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(54) SYSTEM AND METHODS FOR AT-HOME ULTRASOUND IMAGING

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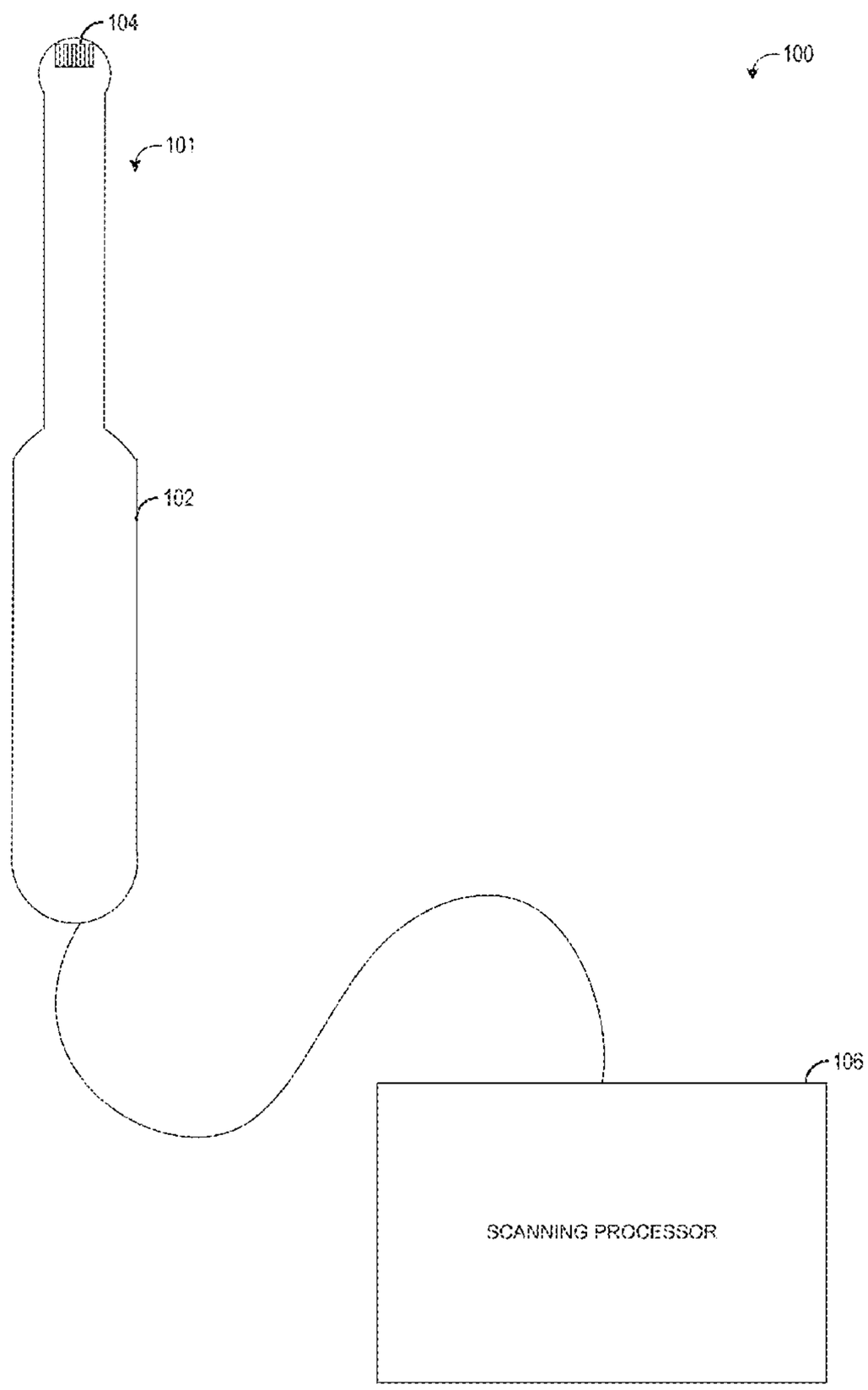
(57) **ABSTRACT**

Various methods and systems are provided for a guided at-home ultrasound imaging session. In one example, a system for ultrasonically scanning a tissue sample includes a hand-held ultrasound probe including a transducer array of transducer elements, a probe position tracking device including one or more position sensors coupled to the ultrasound probe, and a controller. The controller is configured to, during an imaging session, determine a position of the ultrasound probe relative to a target position based on position data collected by the probe position tracking device, and responsive to an indication that the ultrasound probe is at the target position, acquire image data with the transducer array.



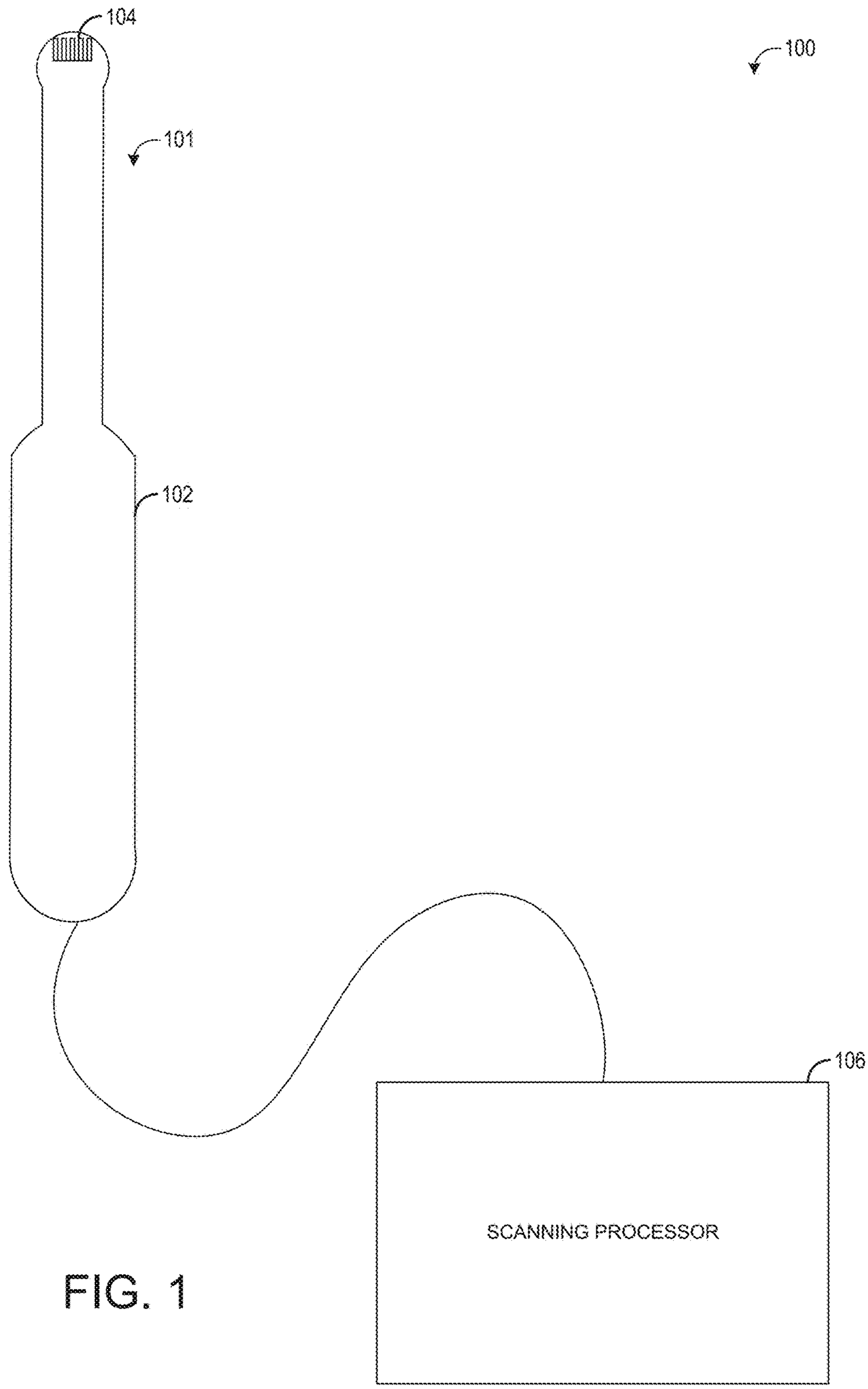


FIG. 1

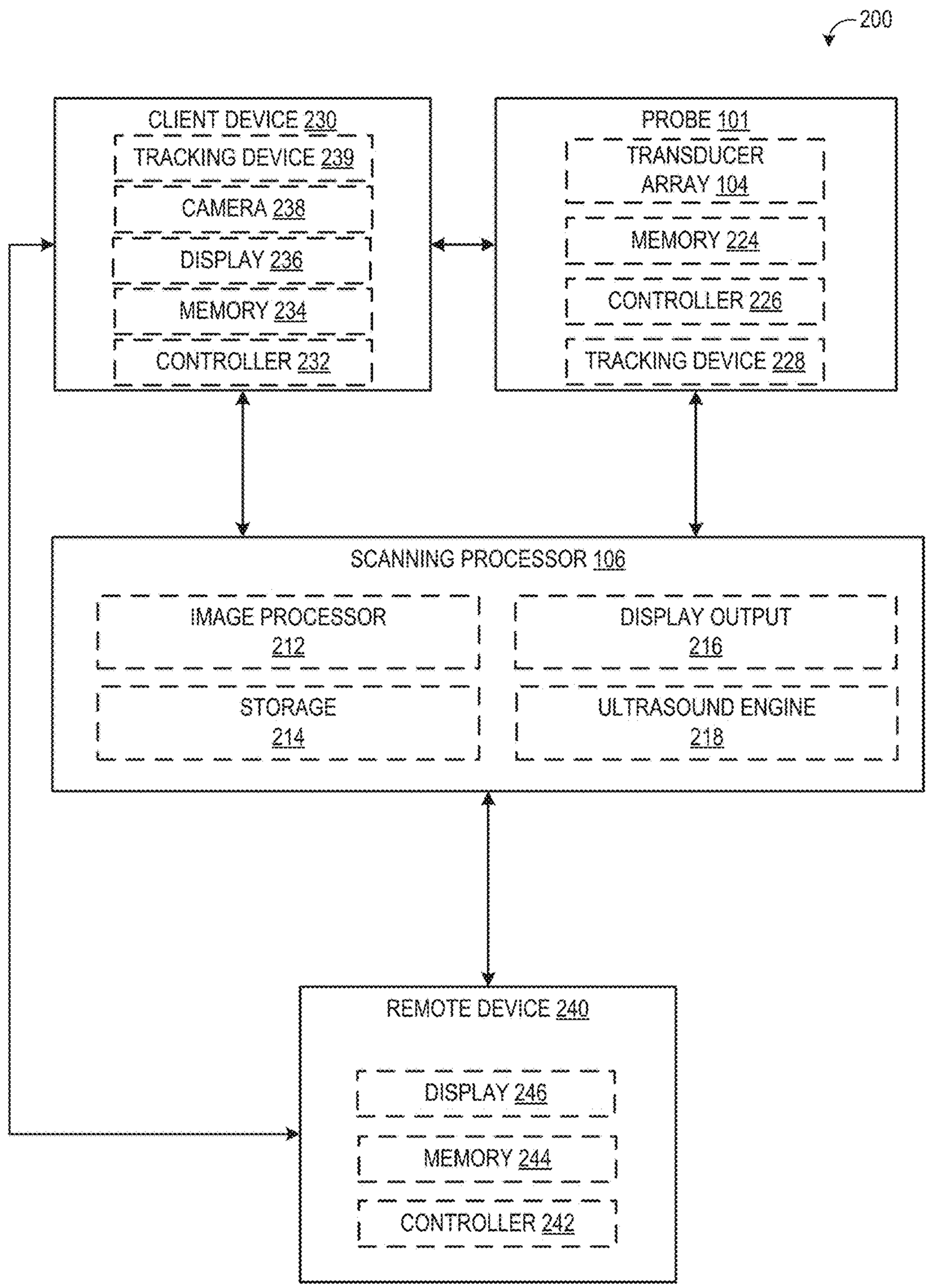

200
CLIENT DEVICE 230
TRACKING DEVICE 239
CAMERA 238
DISPLAY 236
MEMORY 234
CONTROLLER 232
PROBE 101
TRANSDUCER ARRAY 104
MEMORY 224
CONTROLLER 226
TRACKING DEVICE 228
SCANNING PROCESSOR 106
IMAGE PROCESSOR 212
DISPLAY OUTPUT 216
STORAGE 214
ULTRASOUND ENGINE 218
REMOTE DEVICE 240
DISPLAY 246
MEMORY 244
CONTROLLER 242

FIG. 2

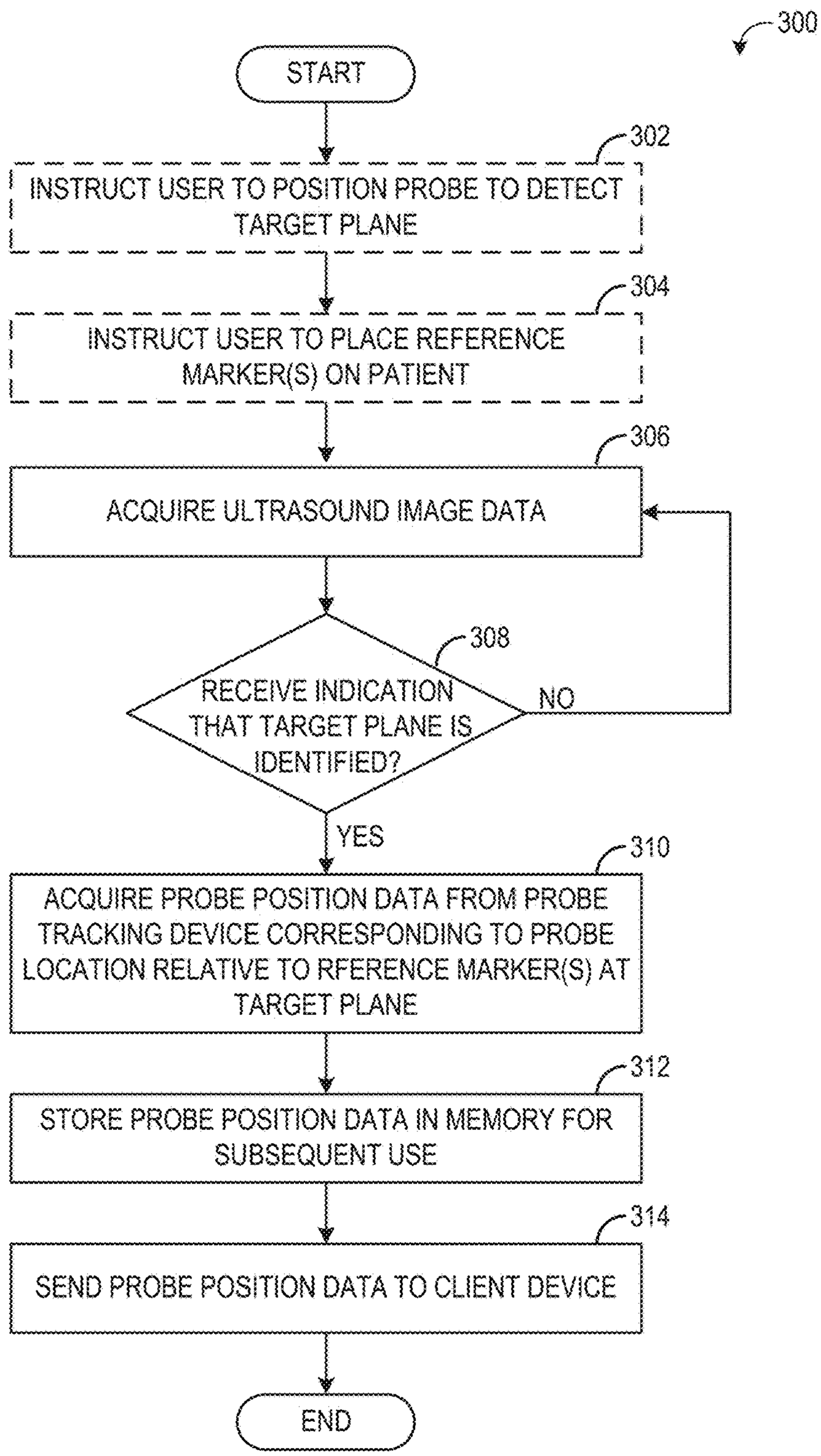

300
START
302
INSTRUCT USER TO POSITION PROBE TO DETECT TARGET PLANE
304
INSTRUCT USER TO PLACE REFERENCE MARKER(S) ON PATIENT
306
ACQUIRE ULTRASOUND IMAGE DATA
308
RECEIVE INDICATION THAT TARGET PLANE IS IDENTIFIED?
NO
YES
310
ACQUIRE PROBE POSITION DATA FROM PROBE TRACKING DEVICE CORRESPONDING TO PROBE LOCATION RELATIVE TO RFERENCE MARKER(S) AT TARGET PLANE
312
STORE PROBE POSITION DATA IN MEMORY FOR SUBSEQUENT USE
314
SEND PROBE POSITION DATA TO CLIENT DEVICE
END

FIG. 3

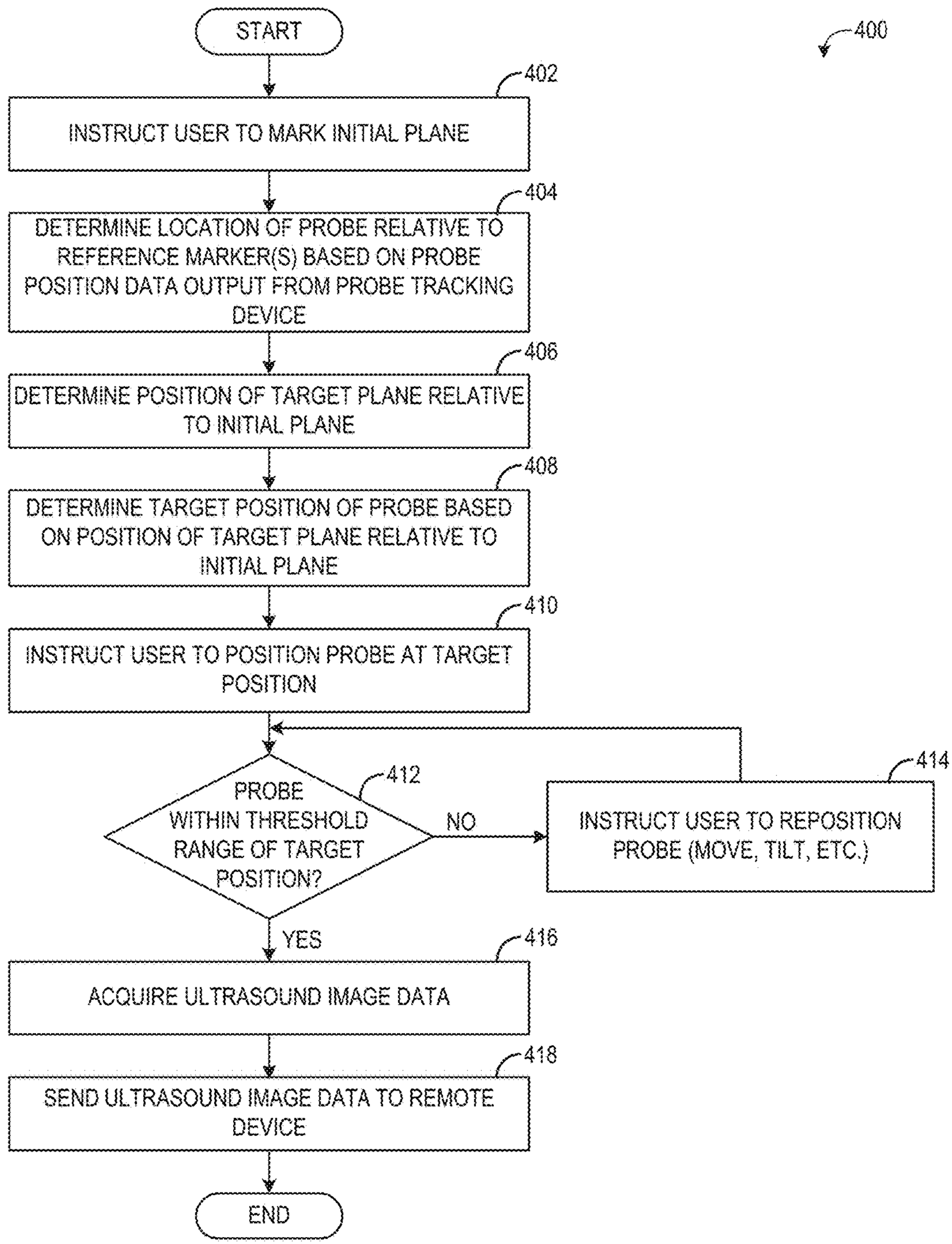

400
START
402
INSTRUCT USER TO MARK INITIAL PLANE
404
DETERMINE LOCATION OF PROBE RELATIVE TO REFERENCE MARKER(S) BASED ON PROBE POSITION DATA OUTPUT FROM PROBE TRACKING DEVICE
406
DETERMINE POSITION OF TARGET PLANE RELATIVE TO INITIAL PLANE
408
DETERMINE TARGET POSITION OF PROBE BASED ON POSITION OF TARGET PLANE RELATIVE TO INITIAL PLANE
410
INSTRUCT USER TO POSITION PROBE AT TARGET POSITION
412
PROBE WITHIN THRESHOLD RANGE OF TARGET POSITION?
NO
414
INSTRUCT USER TO REPOSITION PROBE (MOVE, TILT, ETC.)
YES
416
ACQUIRE ULTRASOUND IMAGE DATA
418
SEND ULTRASOUND IMAGE DATA TO REMOTE DEVICE
END

FIG. 4

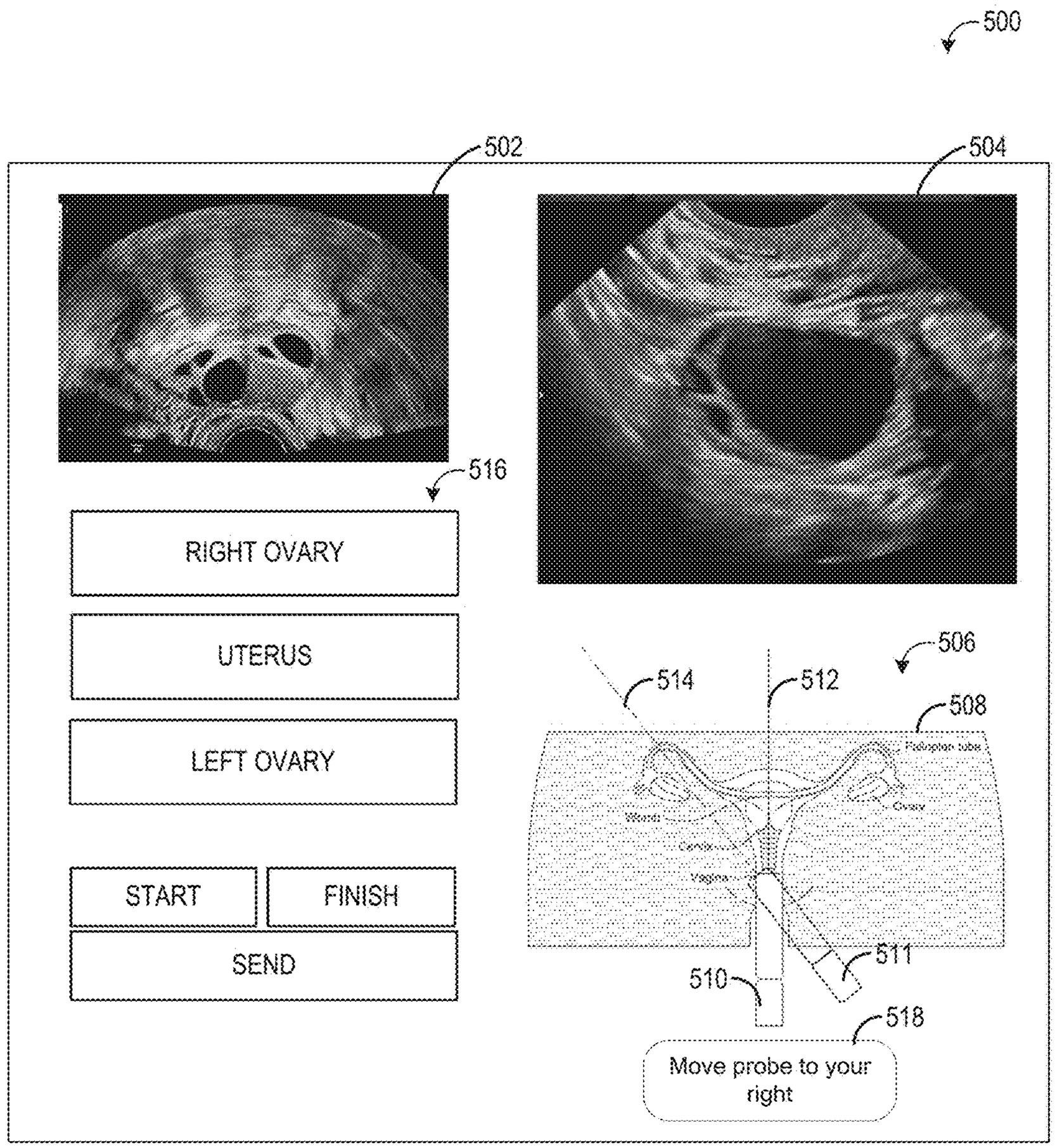

500
502
504
516
RIGHT OVARY
UTERUS
LEFT OVARY
START
FINISH
SEND
506
514
512
508
Fallopian tube
Ovary
Uterus
Cervix
Vagina
511
510
518
Move probe to your right

FIG. 5

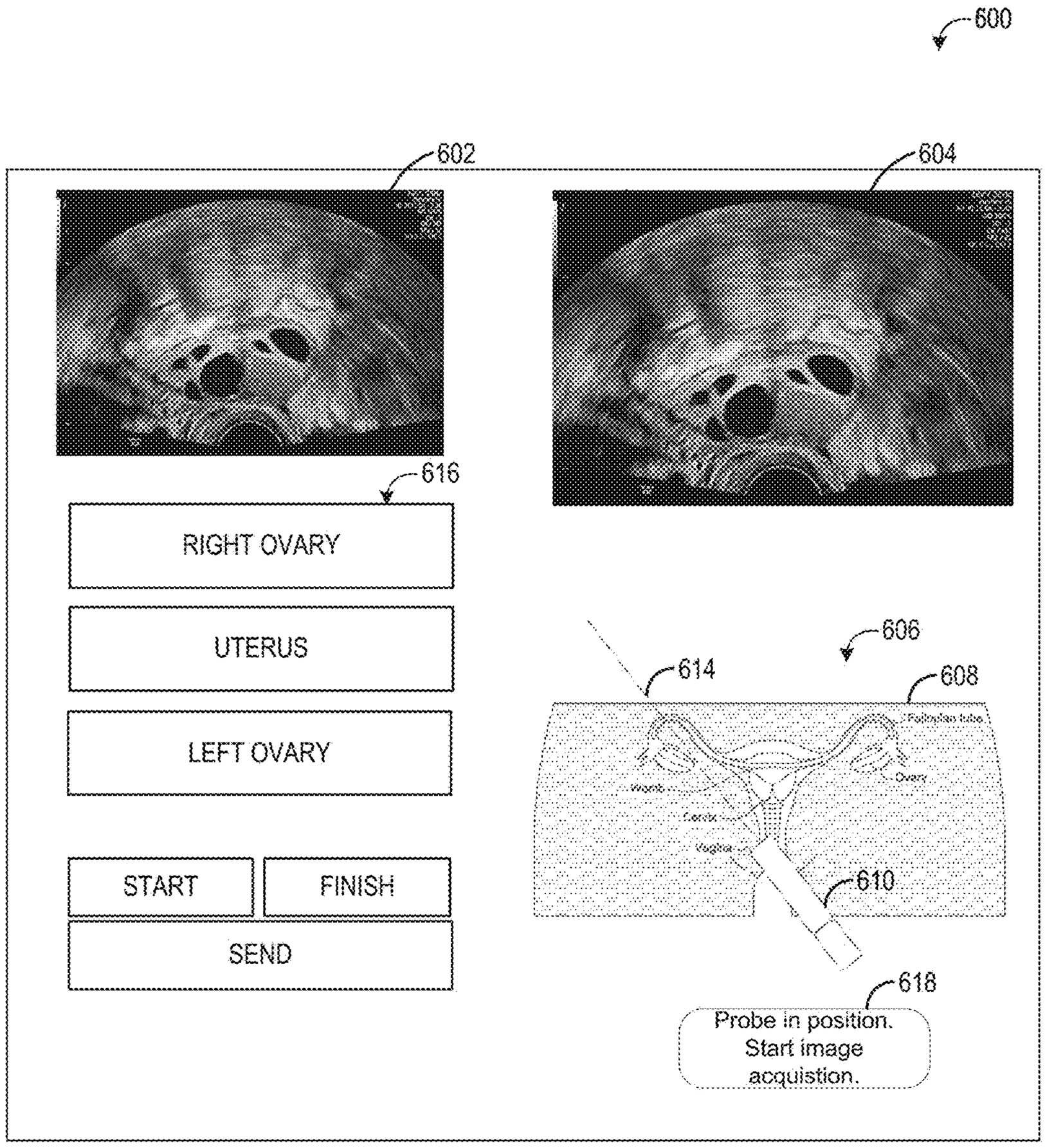

600
602
604
616
RIGHT OVARY
UTERUS
LEFT OVARY
START
FINISH
SEND
606
614
608
610
618
Probe in position.
Start image
acquistion.

FIG. 6

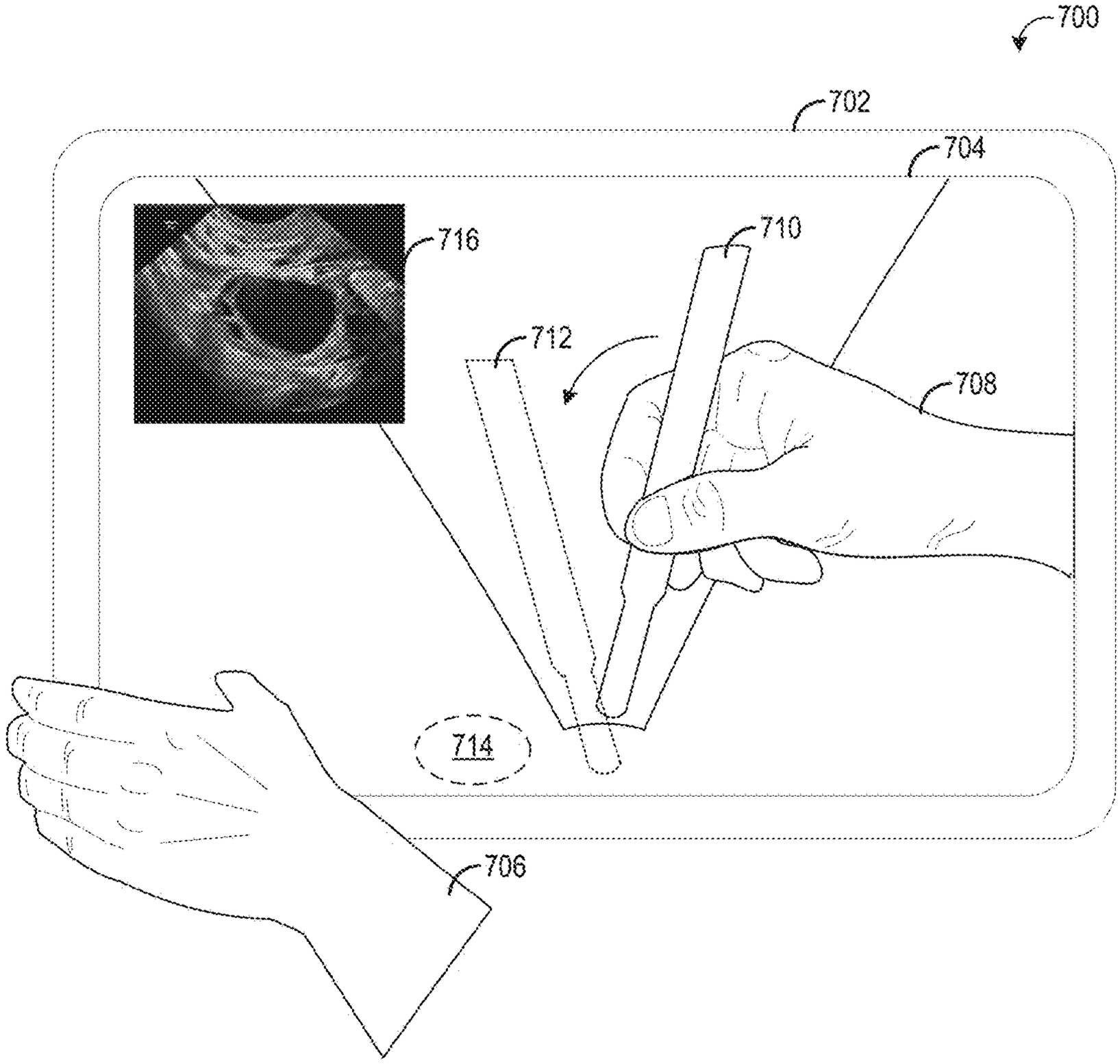


FIG. 7

SYSTEM AND METHODS FOR AT-HOME ULTRASOUND IMAGING

FIELD

[0001] Embodiments of the subject matter disclosed herein relate to medical imaging and the facilitation of ultrasonic tissue scanning.

BACKGROUND

[0002] Certain medical procedures, such as in vitro fertilization, may include multiple, frequent medical imaging sessions in order to monitor the progress of the procedure. These frequent medical imaging sessions may place a burden on the patient.

BRIEF DESCRIPTION

[0003] In one embodiment, a system for ultrasonically scanning a tissue sample includes a hand-held ultrasound probe comprising a transducer array of transducer elements, a probe position tracking device including one or more position sensors coupled to the ultrasound probe, and a controller. The controller is configured to, during an imaging session, determine a position of the ultrasound probe relative to a target position based on position sensor data collected by the one or more position sensors during an imaging session, and responsive to an indication that the ultrasound probe is at the target position, acquire image data with the transducer array.

[0004] In this way, the position sensor data may be used to identify the current position of the probe relative to a target position. In one example, the target position of the probe may be a position at which the probe can acquire image data in a target scan plane. Further, in some examples, if the probe is not currently positioned at the target position, feedback may be provided to a user to move the probe to the target position, and then image data may be acquired. This configuration may assist non-clinical users in performing at-home ultrasound imaging, thus reducing the number of in-clinic medical imaging sessions.

[0005] It should be understood that the brief description above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0007] FIG. **1** shows an example of an ultrasound imaging system according to an embodiment of the invention;

[0008] FIG. **2** shows an example schematic of various system components of an ultrasound imaging system according to an embodiment of the invention;

[0009] FIG. **3** illustrates a method for identifying a target scan plane according to an embodiment of the invention;

[0010] FIG. **4** illustrates a method for at-home ultrasound imaging according to an embodiment of the invention;

[0011] FIGS. **5** and **6** illustrate example user interfaces that may be displayed to an operator during at-home ultrasound imaging according to an embodiment of the invention; and

[0012] FIG. **7** illustrates an example augmented reality user interface that may be displayed to an operator during at-home ultrasound imaging according to an embodiment of the invention.

DETAILED DESCRIPTION

[0013] The following description relates to various embodiments of an at-home ultrasound system, which may be used during in vitro fertilization (IVF) monitoring. The at-home ultrasound system may include a transvaginal (TV) ultrasound probe, such as the probe illustrated in FIG. **1**. In one example, the TV probe may include an ultrasound transducer and a position tracking system that may include one or more position sensors to track the location of the probe, such as the sensors depicted in FIG. **2**. The probe may be used to provide semi-automated at-home ultrasound imaging. For example, the sensor information may be used to instruct an operator to position the probe at one or more target locations during the at-home ultrasound imaging. The image information acquired during the imaging may be used to construct a three-dimensional volume from which images may be generated and sent to a remote computing device (e.g., accessible by a clinician) for evaluation. Example methods for performing semi-automated at-home ultrasound imaging using an ultrasound probe are illustrated in FIGS. **3** and **4**. Example user interfaces that may be displayed to an operator during a semi-automated at-home IVF monitoring are illustrated in FIGS. **5**-**7**.

[0014] In vitro fertilization is an assisted reproductive technology that involves hormonal treatment given to women to trigger their ovaries to produce multiple oocytes. During this treatment, multiple ultrasounds are performed to view the ovaries over a period of time and the acquired ultrasound images may be assessed to determine if the hormonal treatment is working and that the follicles are maturing optimally, and further to identify an optimal time for harvesting of the oocytes. In a typical IVF treatment protocol, a patient may undergo five to six ultrasound imaging sessions over a two-week period. This high frequency of ultrasound imaging sessions may be intrusive and burdensome for the patient, particularly if the patient lives a long distance from a clinic that can perform the ultrasound imaging.

[0015] Thus, according to embodiments disclosed herein, frequent monitoring of a medical procedure via ultrasound imaging, such as IVF hormonal treatment monitoring, may be performed by the patient with an at-home ultrasound system. Using the at-home ultrasound system, the patient may perform the ultrasound imaging at home and then send acquired images to a clinician for evaluation. In order to assist the patient with achieving accurate positioning of the ultrasound probe, and thus consistent and accurate image acquisition of the tissue of interest, the ultrasound probe may be equipped with a position tracking system that can determine the current position of the probe relative to a reference marker placed on the patient during an initial, in-clinic ultrasound exam. Also during the initial, in-clinic ultrasound exam, a clinician may identify one or more target scan planes for image acquisition, and the position of the ultrasound probe (relative to the reference marker) for image

acquisition at each target scan plane may be stored and sent to a client computing device of the at-home ultrasound system. Then, when the patient performs ultrasound imaging at home, the patient may be guided to adjust the position of the ultrasound probe until the probe is positioned at a target position to acquire images in the one or more target scan planes. Once the probe is at the target position, image acquisition may proceed. Generated images may then be sent to a remote device accessible by the clinician for evaluation.

[0016] Although several examples herein are presented in the particular context of human uterus/ovary ultrasound, it is to be appreciated that the present teachings are broadly applicable for facilitating ultrasonic scanning of any human or animal body part (e.g., abdomen, legs, feet, arms, neck, etc.). Moreover, although several examples herein are presented in the particular context of manual/hand-held scanning (e.g., in which the ultrasound probe is moved by an operator), it is to be appreciated that one or more aspects of the present teachings can be advantageously applied in a mechanized scanning context (e.g., a robot arm or other automated or semi-automated mechanism).

[0017] FIG. **1** illustrates an example hand-held ultrasound system **100** that is configured for performing transvaginal ultrasounds. The hand-held ultrasound system **100** includes a transvaginal (TV) probe **101** that includes a housing **102** in which an ultrasound transducer array **104** is positioned. The transducer array is positioned at the scan head and is inserted into the tissue to be scanned, thus producing a sharper image relative to externally-applied probes because of the proximity of the transducer array to the tissue lining. The probe **101** may comprise a position tracking device including one or more position sensors (shown in FIG. **2**) to allow position and orientation sensing for the transducer. Suitable position sensors (e.g., gyroscopic, magnetic, optical, radio frequency (RF)) may be used.

[0018] A fully-functional ultrasound engine for driving an ultrasound transducer and generating volumetric trans-vaginal ultrasound data from the scans in conjunction with the associated position and orientation information may be coupled to the probe, for example the ultrasound engine may include a processor and memory and/or be implemented with a processor and memory. The ultrasound engine may be included as part of a scanning processor **106** coupled to the probe. The volumetric scan data can be transferred to another computer system for further processing using any of a variety of data transfer methods known in the art. A general purpose computer, which can be implemented on the same computer as the ultrasound engine, is also provided for general user interfacing and system control. The ultrasound system may be a self-contained stand-alone unit that may be moved from room to room, such as a cart-based system, a hand-carried system or other portable system. Further the ultrasound system of FIG. **1** may be remotely controlled, configured, and/or monitored by a remote station connected across a network.

[0019] FIG. **2** is a block diagram **200** schematically illustrating various system components of an ultrasound imaging system, including the probe **101**, the scanning processor **106**, a client device **230**, and a remote device **240**. In some embodiments, the scanning processor may be further coupled to a remote department information system, hospital information system, and/or to an internal or external network to allow operators at different locations to supply commands and parameters and/or gain access to image data (as explained in more detail below, remote device **240** is one non-limiting example of one such remote system to which the scanning processor may be coupled).

[0020] Referring first to the probe **101**, the probe **101** comprises the transducer array **104**. As explained above with respect to FIG. **1**, the transducer array may be positioned within the housing, and the housing and transducer array may be configured to be moved manually by an operator during an ultrasound exam. The transducer array may include an array of transducer elements, such as piezoelectric elements, that convert electrical energy into ultrasound waves and then detect the reflected ultrasound waves.

[0021] The probe **101** may further include a memory **224**. Memory **224** may be a non-transitory memory configured to store various parameters of the transducer array **104**, such as transducer position information obtained from a position tracking device **228** of the probe, transducer usage data (e.g., number of scans performed, total amount of time spent scanning, etc.), as well as specification data of the transducer (e.g., number of transducer array elements, array geometry, etc.) and/or identifying information of the probe **101**, such as a serial number of the probe. Memory **224** may include removable and/or permanent devices, and may include optical memory, semiconductor memory, and/or magnetic memory, among others. Memory **224** may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, and/or additional memory. In an example, memory **224** may include RAM. Additionally or alternatively, memory **224** may include EEPROM.

[0022] Memory **224** may store non-transitory instructions executable by a controller or processor, such as controller **226**, to carry out one or more methods or routines as described herein below. Controller **226** may receive output from various sensors of the tracking device **228** and trigger actuation of one or more actuators and/or communicate with one or more components in response to the sensor output. In one example, the tracking device **228** may include one or more position sensors, accelerometers, gyroscopes, pressure sensors, strain gauge sensors, and/or temperature sensors. The tracking device **228** may further include a reference marker detector configured to detect a reference marker positioned on a patient undergoing ultrasound scanning. The reference marker detector may be configured to detect a magnetic reference marker, optical reference marker, or other suitable reference marker positioned internally or externally of the patient. Prior to and/or during image acquisition, the position of the probe (in six degrees of freedom, including translation across and rotation about three perpendicular axes) relative to the reference marker may be determined from the output of the position sensor(s) of the tracking device **228** and stored in memory **224** and/or sent to the scanning processor **106**. The output from the sensors may be used to provide feedback to an operator of the probe **101** (via a displayed user interface of scanning processor **106**, client device **230**, and/or another device). For example, the operator may be instructed to reposition the probe prior to image acquisition, if the probe is not located at a predetermined position. In another example, the operator may be instructed to adjust an angle, depth, and/or location of probe during scanning.

[0023] Probe **101** may be in communication with scanning processor **106** to send raw scanned data to an image processor **212**, for example. Additionally, data stored in

memory **224** and/or output from tracking device **228** may be sent to scanning processor **106** in some examples. Further, various actions of the probe **101** (e.g., activation of the transducer elements) may be initiated in response to signals from the scanning processor **106**. Probe **101** may optionally communicate with a display of the scanning processor and/or display **236** of the client device, in order to notify a user to reposition the probe **101**, as explained above, or to receive information from a user, for example.

[0024] Turning now to scanning processor **106**, it includes an image processor **212**, storage **214**, display output **216** configured to send information for display on a display device of the scanning processor **106** and/or another display device (such as a display of remote device **240**), and ultrasound engine **218**. Ultrasound engine **218** may drive activation of the transducer elements of the transducer array **104**. Further, ultrasound engine **218** may receive raw image data (e.g., ultrasound echoes) from the probe **101**. The raw image data may be sent to image processor **212** and/or to a remote processor (via a network, for example) and processed to form a displayable image of the tissue sample which may be sent to a coupled display device via the display output **216**. It is to be understood that the image processor **212** may be included with the ultrasound engine **218** in some embodiments.

[0025] Information may be communicated from the ultrasound engine **218** and/or image processor **212** to a user of the ultrasound probe system via the display output **216** of the scanning processor **106**. In one example, the user may include an ultrasound technician, nurse, or physician such as a radiologist. For example, after acquiring imaging data (e.g. ultrasound imaging data) in real time, an image may be generated from the data and displayed on a display device (of the scanning processor **106** or an operatively coupled device) via the display output **216**. In another example, information relating to parameters of the scan, such as the progress of the scan, may be sent to the display via the display output **216**. In another example, the display output **216** may output a user interface configured to display images or other information to a user. Further, the user interface may be configured to receive input from a user and send the input to the scanning processor **106**. User input may be via a touch screen of a display in one example. However, other types of user input mechanisms are possible, such as a mouse, keyboard, etc.

[0026] Scanning processor **106** may further include storage **214**. Similar to memory **224** of the probe, storage **214** may include removable and/or permanent devices, and may include optical memory, semiconductor memory, and/or magnetic memory, among others. Storage **214** may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, and/or additional memory. Storage **214** may store non-transitory instructions executable by a controller or processor, such as ultrasound engine **218** or image processor **212**, to carry out one or more methods or routines as described herein below. Storage **214** may store position information of the ultrasound probe as communicated via the tracking device **228**. Storage **214** may store raw image data received from the ultrasound probe, processed image data received from image processor **212** or a remote processor, and/or additional information.

[0027] The scanning processor **106** and/or probe **101** may be communicatively coupled to a client device **230**. The client device **230** may include a suitable computing device, such as a laptop, tablet, or mobile device. The client device **230** may include a controller **232**, memory **234**, display **236**, and camera **238**. The controller **232** may include an image processor and ultrasound engine, similar to the image processor and ultrasound engine of the scanning processor **106**. In this way, the client device **230** may drive actuation of the elements of the transducer array **104** of the probe **101**, receive raw image data from the probe **101**, and/or process the raw image data into one or more images. The controller **232** may further execute instructions stored in memory **234** in order to carry out one or more of the methods described herein.

[0028] Memory **234** may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, and/or additional memory. Memory **234** may store non-transitory instructions executable by a controller or processor, such as controller **232**, to carry out one or more methods or routines as described herein below. Memory **234** may store position information of the ultrasound probe as communicated via the tracking device **228** of the probe. Memory **234** may store raw image data received from the ultrasound probe, processed image data received from the image processor, and/or additional information.

[0029] The display **236** may display suitable information, such as one or more user interfaces, images, etc. The display **236** may display content sent from controller **232** or other suitable processor. The camera **238** may include both forward-facing and rear-facing image sensors each configured to acquire visible light and/or light-based depth images. Visible light images and/or light-based depth images may be displayed on display **236** in the form of still images and/or videos. In some examples, data from the forward- and/or rear-facing image sensors may also be used to determine direction/location and orientation data (e.g. from imaging environmental features) that enables position/motion tracking of the client device **230** in the real-world environment.

[0030] Client device **230** may further include a tracking device **239**. Tracking device **239** may be configured to provide position and/or orientation data of the client device **230** to the controller **232**. In one example, the tracking device may be configured as an inertial movement unit (IMU) including a three-axis or three-degree of freedom (3DOF) position sensor system. This example position sensor system may, for example, include three gyroscopes to indicate or measure a change in orientation of the client device within 3D space about three orthogonal axes (e.g., roll, pitch, and yaw). The orientation derived from the sensor signals of the IMU may be used to display, via the display **236**, one or more augmented reality images with a realistic and stable position and orientation.

[0031] In another example, the IMU may be configured as a six-axis or six-degree of freedom (6DOF) position sensor system. Such a configuration may include three accelerometers and three gyroscopes to indicate or measure a change in location of the client device along three orthogonal spatial axes (e.g., x, y, and z) and a change in device orientation about three orthogonal rotation axes (e.g., yaw, pitch, and roll). In some embodiments, position and orientation data from the image sensors and the IMU may be used in conjunction to determine a position and orientation of the client device.

[0032] Client device **230** may be communicatively coupled to a remote device **240**. Remote device **240** may include a suitable computing device usable to store and/or

display acquired ultrasound images, and may also be communicatively coupled to scanning processor **106**. Remote device **240** may be part of a picture archiving and communication system (PACS) that is configured to store patient medical histories, imaging data, test results, diagnosis information, management information, and/or scheduling information, for example. The remote device **240** may comprise a PACS server that includes computer-readable storage media suitable for storing image data for later retrieval and viewing at a PACS workstation, for example. Remote device **240** may include a controller **242**, memory **244**, and/or display **246**. Memory **244** may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, and/or additional memory. Memory **244** may store non-transitory instructions executable by a controller or processor, such as controller **242**, to carry out one or more methods or routines as described herein below. Memory **244** may store position information of the ultrasound probe as communicated via the tracking device **228** of the probe. Memory **244** may store raw image data received from the ultrasound probe, processed image data received from the image processor, and/or additional information.

[0033] Turning now to FIG. **3**, a method **300** for identifying a target scan plane during an imaging session prior to an at-home imaging session is illustrated. Method **300** may be executed by a computing device such as client device **230**, scanning processor **106**, and/or a computing device in communication with the scanning processor **106**, such as remote device **240**, according to instructions stored in memory thereof, in conjunction with a hand-held ultrasound probe, such as probe **101**.

[0034] At **302**, method **300** optionally includes instructing a user to position the ultrasound probe to detect a target plane. The user may be a clinician, such as a sonographer, and may also be referred to herein as a first operator. Instructing the user may include outputting instructions (e.g., via a display device) that may guide or otherwise instruct the user to adjust the position of the ultrasound probe until the probe is imaging the target plane. The target plane may include a predetermined scan plane of desired tissue to be scanned (e.g., an ovary of a patient).

[0035] At **304**, method **300** optionally includes providing further instructions to the user to place one or more reference markers on the patient. The reference markers may include markers detectable by a suitable detection system, such as magnetic or optical markers. The instructions may guide the user to place the markers at designated positions in some examples. For example, the one or more reference markers may be placed at or near the target plane, on a designated portion of the patient's anatomy, etc.

[0036] At **306**, method **300** includes acquiring ultrasound image data of the tissue. The received image data may include ultrasound echoes of ultrasound waves transmitted by the transducer elements of the transducer array of the ultrasound probe. The ultrasound echoes may be sent to an image processor such as image processor **212** to be processed into a real-time image of the tissue that may be displayed via display output **216** of the scanning processor **106**. In some examples, the image data may include volumetric ultrasound data.

[0037] At **308**, method **300** determines if the target plane has been identified. The identification of the target plane may be determined based on user input in one example. For example, the user of the ultrasound probe may press a button, enter input on a touch screen, or provide other suitable user input that indicates the ultrasound probe is currently imaging in the target plane. In another example, the target plane may be identified automatically by the computing device using image recognition trained via machine learning, for example. If it is determined that the target plane was not identified, method **300** reverts back to **306** and continues to acquire ultrasound image data of the tissue.

[0038] However, if it is determined that the target plane was identified, method **300** proceeds to **310** to acquire probe position data from a probe position tracking device, such as tracking device **228**, which may include one or more probe position sensors. The probe position data may indicate the current probe location and orientation relative to the one or more reference markers at the target plane, and thus the method may also include determining respective positions of each reference marker via the probe position tracking device. At **312**, method **300** stores the probe position data of the probe relative to the reference markers at the target plane in the memory of the computing device, for subsequent at-home ultrasound probe use. Method **300** at **314** optionally sends the probe position data to a remotely connected client device. For example, if method **300** is performed by scanning processor **106**, remote device **240**, or another device permanently located in a clinic/hospital, the probe position data may be sent to a client device such as device **230** of FIG. **2**. The probe position data may include probe position information (e.g., in six degrees of freedom) relative to each position of each reference marker, and may further include the target plane scanned by the probe at that probe position, such as right ovary, left ovary, uterus, etc. Method **300** then returns.

[0039] Turning now to FIG. **4**, a method for at-home ultrasound imaging is illustrated. Method **400** may be executed by a computing device, such as client device **230**, according to instructions stored in memory thereof, in conjunction with a hand-held ultrasound probe, such as probe **101** or another similarly configured probe. For example, the probe used during the execution of method **300** described above may be the same probe used in the execution of method **400**, or it may be a different, though similarly configured, probe. Likewise, the computing device executing method **400** may be the same computing device that executed method **300**, or it may be a different computing device in communication with the computing device that executed method **300**.

[0040] At **402**, method **400** includes instructing a user to position the ultrasound probe and detect an initial plane. The user may be a patient undergoing IVF treatment or another non-clinical user, and may also be referred to herein as a second operator. The user may identify the initial plane via instructions and image data displayed via the user interface of a display associated with the computing device, for example. The displayed image data may include one or more images such as a reference image of the desired target plane and a real-time image generated from image data acquired by the ultrasound probe at the current probe position, for example as shown in FIGS. **5** and **6**, described in more detail below. In some examples, the generated images may include position identifying information. The user interface may further include instructions for guiding the user of the probe

to mark an initial position of the probe as the initial plane, such as by pressing a button on the probe or other by enter another user input.

[0041] At **404**, method **400** determines the current location of the probe at the initial plane relative to the location(s) of the reference marker(s) based on probe position data output from the probe tracking device that includes position sensor (s). As explained above, the probe may include one or more position sensors that may output position sensor data usable to determine a current position of the probe and the probe may include a reference marker detector that may output a position of each reference marker. At **406**, method **400** determines the position and orientation of the target plane relative to the initial plane. The target plane may be identified in a previous imaging session by a physician or other clinician and the position of the target plane may be stored in memory of the client device executing method **500**.

[0042] At **408**, method **400** determines a target position of the probe based on the position of the target plane relative to the initial plane. The target position of the probe may be a position at which the target plane is imageable by the probe. As explained above, the computing device may obtain the stored probe position data indicating the target position of the probe relative to the reference markers and/or the target plane. The computing device may further compute a distance and/or a clock position for the probe to be moved in order to be positioned at the desired target plane. The computed distance and/or clock position relative to one or more reference marker(s) may then be displayed as instructions on the display for the user, at least in some examples.

[0043] Accordingly, at **410**, method **400** instructs the operator to position the probe at the target position. For example, a user interface on the display may display instructions guiding the operator to position the ultrasound probe. The computing device may receive output from the position sensor(s) while the operator is positioning the probe, and the computing device may instruct the operator to position the ultrasound probe based on the output from the position sensor(s). For example, the computing device may determine that the probe is positioned two cm to the right of the target position and then output instructions to the user to move the probe two cm to the left.

[0044] At **412**, method **400** determines if the probe is within a threshold range of the target position. The computing device may receive output from the position sensor(s) after the operator has completed positioning the probe and may determine from the received output if the probe is within a threshold range of the target position. The threshold range may be a suitable range of distances, angles, depths, etc., around the target position, such as within 1 cm or less of the target position (e.g., left, right, up, and down), within 5 degrees of the target position (e.g., of a horizontal, vertical, and/or lateral axis), etc. If the ultrasound probe is not within the threshold range of the target position, method **400** moves to **414** to instruct the operator to reposition (e.g. move, tilt, etc.) the probe. Method **400** then returns to continue assessing if the probe is within the threshold range of the target position.

[0045] If the ultrasound probe is within the threshold range of the target position as determined by the position sensor data output, then method **400** proceeds to **416** to acquire ultrasound image data. In some examples, the method may automatically acquire ultrasound image data responsive to the probe within a threshold range of the target position, though it should be appreciated that in other examples, the method may acquire ultrasound image data responsive to manual user input received once the user has positioned the probe within the threshold range. The image data may include ultrasound echoes of ultrasound waves transmitted by the transducer elements of the transducer array of the ultrasound probe. The ultrasound echoes may be sent to an image processor to be processed into a real-time image of the tissue that may be displayed. In some examples, the image data may include volumetric ultrasound data. While method **400** has been described with respect to only acquiring image data at **416** once the probe is within range of the target position, it is to be understood that in some examples, image data may be acquired via the ultrasound probe throughout the execution of method **400**. In one example, non-volumetric ultrasound data may be acquired prior to **416** in order to allow the user to visualize the initial plane and then eventually the target plane, and then once the probe is at the target position, volumetric image data acquisition may proceed.

[0046] At **418**, method **400** proceeds to send the acquired ultrasound image data to a remote device, such as remote device **240**. In some examples, the ultrasound image data may include positional information corresponding to the precise tissue anatomy that indicates the plane of each image and the direction/position relative to the desired target plane and/or reference marker(s). By doing so, future ultrasound exams may be conducted and images of the same location taken over each exam may be compared, to facilitate accurate compare-to-prior workflow exams. Method **400** then returns.

[0047] Thus, method **400** of FIG. **4** facilitates an at-home ultrasound imaging session by obtaining probe position data indicative of a position of the ultrasound probe relative to one or more reference markers, and using the probe position data to guide a (non-clinically trained) user to position the ultrasound probe at a target position. The target position of the ultrasound probe may be a position at which the probe is able to image at a designated/target scan plane. The target position of the probe at the target scan plane may be specified during a prior imaging session conducted by a clinician, for example, and stored in memory of the computing device coupled to (and configured to drive) the ultrasound probe. Once the ultrasound probe is in the target position (or within a threshold range of the target position), volumetric ultrasound image data may be acquired by the ultrasound probe. The image data may be sent to a remote computing device accessible by a clinician, where the image data may be evaluated by the clinician to monitor the progress of medical procedure (e.g., to measure follicle size and in turn determine the optimal time for oocyte retrieval during IVF).

[0048] In some examples, the computing device may be configured to automatically monitor the progress of the medical procedure in addition to or alternative to sending the image data to the clinician for evaluation. As explained above, the at-home ultrasound imaging session may be part of an on-going medical procedure such as IVF follicle monitoring. The computing device may be configured to perform image recognition on the acquired ultrasound image data to automatically identify a stage of the medical procedure. For example, the computing device may compare the acquired image data with the reference image of the target plane taken during the prior imaging session, pixel by pixel

or voxel by voxel, to determine changes in the anatomy of the tissue scanned. In another example, the computing device may be configured to detect one or more anatomical features and determine changes in the acquired real-time image(s) compared to the reference image at the target plane taken at a previous time. In some examples, the use of convoluted neural networks may aid and/or improve feature detection and identification, as permitted by algorithm performance and system features. The position sensor output information may be used to aid or enhance this registration, for example by aligning image data sets or by defining a region of interest where the anatomical feature is likely to be located (in order to expedite the detection of the anatomical feature, for example). In one example, the acquired ultrasound image at the target plane may be compared with another acquired ultrasound image taken via the same method certain time duration prior (e.g., a week prior) to determine changes in the tissue anatomy.

[0049] Further, while method **400** described above included the user marking an initial scan plane, determining a position of the target plane relative to the initial plane, and determining a target position of the probe relative to the initial plane and target plane, in some examples the marking of the initial scan plane may be dispensed with, or may not be used during the probe position adjustment. For example, the computing device may begin tracking the position of the probe responsive to user input, responsive to the ultrasound probe being powered on, or responsive to the computing system automatically detecting that the probe is being used to image the anatomy of interest (e.g., responsive to the probe being inserted into the patient). Once the tracking of the probe has commenced, the target position of the probe relative to the one or more reference markers may be obtained from memory of the computing device, where the target position indicates the position of the probe relative to the one or more reference markers at the target scan plane. Suitable tracking mechanisms (e.g., dead reckoning) may be used to track the position of the probe as the user manipulates the probe and to determine instructions to be output to the user to guide the user to adjust the position of the probe until the probe reaches the target position. Once the probe is at the target position, the user may be instructed to enter an input to initiate image acquisition or the computing device may automatically initiate image acquisition once it determines the probe is at the target position.

[0050] FIG. **5** shows an example user interface **500** that may be output (e.g. by controller **232** for display via a display device, such as display **236**) during the execution of method **400** (e.g., during an-home ultrasound exam). User interface **500** may include a reference image **502** (e.g., an image of the target scan plane acquired during a prior imaging session), a real time image **504**, a navigation tool **506**, and a plurality of control buttons **516**. The navigation tool **506** may include a depiction **508** of the anatomy being imaged, a depiction **510** of the probe, a depiction **511** of a target probe position, a current scan plane marker **512**, and a target scan plane marker **514**. The user interface may further include instructions **518** to guide the user to adjust the probe. The control buttons may include buttons indicating the target anatomy (e.g., right ovary, uterus, and left ovary), a start button, a finish button, and a send button.

[0051] At the beginning of the ultrasound imaging session, the user may indicate which anatomy is to be imaged by selecting one of the target anatomy buttons (e.g., by touching the right ovary button). This may notify the computing device which target scan plane and hence which target probe position is to be used to guide the user prior to image acquisition.

[0052] As shown by the user interface **500**, the probe is not positioned at the target position and hence the probe is not imaging at the target scan plane. For example, the depiction **510** of the probe shows that the probe is aligned with the current scan plane marker **512** and not with the target probe position or the target scan plane marker **514**. Thus, user interface **500** prompts the user to move the probe to the indicated target plane and target probe position after computing the initial plane location relative to the target plane and/or reference marker location. The user interface may include instructions that are given in real-time, e.g., as the operator moves and positions the probe, the depicted location of the probe may change to reflect the updated location of the probe. The instructions **518** may be displayed to include text that guides the operator to the target plane, e.g., "move the probe 1 cm to your right." In some examples, the depiction **508** of the anatomy, the depiction **510** of the probe, and depiction **511** of the target probe position may be illustrated as mirror images of the user, where the right side of the user is depicted on the left side of the image and vice versa, while in other examples, the depiction **508** of the anatomy, the depiction **510** of the probe, and depiction **511** of the target probe position may be illustrated as non-mirror images where the right side of the user is depicted on the right side of the image and vice versa. The instructions **518** may take into account the perspective of the user relative to the display and depictions on the display and may define that the user is to move the probe relative to the user (as illustrated), relative to a portion of the anatomy, or other suitable instruction.

[0053] FIG. **6** shows another example user interface **600** that may be output (e.g. for display via a display device, such as display **236**) during the execution of method **400** (e.g., during an-home ultrasound exam). User interface **600** may include a reference image **602** (e.g., an image of the target scan plane acquired during a prior imaging session), a real time image **604**, a navigation tool **606**, and a plurality of control buttons **616**. The navigation tool **606** may include a depiction **608** of the anatomy being imaged, a depiction **610** of the probe, and a target scan plane marker **614**. The user interface may further include instructions **618** to the user. The control buttons may include buttons indicating the target anatomy (e.g., right ovary, uterus, and left ovary), a start button, a finish button, and a send button, as explained above with respect to FIG. **5**.

[0054] As illustrated by user interface **600**, the user has moved the probe to the target position. As such, the probe is aligned with the target scan plane, and the real time image is imaging the same scan plane as the reference image (while FIG. **6** shows the reference image being identical to the real time image, in some examples the real time image may have a different appearance than the reference image, due to changes in the oocyte/follicle development, for example). The instructions **618** are notifying the user that the probe is in the target position and that image acquisition can begin. The user may initiate image acquisition by touching the start button, at least in one example. In other examples, the computing device may automatically initiate image acquisition once it determines the probe is in the target position.

[0055] When image acquisition begins, the start button may be highlighted or have another visual indicator that indicates acquisition is occurring. When image acquisition is complete, the finish button may be highlighted and/or the send button may be highlighted, to notify the user that the image data is ready to send to the remote device. Additionally, the button of the target anatomy that was just imaged (e.g., the right ovary) may be highlighted to notify the user that the image acquisition for that anatomy is complete.

[0056] FIG. **7** illustrates an example of an augmented reality user interface **700** that may be displayed during an at-home ultrasound imaging session. The augmented reality user interface **700** may be displayed on a display **704** of a client device **702**, herein in the form of a tablet. Client device **702** is a non-limiting example of client device **230** of FIG. **2**.

[0057] Client device **702** is being held by a user, as shown by left hand **706** of the user. Client device **702** is collecting visible light images of the user via the camera of client device **702** and displaying the visible light images in real-time on display **704**. Accordingly, a right hand **708** of the user is depicted in the visible light images displayed on display **704**. The user is holding an ultrasound probe (such as probe **101**), and thus an ultrasound probe **710** is also depicted in the visible light images displayed on display **704**. The client device **702** may be configured to generate a 2D or 3D model of the physical environment surrounding the client device **702** based on visible light and/or light-based depth information collected by the camera of the client device **702** as well as position and orientation information collected by the tracking device of the client device **702**. In some examples, the user may be instructed to move the client device **702** in order to allow the client device **702** to obtain sufficient image, position, and orientation information to generate the 2D or 3D model of the physical environment.

[0058] In some examples, the client device **702** may include a reference marker **714** of the user in the generated 2D or 3D model. The reference marker **714** may be a magnetic, optical, or other suitable reference marker that may be visible in the visible light images displayed on display **704**, although in some examples the reference marker **714** may not be visible (e.g., the reference marker may be positioned within the user).

[0059] As explained above, a target probe position may be determined during a prior imaging session and saved in memory of the client device **702**. The target probe position may include a position and orientation of the probe relative to the reference marker **714** at which the target scan plane may be imaged. The client device **702** may determine the current position of the ultrasound probe relative to the reference marker based on the generated model, ultrasound probe position data, collected visible light image data and/or light-based depth data, and client device position/orientation information. The client device **702** may then determine a location of the target probe position in the generated model relative to the reference marker and current probe position.

[0060] The target probe position may be displayed on display **704** as an augmented reality object **712**. Based on the obtained target probe position, the client device **702** may determine a location and orientation of the target probe position within the model and then generate and display the augmented reality object **712** such that it is displayed in a location on display **704** that correlates to the actual target probe position relative to the reference marker **714**. The augmented reality object **712** may be body-locked to the reference marker **714**, such that when a position of the reference marker **714** changes, the position of the augmented reality object **712** changes in corresponding manner. In some examples, one or more a guidance indicators, such as the illustrated arrow, may be displayed to guide the user to reposition the probe into the target probe position. Additional or alternative guidance indicators may include displayed instructions, output audio commands, or other guidance indicators. Further, once ultrasound image acquisition commences, ultrasound images **716** (e.g., obtained and displayed in real-time) may be displayed on the display **704** of the client device **702**.

[0061] The depiction of the target probe position described above (e.g., as an augmented reality object positioned within a generated model of the physical environment) is an example mechanism by which the target probe position may be depicted, and other mechanisms are within the scope of this disclosure. For example, the guidance mechanisms described above (such as the augmented reality-based guidance described with respect to FIG. **7** or the virtual depictions described above with respect to FIGS. **5** and **6**) may be used to provide a coarse positioning of the ultrasound probe to the target probe position. Then, once at the target probe position, the acquired ultrasound image data may be compared to stored ultrasound image data at the target scan plane acquired during a prior imaging session. If the acquired ultrasound image data does not match the stored ultrasound image data, the user may be instructed to perform a fine adjustment of the ultrasound probe position until the acquired ultrasound image data matches the stored ultrasound image data. Because some features of the imaged anatomy of the patient may change over the course of the medical procedure, the comparison of the acquired ultrasound image data and stored ultrasound image data may be restricted to anatomical regions not predicted to change, such as the tissue surrounding the ovaries rather than the ovaries themselves.

[0062] Thus, the methods and systems described herein provide for an ultrasound probe that includes position sensors and memory to allow for intelligent and reproducible guidance of the ultrasound probe. By doing so, precise and reproducible scans of the tissue in question may be performed by the operator over a period of time. Further, the image data obtained may be reconstructed into a three-dimensional volume and sent to a remote device for evaluation by a clinician. Furthermore, due to the inclusion of position information along with image data acquired, subsequent images may be aligned or projected onto previously acquired images that would provide a user with a timeline of how the follicles are maturing.

[0063] The technical effect of providing a position tracking device on an ultrasound probe and using output from the position tracking device to guide a user to position the ultrasound probe at a target position is to enable accurate image acquisition of an anatomy of interest by a non-clinically trained user in a home environment, thus reducing the burden placed on the user during medical procedures that include frequent imaging sessions.

[0064] An example system for ultrasonically scanning a tissue sample is provided. The system includes a hand-held ultrasound probe including a transducer array of transducer elements; a probe position tracking device including one or

more position sensors coupled to the ultrasound probe; and a controller. The controller is configured to, during an imaging session, determine a position of the ultrasound probe relative to a target position based on position data collected by the probe position tracking device; and responsive to an indication that the ultrasound probe is at the target position, acquire image data with the transducer array.

[0065] In an example, the probe is aligned to acquire the image data in a specified target plane when the probe is at the target position, the target plane identified during a prior imaging session. In an example, the controller is configured to receive target position data specifying the target position from a remote device, the target position data identified during the prior imaging session. In another example, the controller is configured to store target position data specifying the target position in memory during the prior imaging session and obtain the target position data to determine the target position during the imaging session.

[0066] In an example, in order to determine the position of the ultrasound probe relative to the target position based on the position data, the controller is configured to determine the position of the ultrasound probe relative to the target position based on the position data and further based on a position of one or more reference markers. In an example, the controller is configured to, responsive to determining that the ultrasound probe is not at the target position, output feedback to guide a user to position the ultrasound probe at the target position. In an example, the controller is coupled to a display device, and the feedback output by the controller is configured to be displayed on the display device via a user interface. In some examples, the feedback may be displayed in the form of an augmented reality object overlaid on visible light images collected by an imaging sensor associated with the display device.

[0067] In an example, the controller is further configured to send the image data to a remote computing device. In an example, the imaging session is performed as part of a medical procedure, and the controller is further configured to perform image recognition on the image data to automatically identify a stage of the medical procedure.

[0068] An example method for an ultrasound imaging device including a hand-held ultrasound probe is provided. The method includes obtaining a target probe position that is relative to a target scan plane and one or more reference markers, the target scan plane specified by a first operator during a first imaging session; determining a current probe position of the ultrasound probe relative to the target probe position based on position data obtained from a tracking device of the ultrasound probe; and responsive to the current probe position being within a threshold range of the target probe position, obtaining image data with the ultrasound probe.

[0069] In an example, the method includes, when the current probe position is outside the threshold range of the target probe position, outputting feedback to guide a second operator to move the ultrasound probe to the target probe position, and obtaining image data with the ultrasound probe may include obtaining image data with the ultrasound probe during a second imaging session, the first imaging session occurring prior to the second imaging session.

[0070] In an example, obtaining image data with the ultrasound probe responsive to the current probe position being within the threshold range of the target probe position includes determining that the current probe position is within the threshold range of the target probe position; responsive to the determining, outputting a notification to inform the second operator that the current probe position is within the threshold range of the target probe position; and obtaining the image data responsive to a user input received from the second operator.

[0071] In an example, obtaining image data with the ultrasound probe responsive to the current probe position being within the threshold range of the target probe position includes determining that the current probe position is within the threshold range of the target probe position; and responsive to the determining, automatically obtaining the image data. In an example, obtaining image data with the ultrasound probe comprises obtaining volumetric image data with the ultrasound probe.

[0072] Another example of a method for an ultrasound imaging device including a hand-held ultrasound probe is provided. The method includes, during a first imaging session: receiving an indication of a first target anatomy to be imaged; obtaining a first target probe position corresponding to a position of the ultrasound probe at which the first target anatomy is imageable in a first target scan plane; determining a current probe position of the ultrasound probe; responsive to the current probe position being outside a threshold range of the first target probe position, outputting instructions to guide a user to adjust the current position of the ultrasound probe; and responsive to the current probe position being within the threshold range of the first target probe position, acquiring volumetric image data of the first target anatomy at the first target scan plane.

[0073] In an example, the method further includes after acquiring volumetric image data of the first target anatomy at the first target scan plane, receiving an indication of a second target anatomy to be imaged; obtaining a second target probe position corresponding to a position of the ultrasound probe at which the second target anatomy is imageable in a second target scan plane; determining the current probe position of the ultrasound probe; responsive to the current probe position being outside a threshold range of the second target probe position, outputting instructions to guide a user to adjust the current position of the ultrasound probe; and responsive to the current probe position being within the threshold range of the second target probe position, acquiring volumetric image data of the second target anatomy at the second target scan plane. In an example, the first target anatomy comprises a first ovary of a patient and the second target anatomy comprises a second ovary of the patient.

[0074] In an example, the method further includes, during a reference imaging session that occurs prior to the first imaging session, identifying the first target probe position based on user input received from a second user and storing the first target probe position in memory of the ultrasound imaging device. In an example, determining the current probe position comprises determining the current probe position based on output from a position tracking device of the ultrasound probe, and wherein the current probe position and target probe position are each relative to a position of a reference marker. In an example, outputting instructions to guide the user to adjust the current position of the ultrasound probe comprises outputting an augmented reality user interface for display on a display device, the augmented reality user interface comprising one or more real-time visible light

images of the user overlaid with an augmented reality object corresponding to the target probe position.

[0075] As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to "one embodiment" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising," "including," or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property. The terms "including" and "in which" are used as the plain-language equivalents of the respective terms "comprising" and "wherein." Moreover, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements or a particular positional order on their objects.

[0076] This written description uses examples to disclose the invention, including the best mode, and also to enable a person of ordinary skill in the relevant art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

1. A system for ultrasonically scanning a tissue sample, comprising:
- a hand-held ultrasound probe including a transducer array of transducer elements;
- a probe position tracking device including one or more position sensors coupled to the ultrasound probe; and
- a controller configured to:
  - during an imaging session, determine a position of the ultrasound probe relative to a target position based on position data collected by the probe position tracking device; and
  - responsive to an indication that the ultrasound probe is at the target position, acquire image data with the transducer array.

2. The system of claim **1**, wherein the probe is aligned to acquire the image data in a specified target plane when the probe is at the target position, the target plane identified during a prior imaging session.

3. The system of claim **2**, wherein the controller is configured to receive target position data specifying the target position from a remote device, the target position data identified during the prior imaging session.

4. The system of claim **2**, wherein the controller is configured to store target position data specifying the target position in memory during the prior imaging session and obtain the target position data to determine the target position during the imaging session.

5. The system of claim **1**, wherein to determine the position of the ultrasound probe relative to the target position based on the position data, the controller is configured to determine the position of the ultrasound probe relative to the target position based on the position data and further based on a position of one or more reference markers.

6. The system of claim **1**, wherein the controller is configured to, responsive to determining that the ultrasound probe is not at the target position, output feedback to guide a user to position the ultrasound probe at the target position.

7. The system of claim **5**, wherein the controller is coupled to a display device, and wherein the feedback output by the controller is configured to be displayed on the display device via a user interface.

8. The system of claim **1**, wherein the controller is further configured to send the image data to a remote computing device.

9. The system of claim **1**, wherein the imaging session is performed as part of a medical procedure, and wherein the controller is further configured to perform image recognition on the image data to automatically identify a stage of the medical procedure.

10. A method for an ultrasound imaging device including a hand-held ultrasound probe, comprising:
- obtaining a target probe position that is relative to a target scan plane and one or more reference markers, the target scan plane specified by a first operator during a first imaging session;
- determining a current probe position of the ultrasound probe relative to the target probe position based on position data obtained from a tracking device of the ultrasound probe; and
- responsive to the current probe position being within a threshold range of the target probe position, obtaining image data with the ultrasound probe.

11. The method of claim **10**, further comprising when the current probe position is outside the threshold range of the target probe position, outputting feedback to guide a second operator to move the ultrasound probe to the target probe position, and wherein obtaining image data with the ultrasound probe comprises obtaining image data with the ultrasound probe during a second imaging session, the first imaging session occurring prior to the second imaging session.

12. The method of claim **11**, wherein obtaining image data with the ultrasound probe responsive to the current probe position being within the threshold range of the target probe position comprises:
- determining that the current probe position is within the threshold range of the target probe position;
- responsive to the determining, outputting a notification to inform the second operator that the current probe position is within the threshold range of the target probe position; and
- obtaining the image data responsive to a user input received from the second operator.

13. The method of claim **11**, wherein obtaining image data with the ultrasound probe responsive to the current probe position being within the threshold range of the target probe position comprises:
- determining that the current probe position is within the threshold range of the target probe position; and
- responsive to the determining, automatically obtaining the image data.

14. The method of claim **10**, wherein obtaining image data with the ultrasound probe comprises obtaining volumetric image data with the ultrasound probe.

15. A method for an ultrasound imaging device including a hand-held ultrasound probe, comprising, during a first imaging session:

receiving an indication of a first target anatomy to be imaged;

obtaining a first target probe position corresponding to a position of the ultrasound probe at which the first target anatomy is imageable in a first target scan plane;

determining a current probe position of the ultrasound probe;

responsive to the current probe position being outside a threshold range of the first target probe position, outputting instructions to guide a user to adjust the current position of the ultrasound probe; and

responsive to the current probe position being within the threshold range of the first target probe position, acquiring volumetric image data of the first target anatomy at the first target scan plane.

16. The method of claim **15**, further comprising:

after acquiring volumetric image data of the first target anatomy at the first target scan plane, receiving an indication of a second target anatomy to be imaged;

obtaining a second target probe position corresponding to a position of the ultrasound probe at which the second target anatomy is imageable in a second target scan plane;

determining the current probe position of the ultrasound probe;

responsive to the current probe position being outside a threshold range of the second target probe position, outputting instructions to guide a user to adjust the current position of the ultrasound probe; and

responsive to the current probe position being within the threshold range of the second target probe position, acquiring volumetric image data of the second target anatomy at the second target scan plane.

17. The method of claim **16**, wherein the first target anatomy comprises a first ovary of a patient and the second target anatomy comprises a second ovary of the patient.

18. The method of claim **15**, further comprising, during a reference imaging session that occurs prior to the first imaging session, identifying the first target probe position based on user input received from a second user and storing the first target probe position in memory of the ultrasound imaging device.

19. The method of claim **15**, wherein determining the current probe position comprises determining the current probe position based on output from a position tracking device of the ultrasound probe, and wherein the current probe position and target probe position are each relative to a position of a reference marker.

20. The method of claim **15**, wherein outputting instructions to guide the user to adjust the current position of the ultrasound probe comprises outputting an augmented reality user interface for display on a display device, the augmented reality user interface comprising one or more real-time visible light images of the user overlaid with an augmented reality object corresponding to the target probe position.

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