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(54) **ULTRASOUND PROBE NAVIGATION USING A HAPTIC FEEDBACK DEVICE**

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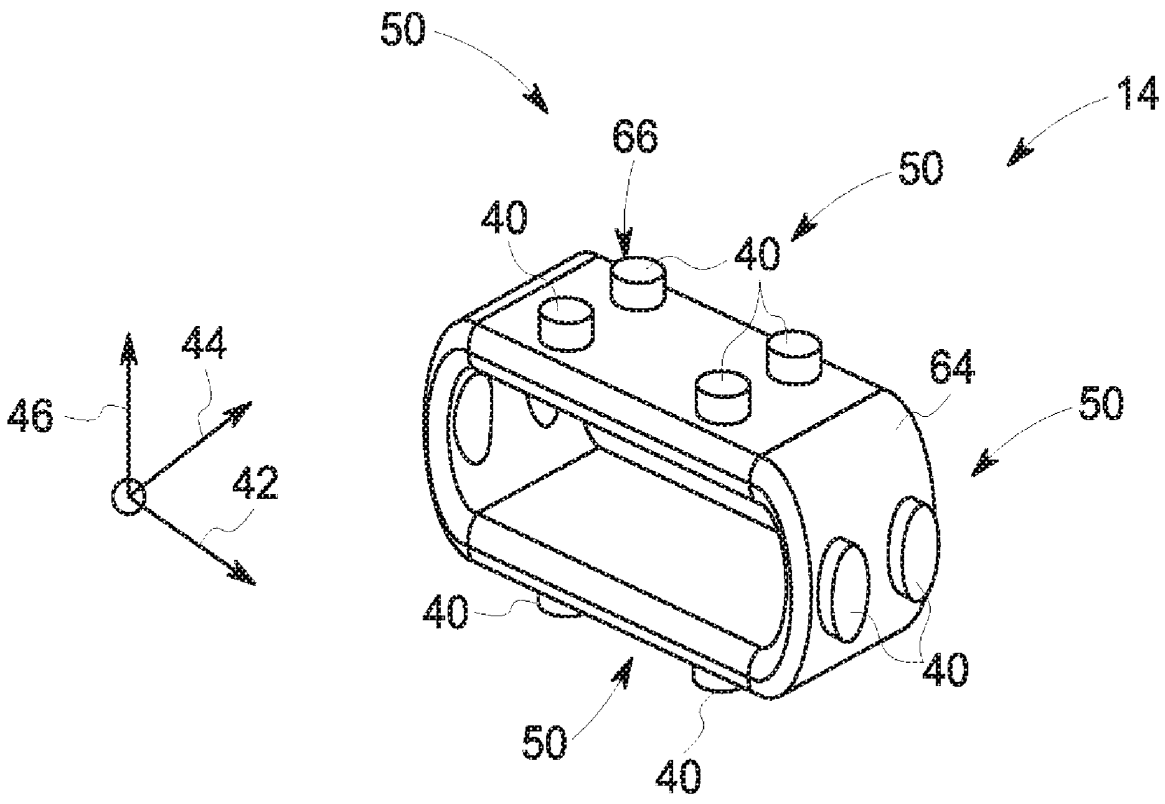
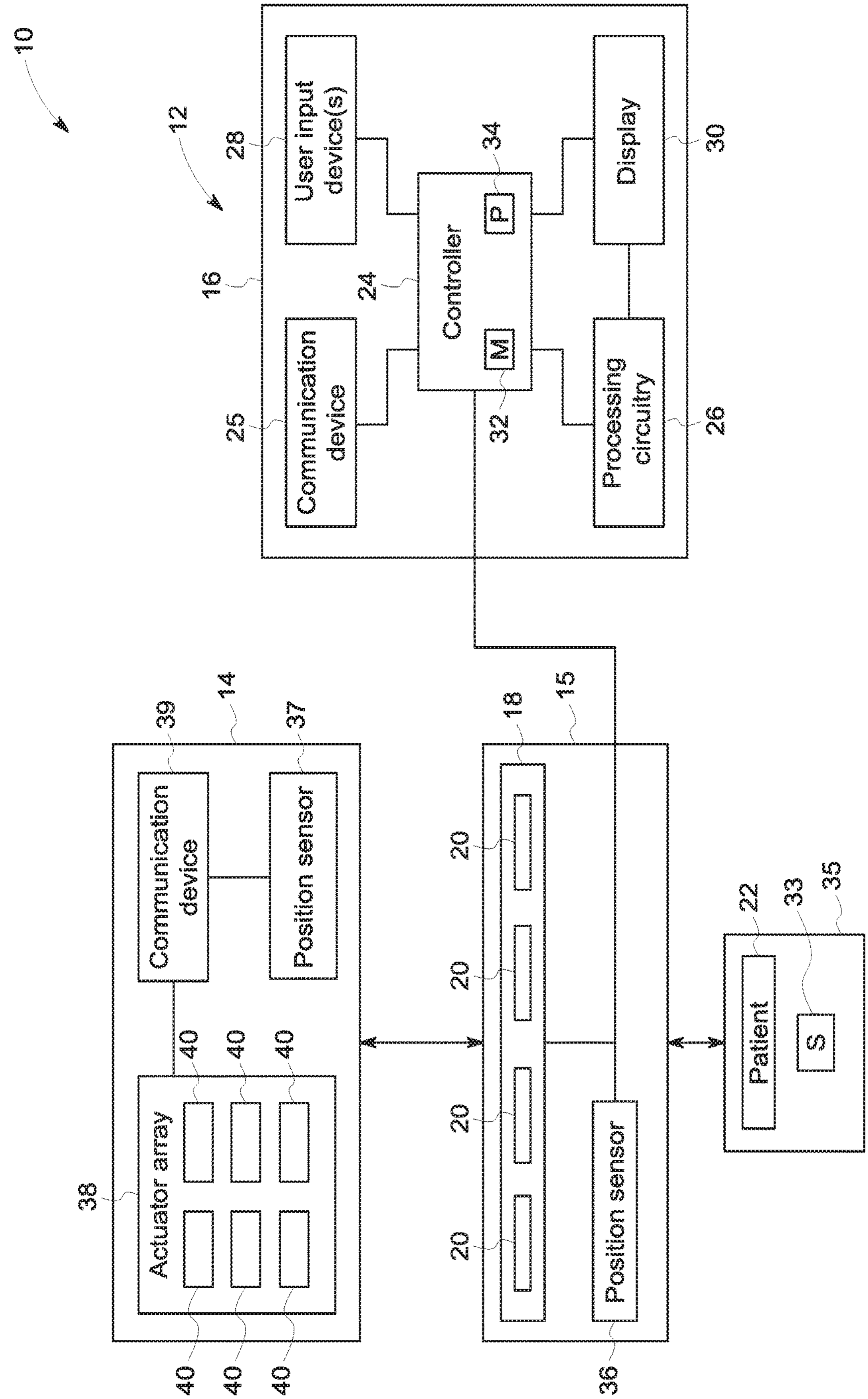
(57) **ABSTRACT**

A wearable device for providing ultrasound guidance feedback may include a housing that has a plurality of haptic actuators, and an opening extending along an axis through the housing. The opening may fit about a body part of an operator of an ultrasound probe, and the haptic actuators may pulse in an actuation pattern indicative of one or more suggested movements of the ultrasound probe to position the ultrasound probe in a desired position to acquire imaging data of a region of interest of a patient.

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12
16
User input device(s)
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Communication device
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Controller
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P
34
M
32
Display
30
Processing circuitry
26
Communication device
39
Position sensor
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Actuator array
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Position sensor
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Patient
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FIG. 1

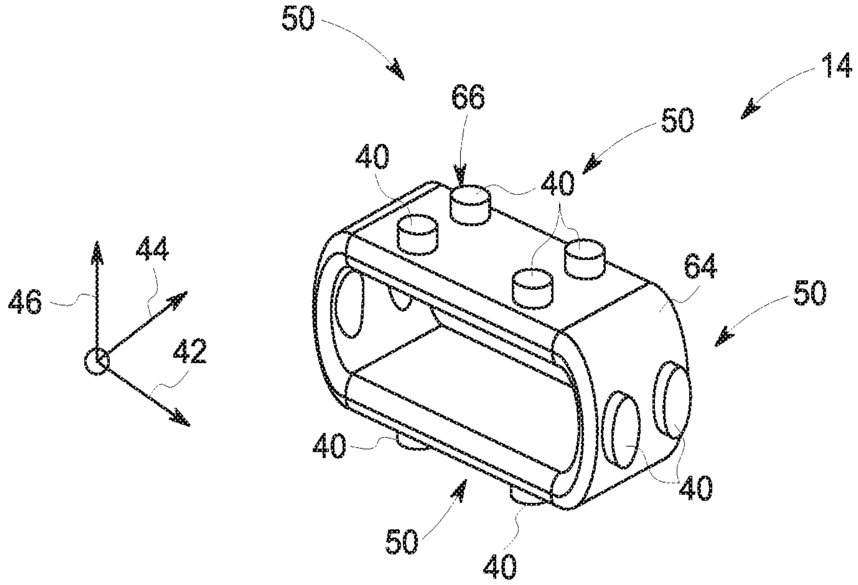

FIG. 2

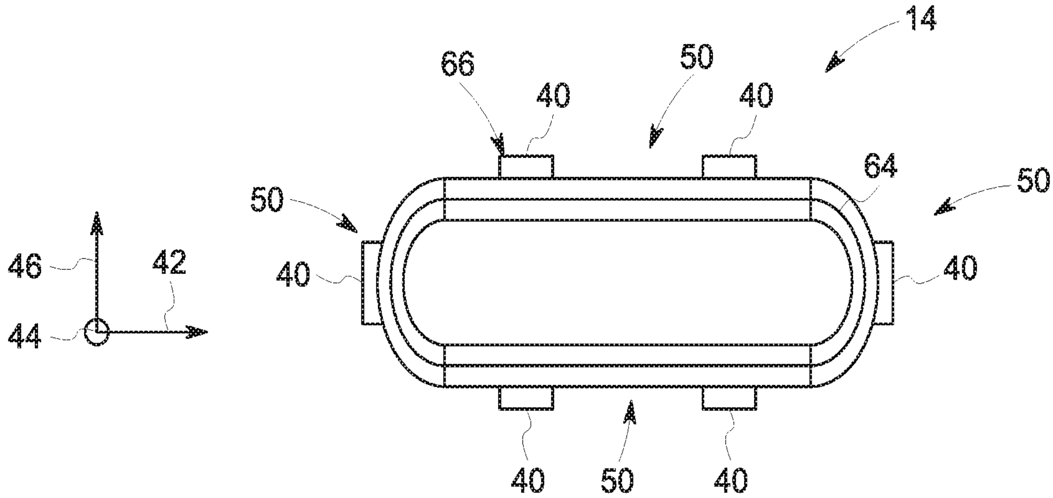

FIG. 3

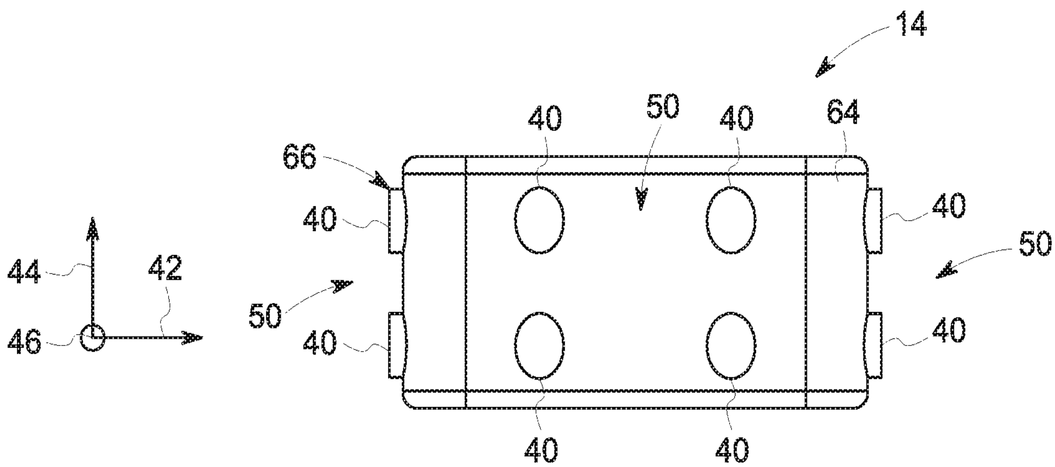

FIG. 4

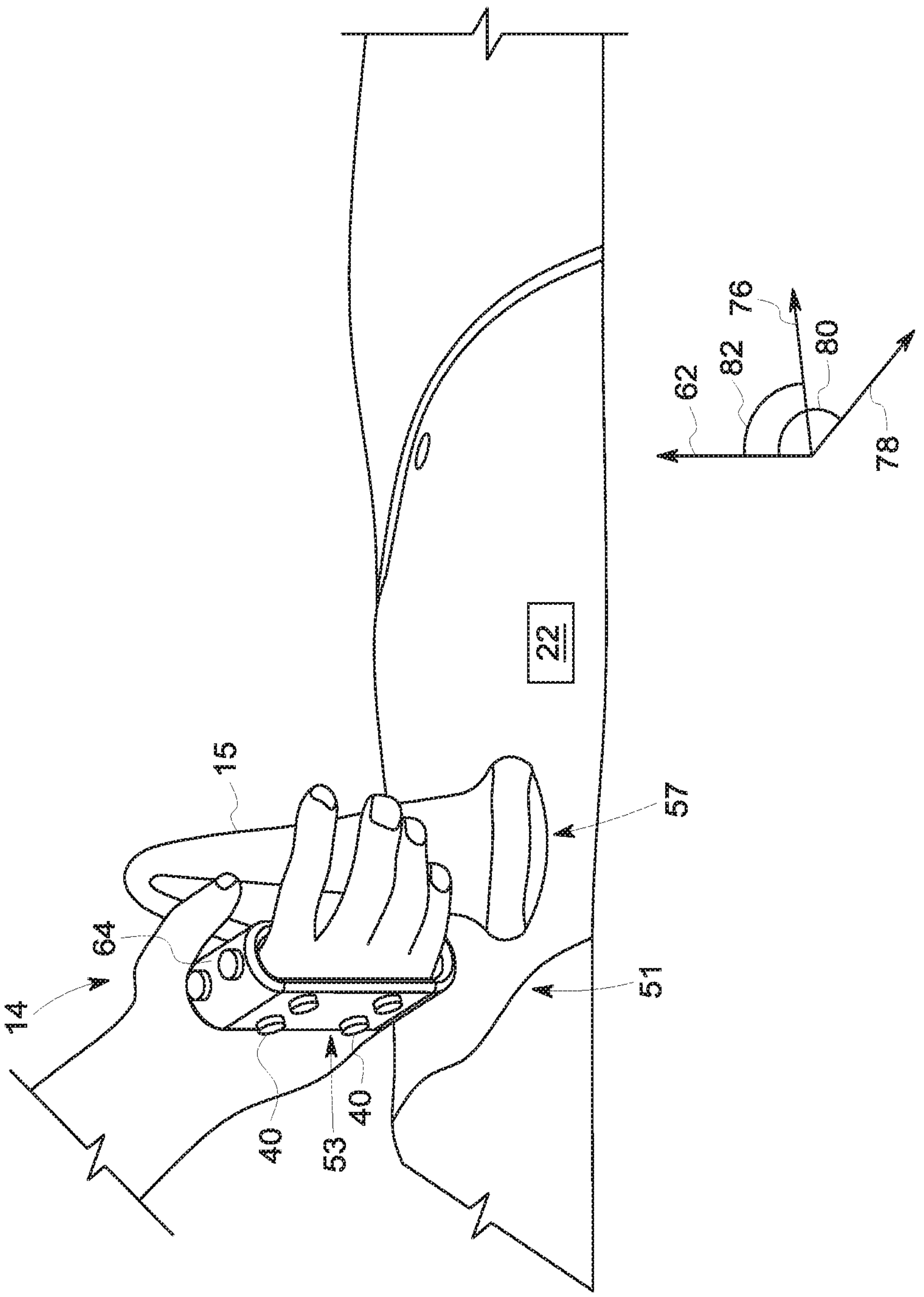

FIG. 5

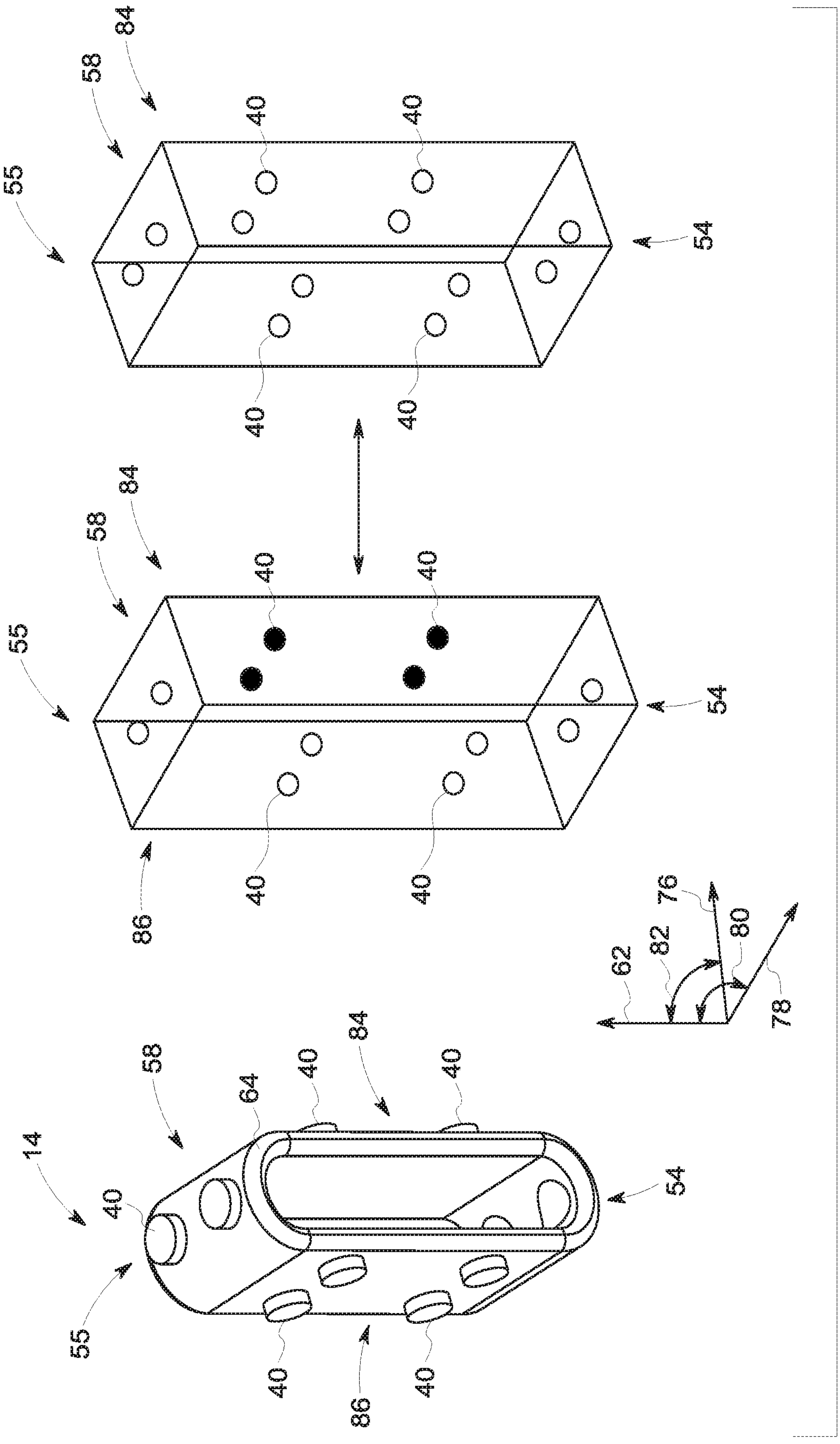
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FIG. 6

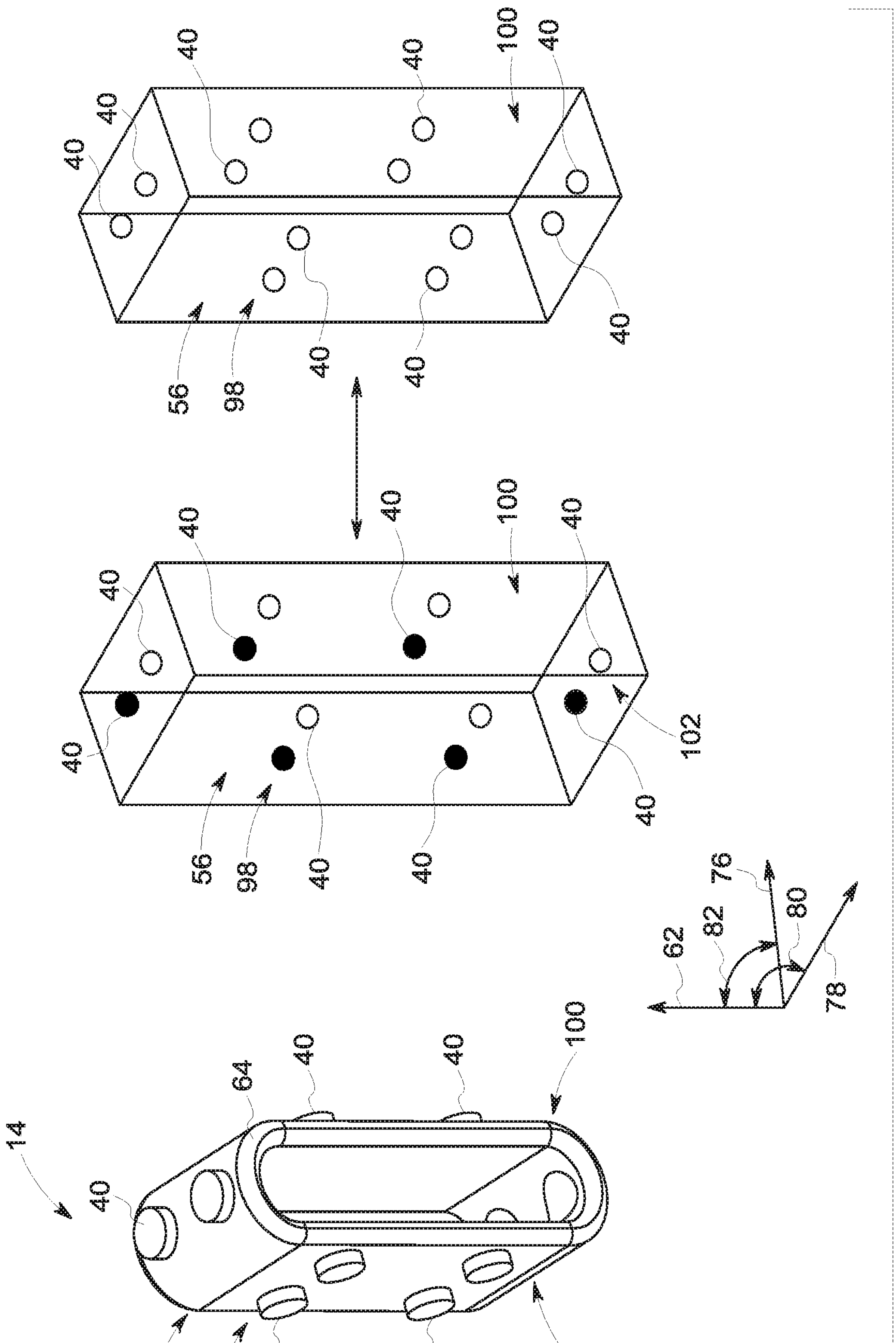

FIG. 7

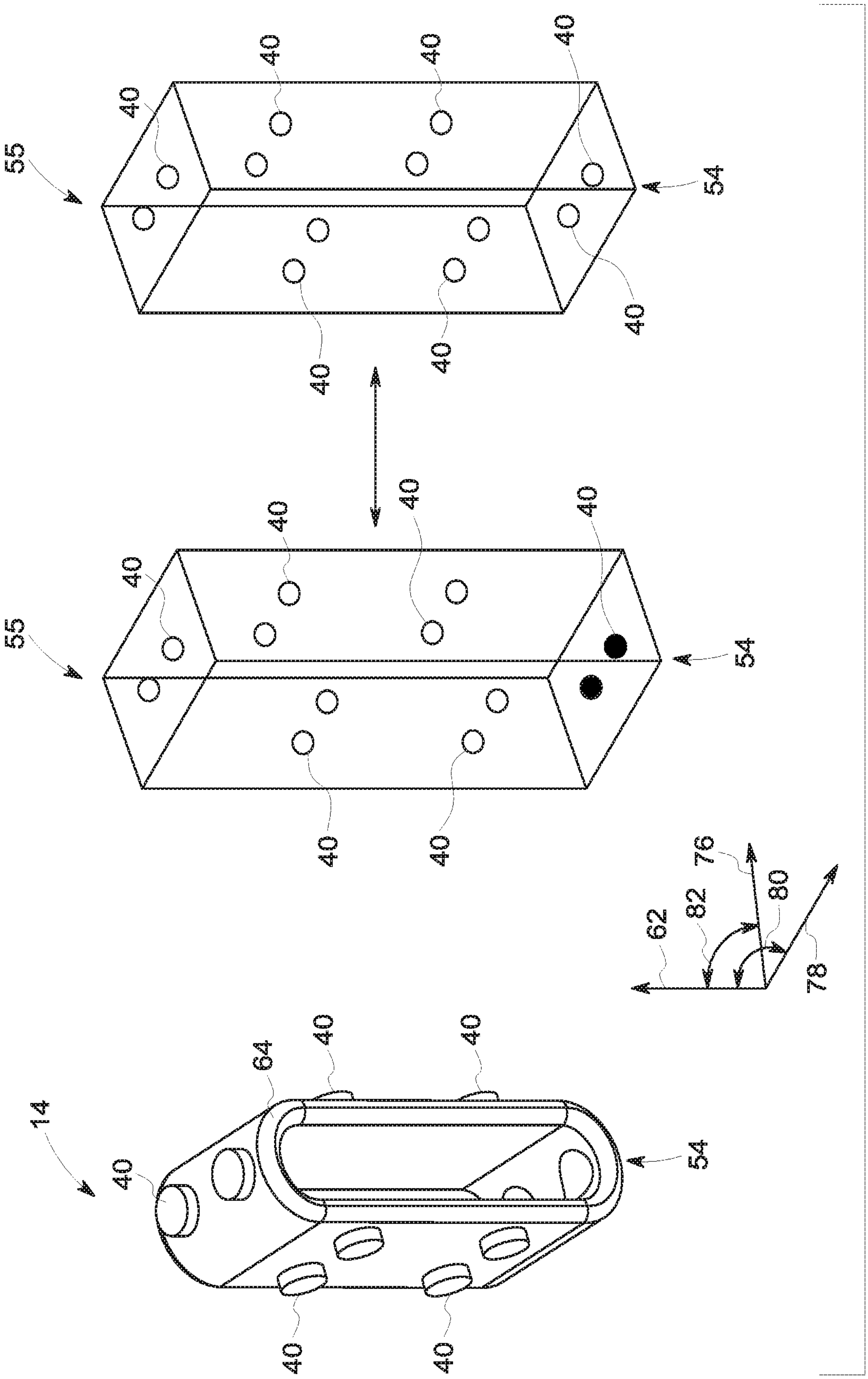

FIG. 8

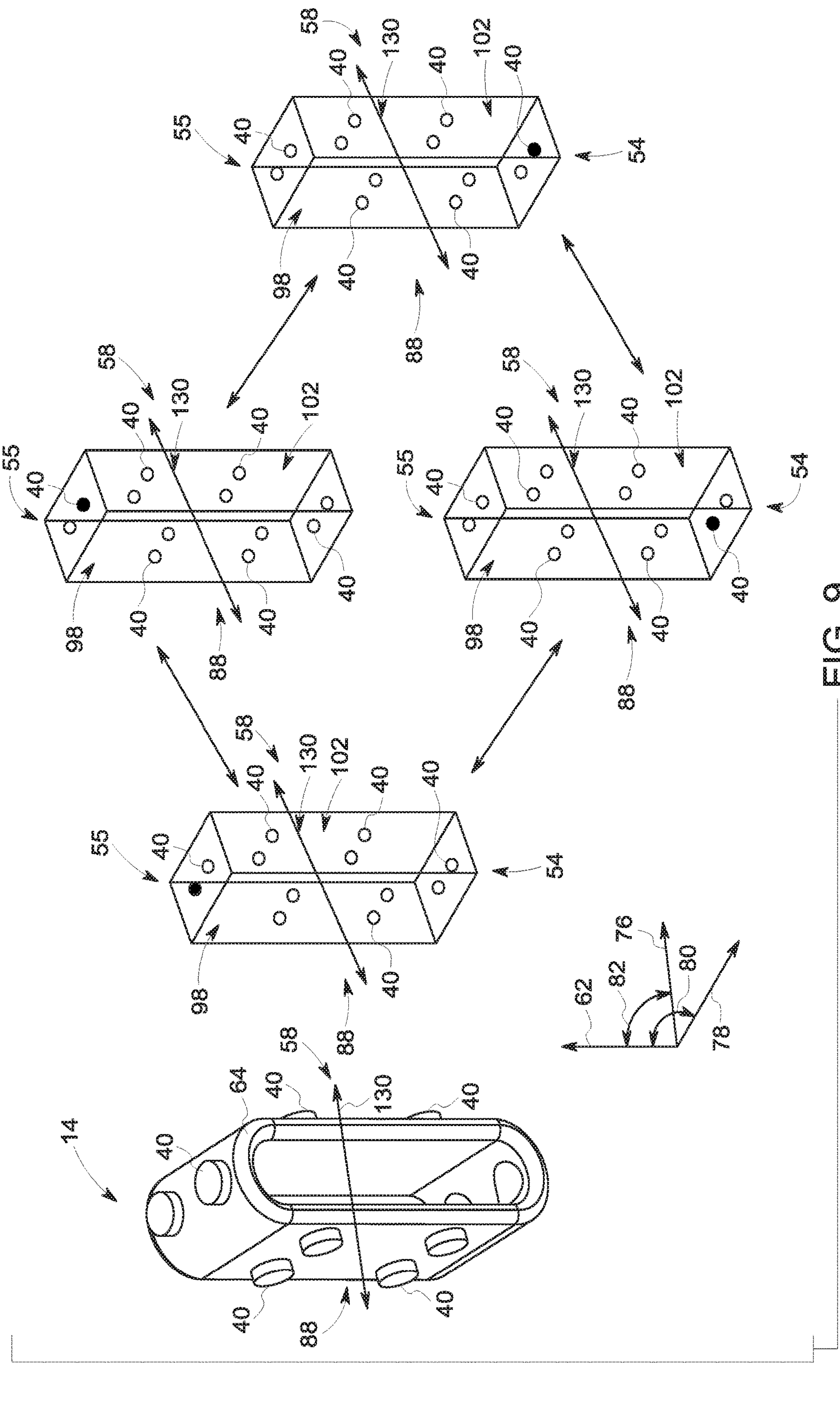

FIG. 9

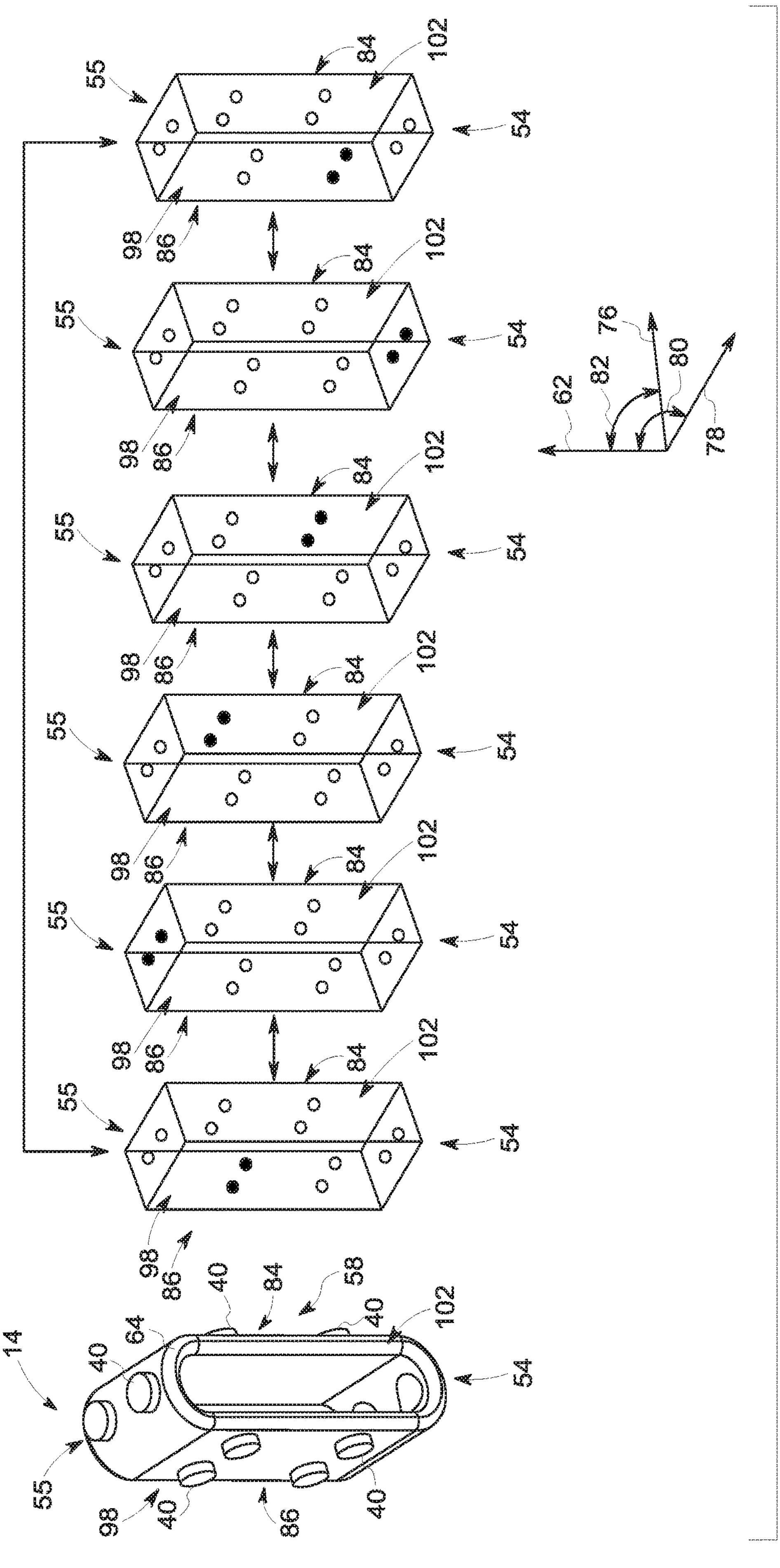

FIG. 10

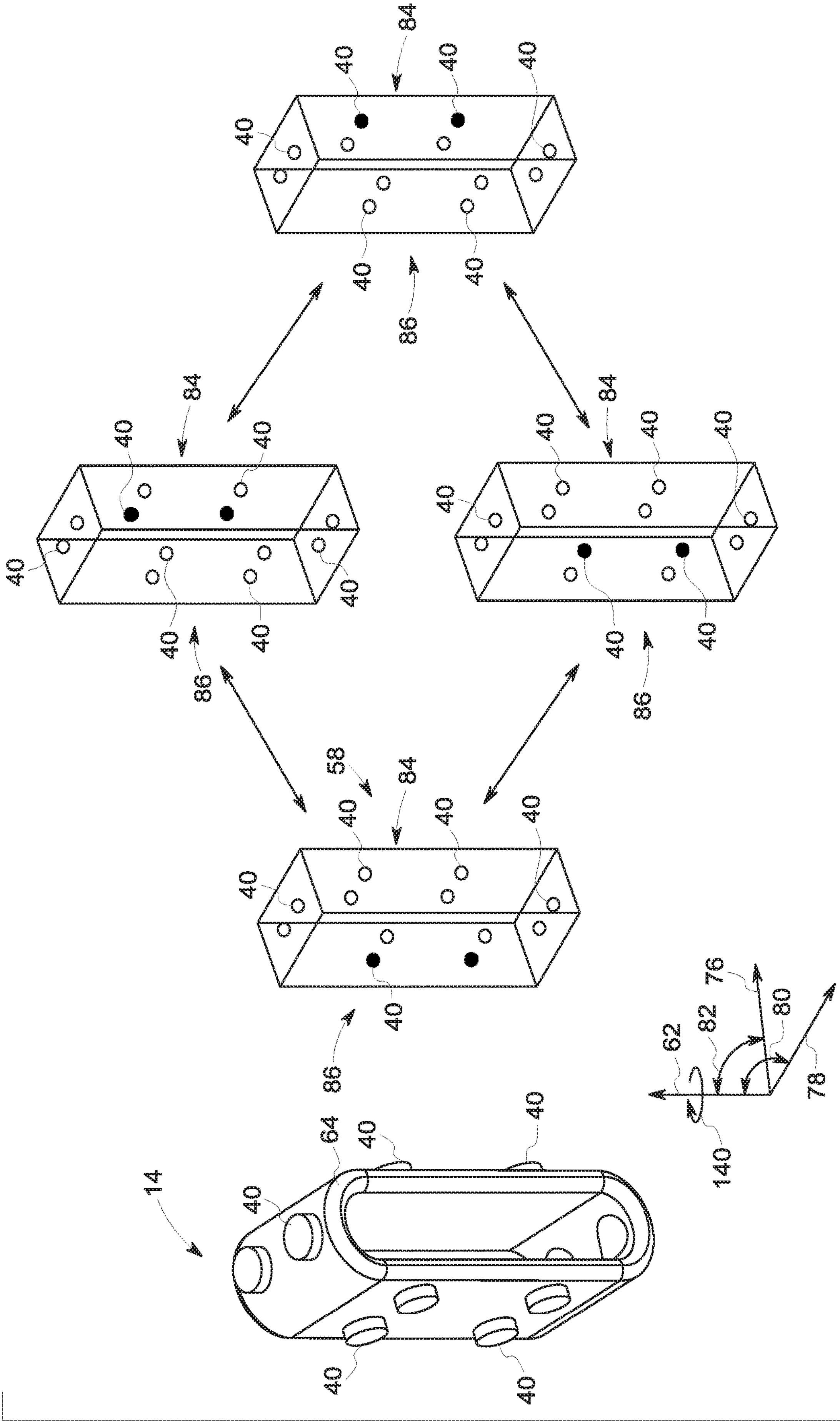

FIG. 11

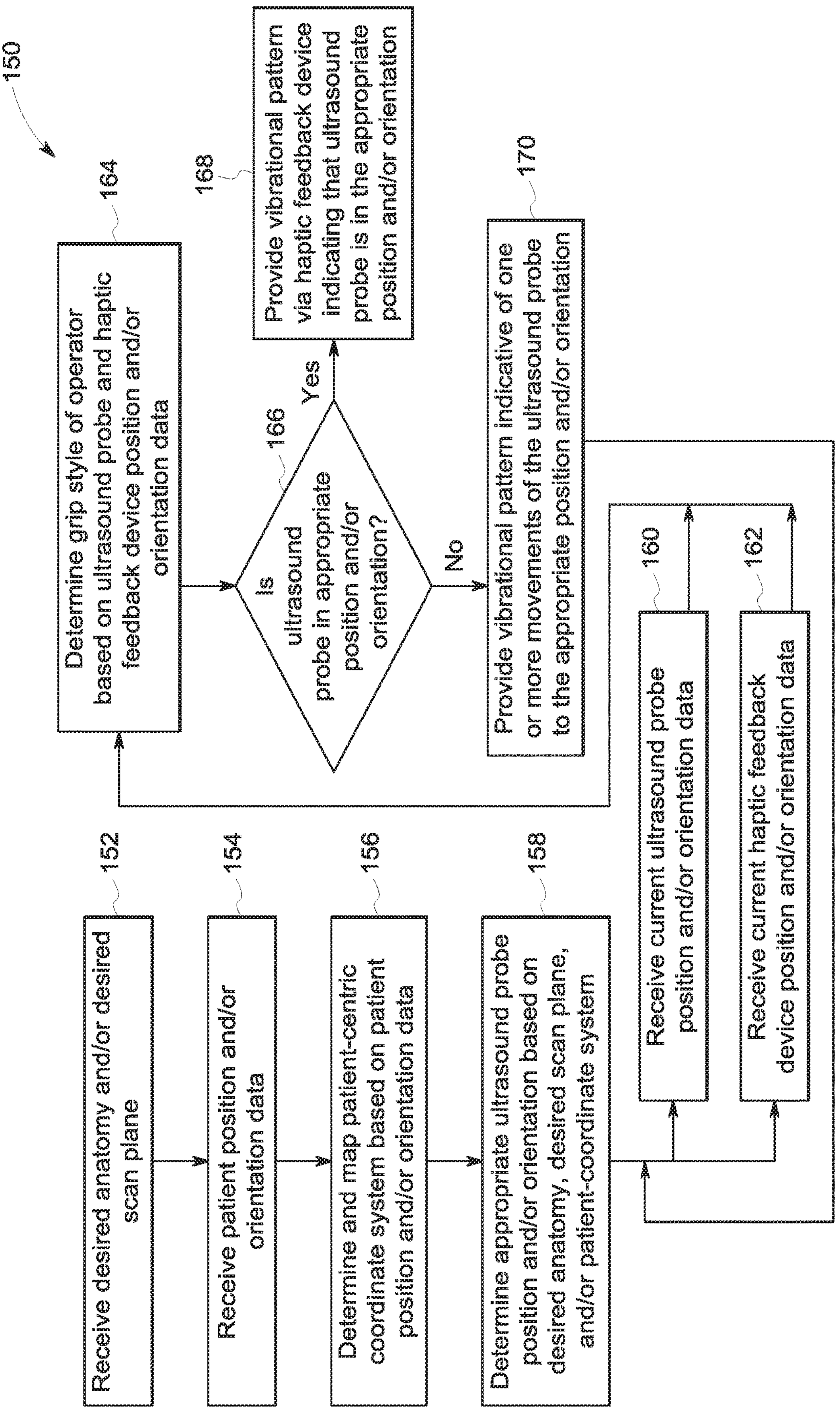
150
Receive desired anatomy and/or desired scan plane
152
Receive patient position and/or orientation data
154
Determine and map patient-centric coordinate system based on patient position and/or orientation data
156
Determine appropriate ultrasound probe position and/or orientation based on desired anatomy, desired scan plane, and/or patient-coordinate system
158
Receive current ultrasound probe position and/or orientation data
160
Receive current haptic feedback device position and/or orientation data
162
Determine grip style of operator based on ultrasound probe and haptic feedback device position and/or orientation data
164
Is ultrasound probe in appropriate position and/or orientation?
166
Yes
Provide vibrational pattern via haptic feedback device indicating that ultrasound probe is in the appropriate position and/or orientation
168
No
Provide vibrational pattern indicative of one or more movements of the ultrasound probe to the appropriate position and/or orientation
170

FIG. 12

ULTRASOUND PROBE NAVIGATION USING A HAPTIC FEEDBACK DEVICE

BACKGROUND

[0001] The subject matter disclosed herein relates to medical imaging, and more particularly to systems and methods for guiding ultrasound probe positioning through haptic feedback.

[0002] 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

[0003] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0004] In one embodiment, an ultrasound imaging system includes an ultrasound probe. The ultrasound imaging system further includes a monitor having a memory and a processor. The processor is communicatively coupled to the ultrasound probe and a haptic feedback device having a plurality of haptic actuators. The processor may determine a current position of the ultrasound probe relative to a region of interest of a patient. The region of interest may include a desired anatomy, a desired scan plane, or both, to be imaged via the ultrasound probe. The processor may also determine whether the current position of the ultrasound probe corresponds to a desired position of the ultrasound probe relative to the region of interest. The desired position of the ultrasound probe facilitates an acquisition of an ultrasound image of the region of interest. In response to determining that the current position of the ultrasound probe does not correspond to the desired position of the ultrasound probe, the processor may transmit a control signal to a plurality of haptic actuators. The control signal may cause the plurality of actuators to pulse in a actuation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the desired position.

[0005] In another embodiment, a wearable device for providing ultrasound guidance feedback may include a housing that has a plurality of haptic actuators, and an opening extending along an axis through the housing. The opening may fit about a body part of an operator of an ultrasound probe, and the haptic actuators may pulse in an actuation pattern indicative of one or more suggested movements of the ultrasound probe to position the ultrasound probe in a desired position to acquire imaging data of a region of interest of a patient.

[0006] In another embodiment, a method may include determining, via a processor, a desired imaging position of the ultrasound probe based at least in part on the region of interest and the desired scan plane. The desired imaging position may facilitate an acquisition of an ultrasound image of the region of interest, the desired scan plane, or both. The method may also include 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 desired imaging position of the ultrasound probe, and in response to determining that the current position of the ultrasound probe does not correspond to the desired imaging position of the ultrasound probe, transmitting, via the processor, a control signal to a plurality of haptic actuators disposed about a haptic feedback device configured to be worn by an operator of the ultrasound probe. The control signal may cause the plurality of haptic actuators to pulse in an actuation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the desired imaging position.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention 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 and a haptic feedback device, in accordance with aspects of the present disclosure;

[0009] FIG. **2** illustrates a perspective view of an embodiment of the haptic feedback device of FIG. **1**, in accordance with aspects of the present disclosure;

[0010] FIG. **3** illustrates a side view of an embodiment of the haptic feedback device of FIG. **1**, in accordance with aspects of the present disclosure;

[0011] FIG. **4** illustrates an overhead view of an embodiment of the haptic feedback device of FIG. **1**, in accordance with aspects of the present disclosure;

[0012] FIG. **5** illustrates a perspective view of an embodiment of the haptic feedback device of FIG. **1** worn about a hand of the operator of an ultrasound probe, in accordance with aspects of the present disclosure;

[0013] FIG. **6** illustrates a schematic of the haptic feedback device of FIG. **1** showing an embodiment of a vibration sequence of vibration actuators of the haptic feedback device to guide movement of an ultrasound probe along an X-axis, in accordance with aspects of the present disclosure;

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

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

[0016] FIG. **9** illustrates a schematic of the haptic feedback device of FIG. **1** showing an embodiment of a vibration sequence of the vibration actuators of the haptic feedback device 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 haptic feedback device of FIG. **1** showing an embodiment of a vibration sequence of the vibration actuators of the haptic feedback device 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 haptic feedback device of FIG. **1** showing an embodiment of a vibration sequence of the vibration actuators of the haptic feedback device to guide rotational 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. For example, to accurately perform ultrasound imaging of a desired anatomy of a patient, an operator must properly align an ultrasound probe of an ultrasound system with the desired anatomy, interpret ultrasound images while controlling settings of the ultrasound system to bring the desired anatomy into view, and navigate the ultrasound probe to identify the appropriate scan planes to store for the examination of the patient. As such, it may be desirable for the ultrasound imaging system to provide guidance to less skilled operators so that such operators may obtain proper ultrasound images for diagnosis. Accordingly, an operator-independent ultrasound imaging system may automate some operational steps that are typically performed by an operator and provide machine guidance to the operator to perform other operational steps. For example, the operator-independent ultrasound imaging system may automate many selections of parameters and/or characteristics that an operator would conventionally adjust to perform ultrasound imaging of a patient. Additionally, a haptic feedback device is provided herein to provide guided ultrasound probe placement to the operator to acquire a desired scan plane of a desired anatomical feature of a patient. For example, the haptic feedback device may assist an operator in positioning and orienting an ultrasound probe to acquire the desired scan plane of a desired anatomical feature of a patient. Such techniques may allow novice, or less skilled, users to obtain accurate ultrasound scans of desired anatomical features of a patient.

[0023] For example, a haptic feedback device (e.g., band or glove) may be worn by an operator and provide vibrational feedback (e.g., haptic feedback) to the operator to assist in positioning and orienting an ultrasound probe to acquire a desired scan plane of a desired anatomical feature of a patient. In one embodiment, the haptic feedback device and the ultrasound probe may each have one or more position and/or orientation sensors, such as inertial measurement units. An operator-independent ultrasound imaging system in communication with the haptic feedback device and the ultrasound imaging system may receive the positional and/or orientation data from the haptic feedback device, the ultrasound probe, or both. The ultrasound imaging system may compare the position and/or orientation of the ultrasound probe with a patient-centric coordinate system (e.g., an anatomical atlas) of a patient. Based on the comparison of the position and/or orientation of the ultrasound probe with the patient-centric coordinate system, the ultrasound imaging system may determine a directional movement, an angular movement, or both, to assist the operator in positioning and/or orienting the ultrasound probe to acquire a desired scan plane of desired anatomical features of the patient. The ultrasound imaging system may then determine the relative orientation of haptic feedback device with respect to the ultrasound probe based on a comparison between the ultrasound probe orientation data and the haptic feedback device orientation data. Based on the relative orientation between the ultrasound probe and haptic feedback device and/or the determined directional movement, angular movement, or both, the ultrasound imaging system may then compute and send a command signal to the haptic feedback device to provide to the operator vibrational feedback that corresponds to the determined directional movement, angular movement, or both. In response to sensing the vibrational feedback through the haptic feedback device, the operator may discern a direction, a change in direction, an orientation, a change in orientation, or the like, that corresponds to the particular vibrational feedback received by the operator. For example, the vibrational feedback may correspond to a command to move the ultrasound probe to the right, to the left, forward, backward, to apply pressure at the current location, to apply less pressure at the current location, to tilt to the right, to tilt to the left, to tilt forward, to tilt backward, to rotate clockwise, to rotate counter-clockwise, or the like. The operator may then move the ultrasound probe in the corresponding direction and/or angle to acquire the desired scan plane of the desired anatomical features of the patient.

[0024] In some embodiments, the ultrasound imaging system may provide vibrational feedback to the operator through the haptic feedback device more than once before the operator is able to acquire the desired scan plane of the desired anatomical features of the patient. For example, the ultrasound imaging system may direct the operator to move the ultrasound probe to the right and then rotate the ultrasound probe clockwise to acquire the desired scan plane of the desired anatomical features of the patient. It should be noted that the ultrasound imaging system may direct the operator to move (or not move) the ultrasound probe in any combination of directions and/or angles to assist the operator in positioning and/or orienting the ultrasound probe to acquire the desired scan plane of the desired anatomical features of the patient.

[0025] In another embodiment, the haptic feedback device may be able to be used with ultrasound probes without inertial measurement units. That is, the haptic feedback device may have one or more inertial measurement units, but the ultrasound probe may not have any inertial measurement units. In such an embodiment, the ultrasound imaging system may receive positional and/or orientation data from the haptic feedback device. The ultrasound imaging system may then compare the position and/or orientation to ultrasound image data acquired via the ultrasound probe. In some embodiments, the ultrasound image data may be acquired in real-time or substantially in real-time. Based on the comparison of the position and/or orientation of the haptic feedback device with the ultrasound image data, the ultrasound imaging system may determine a directional movement, an angular movement, or both, to assist the operator in positioning and/or orienting the ultrasound probe to acquire the desired scan plane of the desired anatomical features of the patient. The ultrasound imaging system may then send a command signal to the haptic feedback device to provide to the operator vibrational feedback that corresponds to the determined directional movement, the angular movement, or both. As such, the haptic feedback device may work with different types of ultrasound probes to provide guided ultrasound probe placement to the operator to acquire the desired scan plane of the desired anatomical feature of the patient.

[0026] 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 via a haptic feedback device **14** to an operator of the ultrasound imaging system **10** to guide placement of an ultrasound probe **15** of the ultrasound imaging system **10**. For example, the haptic feedback device **14** may include a haptic glove, a haptic band, a smartphone, a smartwatch, or any other suitable device that may provide haptic feedback to the operator of the ultrasound imaging system **10**.

[0027] 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 **15** and a workstation **16** (e.g., monitor, console, user interface) which may control operation of the ultrasound probe **15** and may process image data acquired by the ultrasound probe **15**. The ultrasound probe **15** may be coupled to the workstation **16** by any suitable technique for communicating image data and control signals between the ultrasound probe **15** and the workstation **16** such as a wireless, optical, coaxial, or other suitable connection.

[0028] The ultrasound probe **15** contacts the patient during an ultrasound examination. The ultrasound probe **15** 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 **15** is placed in contact with the patient **22**. More specifically, the transducer elements **20** may convert electrical energy from the ultrasound probe **15** 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 **15** 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.

[0029] As previously discussed, the ultrasound probe **15** 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 **15**, facilitate placement guidance of the ultrasound probe **15** via the haptic feedback device **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.

[0030] 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 **15** via the haptic feedback device **14** for acquiring ultrasound images of a desired scan plane of desired anatomical features of a patient **22**, as discussed in greater detail below.

[0031] 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 **15** 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 **15**.

[0032] The controller **24** may also include a communication device **25** that enables the workstation **16** to communicate data between the workstation **16** and the haptic feedback device **14** and/or the ultrasound probe **15**. For example, in the illustrated embodiment, the haptic feedback device **14** may have a communication device **39** that includes a network interface that may enable the haptic feedback device **14** to communicate via various protocols such as various wired or wireless communication protocols, such as Wi-Fi, mobile telecommunications technology (e.g., 2G, 3G, 4G, or LTE), Bluetooth®, near-field-communications technology, and the like.

[0033] In operation, the controller **24** may receive a signal (e.g., a user selection, or input) indicative of a desired anatomical feature of the patient **22** and/or a desired scan plane of the desired anatomical feature 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 touchscreen, a mouse, buttons, switches, or other devices suitable to allow the operator to input the desired anatomical feature and/or the desired scan plane of the desired anatomical feature. Based on the desired anatomical feature and/or the desired scan plane of the desired anatomical feature, the controller **24** may output a signal to the transducer array **18** of the ultrasound probe **15** indicative of an instruction to convert the electrical energy from the ultrasound probe **15** 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**.

[0034] The controller **24** may determine that the ultrasound probe **15** is in an appropriate position and/or orientation (e.g., desired position and/or orientation) to sufficiently image the desired anatomical feature in the desired scan plane. In some embodiments, the haptic guidance system **12** of the ultrasound imaging system **10** may include sensing mechanisms to detect the location of the patient and to determine the position and/or orientation of the haptic feedback device **14** and/or the ultrasound probe **15** with respect to the patient **22**. That is, the haptic guidance system **12** may include one or more patient position and/or orientation sensors **33**, such as weight sensors, contact sensors, cameras, or other suitable sensing mechanisms, disposed about the imaging space **35** of the ultrasound imaging system **10** 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 and/or orientation 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 the position of the patient **22** relative to the imaging space **35**.

[0035] 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 the position of the ultrasound probe **15** 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**. In some embodiments, the patient-centric coordinate system may be created based on an anatomical atlas of the patient. For example, the anatomical atlas may be a voxelated model that represent polygonal 3D structures of internal organs, bony structures, foreign bodies, or the like. The anatomical atlas may be deformable to fit a representation of the patient (e.g., optical camera images).

[0036] 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 may 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 **15**. 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 **15** 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**.

[0037] The ultrasound probe **15** may include a probe position sensor **36** for detecting the position and/or orientation of the ultrasound probe **15**. The probe position sensor **36** may be disposed about the ultrasound probe **15** and may be a position sensor, an orientation sensor, such as a gyroscope, an inertial measurement unit, 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 **15**. 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 **15**. Additionally, or alternatively, the haptic feedback device **14** may include a position sensor **37** for detecting the position and/or orientation of the hand of the operator. The position sensor **37** may be disposed about the haptic feedback device **14** and may be a position sensor, an orientation sensor, such as a gyroscope, an inertial measurement unit, electromagnetic tracking, optical tracking, or any other suitable sensor that may allow for detection of a current position and/or orientation of the hand of the operator. The position sensor **37** may be communicatively coupled to the controller **24** via a wired or wireless connection (e.g., via communication device **39**) and may send one or more signals to the controller **24** indicative of a current position and/or orientation of the hand or wrist of the operator.

[0038] The controller **24** may compare the current position and/or orientation of the ultrasound probe **15** and/or the haptic feedback device **14**, based at least in part on respective signals received from the probe position sensor **36** and position sensor **37** of the haptic feedback device **14**, 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 **15** and/or the haptic feedback device **14** (i.e., the operator's hand) is in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. As such, live ultrasound image data may be used by the controller **24** as feedback to determine if the ultrasound probe **15** and/or the haptic feedback device **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**.

[0039] Additionally, or alternatively, the controller **24** may compare the current position and/or orientation of the ultrasound probe **15**, based at least in part on the signals received from the probe position sensor **36**, to the position and/or orientation of the haptic feedback device **14** based at least in part on the signals received from the position sensor **37**. Based on the comparison, the controller **24** may determine the grip style of the operator's hand on the ultrasound probe **15**. For example, the position and/or orientation data of the ultrasound probe **15** may include a plurality of probe reference points (e.g., x-coordinate, y-coordinate, z-coordinate) relative to the imaging space **35**, and the position and/or orientation data of the haptic feedback device **14** may include a plurality haptic feedback device reference points (e.g., x-coordinate, y-coordinate, z-coordinate) relative to the imaging space **35**. The controller **24** may compare the relative positions of the probe reference points and the haptic feedback device reference points in the imaging space **35** to lookup tables stored in the memory **32** to determine the grip style of the operator's hand on the ultrasound probe **15**. As such, the controller **24** may provide haptic feedback to the operator via the haptic feedback device **14** based on the grip style of the operator and the position and/or orientation of the ultrasound probe **15**. For example, the controller **24** may adjust a particular vibration pattern of the vibration actuators **40** such that the operator may discern the same vibration pattern from the haptic feedback device **14** regardless of the grip style used by the operator.

[0040] 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 **15** and/or the haptic feedback device **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane. As such, live ultrasound image data may be used by the controller **24** as feedback in determining if the ultrasound probe **15** and/or the haptic feedback device **14** 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 the ultrasound probe **15** and/or the haptic feedback device **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 the display of a notification, such as a visual or audible notification. Additionally, or alternatively, the controller **24** may send a signal to the vibration actuators **40** of the haptic feedback device **14** indicative of a particular pulse pattern to convey to the operator of the ultrasound probe **15** that the ultrasound probe **15** and/or the haptic feedback device **14** is in the appropriate position and/or orientation to sufficiently image the target anatomy in the target scan plane.

[0041] 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 **15** and/or the haptic feedback device **14** is in the appropriate position and/or orientation. Additionally, or alternatively, if the controller **24** determines that the ultrasound probe **15** and/or the haptic feedback device **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 **15** into an ultrasound image and send a signal to the display **30** indicative of an instruction to display the ultrasound image.

[0042] 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 **15** and/or the haptic feedback device **14** is in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. If the controller **24** determines that the ultrasound probe **15** and/or the haptic feedback device **14** is not in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane, the controller **24** may guide the operator of the ultrasound probe **15** to move the ultrasound probe **15** into the appropriate position via the haptic feedback device **14**. As such, the haptic feedback device **14** may include an actuator array **38** that includes multiple vibration actuators **40** (e.g., haptic actuators). In one embodiment, the haptic feedback device **14** may be a band or a glove that fits about a hand of the operator of the ultrasound probe **15**. The vibration actuators **40** may be arranged in a particular arrangement around the band to convey to the operator various feedback based on the position and/or orientation of the ultrasound probe **15** with respect to the desired anatomy of the patient and/or the desired scan plane to be imaged. For example, the vibration actuators **40** may be arranged in one row, two rows, three rows, or any other suitable number of rows around the band such that the operator may feel vibrations in various patterns that indicate respective instructions in moving the ultrasound probe, handling the ultrasound probe, or the like. In one embodiment, the instructions may represent a direction of movement associated with the ultrasound probe, a change in orientation of the ultrasound probe, a change in pressure applied to the ultrasound probe, and the like.

[0043] In another embodiment, the haptic feedback device **14** may be a smartphone or a smartwatch. The controller **24** may send a signal to the smartphone or the smartwatch to provide haptic feedback to the operator when the controller **24** determines that the ultrasound probe **15** is in the appropriate position to sufficiently image the desired anatomy in the desired scan plane. In some embodiments, the controller **24** may send a signal to the smartphone or the smartwatch to provide haptic feedback in increasing frequency as the ultrasound probe **15** is moved closer to the appropriate position to sufficiently image the desired anatomy in the desired scan plane and provide haptic feedback in decreasing frequency as the ultrasound probe **15** is moved away from the appropriate position to sufficient image the desired anatomy in the desired scan plane.

[0044] In any case, 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 movement of the ultrasound probe **15** to guide the operator to move the ultrasound probe **15** into the appropriate position and/or orientation. The vibration actuators **40** may be driven by the controller **24** to guide positioning of the ultrasound probe **15** in six degrees-of-freedom (DOF) (i.e., spatial position and angular orientation) by using various vibration patterns. Additional details discussing the vibrational patterns is discussed herein with regard to FIGS. **6**-**11**. By placing the vibration actuators **40** on some or all sides of the haptic feedback device **14**, multiple grip styles of the ultrasound probe **15** may be supported. Once the operator has moved the ultrasound probe **15** in the appropriate position to image the desired anatomy, the operator may further be guided by the controller **24** to make fine adjustments to the position and/or orientation of the ultrasound probe **15** to acquire the desired scan plane. As discussed above, in some embodiments, the controller **24** of the ultrasound imaging system **10** may use 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 desired scan plane.

[0045] With the foregoing in mind, the haptic guidance system **12** of the ultrasound imaging system **10** may provide guidance for the placement of the ultrasound probe **15** relative to the patient **22** through vibrational feedback (e.g., haptic feedback) provided to the operator through haptic feedback device **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 **15**, such that the operator is not looking at the ultrasound probe **15**, but rather is visually focused on the workstation **16** and the live ultrasound image, use of the vibration actuators **40** in the haptic feedback device **14** (e.g., worn or held by the hand of the operator) 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 **15** 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**.

[0046] FIGS. **2**-**4** illustrate various views of the haptic feedback device **14** showing an embodiment of the placement of the vibration actuators **40** of the actuator array **38** of the haptic feedback device **14**. For example, FIG. **2** illustrates a perspective view of the haptic feedback device **14**. FIG. **3** illustrates a side view of the haptic feedback device **14** of FIG. **2**. FIG. **4** illustrates an overhead view of the haptic feedback device **14** of FIGS. **2** and **3**. To facilitate discussion, the haptic feedback device **14** and its components may be described with reference to a lateral axis or direction **42**, a longitudinal axis or direction **44**, and a vertical axis or direction **46**.

[0047] As previously discussed, the vibration actuators **40** may be directed to vibrate in particular vibration patterns (e.g., actuation patterns or excitation patterns) representing particular movements of the ultrasound probe **15** relative to six degrees-of-freedom in which the ultrasound probe **15** can be moved. The vibration patterns of the vibration actuators **40** may guide the operator to position the ultrasound probe **15** in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. The multiple vibration actuators **40** of the actuator array **38** may be distributed about the circumference of the haptic feedback device **14**. That is, each side of the haptic feedback device **14** may include one or more vibration actuators **40** of the actuator array **38**. Although the illustrated embodiment depicts the haptic feedback device **14** as having the vibration actuators **40** arranged in two rows about the circumference of the haptic feedback device **14**, in other embodiments, the vibration actuators **40** may be arranged in one row, three rows, four rows, or any other suitable number of rows to convey guidance to the operator of the ultrasound probe **15**. Additionally, although the illustrated embodiment depicts the haptic feedback device **14** as having twelve vibration actuators **40**, in some embodiments, the haptic feedback device **14** may have two, three, four, five, six, seven, eight, nine, ten, sixteen, or any other suitable number of vibration actuators **40** for conveying guidance to the operator of the ultrasound probe **15**.

[0048] In the illustrated embodiment, each side of the haptic feedback device **14** may form a band. For example, the operator of the ultrasound probe **14** may wear the band around a hand of the operator, an arm of the operator, one or more fingers of the operator, or any other suitable body part. As such, the haptic feedback device **14** may have any suitable shape and/or suitable size that corresponds to the body part of the operator that fits within the band. Although the illustrated embodiment depicts the haptic feedback device **14** as having an elliptical cross-section along the lateral axis **42** of the haptic feedback device **14**, in other embodiments, the haptic feedback device **14** may have a circular, a triangular, a rectangular, a trapezoidal, a square, a diamond, a pentagonal, a hexagonal, a heptagonal, or any other suitable shaped cross-section along the lateral axis **42** of the haptic feedback device **14**. In some embodiments, the haptic feedback device **14** may stretch around the body part of the operator that fits within the band. For example, the haptic feedback device **14** may include stretchable material such that the haptic feedback device **14** may fit around the finger of the operator or the hand of the operator. 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 haptic feedback device **14**. For example, in the context of a band having a circular cross-section, vibration actuators may be provided around the band such that different vibration actuators face different directions adjacent or opposite one another (i.e., face different radial directions with respect to the band), though no structurally distinct or discernible side may be geometrically identifiable.

[0049] The vibration actuators **40** may be integrated into the haptic feedback device **14**. That is, the vibration actuators **40** may each be disposed above, below, or embedded within a housing **64** of the haptic feedback device **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 haptic feedback device **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 **15** and/or or haptic feedback device **14** into the appropriate position for capturing the desired scan plane of the desired anatomy (e.g., anatomy of interest).

[0050] 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 **15** and/or haptic feedback device **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 haptic feedback device housing that protrude in and out at each actuation location, small motion actuators mounted in a shear orientation about the haptic feedback device 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 **15** and/or the haptic feedback device **14** is moved into the appropriate position. For example, a feedback pulse may become faster or slower as the ultrasound probe **15** and/or the haptic feedback device **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 **40**, 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.

[0051] The controller **24** of the ultrasound imaging system **10** may cause vibration of the vibration actuators **40** integrated into the haptic feedback device **14** to guide the operator to move the ultrasound probe **15** into the appropriate position and/or orientation to image the desired anatomy in the desired scan plane. The particular vibration patterns (e.g., excitation patterns) may indicate to the operator how to move the ultrasound probe **15** to acquire an image of the desired anatomy in the desired scan plane. Particular vibration patterns may indicate to the operator to move the ultrasound probe **15** in a particular direction (e.g., left or right), to tilt or rock the ultrasound probe **15**, to rotate the ultrasound probe **15**, and/or to compress (e.g., apply pressure) or decompress (e.g., apply less pressure) the ultrasound probe **15** toward or away from the patient **22**. In some embodiments, the operator may be guided to move the ultrasound probe **15** in more than one degree-of-freedom simultaneously by applying more complex vibration patterns.

[0052] For each vibration pattern discussed below, the vibrations of the vibration actuators **40** may continue until the operator has moved the ultrasound probe **15** and/or haptic feedback device **14** to the appropriate position. In some embodiments, to guide a speed of movement of the ultrasound probe **15** 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 **15** is farther away from the appropriate position, and then may slow down as the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired scan plane. In some embodiments, the repetition rate may be slower when the ultrasound probe **15** is farther away from the appropriate position, and then may increase in speed as the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired 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 **15** is farther away from the appropriate position, and then may decrease in intensity when the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired scan plane. In some embodiments, the vibrations may be lower intensity when the ultrasound probe **15** is farther away from the appropriate position, and then may increase in intensity when the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired 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 **15** into the appropriate position.

[0053] FIG. **5** illustrates a perspective view of the haptic feedback device **14** worn about a hand **51** of the operator **52** of an ultrasound probe **15**. For example, the haptic feedback device **14** may include a band that may be worn about the palm and the back **53** of the hand **51** of the operator **52** being used to move or orient the ultrasound probe **15** and/or the patient-facing surface **57** of the ultrasound probe **15**. As described above, the ultrasound imaging system **10** may determine the grip style of the operator's hand **51** on the ultrasound probe **15**, and send a signal to the haptic feedback device **14** to provide one or more vibration patterns via the vibration actuators **40** to guide the operator in positioning and/or orienting the ultrasound probe **15** to acquire a desired scan plane of the desired anatomical feature of the patient **22**. The particular vibration patterns may guide the operator to move the ultrasound probe **15** in six degrees-of-freedom, including right and left movement, forward and backward movement, compression and decompression (e.g., applying pressure or applying less pressure), tilt along an elevation direction, rock along an azimuth direction, and rotation. Additionally, movement of the ultrasound probe **15** in six degrees-of-freedom is discussed herein 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**.

[0054] With the foregoing in mind, examples of the vibration patterns that may be used with the haptic feedback device **14** to guide particular movement of the ultrasound probe **15** are discussed below with reference to FIGS. **6-11**. In the illustrated embodiment, the orientation of the haptic feedback device **14** is such that the haptic feedback device **14** fits around the hand of the operator while the operator is gripping, for example, the handle of the ultrasound probe **15** (e.g., FIG. **5**). It should be noted that the vibration patterns may be used with other orientations of the haptic feedback device **14** and/or other grip styles utilized by the operator.

[0055] The particular vibration patterns may guide the operator to move the ultrasound probe **15** in six degrees-of-freedom, including right and left movement, forward and backward movement, compression and decompression (e.g., applying pressure or applying less pressure), tilt along an elevation direction, rock along an azimuth direction, and rotation. In FIGS. **6-11**, the vibration patterns are shown as a series of vibration pulses, where open or non-filled vibration actuators **40** indicate still or currently non-vibrating actuators and solid or filled vibration actuators **40** indicate currently vibrating actuators. For reference, it should be noted that with regard to FIGS. **6-11**, 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. For example, as illustrated in FIG. **5**, the back **53** of the hand **51** of the operator **52** is facing to the left of the page along axis **76**, and the palm of the operator is facing to the right of the page along axis **76**. As described further herein, the vibration actuators **40** may be used to guide movement of the ultrasound probe **15** left or right along the X-axis **76** (e.g., toward a left side of the patient **22** or toward a right side of the patient **22**), forward or backward along the Y-axis **78** (e.g., out of the page or into the page), or along the axial axis **62** (e.g., pressure toward the tissue of the patient **22** or less pressure away from the tissue of the patient **22**). Additionally, the vibration actuators **40** may be used to guide a tilting movement of the ultrasound probe **15** forward or backward, thus increasing or decreasing the elevation angle **80** between the axial axis **62** and the Y-axis **78**; guide rocking movement of the ultrasound probe **15** left or right along the azimuth direction to increase or decrease the azimuth angle **82** between the axial axis **62** and the X-axis **76**; or guide a rotational motion of the ultrasound probe **15** in a circumferential direction **140** around the axial axis **62** (e.g., Z-axis) in a clockwise or counterclockwise direction. It should be noted that the vibration patterns and the corresponding directions and/or angles of movement discussed herein are based on the relative positions of the operator's hand **51** within the haptic feedback device **14** and the ultrasound probe **15** as illustrated in FIG. **5**. Additionally, with regard to FIGS. **6-11**, 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

[0056] FIG. **6** 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 **15** along the X-axis **76**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **15** in a linear direction e.g., toward a first side **58** (e.g., right 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 **55**) of the haptic feedback device **14** to pulse, as shown between the left-hand and right-hand depictions of FIG. **6**. Such on-and-off pulsing of the vibration actuators **40** may indicate to the operator of the ultrasound probe **15** to move the ultrasound probe **15** in the direction of the pulsing. In some embodiments, the pulses of the vibration actuators **40** on the first half **84** of the haptic feedback device **14** may be short pulses, long pulses, or a combination thereof

[0057] 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 **15** to the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. For example, the pulse repetition rate of the vibration actuators **40** on the first half **84** of the haptic feedback device **14** may be faster when the ultrasound probe **15** is farther away from the appropriate position, and then may slow down as the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired scan plane, or vice versa. Additionally or alternatively, an intensity of the vibrations may be stronger when the ultrasound probe **15** is farther away from the appropriate position, and then may decrease in intensity when the ultrasound probe **15** 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 haptic feedback device **14** may be longer when the ultrasound probe **15** is farther away from the appropriate position, and then may decrease in length when the ultrasound probe **15** is moved closer to the appropriate position to image the desired anatomy and/or the desired scan plane, or vice versa. Thus, the simple pulsing of the vibration actuators **40** of the first half **84** of the haptic feedback device **14** caused by the controller **24** of the haptic guidance system **12** may guide the operator of the ultrasound probe **15** to move the ultrasound probe **15** in the direction of the pulsing along the X-axis **76**.

[0058] The opposite vibration pattern may be used to guide movement of the ultrasound probe **15** 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) of the haptic feedback device **14** to pulse, indicating to the operator of the ultrasound probe **15** to move the ultrasound probe **15** toward a second side **86** (e.g., left side) of the ultrasound probe **15** in the direction of the pulses. 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 **15** to the appropriate position to sufficiently image the desired anatomy in the desired scan plane.

[0059] Similar vibration patterns may be used with the haptic feedback device **14** to guide movement of the ultrasound probe **15** forward (e.g., away from the operator) and backward (e.g., toward the operator) along the Y-axis **78**, as illustrated in FIG. **7**. For example, the illustrated vibration pattern may be used to guide movement of the ultrasound probe **15** backward toward the operator and toward the back side **56** of the haptic feedback device **14**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on a back half **98** of the haptic feedback device **14** to pulse, indicating to the operator of the ultrasound probe **14** to move the ultrasound probe **15** toward the back side **56** of the haptic feedback device **14** in the direction of the pulses. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **6**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **15** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0060] The opposite vibration pattern may be used to guide movement of the ultrasound probe **14** in the opposite direction (e.g., forward) away from the operator and toward a front side **100** (e.g., side opposite the back side) of the haptic feedback device **14** along the Y-axis **78**. That is, the haptic guidance system **12** may cause the vibration actuators **40** on a front half **102** of the haptic feedback device **14** to pulse, indicating to the operator of the ultrasound probe **15** to move the ultrasound probe **15** forward toward the front side **100** of the haptic feedback device **14** in the direction of the pulses. 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 **15** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0061] Similar vibration patterns may be used to guide compression and decompression of the ultrasound probe **15** along the axial axis **62** (e.g., Z-axis), as illustrated in FIG. **8**. As used herein, the term “compression” may refer to applying pressure to the ultrasound probe **15** such that the ultrasound probe **15** moves toward the tissue of the patient **22**, and the term “decompression” may refer to applying less pressure to the ultrasound probe **15** such that the ultrasound probe **15** is moved in a direction away from the tissue of the patient **22**. For example, the illustrated vibration pattern may be used with the haptic feedback device **14** to guide compression movement of the ultrasound probe **15** toward the tissue of the patient **22** and toward the patient-facing surface **54** of the haptic feedback device **14**. The haptic guidance system **12**, in some embodiments, may cause the vibration actuators **40** on the patient-facing surface **54** of the haptic feedback device **14** to pulse, indicating to the operator of the ultrasound probe **15** to move the ultrasound probe **15** toward the tissue of the patient **22** in the direction of the pulses. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **6**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **15** to the appropriate position to sufficiently image the desired anatomy in the desired scan plane.

[0062] The opposite vibration pattern may be used with the haptic feedback device **14** to guide decompression movement of the ultrasound probe **15** in the opposite direction away from the tissue of the patient **22** and toward a non-patient-facing surface **55** (e.g., surface opposite the patient-facing surface). That is, the haptic guidance system **12** may cause the vibration actuators **40** on the non-patient-facing surface **55** of the haptic feedback device **14** to pulse, indicating to the operator of the ultrasound probe **15** to move the ultrasound probe **15** away from the tissue of the patient **22** in the direction of the pulses. 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 **15** to the appropriate position to sufficiently image the target anatomy in the target scan plane.

[0063] To guide orientation of the patient-facing surface of the ultrasound probe **15**, and thus the transducer array **18**, within the three other degrees-of-freedom via the haptic feedback device **14**, circular vibration patterns may be used, which the operator may follow to adjust the orientation of the ultrasound probe **15** into a desired orientation. For example, FIG. **9** illustrates an embodiment of a vibration pattern that may be used with the haptic feedback device **14** to guide a tilting movement of the ultrasound probe **15** forward or backward along the elevation direction to increase or decrease the elevation angle **80**. As such, the illustrated vibration pattern may be used with the haptic feedback device **14** to guide a tilting movement of the ultrasound probe **15** such that the front side of the ultrasound probe **15** 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 of the ultrasound probe **15** and the patient **22**).

[0064] In the illustrated embodiment, the vibration pattern may be used with the haptic feedback device **14** to guide a tilting movement of the ultrasound probe **15** forward, thus decreasing the elevation angle **80** between the patient **22** and the front side of the ultrasound probe **15**. In some embodiments, the haptic guidance system **12** may send a signal to the haptic feedback device **14** to cause a vibration actuator **40** of the back half **98** of the non-patient-facing surface **55** to pulse, then cause a vibration actuator of the front half **102** of the non-patient facing surface **55** to pulse, then cause a vibration actuator **40** of the front half **102** of the patient-facing surface **54** to pulse, and then cause a vibration actuator **40** of the back half **98** of the patient-facing surface **54** to pulse, thus creating a circular vibration pattern.

[0065] In this manner, the circular vibration pattern may rotate around an axis **130** of the haptic feedback device **14** extending from the second side **88** to the first side **58** of the haptic feedback device **14**. This circular pattern may indicate to the operator to follow the circular pattern to tilt the handle of the ultrasound probe **15** to decrease the elevation angle **80** between the front side of the ultrasound probe **15** and the patient **22**, and thus cause the patient-facing surface **57** of the ultrasound probe **15** to tilt forward. In some embodiments, the pulse length, pulse repetition rate, and/or pulse intensity may vary, as discussed above with reference to FIG. **6**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **15** to the appropriate orientation to sufficiently image the desired anatomy in the desired scan plane.

[0066] The opposite vibration pattern may be used to guide a tilting movement of the handle of the ultrasound probe **15** backward, thus increasing the elevation angle **80** between the patient **22** and the front side of the ultrasound probe **15**. In some embodiments, the haptic guidance system **12** may send a signal to the haptic feedback device **14** to cause a vibration actuator **40** of the front half **102** of the non-patient facing surface **55** to pulse, then cause a vibration actuator **40** of the back half **98** of the non-patient facing surface **55** to pulse, then cause a vibration actuator **40** of the back half **98** of the patient-facing surface **54** to pulse, then cause a vibration actuator **40** of the front half **102** of the patient-facing surface **54** to pulse, thus creating a circular vibration pattern.

[0067] In this manner, the circular vibration pattern may rotate in the opposite direction around the axis **130** of the haptic feedback device **14** extending from the second side **88** to the first side **58** of the haptic feedback device **14**. This circular pattern may indicate to the operator to follow the circular pattern to tilt the handle of the ultrasound probe **15** to increase the elevation angle **80** between the front side of the ultrasound probe **15** and the patient **22**, and thus cause the patient-facing surface **57** of the ultrasound probe **15** to tilt backward. 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 **15** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0068] Similarly, FIG. **10** illustrates an embodiment of a vibration pattern that may be used to guide rocking movement of the ultrasound probe **15** 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 of the ultrasound probe **15** toward the first direction (e.g., right) such that that first side **58** is moved closer to the tissue of the patient **22**, thus decreasing the azimuth angle **82** between the axial axis **62** and the X-axis **76** (e.g., between the first side of the ultrasound probe **15** and the patient **22**). In some embodiments, the haptic guidance system **12** may cause the vibration actuators **40** of the upper row of the second half **86** of the haptic feedback device **14** to pulse, then cause the vibration actuators **40** of the non-patient-facing surface **55** of the haptic feedback device **14** to pulse, then the vibration actuators **40** of the upper row of the first half **86** of the haptic feedback device **14** to pulse, then cause the vibration actuators **40** of the lower row of the first half **86** of the haptic feedback device **14** to pulse, and then cause the vibration actuators **40** of the patient-facing surface **54** to pulse, and then cause the vibration actuators **40** of the lower row of the second half **86** of the haptic feedback device **14** to pulse, thus creating a circular vibration pattern.

[0069] In this manner, the circular vibration pattern may rotate around the Y-axis **78** of the haptic feedback device **14** extending from the front half **102** to the back half **98** of the haptic feedback device **14**. This circular pattern may indicate to the operator to rock the handle of the ultrasound probe **15** toward the first direction to decrease the azimuth angle **82** between the first side of the ultrasound probe **15** and the patient **22**, and thus cause the patient-facing surface **57** of the ultrasound probe **15** 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. **6**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **15** to the appropriate orientation to sufficiently image the desired anatomy in the desired scan plane.

[0070] The opposite vibration pattern may be used to guide rocking movement of the handle the ultrasound probe **15** in the opposite direction toward the second direction (e.g. left), thus increasing the azimuth angle **82** between the first side of the ultrasound probe **15** and the patient **22** and decreasing the azimuth angle **82** between the second side of the ultrasound probe **15** and the patient **22**. That is, the haptic guidance system **12** may cause the vibration actuators **40** of the non-patient-facing surface **55** of the haptic feedback device **14** to pulse, the vibration actuators **40** of the upper row of the second half **86** of the haptic feedback device **14** to pulse, then cause the vibration actuators **40** of the lower row of the second half **86** of the haptic feedback device **14** to pulse, then cause the vibration actuators **40** of the patient-facing surface **54** to pulse, then cause the vibration actuators **40** of the lower row of the first half **86** of the haptic feedback device **14** to pulse, then cause the vibration actuators **40** of the upper row of the first half **86** of the haptic feedback device **14** to pulse, thus creating a circular vibration pattern.

[0071] In this manner, the circular vibration pattern may rotate around the Y-axis **78** of the haptic feedback device **14** extending from the front half **102** to the back half **98** of the haptic feedback device **14**. As discussed above, the pulse speed and/or intensity may be varied as the ultrasound probe **15** 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 **15** to the appropriate orientation to sufficiently image the desired anatomy in the desired scan plane.

[0072] To cause a rotational motion of the ultrasound probe **15** 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**. In some embodiments, the haptic guidance system **12** may send a signal to the haptic feedback device **14** to cause a back set of axially aligned vibration actuators **40** (e.g., a vibration actuator **40** in the lower row aligned with a vibration actuator in the upper row) of the second half **86** of the haptic feedback device **14** to pulse, then cause a back set of axially aligned vibration actuators **40** of the first half **84** of the haptic feedback device **14** to pulse, then cause a front set of axially aligned vibration actuators **40** of the first half **84** of the haptic feedback device **14** to pulse, then cause a front set of axially aligned vibration actuators **40** of the second half **86** of the haptic feedback device **14** to pulse, thus creating a circular vibration pattern in the clockwise direction. The operator may follow the pattern of the vibration to rotate the ultrasound probe **15**, and thus the patient-facing surface **57** of the ultrasound probe **15**, clockwise about the axial axis **62**. In this manner, the circular vibration pattern may rotate around the axial axis **62** (e.g., Z-axis) of the ultrasound probe **15**.

[0073] The opposite vibration pattern, may be used to guide rotational movement of the ultrasound probe **15** counterclockwise about the axial axis **62**. For example, the haptic guidance system may send a signal to the haptic feedback device **14** to cause a back set of axially aligned actuators **40** of the second half **86** of the haptic feedback device **14** to pulse, then cause a front set of axially aligned actuators of the second half **86** of the haptic feedback device **14** to pulse, then cause a front set of axially aligned actuators **40** of the first half of the haptic feedback device **14** to pulse, then cause a back set of axially aligned actuators **40** of the first half of the haptic feedback device **14** to pulse, thus creating a circular vibrational pattern in the counter-clockwise direction. The operator may follow the pattern of the vibration to rotate the ultrasound probe **15**, and thus the patient-facing surface **57** of the ultrasound probe **15**, counter-clockwise 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. **6**, to indicate a distance from and/or to guide a speed of the movement of the ultrasound probe **15** to the appropriate orientation to sufficiently image the target anatomy in the target scan plane.

[0074] The examples discussed above are vibration patterns that may be used with the haptic feedback device **14** to guide the operator to position and/or orient the ultrasound probe **15** to capture the desired scan plane of the desired anatomy. The examples 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 **15**. For example, the example vibration patterns discussed above may be implemented spatially on the haptic feedback device **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 haptic feedback device **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 haptic feedback device **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 haptic feedback device **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 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. **6-11** to convey suggested movement of the ultrasound probe **15** to guide the operator to move the probe to the appropriate position and orientation to image the desired anatomy in the desired scan plane, as different operators may be more receptive to different vibration pattern types.

[0075] Further, as described above, the ultrasound imaging system **10** may determine the grip style of the operator's hand **51** on the ultrasound probe **15**. For example, the ultrasound imaging system **10** may determine that the operator is holding the ultrasound probe **15** in the hand **51** of the operator with a pen-like grip, a hammer grip, or the like. The ultrasound imaging system **10** may then send a signal to the haptic guidance system **12** indicative of the grip style determination such that the haptic guidance system **12** may provide corresponding vibrational feedback to the operator based on the determined grip style. In some embodiments, vibrational feedback provided to the operator via the haptic feedback device **14** is different based the grip style used by the operator on the ultrasound probe **15**. For example, the haptic guidance system **12** may adjust the particular vibrational actuators **40** that pulse based on the grip style used by the operator such that the operator may discern a command to move and/or orient the ultrasound probe **15** regardless of which grip style used.

[0076] With the foregoing in mind, FIG. **12** illustrates a flow chart of a method **150** for guiding movement of the ultrasound probe **15** via the haptic feedback device **14** to position the ultrasound probe **15** in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. Although the following description of the method **150** is described in a particular order, it should be noted that the method **150** is not limited to the depicted order, and instead, the method **150** may be performed in any suitable order. Moreover, although the method **150** is described as being performed by the controller **24** of the haptic guidance system **12**, it should be noted that it may be performed by any suitable computing device.

[0077] At step **152**, the controller **24** of the haptic guidance system **12** may receive the desired anatomy and/or the desired scan plane to be imaged. For example, the desired anatomy in the desired scan plane may be a user input via the haptic guidance system **12**. At step **154**, the controller **24**

may receive position and/or orientation data of the patient **22** via the patient position sensor **33**. That is, the controller **24** may receive one or more signals from the patient position sensor **33** indicative of the position of the patient **22** about the imaging space **35**. Additionally or alternatively, the position of the patient **22** may be determined based on live ultrasound image data acquired via the ultrasound probe **15**. At step **156**, the controller **24** may determine and map a patient-centric coordinate system based at least in part on the received patient position. For example, the patient-centric coordinate system may include an anatomical atlas of the patient **22** that may be mapped to anatomy of the patient **22**. In one embodiment, the patient-centric coordinate system for the patient **22** may be saved in the memory **32**. In another embodiment, this saved coordinate system may be updated based on the current position of the patient **22**. At step **158**, the controller **24** may determine the appropriate position and/or orientation of the ultrasound probe **15** based at least in part on the desired anatomy, the desired scan plane, the patient-centric coordinate system, and/or live ultrasound image data of the patient **22**. In some embodiments, the desired anatomy and/or the desired scan plane in a set of live ultrasound image data may be identified, and an appropriate ultrasound probe position may derive a desired ultrasound probe position and/or orientation to acquire the desired anatomy and/or the desired scan plane in subsequently acquired ultrasound image data.

[0078] At step **160**, the controller **24** may receive current position data and/or orientation data associated with the ultrasound probe **15** from the probe position sensor **36**. In some embodiments, the controller **24** may receive current position data and/or orientation data associated with the ultrasound probe **15**, live ultrasound image data acquired via the ultrasound probe **15**, or both. As described herein, the controller **24** may use the live ultrasound image data to determine whether the ultrasound probe **15** is in the appropriate position and/or orientation to acquire imaging data of the desired anatomy in the desired scan plane of the patient **22**.

[0079] At step **162**, the controller **24** may also receive current position data and/or orientation data associated with the haptic feedback device **14** from the haptic feedback device position sensor **37**. For example, the controller **24** may receive position data and/or orientation data from one or more inertial measurement units, one or more gyroscopes, one or more magnetometers, or the like, associated with the haptic feedback device **14**.

[0080] After receiving current position data and/or orientation data of the ultrasound probe **15**, the haptic feedback device **14**, or both, at step **164**, the controller **24** may determine a grip style used by the operator to maneuver or hold the ultrasound probe **15** with the hand of the operator. As described herein, for example, the position and/or orientation data of the ultrasound probe **15** may include a plurality of probe reference points (e.g., x-coordinate, y-coordinate, z-coordinate) relative to the imaging space **35**, and the position and/or orientation data of the haptic feedback device **14** may include a plurality haptic feedback device reference points (e.g., x-coordinate, y-coordinate, z-coordinate) relative to the imaging space **35**. The controller **24** may compare the relative positions of the probe reference points and the haptic feedback device reference points in the imaging space **35** to lookup tables stored in the memory **32** to determine the grip style used by the operator on the ultrasound probe **15**.

[0081] After determining the grip style used by the operator with the ultrasound probe **15**, the controller **24** may determine whether the position and/or orientation of the ultrasound probe **15** corresponds to the appropriate position and/or orientation to image the desired anatomy in the desired scan plane at step **166**. In some embodiments, the controller may determine whether the position and/or orientation of the ultrasound probe **15** correspond to the appropriate position and/or orientation based at least in part on the patient-centric coordinate system, the position data and/or the orientation data of the ultrasound probe **15**, live ultrasound imaging data, the position data and/or the orientation data of the haptic feedback device **14**, or a combination thereof

[0082] For example, the controller **24** may use the position data and/or orientation data of the ultrasound probe **15**, the position data and/or orientation data of the haptic feedback device **14**, and/or live ultrasound image data captured by the ultrasound probe **15** as feedback to determine whether the ultrasound probe **15** is in the appropriate position and/or orientation to acquire ultrasound imaging data of the desired anatomy in the desired scan plane. If the controller **24** determines that the ultrasound probe **15** is in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane, the method **150** may continue to step **168** in which the controller **24** may send a signal to the vibration actuators **40** of the haptic feedback device **14** to pulse at a particular pulse pattern indicating that the ultrasound probe **15** is in the appropriate position and/or orientation to the operator. In some embodiments, the controller **24** may cause display of a notification, such as a visual or audible notification in addition to providing vibrational feedback to the operator. Additionally or alternatively, the controller **24** may cause automatic storage of the live ultrasound image data in the memory **32** of the ultrasound imaging system **10** after the controller **24** has determined that the ultrasound probe **15** is in the appropriate position and/or orientation.

[0083] Referring back to step **166**, if the controller **24** determines that the ultrasound probe **15** is not in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane, the controller **24** may send a signal to the vibration actuators **40** of the haptic feedback device **14** to pulse at one or more vibration patterns indicative of one or more movements of the ultrasound probe **15** to position and/or orient the ultrasound probe **15** in the appropriate position at step **170**. For example, the controller **24** may send a signal indicative of one or more vibration patterns as described herein with regard to FIGS. **6-11**. The controller **24** may determine which vibration patterns to provide to the operator via the haptic feedback device **14** based at least in part on the patient-centric coordinate system, the position and/or orientation of the ultrasound probe **15**, live ultrasound image data, the position and/or orientation of the haptic feedback device **14**, the grip style used by the operator, or a combination thereof.

[0084] The vibration pattern provided to the operator via the haptic feedback device **14** may indicate to the operator of the ultrasound probe **15** to move the ultrasound in a particular direction or manner to achieve the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. The controller **24** may then continue to repeat steps **160**, **162**, **164**, **166**, and **170** until the controller **24** determines that the ultrasound probe **15** is in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane. After determining that the ultrasound probe **15** is in the appropriate position and/or orientation to sufficiently image the desired anatomy in the desired scan plane, the method **150** may proceed to step **168**, as described herein.

[0085] The haptic guidance system **12** disclosed provides positioning guidance of the ultrasound probe **15** 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 **22**. Additionally, an array of vibration actuators **40** associated with a haptic feedback device **14** may facilitate operator guidance of the ultrasound probe **15** in all six degrees-of-freedom and may accommodate multiple grip styles. In some embodiments, the haptic feedback device **14** may be worn by the operator such that the operator may discern vibration feedback from the haptic feedback device **14** in response to the current position and/or orientation of the ultrasound probe in relation to the desired anatomy and/or the desired scan plane to be imaged. 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 desired anatomy in the desired scan plane.

[0086] 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;

a monitor comprising a memory and a processor, wherein the processor is communicatively coupled to the ultrasound probe and a haptic feedback device comprising a plurality of haptic actuators, and the processor is configured to:

determine a current position of the ultrasound probe relative to a region of interest of a patient, wherein the region of interest comprises a desired anatomy, a desired scan plane, or both, to be imaged via the ultrasound probe;

determine whether the current position of the ultrasound probe corresponds to a desired position of the ultrasound probe relative to the region of interest, wherein the desired position of the ultrasound probe facilitates an acquisition of an ultrasound image of the region of interest; and

in response to determining that the current position of the ultrasound probe does not correspond to the desired position of the ultrasound probe, transmitting a control signal to the plurality of haptic actuators, wherein the control signal causes the plurality of haptic actuators to activate in an actuation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the desired position.

2. The ultrasound imaging system of claim **1**, wherein the haptic feedback device is configured to be worn an operator of the ultrasound probe about a body part of the operator.

3. The ultrasound imaging system of claim **1**, wherein the processor is configured to determine a current orientation of the ultrasound probe and a current orientation of the haptic feedback device, and determine a grip style used by an operator of the ultrasound probe based on the current orientation of the ultrasound probe and the current orientation of the haptic feedback device.

4. The ultrasound imaging system of claim **3**, wherein the processor is configured to determine the actuation pattern based on the grip style used by the operator of the ultrasound probe, and wherein transmitting the control signal to the plurality of haptic actuators is based on the determined actuation pattern.

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

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

7. The ultrasound imaging system of claim **6**, wherein the one or more suggested movements comprise a directional movement, a rotational movement, a tilting movement, a compression, a decompression, or a combination thereof.

8. The ultrasound imaging system of claim **1**, wherein the processor is configured to:

determine an additional current position of the ultrasound probe relative to the region of interest after the ultrasound probe has been moved from the current position;

determine whether the additional current position of the ultrasound probe corresponds to the desired position of the ultrasound probe; and

transmit an additional control signal to the plurality of haptic actuators in response to determining that the additional current position of the ultrasound probe corresponds to the desired position of the ultrasound probe, and wherein the control signal causes the plurality of vibrational actuators to actuate in an additional actuation pattern indicative of the determination that the additional current position corresponds to the desired position.

9. A wearable device for providing ultrasound guidance feedback, comprising:

a housing comprising a plurality of haptic actuators; and

an opening extending along an axis through the housing, wherein the opening is configured to fit about a body part of an operator of an ultrasound probe, and wherein the haptic actuators are configured to pulse in an actuation pattern indicative of one or more suggested movements of the ultrasound probe to position the ultrasound probe in a desired position to acquire imaging data of a region of interest of a patient.

10. The wearable device of claim **9**, wherein the body part of the operator is a hand of the operator, and the wearable device is a glove or a band configured to fit about the hand of the operator.

11. The wearable device of claim **9**, wherein the haptic feedback device comprises one or more accelerometers, one or more gyroscopes, one or more magnetometers, one or more inertial measurement units, or a combination thereof.

12. The wearable device of claim **9**, wherein the plurality of haptic actuators are disposed above the surface of the housing, below the surface of the housing, or embedded within the housing.

13. The wearable device of claim **9**, wherein the plurality of haptic actuators comprise a plurality of axially aligned rows of haptic actuators that are spatially disposed about the circumference of the housing.

14. The wearable device of claim **9**, wherein the actuation pattern is indicative of 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 desired position.

15. The wearable device of claim **9**, wherein the actuation pattern is indicative of suggested movement of the ultrasound probe:

relative to an elevation angle and an azimuth angle to orient a patient-facing surface of the ultrasound probe relative to the patient; or

circumferentially about an axial axis of the ultrasound probe.

16. A method, comprising:

determining, via a processor, a desired imaging position of the ultrasound probe based at least in part on the region of interest and the desired scan plane, wherein the desired imaging position facilitates an acquisition of an ultrasound image of the region of interest, the desired scan plane, or both;

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

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

in response to determining that the current position of the ultrasound probe does not correspond to the desired imaging position of the ultrasound probe, transmitting, via the processor, a control signal to a plurality of haptic actuators disposed about a haptic feedback device configured to be worn by an operator of the ultrasound probe, wherein the control signal causes the plurality of haptic actuators to pulse in an actuation pattern indicative of a suggested movement of the ultrasound probe to position the ultrasound probe in the desired imaging position.

17. The method of claim **16**, comprising determining, via the processor, a current orientation of the ultrasound probe and a current orientation of the haptic feedback device, and determining, via the processor, a grip style used by the operator of the ultrasound probe based on the current orientation of the ultrasound probe and the current orientation of the haptic feedback device.

18. The method of claim **17**, comprising determining, via the processor, the actuation pattern based on the grip style used by the operator of the ultrasound probe, and wherein transmitting the control signal to the plurality of haptic actuators is based on the determined actuation pattern.

19. The method of claim **16**, comprising transmitting an additional control signal to the plurality of haptic actuators in response to determining that the current position of the ultrasound probe corresponds to the desired imaging position of the ultrasound probe, and wherein the additional control signal causes the plurality of haptic actuators to pulse in an additional actuation pattern indicative of the determination that the current position corresponds to the desired position.

20. The method of claim **16**, wherein each haptic actuator of the plurality of haptic actuators comprise a vibration actuator, the actuation pattern comprises a plurality of actuation patterns indicative of respective suggested movements of the ultrasound probe in six degrees-of-freedom, and the plurality of actuation patterns modulate in intensity, speed, or both, as the ultrasound probe is moved a distance from the desired imaging position.

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专利名称(译)	使用触觉反馈设备进行超声探头导航		
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摘要(译)

用于提供超声引导反馈的可穿戴设备可以包括:壳体,其具有多个触觉致动器;以及开口,该开口沿着穿过壳体的轴线延伸。 所述开口可以围绕超声探头的操作者的身体部位,并且触觉致动器可以以指示超声探头的一个或多个建议运动的致动模式脉动,以将超声探头定位在期望的位置以获取成像数据。 患者感兴趣区域的轮廓。