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(54) SYSTEMS AND METHODS FOR GUIDING ULTRASOUND PROBE PLACEMENT USING HAPTIC FEEDBACK

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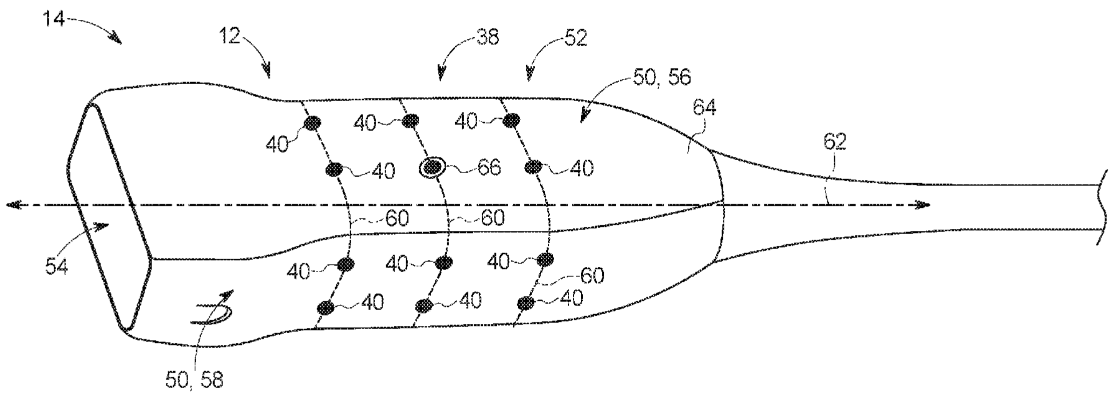
(57) **ABSTRACT**

In accordance with the present approach, an operator may receive assistance in positioning and/or orienting an ultrasound probe so as to acquire a target scan plane of a target anatomy. In accordance with certain embodiments, an ultrasound imaging system and ultrasound probe may be provided that provide haptic feedback guiding ultrasound probe placement. Such automation and guidance may allow novice, or less skilled, users to obtain successful ultrasound scans.



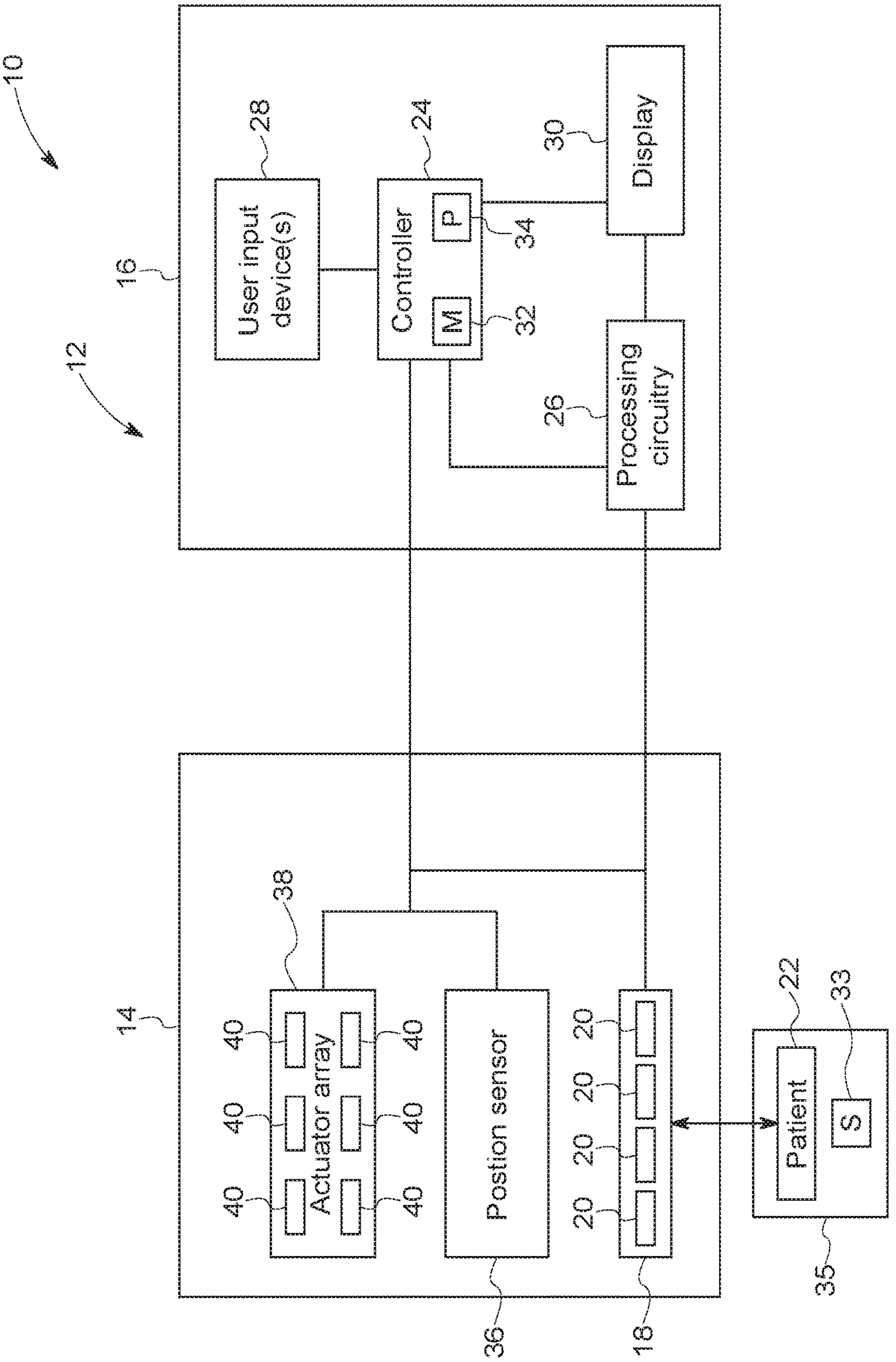

10
12
16
14
User input device(s)
28
Controller
24
M
32
P
34
Display
30
Processing circuitry
26
Actuator array
38
40
Postion sensor
36
20
18
Patient
22
S
33
35

FIG. 1

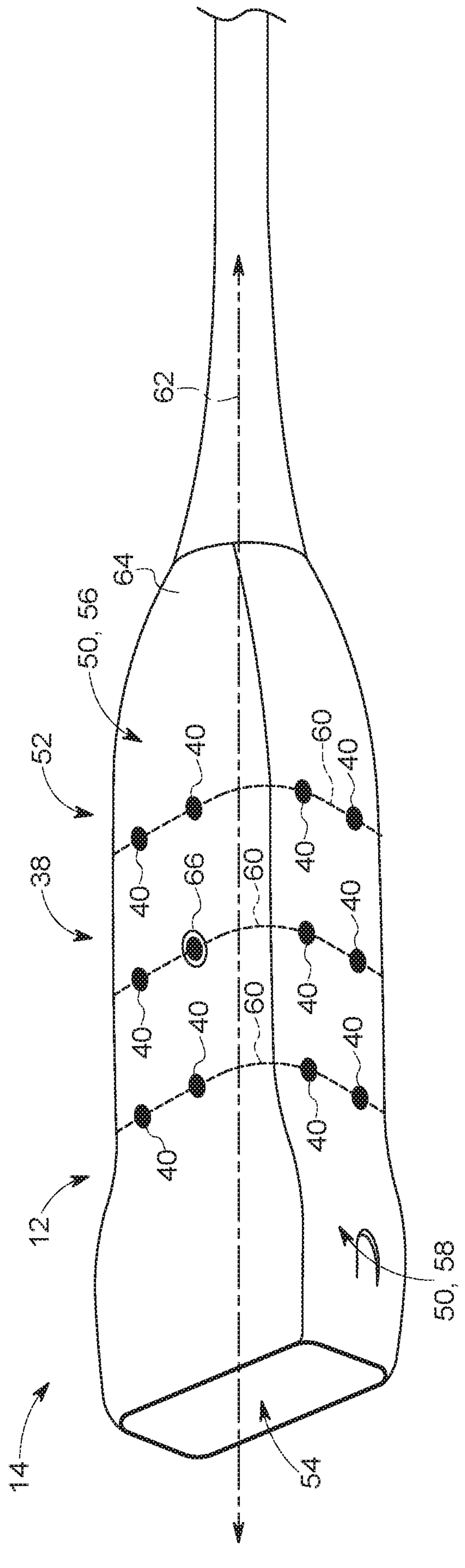


FIG. 2

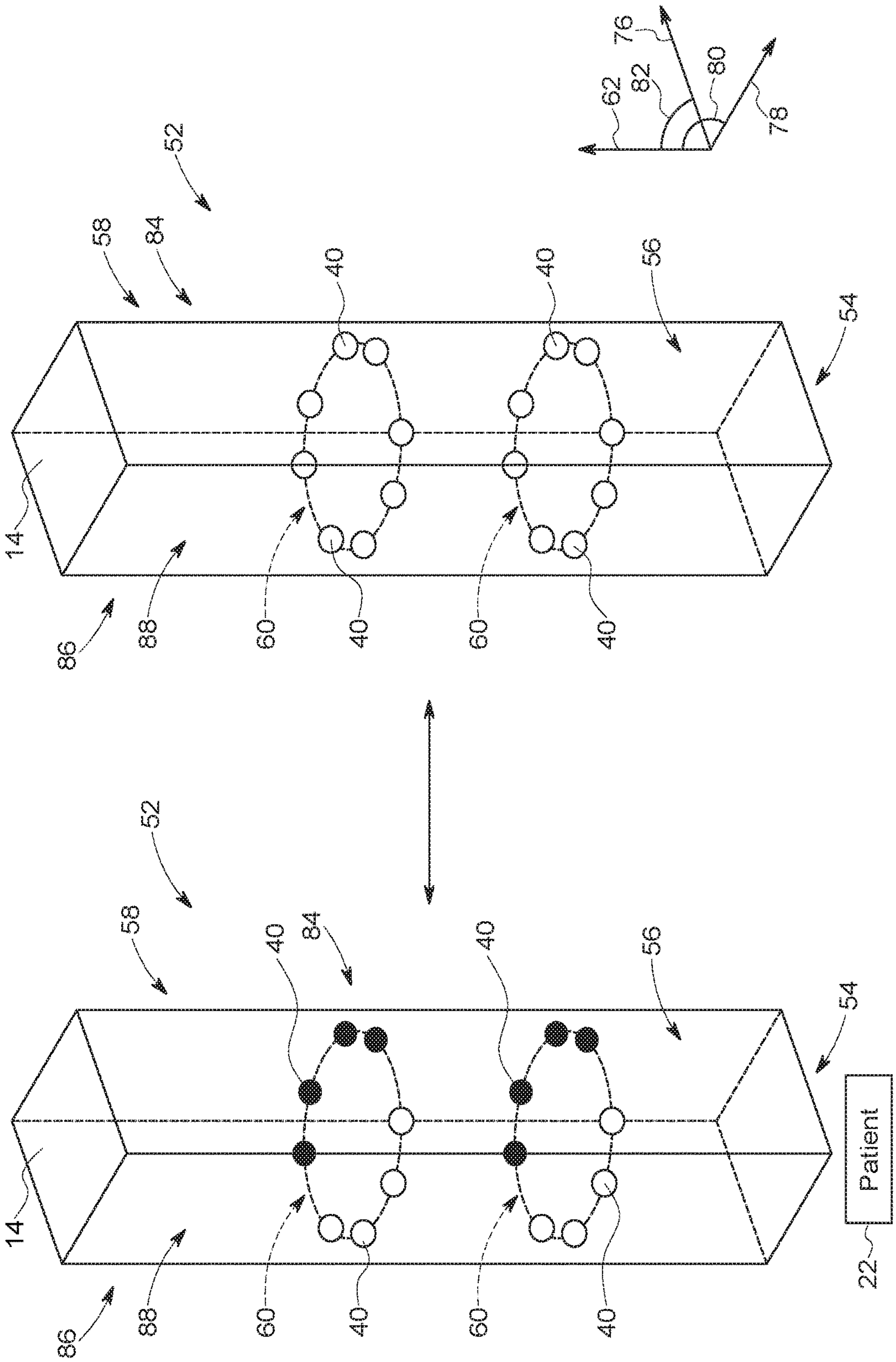


FIG. 3

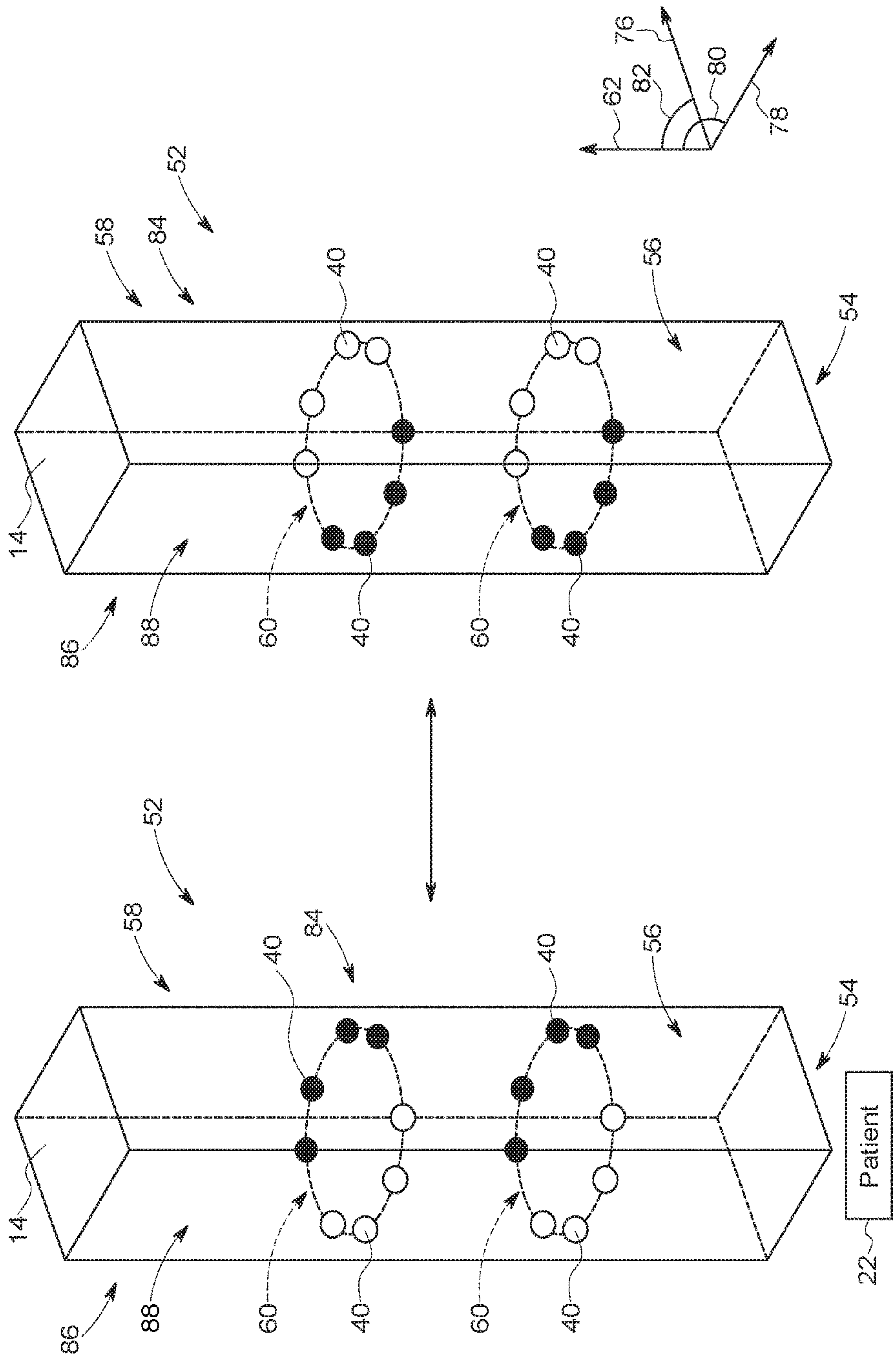


FIG. 4

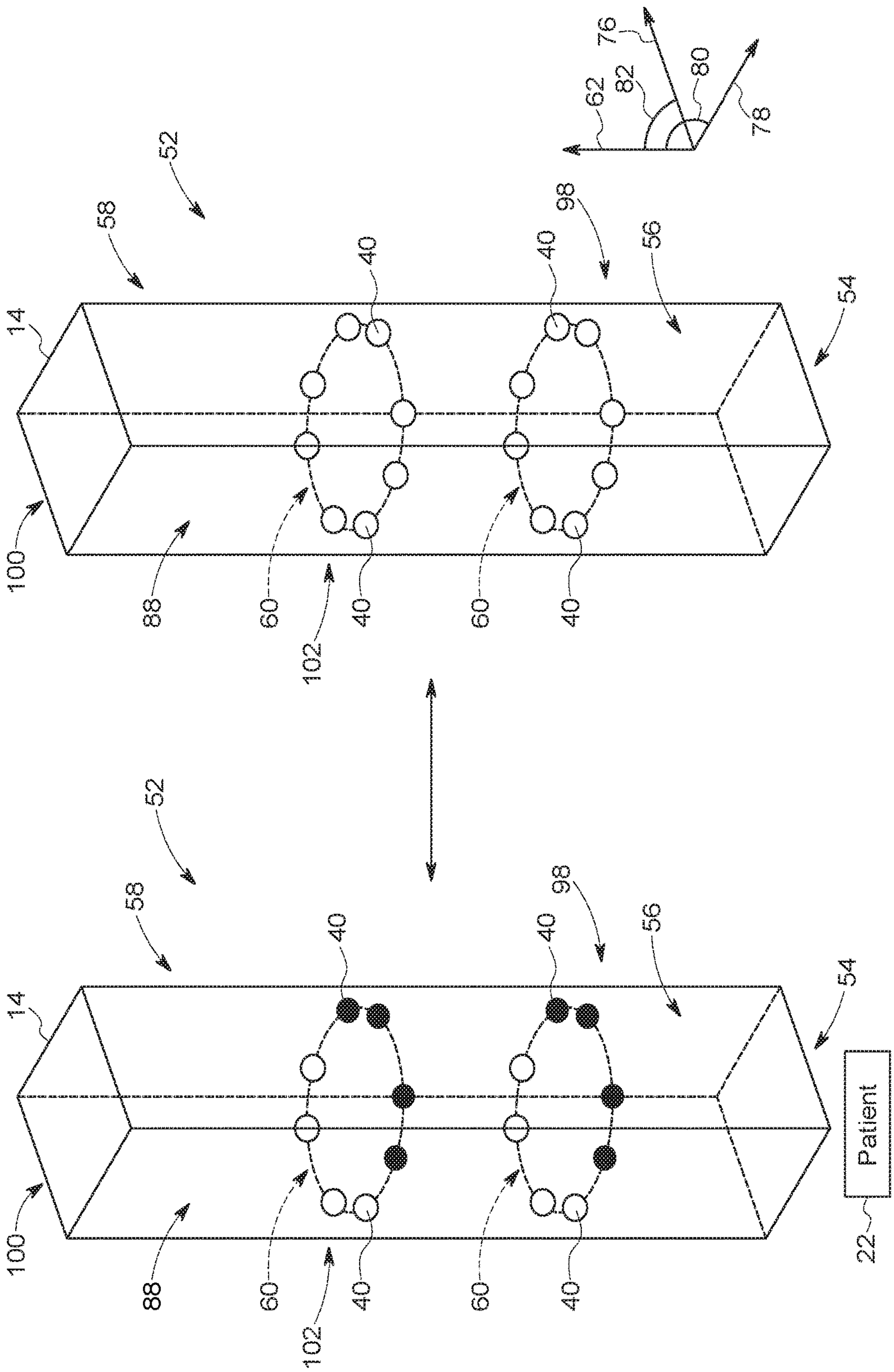


FIG. 5

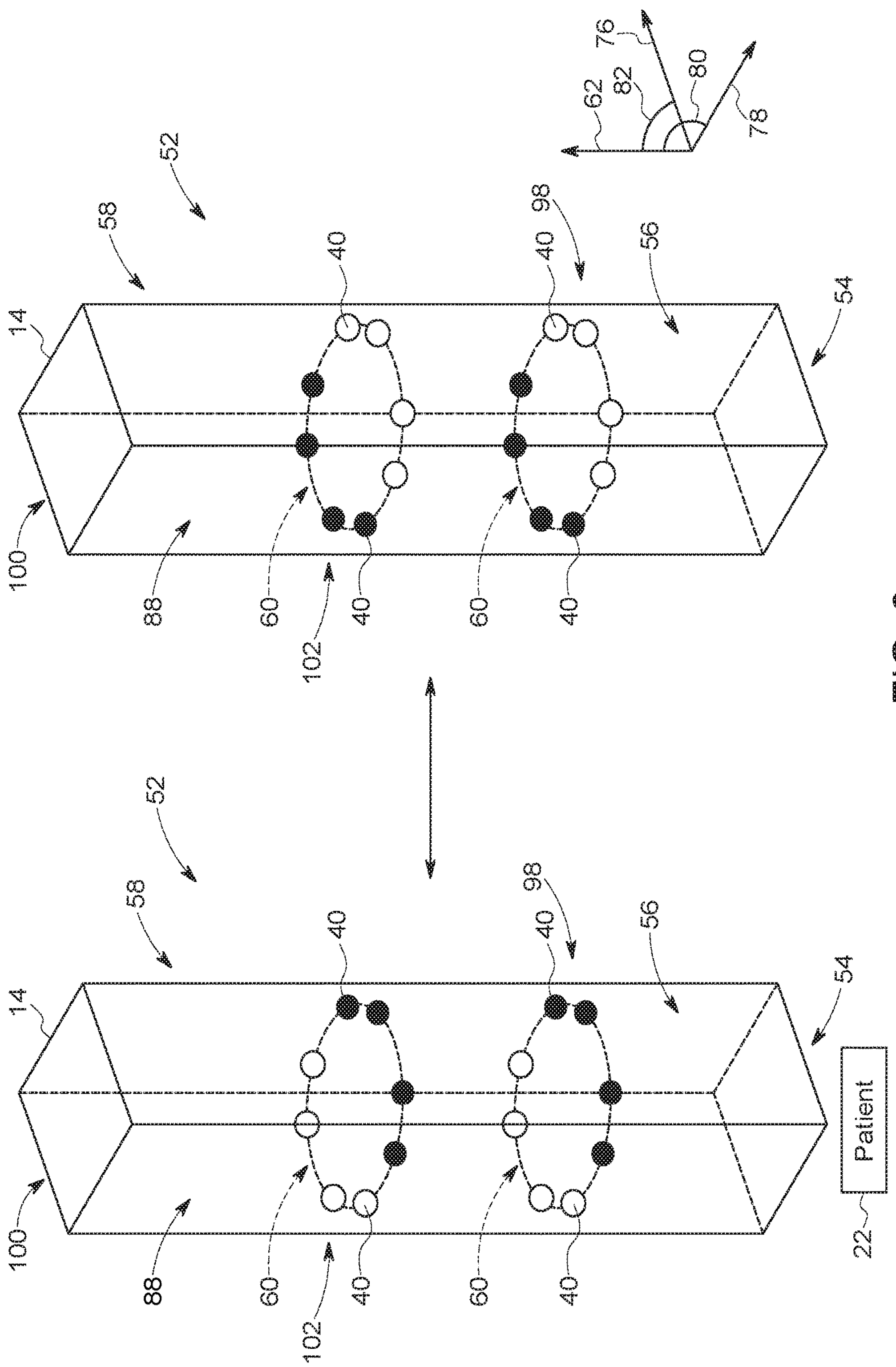


FIG. 6

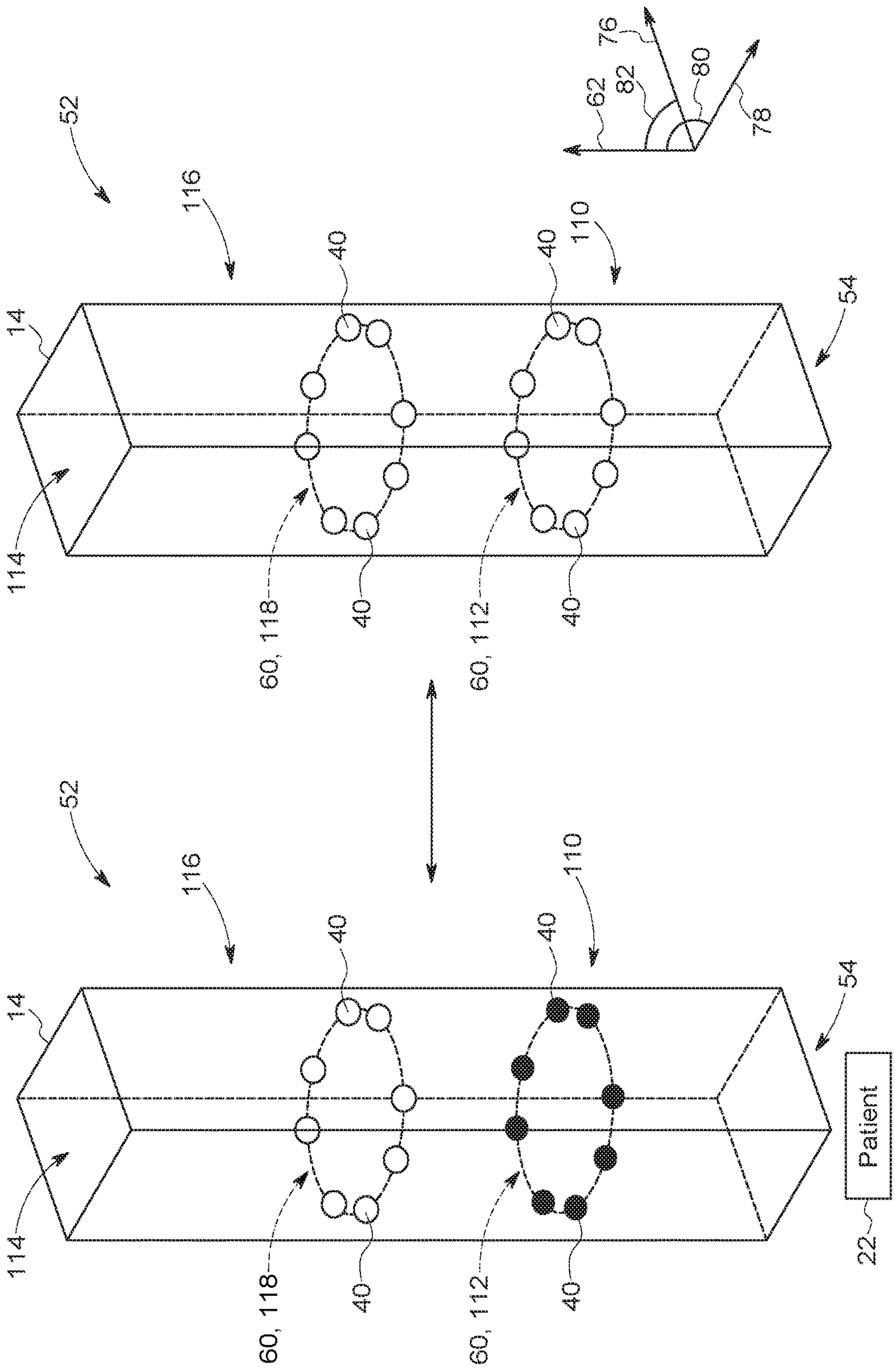


FIG. 7

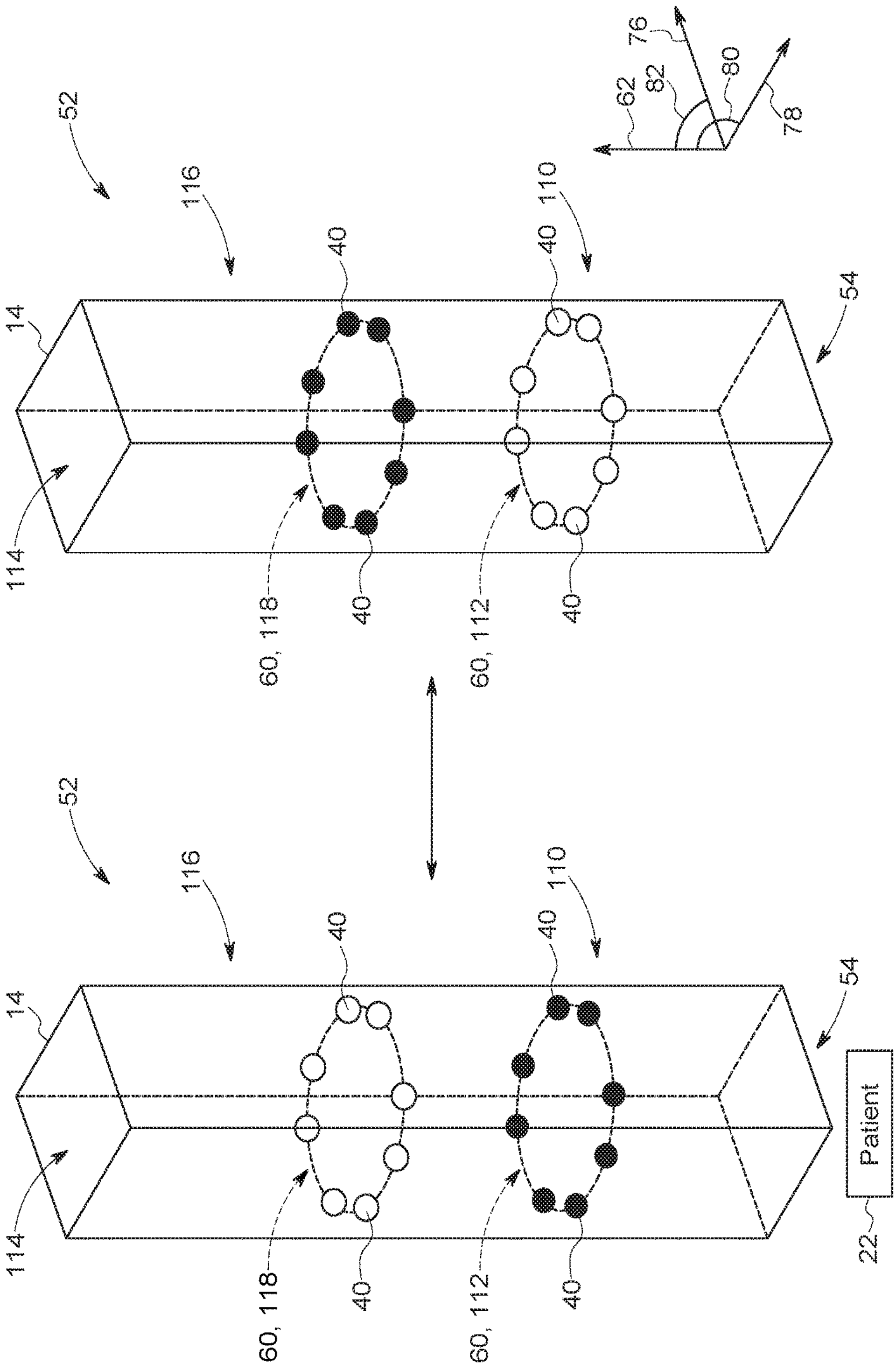


FIG. 8

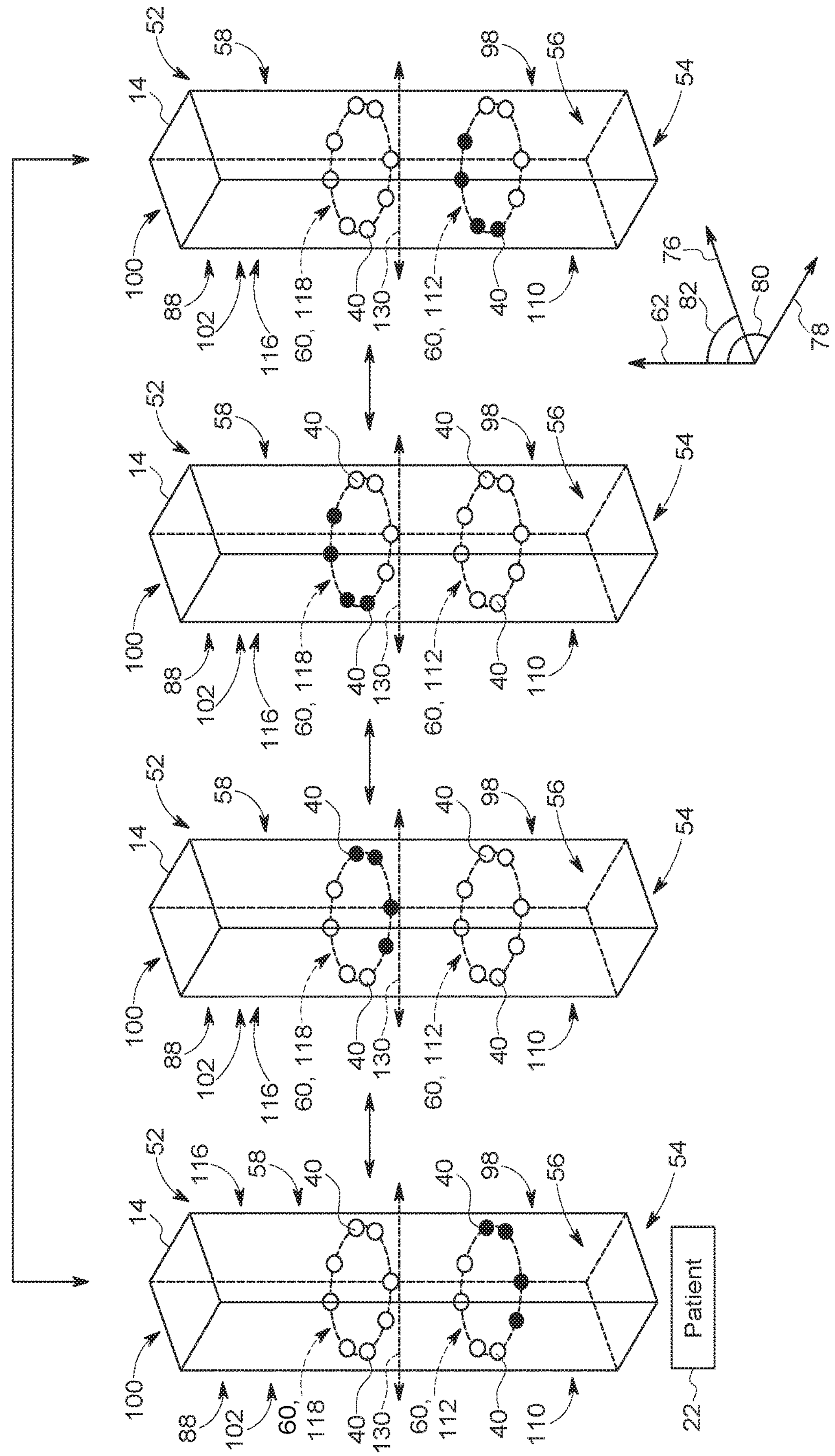


FIG. 9

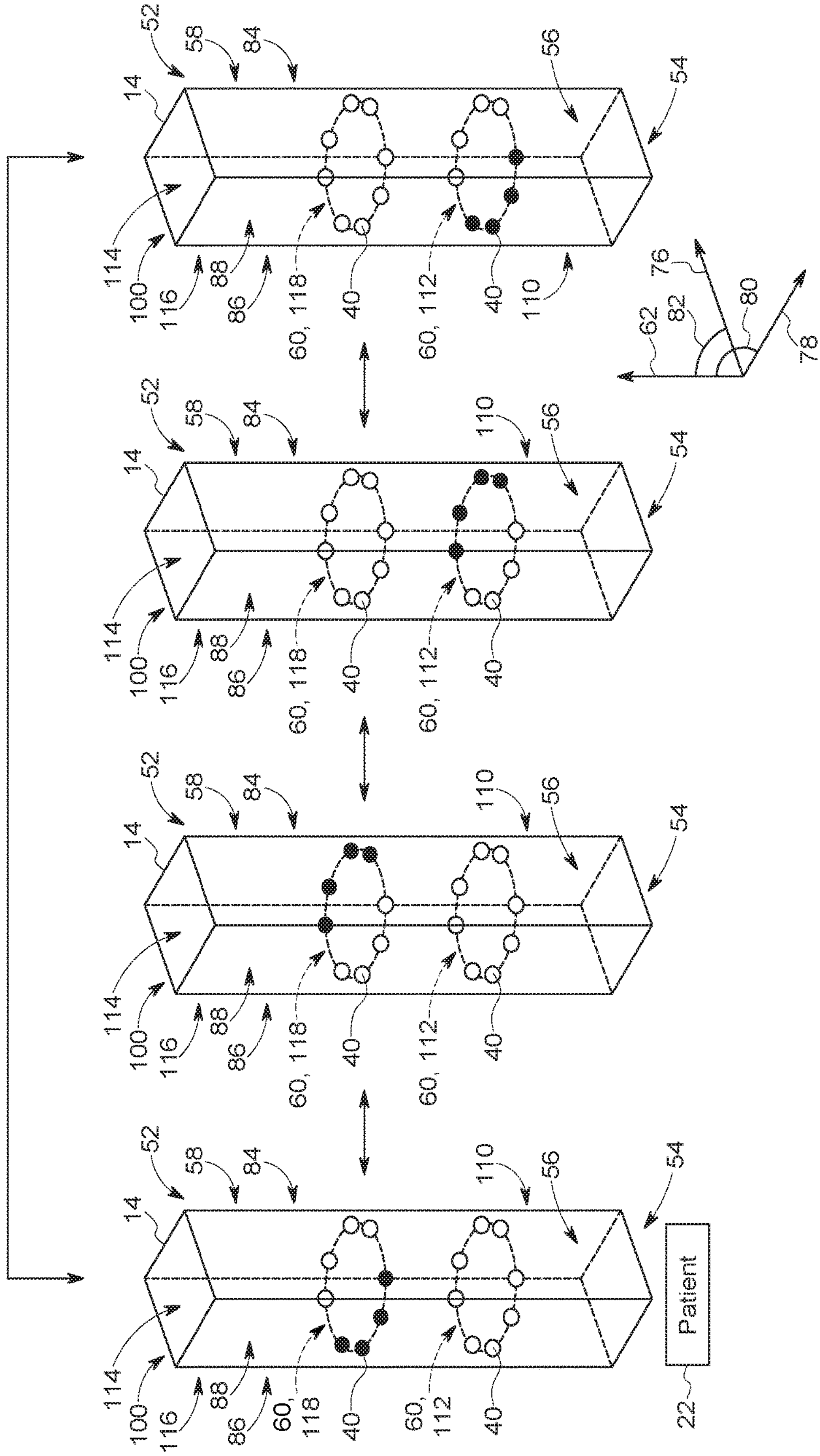


FIG. 10

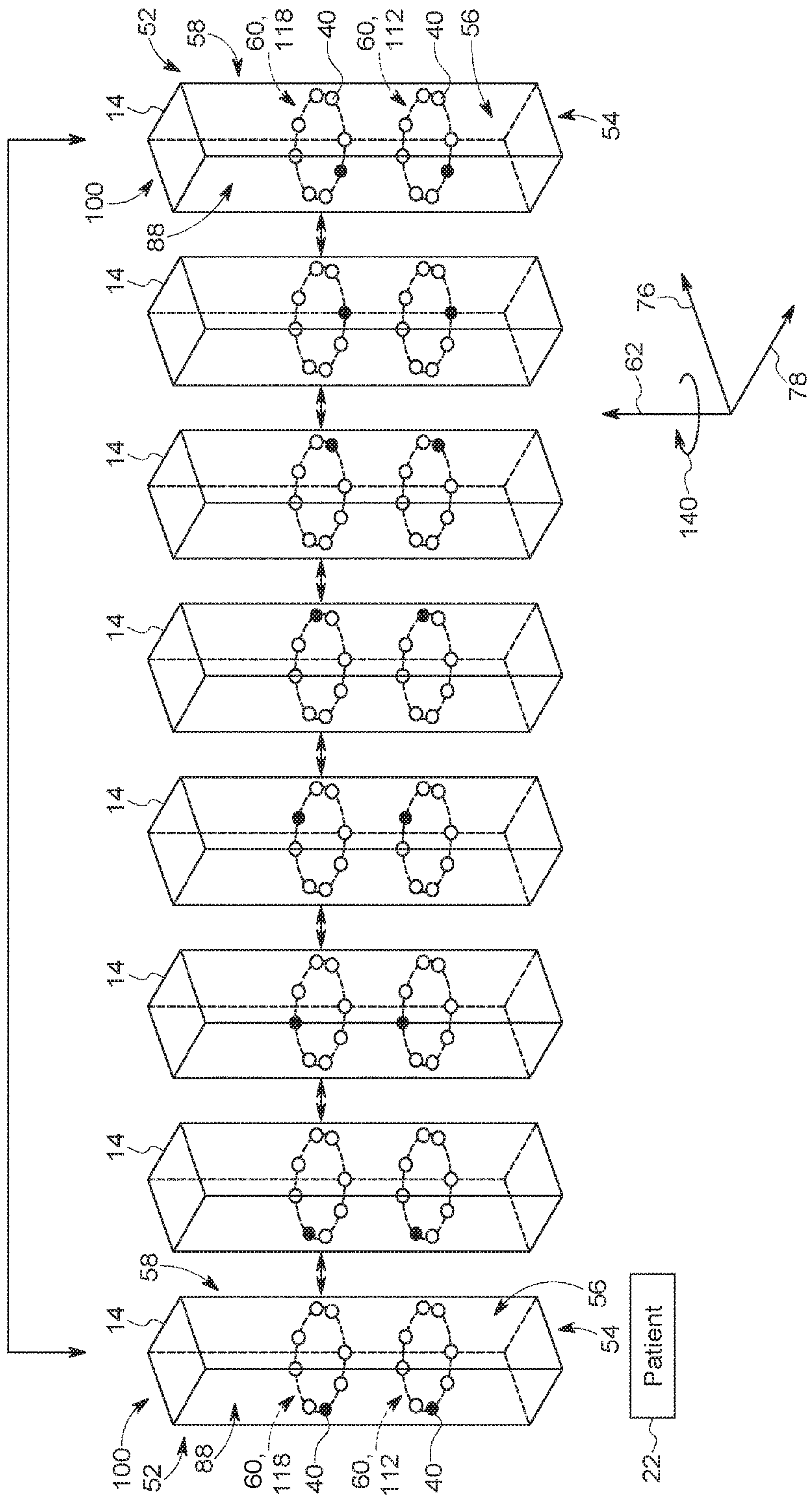


FIG. 11

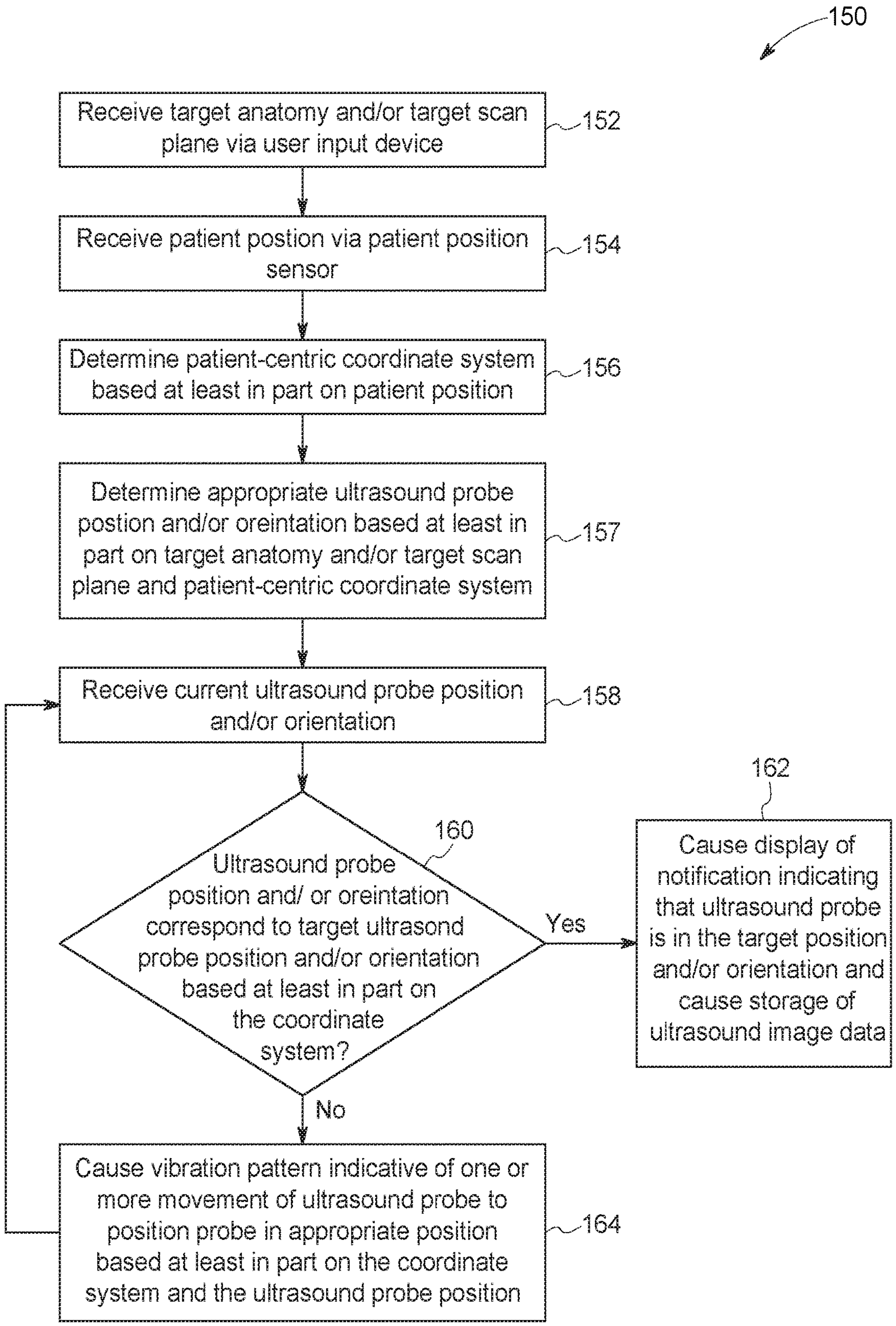

150
Receive target anatomy and/or target scan plane via user input device
152
Receive patient postion via patient position sensor
154
Determine patient-centric coordinate system based at least in part on patient position
156
Determine appropriate ultrasound probe postion and/or oreintation based at least in part on target anatomy and/or target scan plane and patient-centric coordinate system
157
Receive current ultrasound probe position and/or orientation
158
Ultrasound probe position and/ or oreintation correspond to target ultrasond probe position and/or orientation based at least in part on the coordinate system?
160
Yes
Cause display of notification indicating that ultrasound probe is in the target position and/or orientation and cause storage of ultrasound image data
162
No
Cause vibration pattern indicative of one or more movement of ultrasound probe to position probe in appropriate position based at least in part on the coordinate system and the ultrasound probe position
164

FIG. 12

SYSTEMS AND METHODS FOR GUIDING ULTRASOUND PROBE PLACEMENT USING HAPTIC FEEDBACK

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Patent Provisional Application No. 62/556,169, entitled "SYSTEMS AND METHODS FOR GUIDING ULTRASOUND PROBE PLACEMENT USING HAPTIC FEEDBACK", filed Sep. 8, 2017, which is herein incorporated by reference in its entirety.

BACKGROUND

[0002] The subject matter disclosed herein relates to medical imaging, and more particularly to systems and methods for guiding ultrasound probe positioning through haptic feedback.

[0003] An ultrasound imaging system typically includes an ultrasound probe that is applied to a patient's body and a workstation or monitor that is operably coupled to the ultrasound probe. The ultrasound probe may be controlled by an operator of the ultrasound imaging system and is configured to transmit and receive ultrasound signals that are processed into an ultrasound image by the workstation or monitor. The operator positions the ultrasound probe to acquire a target anatomy or region of interest (e.g., a desired tissue or body region to be imaged) in a target scan plane. For example, by viewing real-time images of the acquired ultrasound data on the monitor or a separate display of the ultrasound imaging system, the operator may adjust the ultrasound probe into an appropriate position for imaging the target scan plane of the target region of interest. However, it is recognized that there may be some challenges with such positioning methods. For example, manually finding the appropriate position of the ultrasound probe via viewing the displayed images alone may be difficult, time consuming, and result in less accurate positioning, especially for unskilled users.

BRIEF DESCRIPTION

[0004] In one embodiment, an ultrasound imaging system includes an ultrasound probe having a handle with a plurality of haptic actuators. The ultrasound imaging system further includes a monitor having a memory and a processor. The processor is communicatively coupled to the ultrasound probe and is configured to determine a current position of the ultrasound probe relative to the target region of interest, determine whether the current position of the ultrasound probe corresponds to a target position of the ultrasound probe relative to a target region of interest of a patient, wherein the target region of interest comprises a target anatomy and a target scan plane, and output, in response to determining that the current position of the ultrasound probe relative to the target region of interest does not correspond to the target position of the ultrasound probe, a control signal to one or more of the haptic actuators of the plurality of haptic actuators. The control signal causes one or more of the haptic actuators to activate in an activation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the target position.

[0005] In another embodiment, an ultrasound probe includes a patient-facing surface having one or more transducers. The ultrasound probe further includes a handle having a plurality of haptic actuators. The haptic actuators are configured to actuate in a plurality of actuation patterns to indicate a suggested movement of the handle in six degrees-of-freedom. Each actuation pattern of the plurality of actuation patterns modulates in intensity, speed, or both as the patient-facing surface of the ultrasound probe is moved closer to a target position relative to a patient.

[0006] In another embodiment, a method, includes receiving, via a processor, a target region of interest of a patient to be imaged via an ultrasound probe of an ultrasound imaging system and a target scan plane of the target region of interest, and determining, via the processor, a target imaging position of the ultrasound probe based at least in part on the target region of interest and the target scan plane. The method further includes determining, via the processor, a current position of the ultrasound probe relative to the target region of interest, the desired scan plane, or both, and determining, via the processor, whether the current position of the ultrasound probe corresponds to the target imaging position of the ultrasound probe. The method further includes outputting, via the processor, in response to determining that the current position of the ultrasound probe relative to the target region of interest, the target scan plane, or both, does not correspond to the target position of the ultrasound probe, a control signal to a plurality of haptic actuators disposed on a handle of the ultrasound probe. The control signal causes one or more of the haptic actuators to actuate in an actuation pattern indicative of a suggested movement of the ultrasound probe.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. **1** illustrates a block diagram of an embodiment of an ultrasound imaging system having a haptic guidance system, in accordance with aspects of the present disclosure;

[0009] FIG. **2** illustrates a perspective view of an embodiment of an ultrasound probe of the ultrasound imaging system having the haptic guidance system of FIG. **1**, in accordance with aspects of the present disclosure;

[0010] FIG. **3** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of vibration actuators of the haptic guidance system of FIG. **1** to guide movement of the ultrasound probe along an X-axis, in accordance with aspects of the present disclosure;

[0011] FIG. **4** illustrates a schematic of the ultrasound probe of FIG. **2** showing another embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide movement of the ultrasound probe along the X-axis, in accordance with aspects of the present disclosure;

[0012] FIG. **5** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide movement of the ultrasound probe along a Y-axis, in accordance with aspects of the present disclosure;

[0013] FIG. **6** illustrates a schematic of the ultrasound probe of FIG. **2** showing another embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide movement of the ultrasound probe along the Y-axis, in accordance with aspects of the present disclosure;

[0014] FIG. **7** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide compression movement the ultrasound probe along a Z-axis, in accordance with aspects of the present disclosure;

[0015] FIG. **8** illustrates a schematic of the ultrasound probe of FIG. **2** showing another embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide compression movement the ultrasound probe along the Z-axis, in accordance with aspects of the present disclosure;

[0016] FIG. **9** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide tilting movement of the ultrasound probe along an elevation direction, in accordance with aspects of the present disclosure;

[0017] FIG. **10** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of the vibration actuators of the haptic guidance system of FIG. **1** to guide rocking movement of the ultrasound probe along an azimuth direction, in accordance with aspects of the present disclosure;

[0018] FIG. **11** illustrates a schematic of the ultrasound probe of FIG. **2** showing an embodiment of a vibration sequence of vibration actuators of the haptic guidance system of FIG. **1** to guide rotation movement of the ultrasound probe, in accordance with aspects of the present disclosure; and

[0019] FIG. **12** illustrates a flow diagram of an embodiment of a method for guiding movement of the ultrasound probe using the haptic guidance system of FIG. **1**, in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0020] One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0021] When introducing elements of various embodiments of the present disclosure, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Furthermore, any numerical examples in the following discussion are intended to be non-limiting, and thus additional numerical values, ranges, and percentages are within the scope of the disclosed embodiments.

[0022] As mentioned above, ultrasound imaging systems typically include an ultrasound probe that is applied to a patient's body. Ultrasound imaging systems may be operated by skilled technicians trained in locating the target region of interest on the patient to be imaged and the target scan plan, generally by using the ultrasound image data as guidance. A challenge in the field of ultrasound to widespread growth and adoption of ultrasound imaging systems in every physician's office and throughout the developing world is the lack of skilled sonographers (e.g., technicians) or operators capable of performing such interpretation of the data and manipulation of the probe. As such, it is recognized that it may be desirable for the ultrasound imaging system to provide guidance to less skilled users so that they may obtain proper ultrasound images for diagnosis. Therefore, an operator-independent ultrasound imaging system may consist of a mix of automation of some operational steps that are conventionally performed by an operator and machine guidance of other operational steps. For example, in the operator-independent ultrasound imaging system, many of the buttons or selections that an operator would conventionally adjust may be automated. Additionally, to assist the operator with orienting the ultrasound probe physically into a position to acquire the target scan plane of the target anatomy, described herein are ultrasound imaging systems and ultrasound probes having an integrated haptic feedback system for guided ultrasound probe placement. Such automation and guidance may allow novice, or less skilled, users to obtain successful ultrasound scans.

[0023] With the foregoing in mind, FIG. **1** illustrates a block diagram of an embodiment of an ultrasound imaging system **10** having a haptic guidance system **12** (e.g., haptic feedback system) that may be used to provide haptic feedback to an operator of ultrasound imaging system **10** to guide placement of an ultrasound probe **14** of the ultrasound imaging system **10**. In the illustrated embodiment, the ultrasound system **10** is a digital acquisition and beam former system, but in other embodiments, the ultrasound system **10** may be any suitable type of ultrasound system, not limited to the illustrated type. The ultrasound system **10** may include the ultrasound probe **14** and a workstation **16** (e.g., monitor, console, user interface) which may control operation of the ultrasound probe **14** and may process image data acquired by the ultrasound probe **14**. The ultrasound probe **14** may be coupled to the workstation **16** by any suitable technique for communicating image data and control signals between the ultrasound probe **14** and the workstation **16** such as a wireless, optical, coaxial, or other suitable connection.

[0024] The ultrasound probe **14** contacts the patient during an ultrasound examination. The ultrasound probe **14** may include a patient facing or contacting surface that includes a transducer array **18** having a plurality of transducer elements **20**. Each individual transducer element **20** may be capable of converting electrical energy into mechanical energy for transmission and mechanical energy into electrical energy for receiving. It should be noted that the transducer array **18** may be configured as a two-way transducer capable of transmitting ultrasound waves into and receiving such energy from a subject or patient **22** during operation when the ultrasound probe **14** is placed in contact with the patient

22. More specifically, the transducer elements **20** may convert electrical energy from the ultrasound probe **14** into ultrasound waves (e.g., ultrasound energy, acoustic waves) and transmit the ultrasound waves into the patient **22**. The ultrasound waves may be reflected back toward the transducer array **18**, such as from tissue of the patient **22**, and the transducer elements **20** may convert the ultrasound energy received from the patient **22** (reflected signals or echoes) into electrical signals for transmission and processing by the ultrasound probe **14** and the workstation **16** to provide an ultrasound image that may be analyzed. The number of transducer elements **20** in the transducer array **18** and the frequencies at which the transducer elements **20** operate may vary depending on the application.

[0025] As previously discussed, the ultrasound probe **14** is communicatively coupled to the workstation **16** of the ultrasound imaging system **10** to facilitate image collection and processing. As will be appreciated, the workstation **16** may include a number of elements to control operation of the ultrasound probe **14**, facilitate placement guidance of the ultrasound probe **14**, and facilitate production of ultrasound images. For instance, as illustrated, the workstation **16** may include a controller **24**, processing circuitry **26**, one or more user input devices **28**, and a display **20**. In certain embodiments, the workstation **16** may include additional elements not shown in FIG. **1**, such as additional data acquisition and processing controls, additional image display panels, multiple user interfaces, and so forth.

[0026] The controller **24** may include a memory **32** and a processor **34**. In some embodiments, the memory **32** may include one or more tangible, non-transitory, computer-readable media that store instructions executable by the processor **34** and/or data to be processed by the processor **34**. For example, the memory **32** may include random access memory (RAM), read only memory (ROM), rewritable non-volatile memory such as flash memory, hard drives, optical discs, and/or the like. Additionally, the processor **34** may include one or more general purpose microprocessors, one or more application specific processors (ASICs), one or more field programmable logic arrays (FPGAs), or any combination thereof. The controller **24** may control transmission of the ultrasound waves into the patient **22** via the transducer array **18**. Additionally, the controller **24** may be part of the haptic guidance system **12** of the ultrasound system **10** and may control other elements of the haptic guidance system **12** to guide placement of the ultrasound probe **14** for acquiring ultrasound images of the target scan plane of the target anatomy of the patient **22**, as discussed in greater detail below.

[0027] The processing circuitry **26** may include receiving and conversion circuitry. The processing circuitry **26** may receive the electrical signal data from the transducer array **18** of the ultrasound probe **14** representing reflected ultrasound energy returned from tissue interfaces within the patient **22**. The processing circuitry **26** may process the data from the transducer array **18**, such as correcting for noise artifacts, or the like. The processing circuitry **26** may then convert the signal data into an ultrasound image for presentation via the display **30**. The controller **24** may cause display of the ultrasound image or images produced by the processing circuitry **26** from the signal data received from the transducer array **18** of the ultrasound probe **14**.

[0028] In operation, the controller **24** may receive a signal indicative of a target anatomy of the patient **22** and/or a target scan plane of the target anatomy via the one or more user input devices **28** of the workstation **16**. The one or more user input devices **28** may include a keyboard, a touch-screen, a mouse, buttons, switches, or other devices suitable to allow the operator to input a the target anatomy and/or the desired scan plane of the target anatomy. Based on the target anatomy and/or the target scan plane of the target anatomy, the controller **24** may output a signal to the transducer array **18** of the ultrasound probe **14** indicative of an instruction to convert the electrical energy from the ultrasound probe **14** into ultrasound waves and transmit the ultrasound waves into the patient **22** and to detect the ultrasound energy that is reflected back from the tissue interfaces within the patient **22**.

[0029] The controller **24** may determine that the ultrasound probe **14** is in an appropriate position and/or orientation (e.g., target position and/or orientation) to sufficiently image the target anatomy in the target scan plane. In some embodiments, the haptic guidance system **12** of the ultrasound imaging system **10** may include sensing mechanisms to detect where the patient is and to determine the position and/or orientation of the ultrasound probe **14** with respect to the patient **22**. That is, the haptic guidance system **12** may include one or more patient position sensors **33**, such as weight sensors, contact sensors, cameras, or other suitable sensing mechanisms, that may be disposed about the imaging space **35** of the ultrasound imaging system **10** on or in which the patient **22** is positioned during ultrasound imaging, or at any other suitable position about the ultrasound imaging system **10** suitable for detecting the position of the patient **22**. The patient position sensor **33** may be communicatively coupled to the controller **24** via a wired or wireless connection and may send one or more signals to the controller **24** indicative of the position of the patient about the imaging space **35**. Additionally or alternatively, in some embodiments, a position of the patient **22** relative to the imaging space **35** or the ultrasound imaging system **10** may be determined based at least in part on received demographic information, such as height and weight, of the patient **22**. For example, such demographic information of the patient **22** may be compared to lookup tables stored in the memory **32** to determine a relative position of the patient **22**.

[0030] Based at least in part on the one or more signals received from the patient position sensor **33** and/or the received demographic information of the patient **22**, the controller may determine, develop, or update a patient-centric coordinate system or map that may be used to track position of the ultrasound probe **14** relative to the patient **22**. For example, a general patient coordinate system based on the imaging space **35** may be stored in the memory **32** and the controller **24** may update the general patient coordinate system based at least in part on the signals received from the patient position sensor **33** and/or the received demographic information of the patient **22** to generate the patient-centric coordinate system. As another example, the controller **24** may develop a new patient-centric coordinate system for each patient based at least in part on the signals received from the patient position sensor **33** and/or the received demographic information of the patient **22**. Additionally or alternatively, in some embodiments, the patient position sensor **33** may include an ultrasound probe with integrated position tracking. In such embodiments, an operator could follow a procedure while using the ultrasound probe with integrated position tracking to place the probe on key landmarks or drag the probe across the surface of the patient until the coordinate system is developed. Additionally or alternatively, in some embodiments, the patient-centric coordinate system may be derived based at least in part on image data received from one or more cameras of the ultrasound imaging system **10** that may be used to measure or determine patient position and/or the live ultrasound image data from the ultrasound probe **14**. The patient-centric coordinate system may allow the controller **24** to determine a relative position of the target anatomy within the patient **22** and to determine when the ultrasound probe **14** is positioned appropriately to sufficiently image the target anatomy in the target scan plane. Additionally, the patient-centric coordinate system may be compared or fused with a model of general body anatomy, which may be stored in the memory **32**.

[0031] The haptic guidance system **12** of the ultrasound imaging system **10** may additionally include a probe position sensor **36** for detecting the position and/or orientation of the ultrasound probe **14**. The probe position sensor **36** may be disposed about the ultrasound probe **14** and may be a position sensor, an orientation sensor, such as a gyroscope, inertial tracking mechanism, electromagnetic tracking, optical tracking, or any other suitable sensor that may allow for detection of a current position and/or orientation of the ultrasound probe **14**. The probe position sensor **36** may be communicatively coupled to the controller **24** via a wired or wireless connection and may send one or more signals to the controller **24** indicative of a current position and/or orientation of the ultrasound probe **14**. The controller **24** may compare the current position of the ultrasound probe **14**, based at least in part on the signals received from the probe position sensor **36**, to the patient-centric coordinate system developed based at least in part on the signals received from the patient position sensor **33** and/or the live ultrasound image data. Based on the comparison, the controller **24** may determine whether the ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. As such, the live ultrasound image data may be used by the controller **24** as feedback to determine if the ultrasound probe **14** is in the appropriate position and orientation. The patient-centric coordinate system and the ultrasound image data may be stored in the memory **32**.

[0032] In some embodiments, the controller **24** may control the transducer array **18** and the processing circuitry **26** to obtain and generate ultrasound images while the controller **24** is determining whether the ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. As such, the live ultrasound image data may be used by the controller **24** as feedback in determining if the ultrasound probe is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. Once the controller **24** determines that ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane, the controller **24** may cause display of a notification, such as a visual or audible notification, and/or the controller **24** may send a signal to the vibration actuators **40** of the ultrasound probe **14** indicative of a particular pulse pattern indicating to the operator of the ultrasound probe **14** that the ultrasound probe **14** is in the appropriate position and/or orientation. Additionally or alternatively, in some embodiments, the controller **24** may cause automatic storage in the memory **32** of the live ultrasound image data once it is determined that the ultrasound probe is in the appropriate position and/or orientation. Additionally or alternatively, in some embodiments, if the controller **24** determines that the ultrasound probe **14** is in the appropriate position and/or orientation, the controller **24** may send a signal to the processing circuitry **26** indicative of an instruction to convert the data received from the transducer array **18** of the ultrasound probe **14** into an ultrasound image and a signal to the display **30** indicative of an instruction to display the ultrasound image. Additionally or alternatively, in some embodiments, the controller **24** may not cause the transducer array **18** to produce and transmit the ultrasound waves into the patient **22** and detect the reflected ultrasound energy until it is determined that the ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane.

[0033] If the controller **24** determines that the ultrasound probe **14** is not in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane, the controller **24** may guide the operator of the ultrasound probe **14** to move the ultrasound probe **14** into the appropriate position. As such, the haptic guidance system **12** may include an actuator array **38** including multiple vibration actuators **40** (e.g., haptic actuators) distributed among a grip area on some or all sides of a handle of the ultrasound probe **14**. The controller **24** may send one or more signals to one or more of the vibration actuators **40** to cause the vibration actuators **40** to vibrate in a particular pattern indicative of a particular target movement of the ultrasound probe **14** to guide an operator to move the ultrasound probe **14** into the appropriate position. The vibration actuators **40** may be driven by the controller **24** to guide positioning of the ultrasound probe **14** in six degrees-of-freedom (DOF) (i.e., spatial position and angular orientation) by using various vibration patterns, discussed in greater detail with reference to FIGS. **3-11**. By placing the vibration actuators **40** on some or all sides of the ultrasound probe **14**, multiple grip styles may be supported. Once the operator has located the ultrasound probe **14** in the appropriate position over the target anatomy, the operator may be further guided by the controller **24** to make fine adjustments to the ultrasound probe **14** position and/or orientation to acquire the target scan plane. As discussed above, in some embodiments, the controller **24** of the ultrasound imaging system **10** may use the live (e.g., real-time) ultrasound image data and image processing technology to detect the anatomy and guide this fine positioning while comparing the live ultrasound image data to the target scan plane.

[0034] As such, the haptic guidance system **12** of the ultrasound imaging system **10** may provide guidance for the placement of the ultrasound probe **14** relative to the patient **22** through haptic feedback incorporated directly into the handle of the ultrasound probe **14**. Such haptic feedback and guidance may appeal to an alternate sense perception than sight, which may provide more intuitive guidance to an operator instead of visual cues as the operator is already focused on viewing the ultrasound image, or voice guidance as the operator may be trying to communicate with the patient. For example, visual sense perception of the operator is already used to comprehend the live ultrasound image, to operate the workstation **16**, to communicate with the patient **22**, and in other events taking place near the ultrasound imaging system **10**. Additionally, auditory sense perception is used for communicating with the patient **22**. As tactile sense perception of the operator is already used for moving the ultrasound probe **13**, such that the operator is not looking at the ultrasound probe **14**, but rather is visually focused on the workstation **16** and the live ultrasound image, use of the vibration actuators **40** in the ultrasound probe **14** for probe positioning may take advantage of an underutilized sense perception. By using the actuator array **38** of the multiple vibration actuators **40**, the position and orientation of the ultrasound probe **14** may be guided in all six degrees-of-freedom. As such, the haptic guidance system **12** may allow for more efficient and effective use of the ultrasound imaging system **10** by novice or less-skilled operators and thus, may increase operator independence of the ultrasound imaging system **10**.

[0035] FIG. **2** illustrates a perspective view of the ultrasound probe **14** showing an embodiment of the placement of the vibration actuators **40** of the actuator array **38** of the haptic guidance system **12**. As previously discussed, the vibration actuators **40** may be directed to vibrate in particular vibration patterns (e.g., actuation patterns, excitation patterns) representing particular movements of ultrasound probe **14** relative to six degrees-of-freedom in which the ultrasound probe **14** can be moved. The vibration patterns of the vibration actuators **40** may guide the operator to position the ultrasound probe **14** in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. The multiple vibration actuators **40** of the actuator array **38** may be distributed on some or all sides **50** of a handle **52** of the ultrasound probe **14**. That is, the handle **52** of the ultrasound probe **14** may include the vibration actuators **40** on each side **52** or on only a subset of the available sides **50** of the handle **52**. The sides **50** may form the handle **52** and may be oriented perpendicular to a patient-facing surface **54** (e.g., face) of the ultrasound probe **14**. The illustrated embodiment shows six vibration actuators **40** on a front side **56** (e.g., upper surface) and four vibration actuators **40** on a first side **58** (e.g., left side) of the handle **52** of the ultrasound probe **14**. Additionally, though not shown in the illustrated embodiment, the ultrasound probe **14** may include corresponding vibration actuators **40** on the opposing surfaces, such as a back surface and an opposite side (e.g., right side), of the handle **52**. As such, the actuator array **28** may support and allow for positioning guidance for multiple grip styles.

[0036] Each side **50** of the handle **52** of the ultrasound probe **14** may include two or more vibration actuators **40**. In some embodiments, the locations of the vibration actuators **40** about the handle **52** may create two or more parallel rings **60** of vibration actuators **40** axially offset from each other about an axial axis **62** of the ultrasound probe **14**, with each ring **60** of vibration actuators **40** having vibration actuators **40** disposed on each side **50** of the handle **52**. As will be appreciated, though the term "side" is used herein, this term should be understood broadly to encompass any facings or surfaces of the handle **52** of the ultrasound probe **14**. For example, in the context of a cylindrical or ovoid handle, vibration actuators may be provided around the handle such that different vibration actuators face different directions adjacent or opposite one another (i.e., face different radial directions with respect to the handle), though no structurally distinct or discernible side may be geometrically identifiable.

[0037] The vibration actuators **40** may be integrated into the handle **52**. That is, the vibration actuators **40** may each be disposed below a housing **64** of the ultrasound probe **14**. That is, although the vibration actuators **40** are illustrated as disposed outside of or on an outer surface of the housing **64** for visual clarity, the vibration actuators **40** may be disposed within the handle **52** of the ultrasound probe **14** adjacent to the housing **64**. In some embodiments, each vibration actuator **40** may be housed in a shell **66** such that each vibration actuator **40** is at least partially decoupled from the housing **64**. For example, each vibration actuator **40** may be surrounded by a rubber ring, covering, or other suitable structure, such that the vibrations are spatially contained to the location of the individual vibration actuators **40** and minimal vibration is passed through the housing **64** and thus, providing location-specific vibrations. Location-specific vibration of each vibration actuator **40** may allow the operator to better sense the vibration patterns that may be used to guide the operator to position the ultrasound probe **14** into the appropriate position for capturing the target scan plane of the target anatomy (e.g., anatomy of interest).

[0038] In some embodiments, the guidance method may be varied, as may the actuation mechanisms. The embodiments described herein may facilitate positioning of the ultrasound probe **14** based on haptic feedback in all six degrees-of-freedom (i.e., three denoting spatial position and three denoting orientation, such as angular orientation). In some embodiments, the concepts described herein with respect to the actuator array **38** of the vibration actuators **40** and various vibration patterns may be extended to other actuation mechanisms, such as small motion actuators oriented perpendicular to the probe housing that protrude in and out at each actuation location, small motion actuators mounted in a shear orientation about the probe housing (e.g., parallel with the housing) that drag across the hand of the operator, small electrical currents coupled into the hand through electrodes at each of these locations, small puffs of air at each of these locations, small protrusions in and out of a deformable membrane due to pressurization and depressurization of fluid filled chambers, or the like. As an example of the various possible guidance methods, a simpler haptic feedback approach may fuse visual feedback or voice commands with a single vibration that is provided as the ultrasound probe **14** is moved into the appropriate position, for example a pulse that becomes faster or slower as the ultrasound probe **14** is moved into the appropriate position. In some embodiments, the guidance method may include a fusion of visual feedback, auditory commands, and/or haptic feedback using the vibration actuators, where motion in some degrees-of-freedom may be indicated through haptic feedback and motion in other degrees-of-freedom may be indicated through visual and/or auditory mechanisms.

[0039] The controller **24** of the ultrasound imaging system **10** may cause vibration of the vibration actuators **40** integrated into the handle **52** of the ultrasound probe **14** to guide the operator into the appropriate position and orientation to image the target anatomy in the target scan plane. The particular vibration patterns (e.g., excitation patterns) may indicate to the operator how to move the ultrasound probe **14** to acquire an image of the target anatomy in the target scan plane. Particular vibration patterns may indicate to the operator to move the ultrasound probe **14** in a particular direction, to tilt or rock the ultrasound probe **14**, to rotate the ultrasound probe **14**, and/or to compress or decompress the ultrasound probe **14** toward or away from the patient **22**. In some embodiments, the operator may be guided to move the ultrasound probe **14** in more than one degree-of-freedom simultaneously by applying more complex vibration patterns.

[0040] For each vibration pattern discussed below, the vibrations of the vibration actuators **40** may continue until the operator has moved the ultrasound probe **14** to the appropriate position. In some embodiments, to guide a speed of movement of the ultrasound probe **14** by the operator, a repetition rate of the vibration pattern may vary or modulate. For example, in some embodiments, the repetition rate may be faster when the ultrasound probe **14** is farther away from the appropriate position, and then may slow down as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane. In some embodiments, the repetition rate may be slower when the ultrasound probe **14** is farther away from the appropriate position, and then may increase in speed as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane. Additionally or alternatively, an intensity of the vibrations may vary. For example, in some embodiments, the vibrations may be stronger when the ultrasound probe **14** is farther away from the appropriate position, and then may decrease in intensity when the ultrasound probe **14** is moved closer to the appropriate position to image the target anatomy and/or the target scan plane. In some embodiments, the vibrations may be lower intensity when the ultrasound probe **14** is farther away from the appropriate position, and then may increase in intensity when the ultrasound probe **14** is moved closer to the appropriate position to image the target anatomy and/or the target scan plane. As such, the speed and/or the intensity of the vibrations of the vibration actuators **40** may operate as a closed feedback loop to more accurately and efficiently guide the operator to adjust the ultrasound probe **14** into the appropriate position.

[0041] With the foregoing in mind, examples of the vibration patterns that may be used to guide particular movement of the ultrasound probe **14** are discussed below with reference to FIGS. **3-11**. The particular vibration patterns may guide the operator to move the ultrasound probe **14** in six degrees-of-freedom, including movement right and left, forward and backward, compression and decompression, tilt along an elevation direction, rock along an azimuth direction, and rotation. In FIGS. **3-11**, the vibration patterns are shown as a series of vibration pulses, where open vibration actuators **40** indicate still or currently non-vibrating actuators and solid or filled vibration actuators **40** indicate currently vibrating actuators. Additionally, movement of the ultrasound probe **14** in six degrees-of-freedom is discussed with reference to the axial axis or direction **62** (e.g., Z-axis), an X-axis **76**, a Y-axis **78**, an elevation angle **80**, and an azimuth angle **82**. For reference, it should be noted that with regard to FIGS. **3-11**, directional motion is discussed in terms of the operator being positioned within the page such that forward movement describes movement out of the page and backward movement describes movement into the page. Additionally, with regard to FIGS. **3-11**, while the vibration patterns are described in terms of indicating movement toward the pulsing or longer vibrations or to follow the vibration pattern, in some embodiments, the vibration patterns may indicate movement away from the pulsing or longer vibration or to move opposite the vibration pattern based on operator preferences.

[0042] FIG. **3** illustrates an embodiment of a simple vibration pattern (denoted by iteration between the left-hand and right-hand depictions, as denoted by the two-way arrow) of the vibration actuators **40** that may be used to guide movement of the ultrasound probe along the X-axis **76**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **14** in a linear direction e.g., toward a first side **58** (e.g., left side). That is, the haptic guidance system **12** may cause the vibration actuators **40** on a first half **84** (e.g., a first half about the axial axis **62** extending from the patient-facing surface **54** to an opposite non-patient-facing surface, left half) of the handle **52** of the ultrasound probe **14** to pulse, as shown between the left-hand and right-hand depictions of FIG. **3**. The first half **84** of the ultrasound probe **14** may include half of some or all of the rings **60** of vibration actuators **40** disposed in the first half **84**. Such pulsing on and off of the vibration actuators **40** may indicate to the operator of the ultrasound probe **14** to move the ultrasound probe **14** in a first direction, the direction of the pulsing. In some embodiments, the pulses of the vibration actuators **40** on the first half **84** of the ultrasound probe **14** may be short pulses, long pulses, or a combination thereof.

[0043] In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. For example, the pulse repetition rate of the vibration actuators **40** on the first half **84** of the ultrasound probe **14** may be faster when the ultrasound probe **14** is farther away from the appropriate position, and then may slow down as the ultrasound probe **14** is moved closer to the appropriate position to image the target anatomy and/or the target scan plane, or vice versa. Additionally or alternatively, an intensity of the vibrations may be stronger when the ultrasound probe **14** is farther away from the appropriate position, and then may decrease in intensity when the ultrasound probe **14** is moved closer to the appropriate position to image the target anatomy and/or the target scan plane, or vice versa. Further, additionally or alternatively, the pulse length of the vibrations of the vibration actuators **40** of the first half **84** of the ultrasound probe **14** may be longer when the ultrasound probe **14** is farther away from the appropriate position, and then may decrease in length when the ultrasound probe **14** is moved closer to the appropriate position to image the target anatomy and/or the target scan plane, or vice versa. Thus, the simple pulsing of the vibration actuators **40** of the first half **84** of the ultrasound probe **14** caused by the controller **24** of the haptic guidance system **12** may guide the operator of the ultrasound probe **14** to move the ultrasound probe **14** in the first direction along the X-axis **76**.

[0044] The opposite vibration pattern may be used to guide movement of the ultrasound probe **14** in the opposite direction along the X-axis **76**. That is, the haptic guidance system **12** may cause the vibration actuators **40** on a second half **86** (e.g., a half opposite the first half about the axial axis **62** extending from the patient-facing surface **54** to an opposite non-patient-facing surface, right half) of the handle **52** of the ultrasound probe **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **14** toward a second side **88** (e.g., right side) of the ultrasound probe **14** in a second direction, the direction of the pulses. The second half **86** of the ultrasound probe **14** may include the half of some or all of the rings **60** of vibration actuators **40** in the second half **86**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary as discussed above to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0045] FIG. **4** illustrates an alternate vibration pattern that may be used to guide movement of the ultrasound probe **14** along the X-axis **76**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **14** to the left toward the first side **58**. The haptic guidance system **22**, in some embodiments, may cause the vibration actuators **40** on the second half **86** of the handle **52** of the of the ultrasound probe **14** to pulse in one or more short pulses, and then cause the vibration actuators **40** on the first half **84** of the ultrasound probe **14** to pulse in one or more long pulses indicating to the operator to move the ultrasound probe **14** in the first direction, the direction of the long pulses. As such, the vibration pattern may include alternating short pulses on the second half **86** of the ultrasound probe **14** and long pulses on the first half **84** of the ultrasound probe **14**. In some embodiments, as discussed above with reference to FIG. **3**, the pulse speed and/or pulse intensity of the vibrations of the vibration actuators **40** may be varied as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane to indicate proximity and/or speed of movement to the operator of the ultrasound probe **14**.

[0046] The opposite vibration pattern may be used to guide movement of the ultrasound probe **14** in the opposite direction along the X-axis **76**. That is, the haptic guidance system **12** may cause the vibration actuators **40** on the first half **84** of the handle **52** of the ultrasound probe **14** to pulse in one or more short pulses, and then cause the vibration actuators **40** on the second half **86** of the handle **52** of the ultrasound probe **14** to pulse in one or more long pulses indicating to the operator to move the ultrasound in the second direction, the direction of the long pulses. As such, the vibration pattern may include alternating short pulses on the first half **84** of the ultrasound probe **14** and long pulses on the second half **86** of the ultrasound probe **14**. In some embodiments, as discussed above, the pulse speed and/or pulse intensity of the vibrations of the vibration actuators **40** may be varied as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane to indicate proximity and/or speed of movement to the operator of the ultrasound probe **14**.

[0047] Similar vibration patterns may be used to guide movement of the ultrasound probe **14** forward (e.g., away from the operator) and backward (e.g., toward the operator) along the Y-axis **78**, as illustrated in FIG. **5**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **14** forward away from the operator and toward the front side **56**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on a front half **98**, of the handle **52** of the ultrasound probe **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **14** toward the front side **56** of the ultrasound probe **14** in the direction of the pulses. The front half **98** of the ultrasound probe **14** may include the front half of some or all of the rings **60** of vibration actuators **40**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0048] The opposite vibration pattern may be used to guide movement of the ultrasound probe **14** in the opposite direction (e.g., backward) toward the operator and a back side **100** (e.g., side opposite the front side) of the ultrasound probe **14** along the Y-axis **78**. That is, the haptic guidance system **12** may cause the vibration actuators **40** on a back half **102** of the handle **52** of the ultrasound probe **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **14** backward toward the back side **100** of the ultrasound probe **14** in the direction of the pulses. The back half **102** of the ultrasound probe **14** may include the back half of some or all of the rings **60** of vibration actuators **40**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary as discussed above to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0049] FIG. **6** illustrates an alternate vibration pattern that may be used to guide movement of the ultrasound probe **10** forward (e.g., away from the operator) and backward (e.g., toward the operator) along the Y-axis **78**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **14** forward away from the operator and toward the front side **56**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on the back half **102** of the handle **52** of the ultrasound probe **14** to pulse in one or more short pulses, and then cause the vibration actuators **40** on the front half **98** of the handle **52** of the ultrasound probe **14** to pulse in one or more long pulses indicating to the operator to move the ultrasound probe **14** in the direction of the long pulses. As such, the vibration pattern may include alternating short pulses on the back half **102** of the ultrasound probe **14** and long pulses on the front half **98** of the ultrasound probe **14**. In some embodiments, as discussed above with reference to FIG. **3**, the pulse speed and/or pulse intensity of the vibrations of the vibration actuators **40** may be varied as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane to indicate proximity and/or speed of movement to the operator of the ultrasound probe **14**.

[0050] The opposite vibration pattern may be used to guide movement of the ultrasound probe **14** in the opposite direction (e.g., backward) toward the operator and the back side **100** along the Y-axis **78**. That is, the haptic guidance system **12** may cause the vibration actuators **40** on the front half **98** of the handle **52** of the ultrasound probe **14** to pulse in one or more short pulses, and then cause the vibration actuators **40** on the back half **102** of the handle **52** of the ultrasound probe **14** to pulse in one or more long pulses indicating to the operator to move the ultrasound in the direction of the long pulses. As such, the vibration pattern may include alternating short pulses on the front half **98** of the ultrasound probe **14** and long pulses on the back half **102**

of the ultrasound probe **14**. In some embodiments, as discussed above, the pulse speed and/or pulse intensity of the vibrations of the vibration actuators **40** may be varied as the ultrasound probe **14** is moved closer to appropriate position to image the target anatomy and/or the target scan plane to indicate proximity and/or speed of movement to the operator of the ultrasound probe **14**.

[0051] Similar vibration patterns may be used to guide compression (e.g., toward the tissue of the patient **22**) and decompression (e.g., away from the tissue of the patient **22**) movement of the ultrasound probe **14** along the axial axis **62** (e.g., Z-axis), as illustrated in FIG. **7**. For example, the illustrated vibration pattern may be used to guide compression movement of the ultrasound probe **14** toward the tissue of the patient **22** and toward the patient-facing surface **54**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on a lower half **110** (e.g., half of the ultrasound probe **14** nearest the patient-facing surface **54**) of the handle **52** of the ultrasound probe **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **14** toward the tissue of the patient **22** in the direction of the pulses. The lower half **110** of the ultrasound probe **14** may include one or more of lower rings **112** (e.g., rings **60** nearest the patient-facing surface **54**) of the rings **60** of the vibration actuators **40**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0052] The opposite vibration pattern may be used to guide decompression movement of the ultrasound probe **14** in the opposite direction away from the tissue of the patient **22** and toward a non-patient-facing surface **114** (e.g., surface opposite the patient-facing surface). That is, the haptic guidance system **12** may cause the vibration actuators **40** on an upper half **116** (e.g., half of the ultrasound probe **14** opposite the patient-facing surface **54** and nearest the non-patient-facing surface **114**) of the handle **52** of the ultrasound probe **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **14** away from the tissue of the patient **22** in the direction of the pulses. The upper half **116** of the ultrasound probe **14** may include one or more of upper rings **118** (e.g., rings **60** nearest the non-patient-facing surface **114**) of the rings **60** of the vibration actuators **40**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0053] FIG. **8** illustrates an alternate vibration pattern that may be used to guide compression (e.g., toward the tissue of the patient **22**) and decompression (e.g., away from the tissue of the patient **22**) movement of the ultrasound probe **14** along the axial axis **62** (e.g., Z-axis). For example, the illustrated vibration pattern may be used to guide compression movement of the ultrasound probe **14** toward the tissue of the patient **22** and toward the patient-facing surface **54**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on the upper half **116** of the handle **52** of the ultrasound probe **14** opposite the patient-facing surface **54** of the ultrasound probe **14**, such as the upper ring **118**, to pulse in one or more short pulses, and then cause vibration actuators **40** on the lower half **110** of the handle **52** of the ultrasound probe **14** nearest the patient-facing surface **54** of the ultrasound probe **14**, such as the lower ring **112**, to pulse in one or more long pulses indicating movement in that direction toward the tissue of the patient **22**. As such, the vibration pattern may include alternating short pulses on the upper half **116** of the ultrasound probe **14** and long pulses on the lower half **110** of the ultrasound probe **14** nearest the patient-facing surface **54** of the ultrasound probe **14**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane. Additionally, as discussed above, the ultrasound probe **14** may include any number of rings **60**. As such, the vibration pattern may be cycled through each ring **60**. For example, if the ultrasound probe **14** includes 3 rings **60**, the haptic guidance system **12** may cause the vibration actuators **40** on the upper half **116** of the handle **52** of the ultrasound probe **14** opposite the patient-facing surface **54** of the ultrasound probe **14**, such as the upper ring **118**, to pulse in one or more short pulses, then cause a middle ring **60** to pulse in one or more short pulses, and then cause vibration actuators **40** on the lower half **110** of the handle **52** of the ultrasound probe **14** nearest the patient-facing surface **54** of the ultrasound probe **14**, such as the lower ring **112**, to pulse in one or more long pulses indicating movement in that direction toward the tissue of the patient **22**.

[0054] The opposite vibration pattern may be used to guide decompression movement of the ultrasound probe **14** in the opposite direction away from the tissue of the patient **22** and toward a non-patient-facing surface **114** (e.g., surface opposite the patient-facing surface). That is, the haptic guidance system **12**, may cause the vibration actuators **40** on the lower half **110** of the handle **52** of the ultrasound probe **14** nearest the patient-facing surface **54** of the ultrasound probe **14**, such as the lower ring **112**, to pulse in one or more short pulses, and then cause vibration actuators **40** on the upper half **116** of the handle **52** of the ultrasound probe **14** opposite the patient-facing surface **54** of the ultrasound probe **14**, such as the upper ring **118**, to pulse in one or more long pulses indicating movement in that direction away from the tissue of the patient **22**. As such the vibration pattern may include alternating short pulses on the lower half **110** of the ultrasound probe **14** and long pulses on the upper half **116** of the ultrasound probe **14** opposite the patient-facing surface **54** of the ultrasound probe **14**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary as discussed above to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0055] To guide orientation of the ultrasound probe **14** and the patient-facing surface **54** of the ultrasound probe **14**, and thus the transducer array **18**, within the three other degrees-of-freedom, circular vibration patterns may be used, which the operator may follow to adjust the ultrasound probe **14** into the desired orientation. For example, FIG. **9** illustrates an embodiment of a vibration pattern that may be used to guide tilting movement of the ultrasound probe **14** forward or backward along the elevation direction to increase or decrease the elevation angle **80**. As such, the illustrated vibration pattern may be used guide tilting movement of the ultrasound probe **14** such that the front side **56** is moved closer to or farther from the patient **22**, thus increasing or decreasing the elevation angle **80** between the axial axis **62** and the Y-axis **78** (e.g., between the front side **56** of the ultrasound probe **14** and the patient **22**).

[0056] For example, the illustrated vibration pattern may be used to guide tilting movement of the handle **52** of the ultrasound probe **14** backward, thus increasing the elevation angle **80** between the patient **22** and the front side **56** of the ultrasound probe **14**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** of the front half **98** of the lower ring **112** (e.g., the lower half **110**) to pulse, then cause the vibration actuators **40** of the front half **98** of the upper ring **118** (e.g., the upper half **116**) to pulse, then cause the back half **102** of the upper ring **118** to pulse, and then cause the back half **102** of the lower ring **112** to pulse, thus creating a circular vibration pattern. As such, the vibration pattern may move from the front side **56** nearest the patient-facing surface **54** of the ultrasound probe **14**, to the front side **56** opposite the patient-facing surface **54** of the ultrasound probe **14**, then to the back side **100** opposite the patient-facing surface **54** of the ultrasound probe **14**, and then to the back side **100** nearest the patient-facing surface **54** of the ultrasound probe **14**.

[0057] In this manner, the circular vibration pattern may rotate around an axis **130** of the ultrasound probe **14** extending from the second side **88** to the first side **58** of the ultrasound probe **14**. This circular pattern may indicate to the operator to follow the circular pattern to tilt the handle **52** of the ultrasound probe **14** to increase the elevation angle **80** between the front side **56** of the ultrasound probe **14** and the patient **22**, and thus cause the patient-facing surface **54** of the ultrasound probe **14** to tilt forward (e.g., tilt the patient-facing surface **54** away from the operator). In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0058] The opposite vibration pattern may be used to guide tilting movement of the handle **52** of the ultrasound probe **14** forward, thus decreasing the elevation angle **80** between the patient **22** and the front side **56** of the ultrasound probe **14**. That is, the haptic guidance system **12** may cause the vibration actuators **40** of the front half **98** of the lower ring **112** to pulse, then cause the vibration actuators **40** of the back half **102** of the lower ring **112** to pulse, then cause the back half **102** of the upper ring **118** to pulse, and then cause the front half **98** of the upper ring **118** to pulse, thus creating a circular vibration pattern. As such, the vibration pattern may move from the front side **56** nearest the patient-facing surface **54** of the ultrasound probe **14**, to the back side **100** nearest the patient-facing surface **54** of the ultrasound probe **14**, then to the back side **100** opposite the patient-facing surface **54** of the ultrasound probe **14**, and then to the front side **98** opposite the patient-facing surface **54** of the ultrasound probe **14**. In this manner, the circular vibration pattern may rotate in the opposite direction around the axis **130** of the ultrasound probe **14** extending from the second side **88** to the first side **58** of the ultrasound probe **14**. This circular pattern may indicate to the operator to follow the circular pattern to tilt the ultrasound probe **14** to decrease the elevation angle **80** between the front side **56** of the ultrasound probe **14** and the patient **22**, and thus cause the patient-facing surface **54** of the ultrasound probe **14** to tilt backward (e.g., tilt the patient-facing surface toward the operator). In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0059] Similarly, FIG. **10** illustrates an embodiment of a vibration pattern that may be used to guide rocking movement of the ultrasound probe **14** left or right along the azimuth direction to increase or decrease the azimuth angle **82** (e.g., horizontal angle). For example, the illustrated vibration pattern may be used to guide rocking movement of the handle **52** of the ultrasound probe **14** toward the first direction (e.g., left) such that that first side **58** is moved closer to the tissue of the patient, thus decreasing the azimuth angle **82** between the axial axis **62** and the X-axis **76** (e.g., between the first side **58** of the ultrasound probe and the patient **22**). The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** of the second half **86** of the upper ring **118** (e.g., the upper half **116**) to pulse, then cause the vibration actuators **40** of the first half **84** of the upper ring **118** to pulse, then cause the first half **84** of the lower ring **112** (e.g., the lower half **110**) to pulse, and then cause the second half **86** of the lower ring **112** to pulse, thus creating a circular vibration pattern. As such, the vibration pattern may move from the second side **88** (e.g., right side) opposite the patient-facing surface **54** of the ultrasound probe **14**, to the first side **58** opposite the patient-facing surface **54** of the ultrasound probe **14**, then to the first side **58** nearest the patient-facing surface **54** of the ultrasound probe **14**, and then to the second side **88** nearest the patient-facing surface **54** of the ultrasound probe **14**.

[0060] In this manner, the circular vibration pattern may rotate around the axial axis **62** of the ultrasound probe **14** extending from patient-facing surface **54** to the non-patient-facing surface **114** of the ultrasound probe **14**. This circular pattern may indicate to the operator to rock the handle **52** of the ultrasound probe **14** toward the first direction to decrease the azimuth angle **82** between the first side **58** of the ultrasound probe **14** and the patient **22**, and thus cause the patient-facing surface **54** of the ultrasound probe to face more toward the second direction. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0061] The opposite vibration pattern may be used to guide rocking movement of the handle **52** the ultrasound probe **14** in the opposite direction toward the second direction (e.g. right), thus increasing the azimuth angle **82** between the first side **58** of the ultrasound probe **14** and the patient **22** and decreasing the azimuth angle **82** between the second side **88** of the ultrasound probe **14** and the patient **22**. That is, the haptic guidance system **12** may cause the vibration actuators **40** of the second half **86** of the upper ring **118** to pulse, then cause the vibration actuators **40** of the second half **86** of the lower ring **112** to pulse, then cause the first half **84** of the lower ring **112** to pulse, and then cause the first half **84** of the upper ring **118** to pulse, thus creating a circular vibration pattern. As such, the vibration pattern may move from the second side **88** opposite the patient-facing surface **54** of the ultrasound probe **14**, to the second side **88** nearest the patient-facing surface **54** of the ultrasound probe **14**, then to the first side **58** nearest the patient-facing surface **54** of the ultrasound probe **14**, and then to the first side **58** nearest the patient-facing surface **54** of the ultrasound probe **14**. In this manner, the circular vibration pattern may rotate around an axis **132** of the ultrasound probe **14** extending from the front side **56** to the back side **100** of the ultrasound probe **14**. As discussed above, the pulse speed and/or intensity may be varied as the ultrasound probe is moved closer to the desired position to indicate proximity and/or speed of movement to the operator. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0062] To cause a rotation motion of the ultrasound probe **14** in a circumferential direction **140** around the axial axis **62** (e.g., Z-axis) in a clockwise or counterclockwise direction, the haptic guidance system **12** may cause the vibration actuators **40** to vibrate in a circular pattern, as illustrated in FIG. **11**. The haptic guidance system **12**, in some embodiments, may cause the axially aligned vibration actuators **40** of each of the rings **60** of vibration actuators **40** to pulse in order around the axial axis **62** of the ultrasound probe **14**. The operator may follow the pattern of the vibration to rotate the ultrasound probe clockwise or counterclockwise about the axial axis **62**. To cause the operator to rotate the ultrasound probe **14**, and thus the patient-facing surface **54** of the ultrasound probe **14**, clockwise, as in the illustrated embodiment, the vibration pattern may move from the front side **56** of the ultrasound probe **14**, to the second side **88** of the ultrasound probe **14**, to the back side **100** of the ultrasound probe **14**, to the first side **58** of the ultrasound probe **14**. In this manner, the circular vibration pattern may rotate around the axial axis **62** (e.g., Z-axis) of the ultrasound probe **14**. This circular pattern may indicate to the operator to rotate the ultrasound probe **14** clockwise about the axial axis **62**. The opposite vibration pattern, may be used to guide rotation movement of the ultrasound probe **14** counterclockwise about the axial axis **62**. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **3**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **14** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0063] The examples discussed above of vibration patterns that may be used to guide the operator to position and orient the ultrasound probe in the appropriate position and/or orientation to capture the target scan plane of the target anatomy. The examples discussed of the vibration patterns discussed above are not intended to be limiting, but only as examples of possible vibration, or excitation, patterns. Other vibration patterns may encode or indicate suggested motion, and may be used to guide movement of the ultrasound probe **14**. For example, the example vibration patterns discussed above are implemented spatially on the ultrasound probe **14**, such that the vibration patterns approximately align with the natural spatial locations (e.g., left, right, up, down, forward, backward, rotate). However, in some embodiments, motion direction information may be indicated directly in the vibration patterns with less emphasis on the spatial orientation of the vibration actuators **40**. That is, in some embodiments, all of the vibration actuators **40** of the ultrasound probe **14** or a portion of the vibration actuators **40** may vibrate in a particular pattern to indicate movement in a particular direction or degree-of-freedom. For example, in one embodiment, all of the vibration actuators **40** of the ultrasound probe **14** may vibrate in a short-short-long-rest pattern and then repeat to indicate suggested compression movement toward the patient **22**. Additionally, all of the vibration actuators **40** of the ultrasound probe **14** may vibrate in a long-short-short-rest pattern and then repeat to indicate suggested decompression movement away from the patient **22**. Such vibration patterns that do not rely on the spatial orientation of the vibration actuators **40** and variations of such vibration patterns maybe extrapolated to indicate motion in all six degrees-of-freedom. Additionally or alternatively, vibration patterns that do not rely on the spatial orientation of the vibration actuators **40** may be used in combination with the vibration patterns described in FIGS. **3-11** to convey suggested movement of the ultrasound probe simultaneously in multiple guidance methods to guide the operator to move the probe to the appropriate position and orientation to image the target anatomy in the target scan plane, as different operators may be more receptive to different vibration pattern types.

[0064] FIG. **12** illustrates an embodiment of a method **150** for guiding movement of the ultrasound probe using the haptic guidance system to position the ultrasound probe **14** in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. At step **152**, the controller **24** of the haptic guidance system **12** may receive the target anatomy and/or the target scan plane of the target anatomy to be imaged via the user input device. At step **154**, the controller **24** may receive a position of the patient **22** via the patient position sensor **33**. As such, the controller **24** may receive one or more signals from the patient position sensor **33** indicative of the position of the patient **32** about the imaging space **35**. Additionally or alternatively, in some embodiments, the position of the patient may be determined based on the live ultrasound image data from the ultrasound probe **14**. At step **156**, the controller **24** may determine the patient-centric coordinate system based at least in part on the received patient position. In some embodiments, the patient-centric coordinate system for the current patient **22** may be saved in the memory **32**, and in some embodiments, this saved coordinate system may be updated based on the current position of the patient **22**. At step **157**, the controller **24** may determine the appropriate position and/or orientation of the ultrasound probe **14** based at least in part on the target anatomy, the target scan plane, the patient-centric coordinate system, and/or the live ultrasound image data.

[0065] At step **158**, the controller **24** may receive a current position and or orientation of the ultrasound probe **14** from the probe position sensor **36**. At step **160**, the controller **24** may determine whether the position and/or orientation of the ultrasound probe **14** corresponds to the appropriate position to image the target anatomy in the target scan plane based at least in part on the patient-centric coordinate system and the position of the ultrasound probe **14**. In some embodiments, the controller **24** may use the live ultrasound image data captured by the ultrasound probe **14** as feedback to determine patient position, the appropriate position and orientation of the ultrasound probe **14**, and/or if the ultrasound probe **14** is in the appropriate position and/or orientation. The target anatomy in the time series of images may be recognized and the corresponding ultrasound probe positions during that time series are used to derive a target probe position. If the controller **24** determines that the ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane, the method **150** may continue to step **162** in which the controller **24** may cause display of a notification, such as a visual or audible notification, and/or the controller **24** may send a signal to the vibration actuators **40** of the ultrasound probe **14** indicative of a particular pulse pattern indicating to the operator of the ultrasound probe **14** that the ultrasound probe **14** is in the appropriate position and/or orientation. Additionally or alternatively, in some embodiments, the controller **24** may cause automatic storage in the memory **32** of the live ultrasound image data once it is determined that the ultrasound probe is in the appropriate position and/or orientation. If at step **160** the controller **24** determines that the ultrasound probe is not in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane, the controller **24** may cause one or more vibration pattern indicative of one or more movements of the ultrasound probe **14** to position the ultrasound probe in the appropriate position based at least in part on the patient-centric coordinate system, the ultrasound probe **14** position, and/or the ultrasound image, at step **164**.

[0066] The vibration pattern at step **164** may indicate to the operator of the ultrasound probe **14** to move the ultrasound in a particular direction or manner to achieve the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. The controller **24** may then continue to repeat steps **158**, **160**, and **164** until the controller **24** determines that the ultrasound probe **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane.

[0067] The haptic guidance system disclosed provides positioning guidance of the ultrasound probe by utilizing an alternate sense perception of the operator (e.g., tactile sense perception). Such haptic feedback may provide more intuitive guidance to the operator instead of visual cues, or voice guidance, as the operator is already focused on viewing the ultrasound machine and communicating with the patient. Additionally, an array of vibration actuators may allow guidance of the ultrasound probe in all six degrees-of-freedom and may accommodate multiple grip styles. Further, in the big picture, an operator-independent ultrasound imaging system, such as the system described above including the haptic guidance system, may allow novice users to successfully image the target anatomy in the target scan plane. Thus, ultrasound technology may become a more common technology used in every physician's office.

[0068] While only certain features of the present disclosure have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended embodiments are intended to cover all such modifications and changes as fall within the scope of the disclosure.

1. An ultrasound imaging system, comprising:

an ultrasound probe comprising a handle comprising a plurality of haptic actuators; and

a monitor comprising a memory and a processor, wherein the processor is communicatively coupled to the ultrasound probe and configured to:

determine a current position of the ultrasound probe relative to the target region of interest;

determine whether the current position of the ultrasound probe corresponds to a target position of the ultrasound probe relative to a target region of interest of a patient, wherein the target region of interest comprises a target anatomy and a target scan plane; and

output, in response to determining that the current position of the ultrasound probe relative to the target region of interest does not correspond to the target position of the ultrasound probe, a control signal to one or more of the haptic actuators of the plurality of haptic actuators, wherein the control signal causes one or more of the haptic actuators to activate in an activation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the target position.

2. The ultrasound imaging system of claim **1**, wherein the processor is further configured to receive a patient position via a patient position sensor of the ultrasound imaging system and to determine a coordinate system based at least in part on the patient position.

3. The ultrasound imaging system of claim **2**, wherein the processor is configured to determine whether the current position of the ultrasound probe corresponds to the target position based at least in part on the determined coordinate system.

4. The ultrasound imaging system of claim **2**, wherein the patient position sensor comprises one or more of cameras, contact sensors, weight sensors, an ultrasound probe comprising integrated position tracking, ultrasound image data from the ultrasound probe, or any combination thereof.

5. The ultrasound imaging system of claim **1**, wherein the haptic actuators comprise vibration motors.

6. The ultrasound imaging system of claim **1**, wherein the haptic actuators comprise motion actuators, electrodes, or deformable fluid filled chambers.

7. The ultrasound imaging system of claim **1**, wherein the target position of the ultrasound probe comprises a target position and a target orientation of the ultrasound probe relative to the region of interest of the patient.

8. The ultrasound imaging system of claim **1**, wherein the activation pattern is indicative of one or more suggested movements in six degrees-of-freedom.

9. An ultrasound probe, comprising:

a patient-facing surface comprising one or more transducers; and

a handle comprising a plurality of haptic actuators, wherein the haptic actuators are configured to actuate in a plurality of actuation patterns to indicate a suggested movement of the handle in six degrees-of-freedom, and wherein each actuation pattern of the plurality of actuation patterns modulates in intensity, speed, or both as the patient-facing surface of the ultrasound probe is moved a distance from a target position relative to a patient.

10. The ultrasound probe of claim **9**, comprising a probe position sensor configured to measure a position of the ultrasound probe relative to the patient.

11. The ultrasound probe of claim **9**, wherein the haptic actuators are disposed below a housing surface of the ultrasound probe and are arranged in two or more actuation rings axially offset from each other about an axial axis of the ultrasound probe.

12. The ultrasound probe of claim **11**, wherein each actuation ring comprises one or more of the haptic actuators per side of the ultrasound probe.

13. The ultrasound probe of claim **9**, wherein the actuation patterns communicate suggested movement of the ultrasound probe relative to an X-axis, a Y-axis, and a Z-axis to position the ultrasound probe in the target position relative to the patient, wherein suggested movement relative to the Z-axis comprises suggested compression movement and decompression movement of the ultrasound probe relative to the patient, and wherein compression movement comprises movement of the ultrasound probe toward the patient.

14. The ultrasound probe of claim **9**, wherein the actuation patterns communicate suggested movement of the ultrasound probe relative to an elevation angle and an azimuth angle to orient the patient-facing surface of the ultrasound probe relative to the patient.

15. The ultrasound probe of claim **9**, wherein the actuation patterns communicate suggested rotation movement of the ultrasound probe circumferentially about an axial axis of the ultrasound probe.

16. The ultrasound probe of claim **9**, wherein each haptic actuator of the plurality of haptic actuators comprises a shell configured to spatially contain the respective haptic actuator such that actuation of the respective haptic actuator in the plurality of actuation patterns is location specific.

17. A method, comprising:

receiving, via a processor, a target region of interest of a patient to be imaged via an ultrasound probe of an ultrasound imaging system and a target scan plane of the target region of interest;

determining, via the processor, a target imaging position of the ultrasound probe based at least in part on the target region of interest and the target scan plane;

determining, via the processor, a current position of the ultrasound probe relative to the target region of interest, the desired scan plane, or both;

determining, via the processor, whether the current position of the ultrasound probe corresponds to the target imaging position of the ultrasound probe; and

outputting, via the processor, in response to determining that the current position of the ultrasound probe relative to the target region of interest, the target scan plane, or both, does not correspond to the target position of the ultrasound, a control signal to a plurality of haptic actuators disposed on a handle of the ultrasound probe, wherein the control signal causes one or more of the haptic actuators to actuate in an actuation pattern indicative of a suggested movement of the ultrasound probe.

18. The method of claim **17**, comprising:

determining, via the processor, a position of the patient relative to the ultrasound imaging system; and

determining, via the processor, a patient-centric coordinate system based at least in part on the position of the patient.

19. The method of claim **18**, wherein determining whether the current position of the ultrasound probe corresponds to the target imaging position of the ultrasound probe is based at least in part on the patient-centric coordinate system.

20. The method of claim **17**, wherein the haptic actuators comprise vibration actuators, and, wherein the actuation pattern comprises a plurality of actuation patterns each indicative of a suggested movement of the ultrasound probe in six degrees-of-freedom, and wherein the plurality of actuation patterns modulate in intensity, speed, or both as the ultrasound probe is moved a distance from the target imaging position.

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摘要(译)

根据本方法，操作者可以接收定位和/或定向超声探头的辅助，以便获取目标解剖结构的目标扫描平面。根据某些实施例，可以提供超声成像系统和超声探头，其提供引导超声探头放置的触觉反馈。这种自动化和指导可以允许新手或不太熟练的用户获得成功的超声扫描。