shown in FIG. **4**, ultrasound system **100** may include a user interface **410**, a frequency manager **420**, an image generator **430**, a classifier **440**, and a data collector **450**.

[0064] User interface **410** may generate a user interface (e.g., a graphical user interface) that displays ultrasound images to a user via display **122** and that is configured to receive selections and/or commands from the user via a touchscreen associated with display **122**, via one or more control keys located on base unit **120** and/or on ultrasound probe **110**, via a microphone included in base unit **120**, and/or via another type of input method. For example, a user may select a type of ultrasound image, a set of transmission frequencies, a set of frequency components to be extracted from returned echo signals, whether to use a classifier to characterize the area of interest, a type of characterization to be performed by the classifier, and/or other types of selections relating to ultrasound scanning to be performed.

[0065] Frequency manager **420** may manage frequency components associated with ultrasound probe **110**. Frequency manager **420** may select one or more transmission frequencies for transducer **260** (or transducer array **275** or **285**). As an example, frequency manager **420** may select a fundamental frequency, one or more integer harmonic frequencies of the fundamental frequency, and/or one or more non-integer harmonic frequencies of the fundamental frequency. Furthermore, frequency manager **420** may select to transmit one or more harmonic frequencies simultaneously with the fundamental frequency and/or with each other, may select to transmit one or more harmonic frequencies alternatively with the fundamental frequency and/or with each other, and/or may select a combination of simultaneous and alternate transmission of harmonic frequencies. As another example, frequency manager **420** may select a broadband ultrasound transmission signal.

[0066] Furthermore, frequency manager **420** may select one or more harmonic frequency components to retrieve from returned ultrasound echo signals. For example, frequency manager **420** may select one or more bandpass filters, may select one or more outputs of an STFT or WPD function, and/or may otherwise select which harmonic frequency components are to be extracted from received echo signals. Moreover, frequency manager **420** may select to compute one or more parameters, such as power ratios, attenuation coefficients, P-mode values, etc., based on the harmonic frequency components retrieved from received echo signals. In some implementations, frequency manager **420** may provide the retrieved harmonic frequency components, and/or computed parameters, as inputs to classifier **440**.

[0067] In some implementations, frequency manager **420** may select one or more transmission frequencies based on a user selection via, for example, user interface **410**. In other implementations, frequency manager **420** may select one or

more transmission frequencies, and/or one or more echo signal harmonic frequency components and/or power ratios to be computed, automatically (e.g., without user selection of transmission frequencies) based on one or more parameters, such as, for example, the particular area of interest to be scanned (e.g., organ, tissue, etc.), the type of ultrasound image selected, the type of classifier selected, and/or another type of parameter associated with an ultrasound scan.

[0068] Image generator **430** may generate ultrasound images based on received echo signals. For example, image generator **430** may instruct data collector **450** to obtain a particular type of ultrasound image, to move to a particular plane (e.g., a particular position of theta motor **220**), and to generate an ultrasound image of a particular type for the particular plane (e.g., using phi motor **240** and transducer **260**).

[0069] Classifier **440** may receive as input one or more harmonic frequency components and/or computed parameters and may output a classification output that characterizes the area of interest. For example, the classifier input may include one or more matrices of pixel values for an image generated based on particular harmonic frequency component and/or computed parameter. Classifier **440** may include a probabilistic classifier that outputs a probability value that a particular pixel corresponds to a particular structure, tissue, and/or fluid; a binary classifier that outputs a yes or no value for a particular pixel if the particular pixel is identified as belonging to a class (e.g., a particular organ, tissue, fluid, etc.); a multiclass classifier that outputs a particular value for a particular pixel indicating to which of a set of classes the particular pixel has been classified; and/or another type of classifier.

[0070] Classifier **440** may be implemented as a neural network classifier, a linear classifier, a naive Bayesian classifier, a kernel density estimation classifier, a decision tree classifier, a support vector machine classifier, a maximum entropy classifier, and/or another type of classifier. In some implementations, classifier **440** may be trained on a training set of images associated with predetermined classification output values (e.g., supervised learning). In other implementations, classifier **440** may be trained using a training set of images without predetermined classification (e.g., unsupervised learning).

[0071] Data collector **450** may be configured to collect ultrasound image data from ultrasound probe **110**. Data collector **450** may include a phi motor controller **460**, a theta motor controller **470**, and a transducer controller **480**. Phi motor controller **460** may control phi motor **240**. Theta motor controller **470** may control theta motor **220**. Transducer controller **480** may control transducer **260** (or 1D transducer array **275** or 2D transducer array **285**).

[0072] Although FIG. **4** shows exemplary components of ultrasound system **100**, in other implementations, ultrasound system **100** may include fewer components, different components, additional components, or differently arranged components than depicted in FIG. **4**. Additionally or alternatively, one or more components of ultrasound system **100** may perform one or more tasks described as being performed by one or more other components of ultrasound system **100**.

[0073] FIG. **5** is a flowchart of a process for multiple frequency ultrasound scanning according to an implementation described herein. In some implementations, the process of FIG. **5** may be performed by ultrasound system **100**. In other implementations, some or all of the process of FIG. **5** may be performed by another device or a group of devices separate from ultrasound system **100**.

[0074] The process of FIG. **5** may include selecting the transmission frequency spectrum (block **510**). As an example, a user may select a particular fundamental frequency and one or more harmonics of the fundamental frequency as the transmission frequency spectrum. The one or more harmonics may include integer harmonics of the fundamental frequency and/or non-integer harmonics of the fundamental frequency. Furthermore, the user may select which harmonics are to be transmitted simultaneously with the fundamental frequency and/or with each other and which harmonics are to be transmitted alternatively. Thus, the user may specify a transmission sequence for the selected harmonics. As another example, the user may select to transmit a broadband pulse in a particular frequency range (e.g., from 2 MHz to 10 MHz, etc.). As yet another example, a user may select to transmit a particular set of harmonics alternating with a broadband pulse. In other implementations, a transmission frequency spectrum may be selected automatically (e.g., without user selection) based on one or more parameters, such as, for example, the particular area of interest, organ, or tissue to be scanned, the type of ultrasound image selected, the type of classifier selected, and/or another type of parameter associated with an ultrasound scan.

[0075] Echo signal frequency components may be selected (block **520**). As an example, the user may select one or more harmonic frequency components to be extracted from the returned echo signals. For example, the user may specify one or more frequency ranges that are to be passed by a bandpass filter or output by a STFT or WPD function to generate the harmonic frequency components. In other implementations, the one or more harmonic frequency components may be selected automatically (e.g., without user selection) based on one or more parameters, such as, for example, the particular area of interest, organ, or tissue to be scanned, the type of ultrasound image selected, the type of classifier selected, and/or another type of parameter associated with an ultrasound scan. Additionally, one or more parameters to be computed may be selected, such as one or more power ratios, attenuation coefficients, P-mode values for a particular structure, organ, fluid, etc., and/or other types of parameters that may be derived from multi-frequency ultrasound data. For example, one or more power ratios may be selected to be computed (e.g., an attenuation ratio between the fundamental frequency and the first harmonic, an attenuation ratio between the fundamental frequency and a second harmonic, an attenuation ratio between the first harmonic and the second harmonic, etc.). Up to $n*(n-1)$ power ratios may be selected, where n corresponds to the number of frequency components selected to be retrieved.

[0076] Ultrasound signals based on the selected transmission frequency spectrum may be transmitted toward an area of interest in a patient's body (block **530**). For example, data collector **450** may control transducer **260** to generate ultrasound pulses based on the selected transmission frequency spectrum. Echo signals from the area of interest may be received (block **540**) and the selected echo signal frequency components may be obtained from the received echo signals (block **550**). For example, frequency manager **420** may use a bandpass filter bank, an STFT or WPD function, and/or another technique to obtain the selected echo signal frequency components from the returned echo signals. One or

more parameters associated with the obtained frequency components may be computed (block **560**). For example, in some implementations, frequency manager **420** may compute one or more power ratios selected by the user or selected automatically. In other implementations, frequency manager **420** may compute attenuation coefficients, P-mode values (e.g., probability values that particular pixels correspond to a particular tissue, organ, fluid, etc.), a parameter that described a relationship between three or more frequency components (e.g., an average power or attenuation for three or more frequency components, etc.), and/or any other parameter that may be derived from multi-frequency ultrasound data.

[0077] Images based on particular echo frequency components or based on particular computed parameters may be generated (block **570**) and provided to the user via a user interface (block **580**). As an example, image generator **430** may generate an ultrasound image (e.g., a B-mode image) in which the brightness, intensity, or shade of a particular pixel represents the amplitude value for a retrieved frequency component at the location represented by the particular pixel. As another example, image generator **430** may generate an ultrasound image (e.g., a B-mode image) in which the brightness, intensity, or shade of a particular pixel represents the power ratio value between two retrieved frequency components at the location represented by the particular pixel. As yet another example, image generator **430** may generate an ultrasound image in which the brightness, intensity, or shade of a particular pixel represents a different type of computed parameter, such as computed attenuation coefficients, P-mode values, and/or any other type of parameter that may be derived from multi-frequency ultrasound data.

[0078] As yet another example, image generator **430** may combine two or more of the generated ultrasound images to generate a color map. The color map may assign a particular color to a particular harmonic frequency echo signal and/or a particular computed parameter and the brightness, intensity, or shade of the assigned color at a particular pixel may correspond to the value of the particular harmonic frequency echo signal and/or computed parameter associated with the assigned color at the location represented by the particular pixel. Multiple harmonic frequency echo signals and/or computed parameters may be displayed on the image using multiple colors.

[0079] One or more of the generated images may be displayed together on display **122**. Additionally or alternatively, the user may toggle between the generated images using a selection item (e.g., button, etc.) displayed on display **122**, a gesture on the touchscreen associated with display **122**, a button on control unit **120** or ultrasound probe **110**, a voice command, and/or using another selection method.

[0080] Additionally or alternatively, the echo frequency components or computed parameters may be provided as inputs to a classifier (block **575**) and the classifier output may be used to characterize the area of interest (block **585**). For example, the generated images may be provided to classifier **440** that has been trained to characterize the area of interest. For example, classifier **440** may be trained to identify a particular target (e.g., organ, fluid type, structure, tissue, medical instrument, ultrasound artifact, etc.); to distinguish a first target (e.g., organ, fluid type, structure, tissue, medical instrument, type of ultrasound artifact, etc.) from a second target; to identify a boundary between a first target (e.g., organ, fluid type, structure, tissue, medical instrument, ultrasound artifact, etc.) and a second target; to distinguish a fluid area from a non-fluid area; and/or to otherwise characterize a particular area of interest. Classifier **440** may, for example, generate an image that identifies pixels classified into a first class with a first value (e.g., a dark shading) and pixels classified into a second class with a second value (e.g., a light shading). Furthermore, classifier **440** may be trained to distinguish between three or more different targets (e.g., organs, fluid types, structures, tissues, medical instruments, ultrasound artifacts, etc.) and may generate an image that identifies pixels classified into one of a set of classes, where each class corresponds to a different type of target. For example, each type of target may be associated with a different color, different shading intensity, different fill patterns, etc. Additionally, each type of target may be labeled with a label that identifies the type of target.

[0081] FIG. **6** is a diagram of a first exemplary multiple frequency ultrasound scanning implementation **600**. As shown in FIG. **6**, in implementation **600**, multiple harmonic frequency signals are transmitted along with a fundamental frequency. An ultrasound signal generator **610** may generate an ultrasound pulse at a single frequency **620** or at multiple frequencies **630**. For example, in order to generate multiple frequencies **630**, ultrasound signal generator **610** may include multiple transducers, with each transducer configured to generate an ultrasound pulse at a particular frequency. For example, the multiple transducers may generate pulses at a fundamental frequency and one or more (integer or non-integer) harmonics of the fundamental frequency. Ultrasound signal generator **610** may include an excitation pulse generator, a set of transducers, and controlling electronics. Frequency manager **420** may select which ultrasound transducers are activated during a particular data collection event. The generated ultrasound pulses may be transmitted into patient **160**. Data collector **450** may include receiver circuitry coupled to the transducers to obtain echo signals from ultrasound signal generator **610** that include multi-frequency harmonic echo signals **640** and may provide the multi-frequency harmonic echo signals **640** to a bandpass filter bank **650**. Bandpass filter bank **650** may include a first bandpass filter to pass a frequency range centered around the fundamental frequency, a second bandpass filter to pass a frequency range centered around the first harmonic frequency, and a third bandpass filter to pass a frequency range centered around the second harmonic frequency. Bandpass filter bank **650** may provide frequency component signals **660** to multi-frequency analyzer **670**.

[0082] Multi-frequency analyzer **670** may select particular ones of frequency component signals **660** and provide the selected frequency component signals **660** to image generator **430** (not shown in FIG. **6**). Image generator **430** may generate a first image based on the fundamental frequency, a second image based on the first harmonic frequency, and a third image based on the second harmonic frequency. Image generator **430** may provide the generated images to user interface **410** and user interface **410** may display one or more of the images on display **122**. The user may use a toggle control **680**, such as a button on display **122**, to toggle between the generated images (see FIGS. **8** and **9**).

[0083] FIG. **7** is a diagram of a second exemplary multiple frequency ultrasound scanning implementation **700**. As shown in FIG. **7**, in implementation **700**, broadband ultra-

sound signals are transmitted by transducer **260** (or transducer array **275** or **285**). A broadband ultrasound signal generator **710** (e.g., implemented by frequency manager **420**) may generate broadband signals **720**. Broadband ultrasound signal generator **710** may include an excitation pulse generator, a broadband transducer, and controlling electronics.

[0084] The generated broadband ultrasound signals **720** may be transmitted into patient **160**. Data collector **450** may obtain echo signals from patient **160** that include broadband echo signals **730** and may provide the broadband echo signals **730** to a bandpass filter bank **740**. Bandpass filter bank **740** may be implemented as, for example, a set of bandpass filters, an STFT signal processor, a WD signal processor, a WPD signal processor, and/or another type of bandpass filter bank implementations, For example, bandpass filter bank **740** may be implemented as a digital signal processor configured to retrieve **128** frequency components signals **750** from harmonic echo signals **730** using an STFT operation. Frequency component signals **750** may be provided as inputs to multi-frequency analyzer **760**. Multi-frequency analyzer **760** may include, for example, classifier **440** implemented as a neural net trained to detect an organ (e.g., bladder). Classifier **440** may output an image that includes pixels of a first color, brightness, or shading for areas detected by classifier **440** as corresponding to the organ and pixels of a second color, brightness, or shading for areas that do not correspond to the organ (see FIG. **10**). The user may use a toggle control **680**, such as a button on display **122**, to toggle between different images generated by classifier **440**. For example, the user may toggle between different shading or contrast levels, between different detected targets (e.g., different organs, etc.), between different detected target boundaries, etc.

[0085] FIG. **8** is a diagram of a first user interface **800** according to an implementation described herein. As shown in FIG. **8**, in some implementations, a first ultrasound image **810** and a second ultrasound image **820** may be displayed together on display **122**. First ultrasound image **810** may correspond to an image based on a first harmonic component and second ultrasound image **820** may correspond to a second harmonic component. For example, first ultrasound image **810** may correspond to a graphical representation of the power ratio between the fundamental frequency and the first harmonic frequency and second ultrasound image **820** may correspond to a graphical representation of the power ratio of the first harmonic frequency and the second harmonic frequency. While FIG. **8** illustrates a first harmonic component and a second harmonic component, other types of images based on multi-frequency ultrasound data may be generated and displayed, such as an image that combines one or more harmonic components (e.g., by adding pixel values, by averaging pixel values, etc.), an image that displays P-mode values, an image that displays a computed parameter (e.g., a power ratio between a first harmonic component and a second harmonic component, and/or any other type of image that may be generated based on multi-frequency ultrasound data.

[0086] FIG. **9** is a diagram of a second user interface **900** according to an implementation described herein. As shown in FIG. **9**, second user interface **900** shows a user toggling between different images **910**, **920**, **930**, and **940** based on retrieved harmonic components. For example, display **122** may toggle between images **910**, **920**, **930**, and **940** as the user presses a selection object on the touchscreen associated with display **122** (and/or another key or button associated with ultrasound system **100**). In yet other implementations, images **910**, **920**, **930**, and **940** may be displayed in a tiled configuration and toggling may change which tile is moved to the front.

[0087] FIG. **10** is a diagram of a third user interface **1000** according to an implementation described herein. As shown in FIG. **10**, images **910**, **920**, **930**, and **940** may be provided as inputs to classifier **440** and classifier **440** may output an image **1010** that identifies an organ in the area of interest captured in images **910**, **920**, **930**, and **940**. While FIG. **10** illustrates images **910-940** as inputs to classifier **440**, the inputs to classifier **440** may not be limited to images. Classifier **440** may take as input any information derived from received multi-frequency ultrasound data, such as one or more computed parameters (e.g., power ratios, attenuation coefficients, global power level per frequency component. etc.) instead of, or in addition to, receiving as input one or more sets of image pixel data.

[0088] In the preceding specification, various preferred embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the broader scope of the invention as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

[0089] For example, while a series of blocks have been described with respect to FIG. **5**, the order of the blocks may be modified in other implementations. Further, non-dependent blocks may be performed in parallel.

[0090] Although embodiments described above refer to scanning a bladder, other organs, joints, vessels, and/or body areas, such as an aorta, prostate, kidney, uterus, ovaries, heart, etc., could scanned and/or imaged in other implementations. Furthermore, medical instruments, such as catheters, needles, cannulas, etc. may be scanned and/or imaged using the implementations described herein. Moreover, implementations described herein may be used to detect and identify ultrasound artifacts. Furthermore, in some implementations, obtaining an adequate aiming mode and then proceeding to a 3D scan may be automatic based on a size of an image and/or another parameter.

[0091] It will be apparent that systems and/or methods, as described above, may be implemented in many different forms of software, firmware, and hardware in the implementations illustrated in the figures. The actual software code or specialized control hardware used to implement these systems and methods is not limiting of the embodiments. Thus, the operation and behavior of the systems and methods were described without reference to the specific software code—it being understood that software and control hardware can be designed to implement the systems and methods based on the description herein.

[0092] Further, certain portions, described above, may be implemented as a component that performs one or more functions. A component, as used herein, may include hardware, such as a processor, an ASIC, or a FPGA, or a combination of hardware and software (e.g., a processor executing software).

[0093] It should be emphasized that the terms "comprises"/"comprising" when used in this specification are

taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

[0094] The term "logic," as used herein, may refer to a combination of one or more processors configured to execute instructions stored in one or more memory devices, may refer to hardwired circuitry, and/or may refer to a combination thereof. Furthermore, a logic may be included in a single device or may be distributed across multiple, and possibly remote, devices.

[0095] For the purposes of describing and defining the present invention, it is additionally noted that the term "substantially" is utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

[0096] No element, act, or instruction used in the present application should be construed as critical or essential to the embodiments unless explicitly described as such. Also, as used herein, the article "a" is intended to include one or more items. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A method performed by a computing device, the method comprising:
- transmitting, by the computing device, ultrasound signals using an ultrasound probe toward an area of interest in a patient's body, wherein the ultrasound signals include a fundamental frequency signal and at least one harmonic frequency signal;
- receiving, by the computing device, echo signals from the area of interest based on the transmitted ultrasound signals;
- obtaining, by the computing device, a fundamental frequency echo signal and at least one harmonic frequency echo signal from the received echo signals; and
- generating, by the computing device, a visual representation of the area of interest based on the obtained fundamental frequency echo signal and the obtained at least one harmonic frequency echo signal.

2. The method of claim **1**, wherein transmitting the ultrasound signals using an ultrasound probe includes:
- transmitting a broadband ultrasound signal.

3. The method of claim **1**, wherein the at least one harmonic frequency signal includes a non-integer harmonic signal.

4. The method of claim **1**, wherein obtaining the fundamental frequency echo signal and the at least one harmonic frequency echo signal from the received echo signals includes:
- retrieving an echo signal corresponding to a non-integer harmonic of the fundamental frequency.

5. The method of claim **1**, wherein obtaining the fundamental frequency echo signal and the at least one harmonic frequency echo signals from the received echo signals includes:
- retrieving a plurality of echo signals corresponding to a plurality of harmonics of the fundamental frequency using a plurality of bandpass filters.

6. The method of claim **5**, retrieving the plurality of echo signals includes performing at least one of:
- a Short-Time Fourier Transform (STFT) operation,
- a Wavelet Decomposition (WD), or
- a Wavelet Packet Decomposition (WPD) operation.

7. The method of claim **5**, wherein generating the visual representation of the area of interest includes:
- generating a plurality of ultrasound images, wherein a particular one of the plurality of ultrasound images is based on a particular one of the plurality of echo signals.

8. The method of claim **5**, wherein generating the visual representation of the area of interest includes:
- providing the plurality of echo signals as inputs into a classifier, wherein the classifier is trained to at least one of:
- distinguish between a first target and a second target in the area of interest based on the plurality of echo signals,
- identify an area that includes a target in the area of interest based on the plurality of echo signals,
- identify a target boundary in the area of interest based on the plurality of echo signals.

9. The method of claim **5**, further comprising:
- calculating a plurality of parameters between the plurality of echo signals.

10. The method of claim **9**, wherein generating the visual representation of the area of interest includes:
- generating a plurality of ultrasound images, wherein a particular one of the plurality of ultrasound images is based on a particular one of the plurality of parameters.

11. The method of claim **9**, wherein generating the visual representation of the area of interest includes:
- providing the plurality of power ratios as inputs into a classifier, wherein the classifier is trained to at least one of:
- distinguish between a first target and a second target in the area of interest based on the plurality of power ratios,
- identify an area that includes a target in the area of interest based on the plurality of power ratios, or
- identify a target boundary in the area of interest based on the plurality of power ratios.

12. A system comprising:
- an ultrasound probe; and
- a controller unit configured to:
  - communicate with the ultrasound probe;
  - transmit ultrasound signals via the ultrasound probe toward an area of interest in a patient's body, wherein the ultrasound signals include a fundamental frequency signal and at least one harmonic frequency signal;
  - receive echo signals from the area of interest based on the transmitted ultrasound signals;
  - obtain a fundamental frequency echo signal and at least one harmonic frequency echo signal from the received echo signals; and
  - generate a visual representation of the area of interest based on the obtained fundamental frequency echo signal and the obtained at least one harmonic frequency echo signal.

13. The system of claim **12**, wherein, when transmitting the ultrasound signals via the ultrasound probe, the controller unit is configured to at least one of:
- transmit a broadband ultrasound signal, or
- transmit at least one non-integer harmonic signal.

14. The system of claim **12**, wherein, when obtaining the fundamental frequency echo signal and the at least one harmonic frequency echo signal from the received echo signals, the controller unit is further configured to:

retrieve a plurality of echo signals corresponding to a plurality of harmonics of the fundamental frequency using a plurality of bandpass filters.

15. The system of claim **14**, wherein, when generating the visual representation of the area of interest, the controller unit is further configured to:

generate a plurality of ultrasound images, wherein a particular one of the plurality of ultrasound images is based on a particular one of the plurality of echo signals.

16. The system of claim **14**, wherein, when generating the visual representation of the area of interest, the controller unit is further configured to:

provide the plurality of echo signals as inputs into a classifier, wherein the classifier is trained to at least one of:

distinguish between a first target and a second target in the area of interest based on the plurality of echo signals,

identify an area that includes a target in the area of interest based on the plurality of echo signals, or

identify a target boundary in the area of interest based on the plurality of echo signals.

17. The system of claim **14**, wherein the controller unit is further configured to:

calculate a plurality of parameters between the plurality of echo signals.

18. The system of claim **17**, wherein, when generating the visual representation of the area of interest, the controller unit is further configured to:

generate a plurality of ultrasound images, wherein a particular one of the plurality of ultrasound images is based on a particular one of the plurality of parameters.

19. The system of claim **17**, wherein, when generating the visual representation of the area of interest, the controller unit is further configured to:

provide the plurality of parameters as inputs into a classifier, wherein the classifier is trained to at least one of:

distinguish between a first target and a second target in the area of interest based on the plurality of parameters,

identify an area that includes a target in the area of interest based on the plurality of parameters, or

identify a target boundary in the area of interest based on the plurality of parameters.

20. A device comprising:

logic configured to:

transmit ultrasound signals via an ultrasound probe toward an area of interest in a patient's body, wherein the ultrasound signals include a fundamental frequency signal and at least one harmonic frequency signal;

receive echo signals from the area of interest based on the transmitted ultrasound signals;

obtain a fundamental frequency echo signal and at least one harmonic frequency echo signal from the received echo signals; and

generate a visual representation of the area of interest based on the obtained fundamental frequency echo signal and the obtained at least one harmonic frequency echo signal.

* * * * *

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申请号	US16/287088	申请日	2019-02-27
申请(专利权)人(译)	VERATHON INC.		
当前申请(专利权)人(译)	VERATHON INC.		
[标]发明人	CHOI JOON HWAN YANG FUXING		
发明人	CHOI, JOON HWAN YANG, FUXING		
IPC分类号	A61B8/08 A61B8/14 A61B5/00 A61B8/00		
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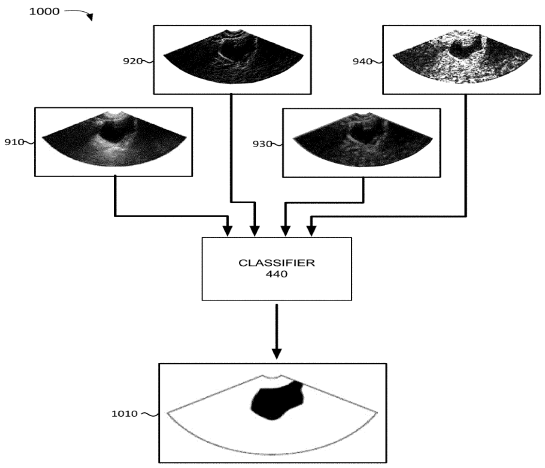
摘要(译)

系统可包括超声探头和配置成与超声探头通信的控制器单元。控制器单元还可以被配置为使用超声探头朝向患者体内的感兴趣区域发送超声信号，其中超声信号包括基频信号和至少一个谐波频率信号;基于发送的超声信号接收来自感兴趣区域的回波信号;从接收到的回波信号中获得基频回波信号和至少一个谐波频率回波信号;基于所获得的基频回波信号和所获得的至少一个谐波频率回波信号，生成感兴趣区域的视觉表示。