



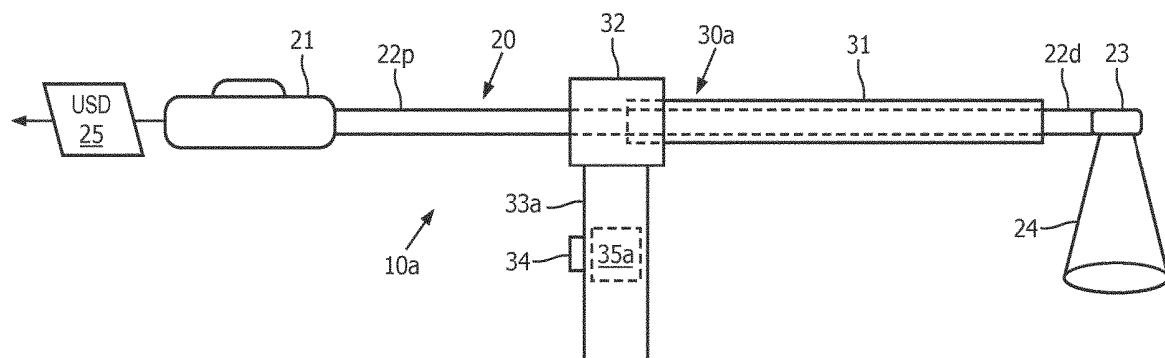
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(19) **United States**(12) **Patent Application Publication**
TOPOREK et al.(10) **Pub. No.: US 2020/0187898 A1**(43) **Pub. Date: Jun. 18, 2020**(54) **A LAPAROSCOPIC ADAPTER, AN
ECHOCARDIOGRAPHY PROBE AND A
METHOD FOR COUPLING THE ADAPTER
TO THE PROBE**(71) Applicant: **KONINKLIJKE PHILIPS N.V.,
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POPOVIC, BOSTON, MA (US)**(21) Appl. No.: **16/628,314**(22) PCT Filed: **Jul. 5, 2018**(86) PCT No.: **PCT/EP2018/068266**

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7, 2017.**Publication Classification**(51) **Int. Cl.****A61B 8/12** (2006.01)**A61B 8/00** (2006.01)**A61B 8/08** (2006.01)**A61B 46/10** (2006.01)(52) **U.S. Cl.**CPC **A61B 8/12** (2013.01); **A61B 8/445**(2013.01); **A61B 8/467** (2013.01); **A61B****1/3132** (2013.01); **A61B 8/483** (2013.01);**A61B 8/4466** (2013.01); **A61B 46/10**(2016.02); **A61B 8/0883** (2013.01)(57) **ABSTRACT**

A 3D echocardiography probe (20) (e.g., a 3D transesophageal echocardiography probe or a 3D intracardiac echocardiography probe) can be adapted into a 3D laparoscopic ultrasound probe (10a) for laparoscopic procedures. The 3D echocardiography probe includes a flexible shaft (22d, 22p) to which a laparoscopic adapter (30a) can be coupled. The laparoscopic adapter comprises a laparoscopic sleeve (31) configured to partially encircle a portion of the flexible shaft of the 3D echocardiography probe and a probe handle (33a) mountable to the laparoscopic sleeve (31).



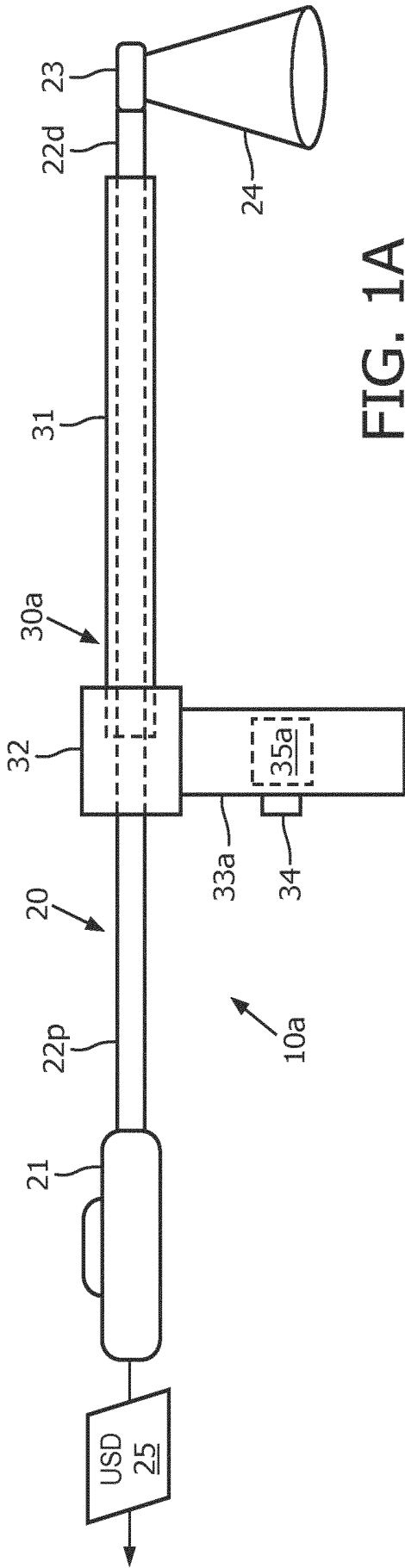


FIG. 1A

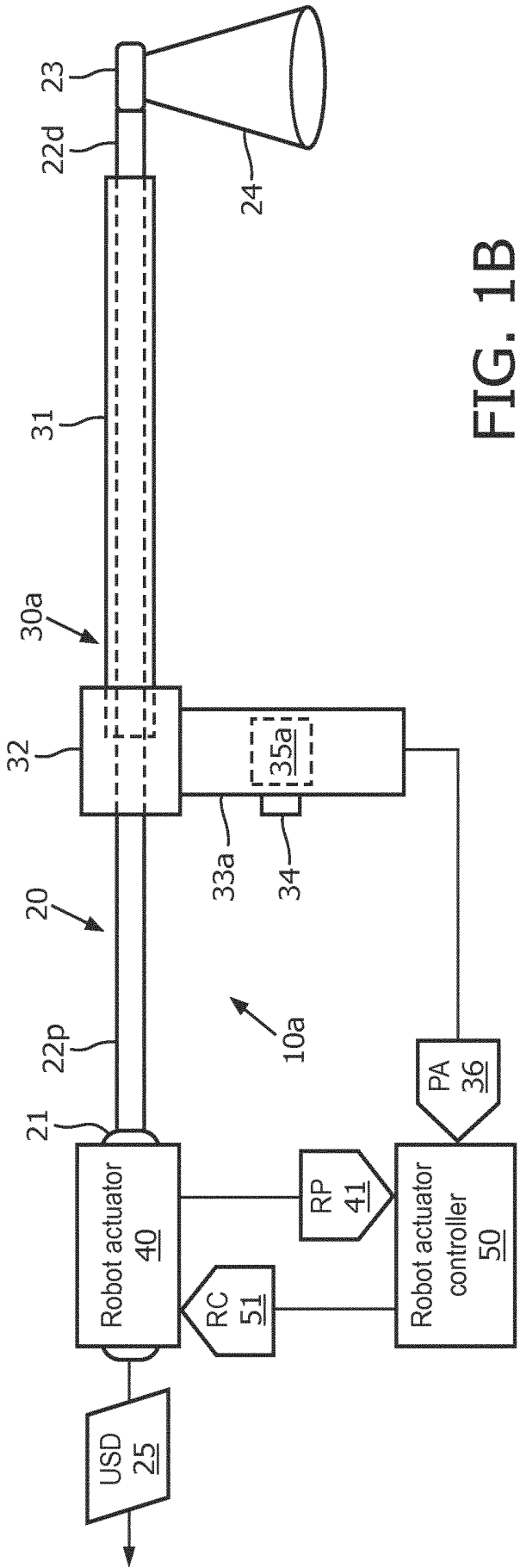


FIG. 1B

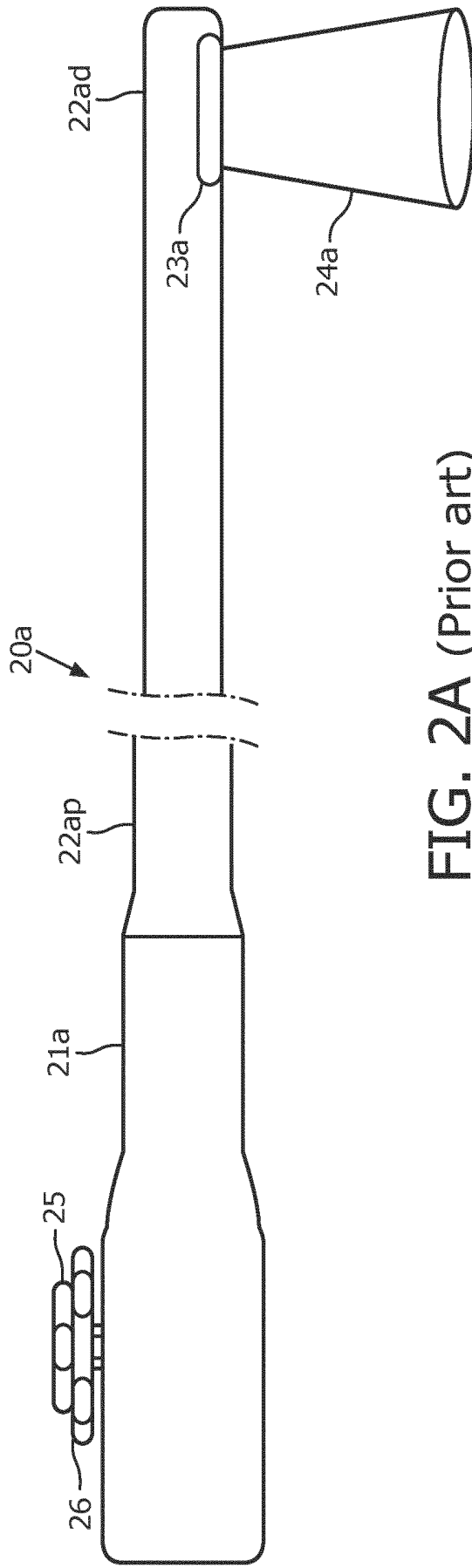


FIG. 2A (Prior art)

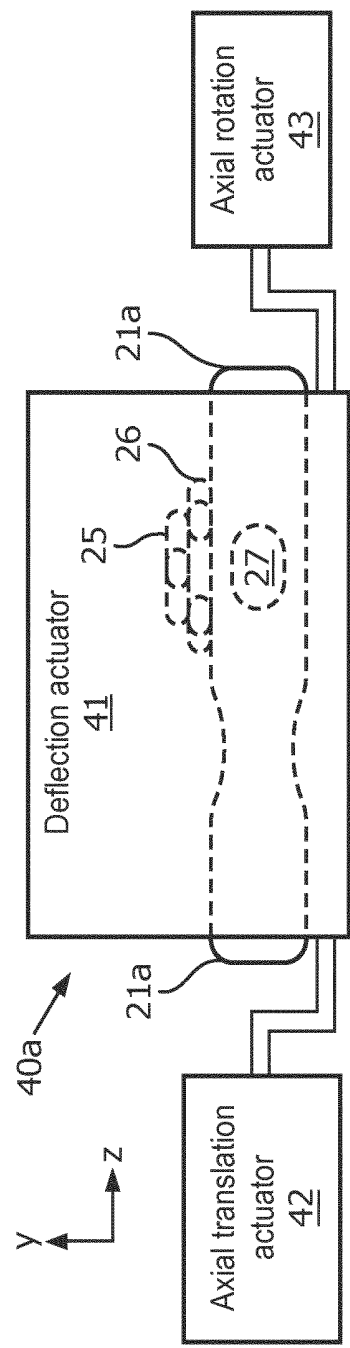


FIG. 2B (Prior art)

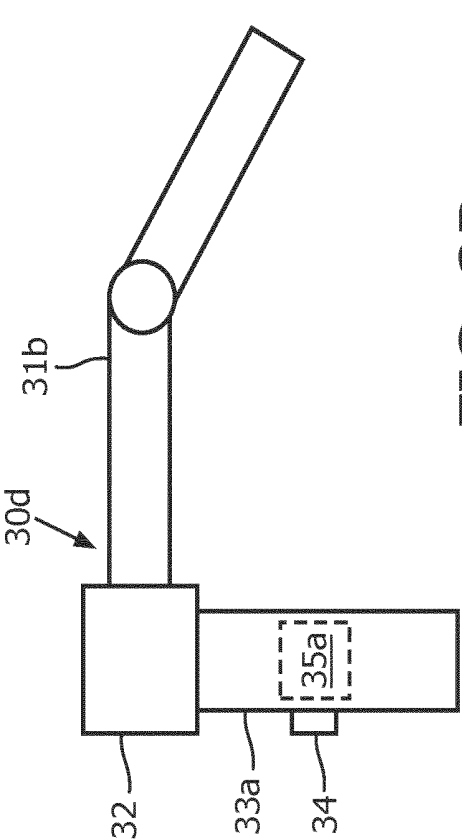


FIG. 3B

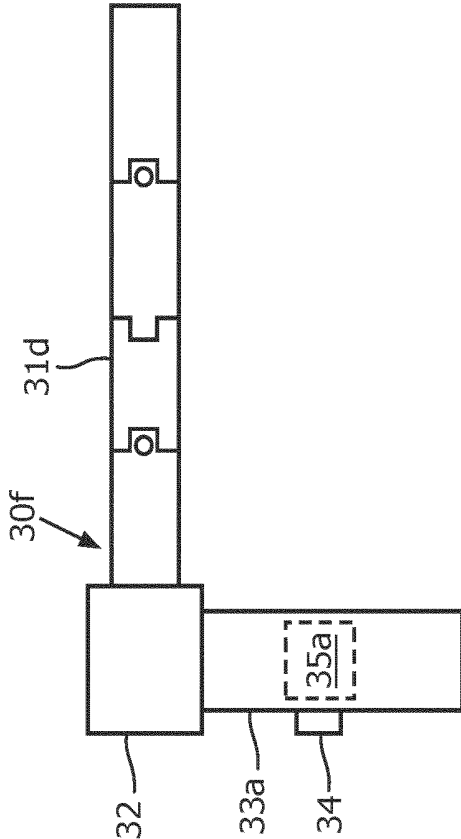


FIG. 3D

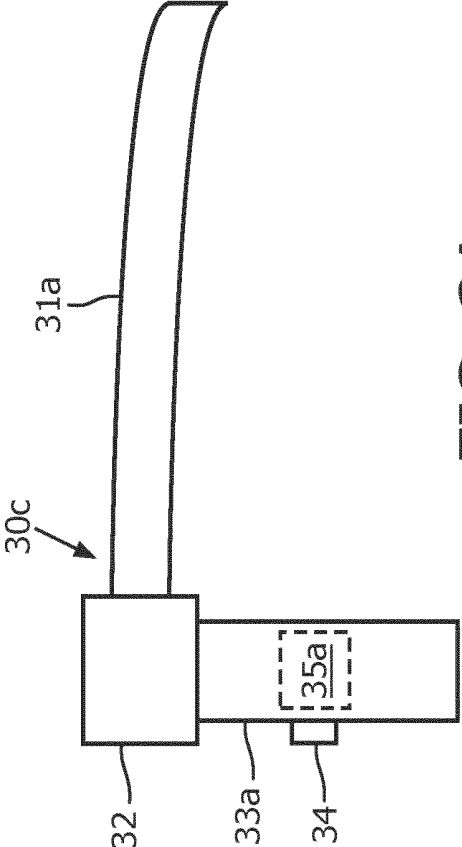


FIG. 3A

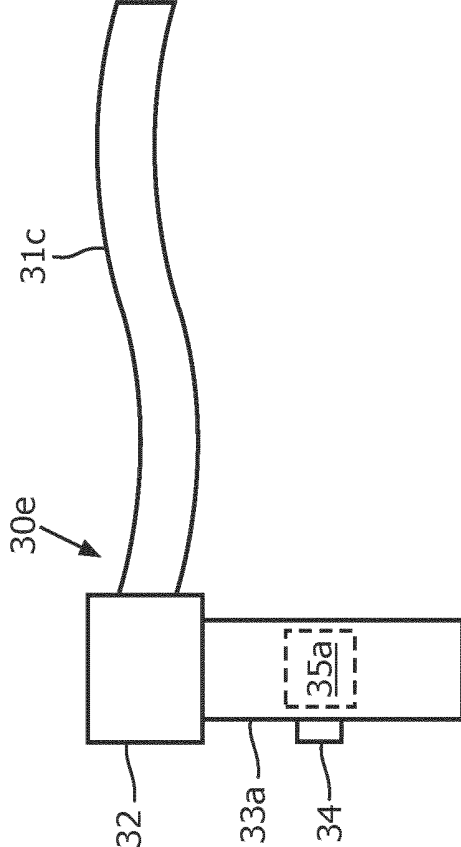
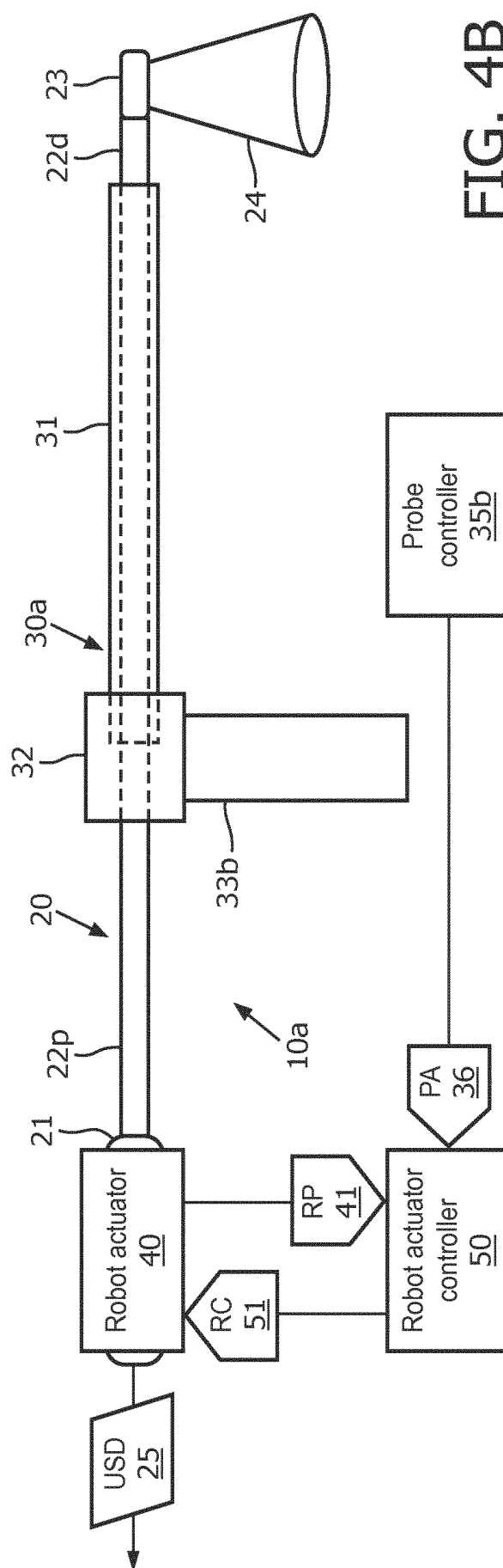
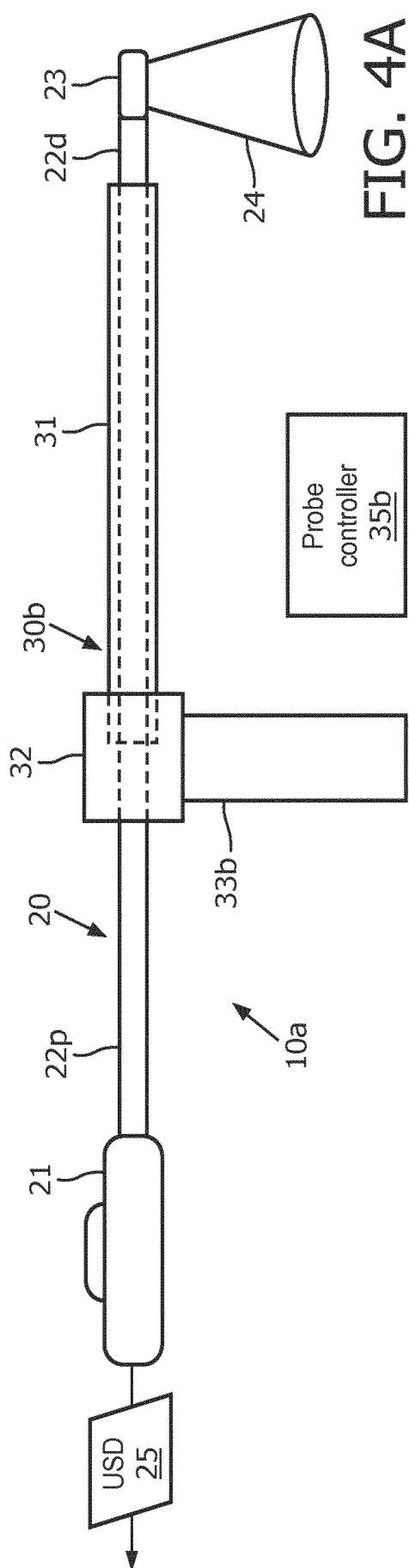


FIG. 3C



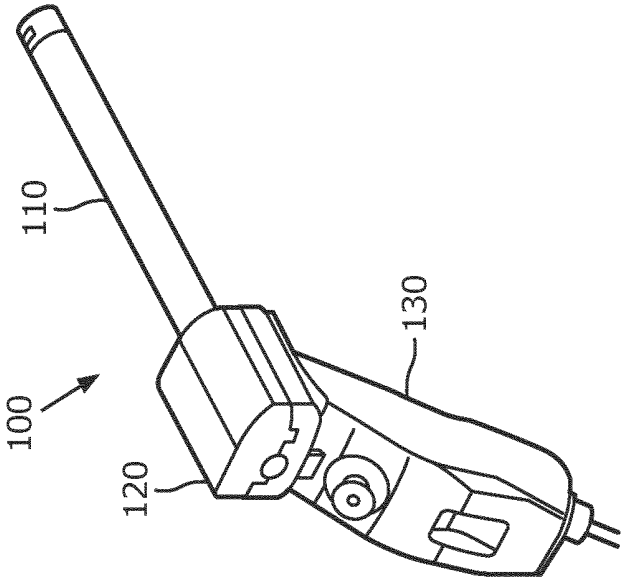


FIG. 5A

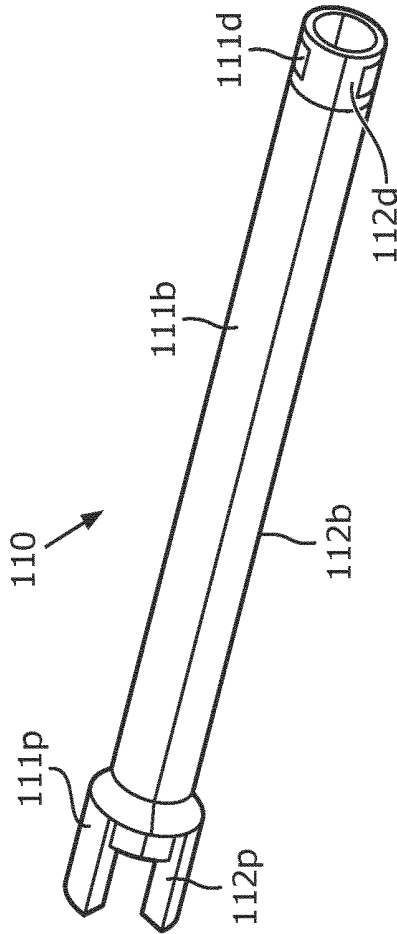


FIG. 5B

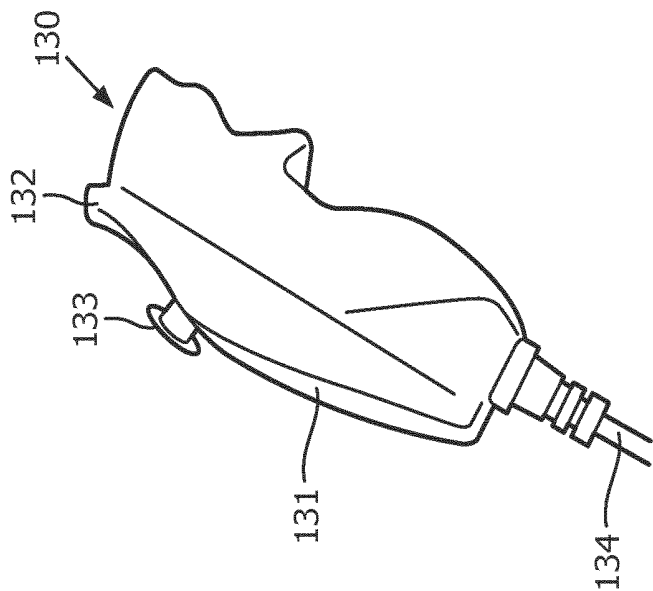


FIG. 5D

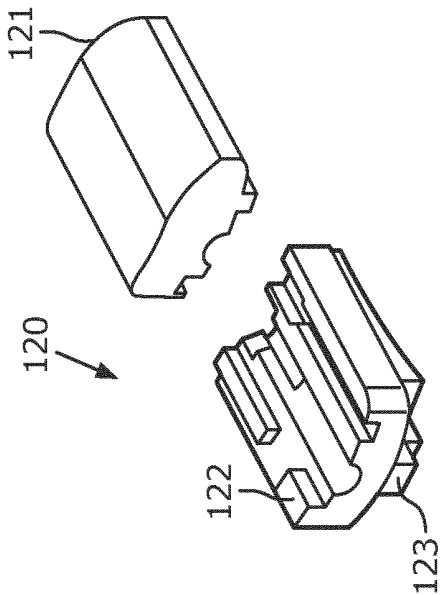


FIG. 5C

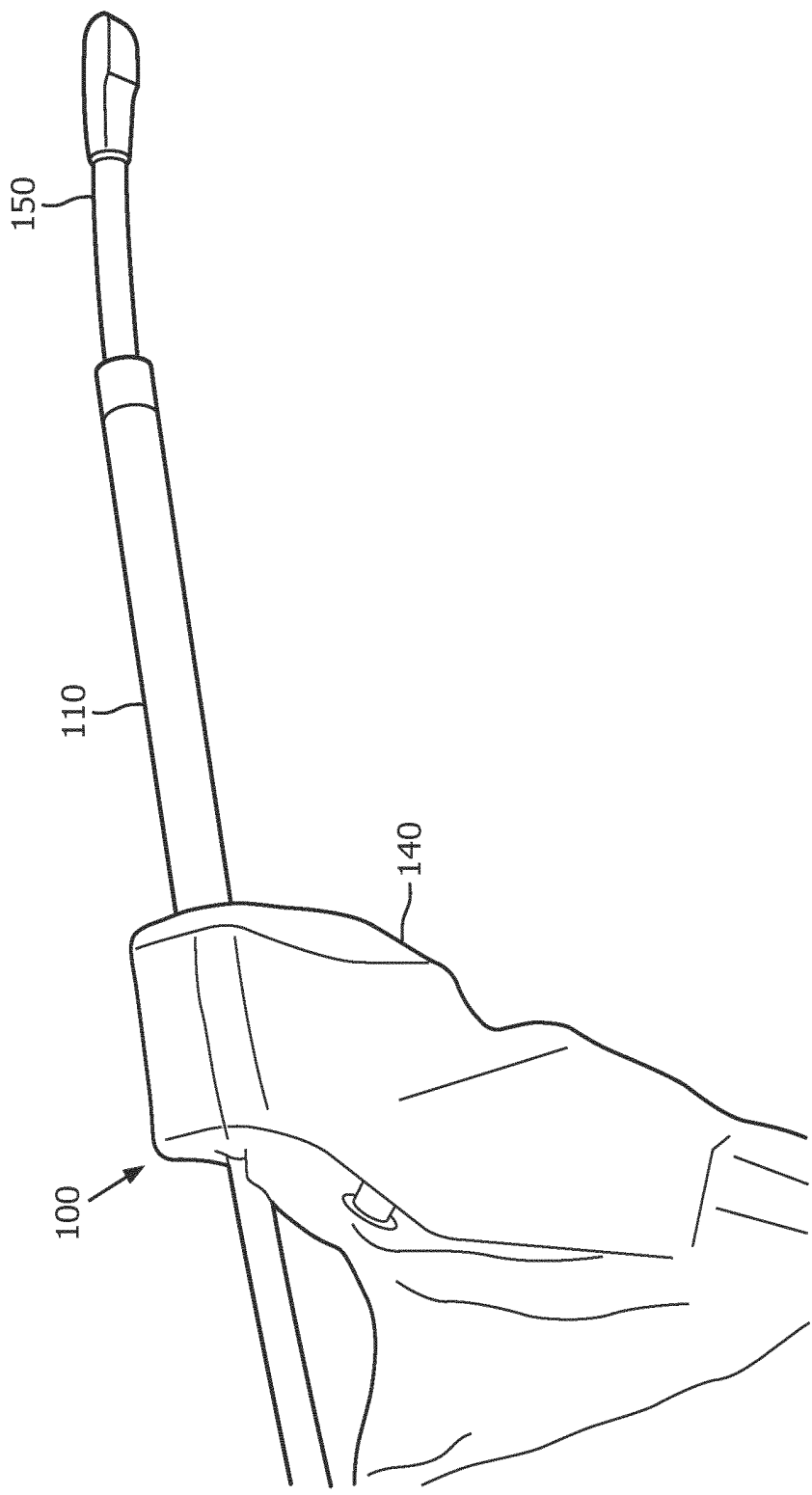


FIG. 5E

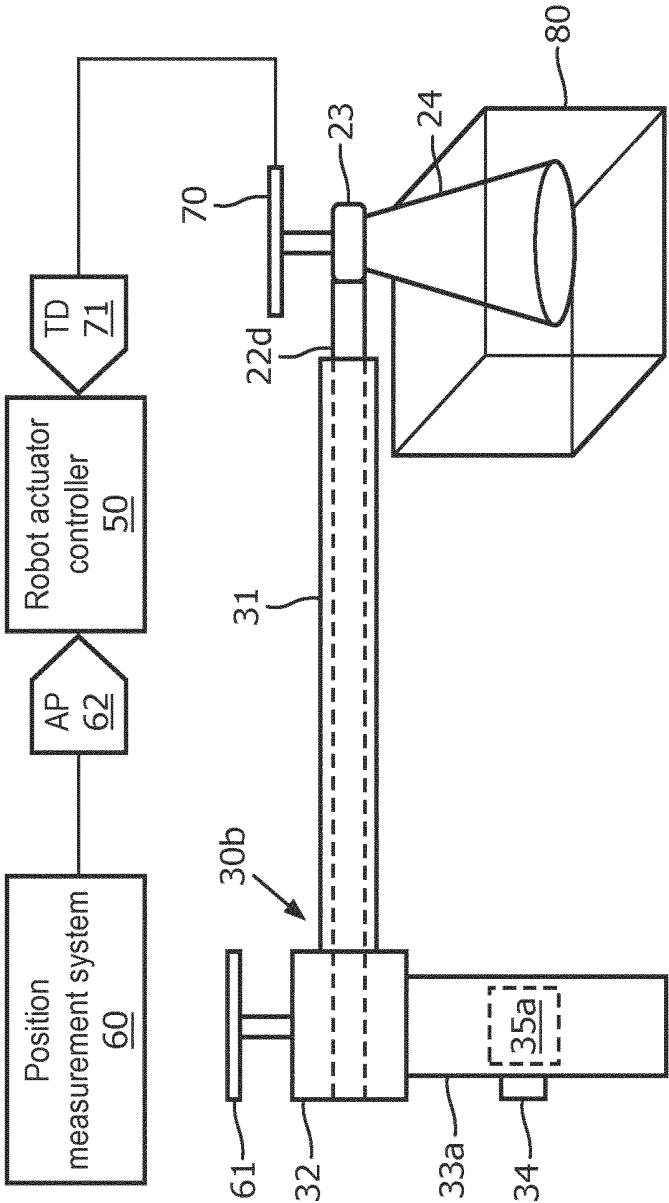


FIG. 6A

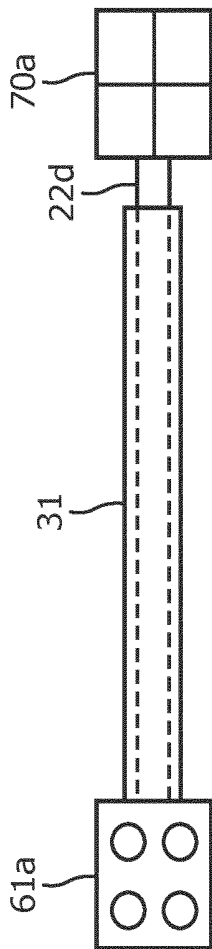


FIG. 6B

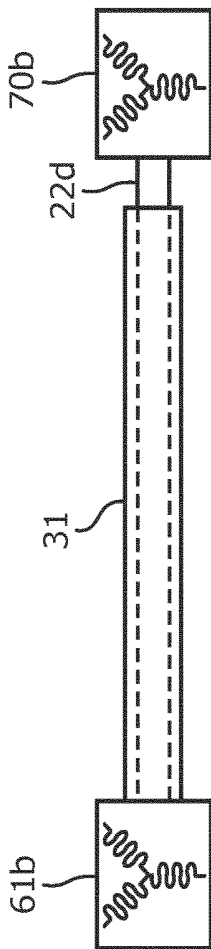
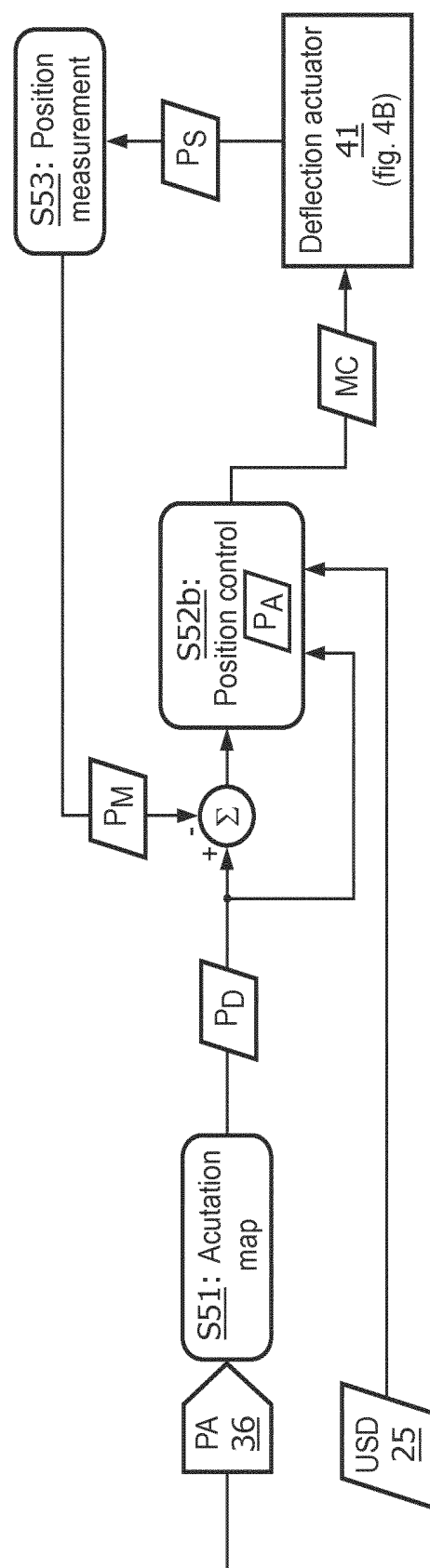
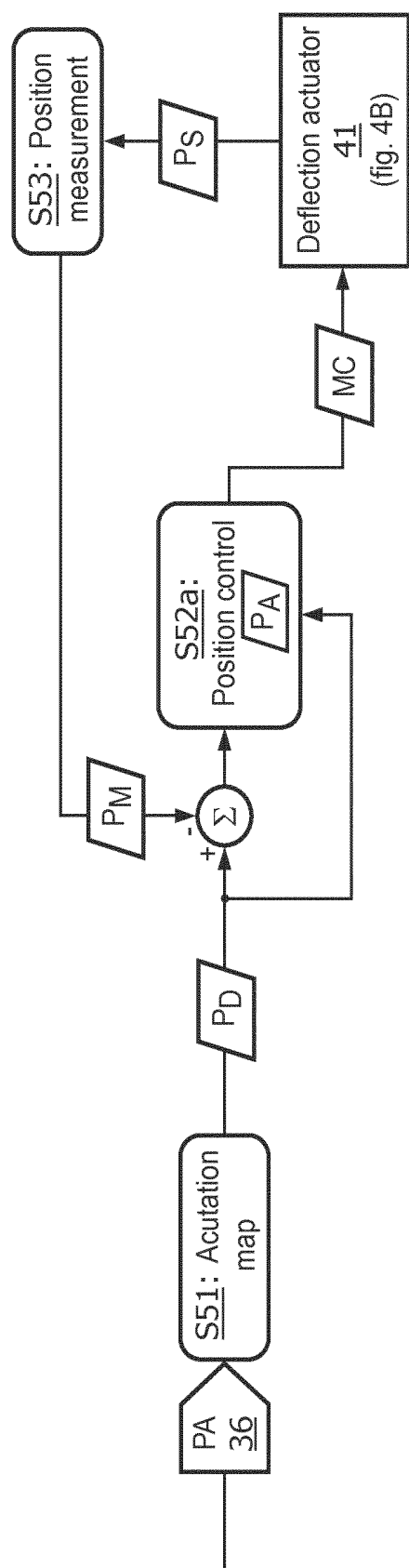


FIG. 6C



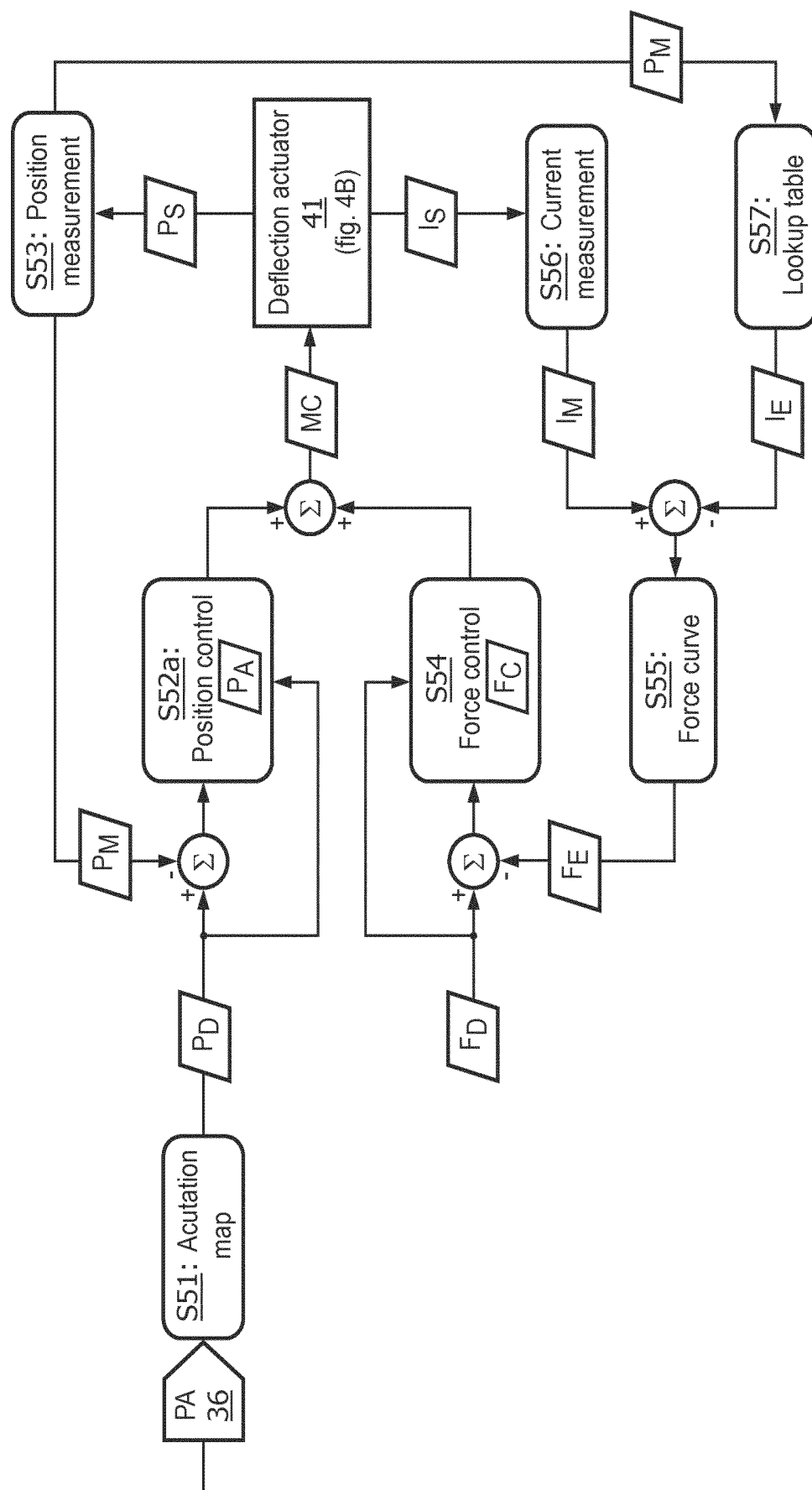


FIG. 7C

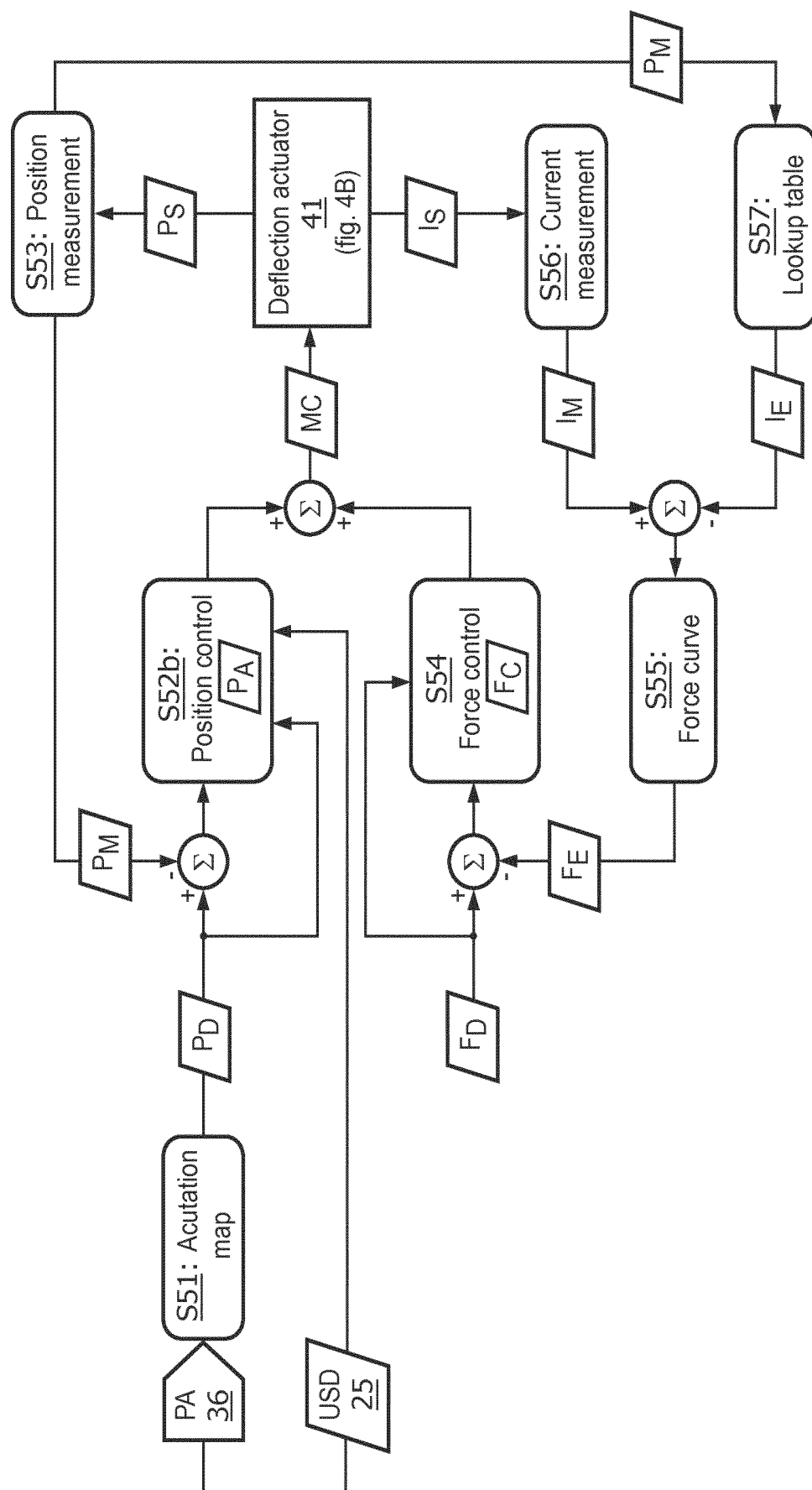


FIG. 7D

A LAPAROSCOPIC ADAPTER, AN ECHOCARDIOGRAPHY PROBE AND A METHOD FOR COUPLING THE ADAPTER TO THE PROBE

FIELD OF THE INVENTION

[0001] The present disclosure generally relates to laparoscopic procedures (e.g., prostatectomy, apenectomy, nephrectomy and hepatectomy). The present disclosure specifically relates to an adaption of a three-dimensional (“3D”) echocardiography probe into a 3D laparoscopic ultrasound (“LUS”) probe for the performance of a laparoscopic procedure.

BACKGROUND OF THE INVENTION

[0002] During minimally invasive laparoscopic procedures, any endoscopic feedback provided to a surgeon has proved to be limited. Specifically, the surgeon using endoscopic camera may only view an outer surface of an organ. Therefore surgeons lose their tactile feedback, sense of orientation and all other information that are usually provided during conventional surgery. To overcome this endoscopic limitation, two-dimensional (“2D”) laparoscopic ultrasound (“LUS”) probes designed to have direct contact with a parenchyma of an organ were introduced to provide an intra-operative visualization of the inner structures of the organ. A clear disadvantage of 2D ultrasound is lack of volumetric information which could be of interest for precise assessment of the region of interest of the organ in relation to adjacent critical structures. Additionally, since laparoscopic procedures use a fixed fulcrum as an access point, the inverted hand-instrument movement make it very difficult to understand a location and an orientation of an ultrasound image plane with respect to the organ. Thus, limiting a field of view of 2D LUS probes to a single plane may lead to a misdiagnosis and/or ineffective treatment of the organ.

SUMMARY OF THE INVENTION

[0003] Currently, while 3D ultrasound probes exist, 3D ultrasound probes for use during laparoscopic procedures do not exist. The present disclosure describes an adaption of a 3D echocardiography probe into a 3D laparoscopic ultrasound (“LUS”) probe.

[0004] For purposes of describing and claiming the inventions of the present disclosure:

[0005] (1) the term “laparoscopic procedure” broadly encompasses any and all types of laparoscopic procedures, as known in the art of the present disclosure or hereinafter conceived, for an imaging, a diagnosis and/or a treatment of a patient anatomy;

[0006] (2) the term “3D echocardiography probe” broadly encompasses any and all types of probes, as known in the art of the present disclosure or hereinafter conceived, incorporating an ultrasound transducer integrated within a flexible shaft for a ultrasound volume scanning of a patient anatomy. Examples of an 3D echocardiography probe include, but are not limited to, 3D transesophageal echocardiography (“TEE”) probes and 3D intracardiac echocardiography (“ICE”) probes;

[0007] (3) the term “3D transesophageal echocardiography probe” broadly encompasses any and all types of 3D echocardiography probe, as known in the art of the present

disclosure or hereinafter conceived, for a ultrasound volume scanning of a patient transesophageal;

[0008] (4) the term “3D intracardiac echocardiography probe” broadly encompasses any and all types of 3D echocardiography probe, as known in the art of the present disclosure or hereinafter conceived, for a ultrasound volume scanning of a patient heart;

[0009] (5) the term “3D laparoscopic ultrasound probe” broadly encompasses any and all types of 3D echo probes adapted into a 3D laparoscopic ultrasound probe in accordance with the inventive principles of the present disclosure exemplary described herein;

[0010] (6) the term “laparoscopic adapter” broadly encompasses any and all types of devices for adapting a 3D transesophageal echocardiography probe into a 3D laparoscopic ultrasound probe in accordance with the inventive principles of the present disclosure exemplary described herein;

[0011] (7) the term “laparoscopic sleeve” broadly encompasses any and all types of tubular structures suitable for a laparoscopic procedure in accordance with the inventive principles of the present disclosure exemplary described herein;

[0012] (8) the term “robot actuator” broadly encompasses all robot actuators, as known in the art of the present disclosure and hereinafter conceived, for actuation of a deflection of a 3D transesophageal echocardiography probe;

[0013] (9) the term “controller” broadly encompasses all structural configurations, as understood in the art of the present disclosure and as exemplary described in the present disclosure, of an application specific main board or an application specific integrated circuit for controlling an application of various inventive principles of the present disclosure as subsequently described in the present disclosure. The structural configuration of the controller may include, but is not limited to, processor(s), computer-usable/computer readable storage medium(s), an operating system, application module(s), peripheral device controller(s), slot(s) and port(s). A controller may be housed within or linked to a workstation. Examples of a “workstation” include, but are not limited to, an assembly of one or more computing devices, a display/monitor, and one or more input devices (e.g., a keyboard, joysticks and mouse) in the form of a standalone computing system, a client computer of a server system, a desktop or a tablet;

[0014] (10) the descriptive labels for term “controller” herein facilitates a distinction between controllers as described and claimed herein without specifying or implying any additional limitation to the term “controller”;

[0015] (11) the term “application module” broadly encompasses an application incorporated within or accessible by a controller consisting of an electronic circuit and/or an executable program (e.g., executable software stored on non-transitory computer readable medium(s) and/or firmware) for executing a specific application;

[0016] (12) the term “position measurement system” broadly encompasses all measurement systems, as known in the art of the present disclosure and hereinafter conceived, for measuring a position (e.g., a location and/or an orientation) of an object within a coordinate space. Examples of a position measurement system include, but is not limited to, an electromagnetic (“EM”) measurement system (e.g., the Auora® electromagnetic measurement system), an optical-fiber based measurement system (e.g., Fiber-Optic

RealShape™ (“FORS”) measurement system), an ultrasound measurement system (e.g., an InSitu or image-based US measurement system), an optical measurement system (e.g., a Polaris optical measurement system), a radio frequency identification measurement system and a magnetic measurement system;

[0017] (13) the terms “signal”, “data” and “command” broadly encompasses all forms of a detectable physical quantity or impulse (e.g., voltage, current, or magnetic field strength) as understood in the art of the present disclosure and as exemplary described in the present disclosure for transmitting information and/or instructions in support of applying various inventive principles of the present disclosure as subsequently described in the present disclosure. Signal/data/command communication between various components of the present disclosure may involve any communication method as known in the art of the present disclosure including, but not limited to, signal/data/command transmission/reception over any type of wired or wireless datalink and a reading of signal/data/commands uploaded to a computer-usable/computer readable storage medium; and

[0018] (14) the descriptive labels for terms “signal”, “data” and “commands” herein facilitates a distinction between signals/data/commands as described and claimed herein without specifying or implying any additional limitation to the terms “signal”, “data” and “command”.

[0019] A first embodiment of the inventions of the present disclosure is a 3D echocardiography probe (e.g., a 3D transesophageal echocardiography probe or a 3D intracardiac echocardiography probe) probe adapted into a 3D laparoscopic ultrasound probe for laparoscopic procedures. The 3D echocardiography probe includes a flexible shaft, and a laparoscopic adapter coupled to the flexible shaft. The laparoscopic adapter adapts the 3D echocardiography probe into the 3D laparoscopic ultrasound probe.

[0020] A second embodiment of the inventions of the present disclosure is the laparoscopic adapter employing a laparoscopic sleeve partially encircling or fully encircling (i.e., enclosing) a portion or an entirety of the flexible shaft of the 3D echocardiography probe, and a probe handle mounted to the laparoscopic sleeve.

[0021] A third embodiment of the inventions of the present disclosure is a method for adapting the 3D echocardiography probe into the 3D laparoscopic ultrasound probe for laparoscopic procedures. The method involves a coupling of the laparoscopic sleeve to the flexible shaft of the 3D echocardiography probe with the laparoscopic sleeve partially encircling or fully encircling (i.e., enclosing) a portion or an entirety of the flexible shaft. The method further involves a mounting of the probe handle to the laparoscopic sleeve.

[0022] A fourth embodiment of the inventions of the present disclosure is a 3D laparoscopic ultrasound system employing a 3D laparoscopic ultrasound probe of the present disclosure, and further employing a robot actuator for actuating a deflection of the flexible shaft of the 3D echocardiography probe and a robot actuator controller for controlling an actuation by the robot actuator of a deflection of the flexible shaft of the 3D echocardiography probe.

[0023] A fifth embodiment of the inventions of the present disclosure is a 3D laparoscopic ultrasound system of the present disclosure further employing a probe controller for generating a probe actuation signal indicating a delineated deflecting of the 3D echocardiography probe. The robot

actuator controller controls the actuation by the robot actuator of the deflection of the flexible shaft of the 3D echocardiography probe in response to a generation of the probe actuation signal by the probe controller.

[0024] A sixth embodiment of the inventions of the present disclosure is a probe handle of the present disclosure including the probe controller for generating a probe actuation signal indicating the delineated deflecting of flexible shaft of the 3D echocardiography probe.

[0025] A seventh embodiment of the inventions of the present disclosure is a 3D laparoscopic ultrasound system of the present disclosure further employing a probe measurement system for measuring a position (e.g., a location and/or an orientation) of a volume image by the 3D laparoscopic ultrasound probe within a coordinate system.

[0026] An eighth embodiment of the inventions of the present disclosure is a robot actuator controller of the present disclosure incorporates a sensorless force control technique and/or an organ scanning technique.

[0027] The foregoing embodiments and other embodiments of the inventions of the present disclosure as well as various features and advantages of the present disclosure will become further apparent from the following detailed description of various embodiments of the inventions of the present disclosure read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the inventions of the present disclosure rather than limiting, the scope of the inventions of present disclosure being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1A illustrates a first exemplary embodiment of a 3D laparoscopic ultrasound scope in accordance with the inventive principles of the present disclosure.

[0029] FIG. 1B illustrates a first exemplary embodiment of a 3D laparoscopic ultrasound actuation system in accordance with the inventive principles of the present disclosure.

[0030] FIG. 2A illustrates an exemplary embodiment of a 3D transesophageal echocardiography probe as known in the art of the present disclosure.

[0031] FIG. 2B illustrates an exemplary embodiment of a robot actuator for a 3D transesophageal echocardiography probe as known in the art of the present disclosure.

[0032] FIGS. 3A-3D illustrates exemplary embodiments of a laparoscopic sleeve in accordance with the inventive principles of the present disclosure.

[0033] FIG. 4A illustrates a second exemplary embodiment of a 3D laparoscopic ultrasound scope in accordance with the inventive principles of the present disclosure.

[0034] FIG. 4B illustrates a second exemplary embodiment of a 3D laparoscopic ultrasound actuation system in accordance with the inventive principles of the present disclosure.

[0035] FIGS. 5A-5E illustrates a third exemplary embodiment of a 3D laparoscopic ultrasound scope in accordance with the inventive principles of the present disclosure.

[0036] FIGS. 6A-6C illustrates exemplary embodiments of a 3D laparoscopic ultrasound measurement system in accordance with the inventive principles of the present disclosure.

[0037] FIG. 7A illustrates an exemplary embodiment of a robot actuator control scheme in accordance with the inventive principles of the present disclosure.

[0038] FIG. 7B illustrates an exemplary embodiment of a robot actuator control scheme incorporating an organ scanning control technique in accordance with the inventive principles of the present disclosure.

[0039] FIG. 7C illustrates an exemplary embodiment of a robot actuator control scheme incorporating a sensorless force control technique in accordance with the inventive principles of the present disclosure.

[0040] FIG. 7D illustrates an exemplary embodiment of a robot actuator control scheme incorporating a sensorless force control technique and an organ scanning technique in accordance with the inventive principles of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0041] The inventions of the present disclosure are premised on an adaptation of a 3D echocardiography probe (e.g., a 3D transesophageal echocardiography (“TEE”) probe or a 3D intracardiac echocardiography (“ICE”) probe) into a 3D laparoscopic ultrasound (“LUS”) probe.

[0042] To facilitate an understanding of the inventions of the present disclosure, the following description of FIGS. 1-4 teaches basic inventive principles of an adaptation of a 3D TEE probe into a 3D LUS probe. From the description of FIGS. 1-7, those having ordinary skill in the art will appreciate how to apply the inventive principles of the present disclosure to making and using numerous and varied embodiments of an adaption of a 3D echocardiography probe of any type into a 3D LUS probe of the present disclosure.

[0043] Referring to FIG. 1A, an exemplary 3D LUS probe 10a of the present disclosure employs a 3D TEE probe 20 as known in the art of the present disclosure and a laparoscopic adapter 30a of the present disclosure.

[0044] 3D TEE probe 20 includes an actuation handle 21, a flexible shaft 22 having a proximal end 22p integrated into actuation handle 21 and a 3D ultrasound transducer integrated with a distal end 22d of flexible shaft 22. Actuation handle 21 provides for an actuation of a deflection of distal end 22d of flexible shaft 22 with one (1) or two (2) degrees of freedom as known in the art of the present disclosure. Ultrasound transducer 23 provides for a generation of an ultrasound data 25 representative of an imaging of an ultrasound volume 24 as known in the art of the present disclosure.

[0045] In one embodiment 20a of 3D TEE probe 20 as shown in FIG. 2A, a flexible shaft 22a has a proximal end 22ap integrated into actuation handle 21a and a 3D ultrasound transducer 23a is integrated with a distal end 22d of flexible shaft 22. Actuation handle 21a of 3D TEE probe 20a employs a yaw actuation dial 25 for adjusting a yaw degree freedom of probe head 22ad, and a pitch actuation dial 26 for adjusting a pitch degree freedom of probe head 22ad.

[0046] Referring back to FIG. 1A, laparoscopic adapter 30 includes a laparoscopic sleeve 31, an adapter mount 32, and a handle 33a.

[0047] Laparoscopic sleeve 31 has a shaft channel for receiving flexible shaft 20 as symbolically shown by the dashed lines within laparoscopic sleeve 31.

[0048] In practice, the shaft channel of laparoscopic sleeve 31 may be open whereby laparoscopic sleeve 31 partially encircles a portion of flexible shaft 22 or alternatively, the shaft channel of laparoscopic sleeve 31 may be closed

whereby laparoscopic sleeve 31 fully encircles (i.e., encloses) a portion of flexible shaft 22 as shown in FIG. 1A.

[0049] Also in practice, the shaft channel laparoscopic sleeve 31 may be dimensioned to loosely or tightly receive flexible shaft therein.

[0050] Further in practice, laparoscopic sleeve 31 has a material composition and geometrical configuration suitable for laparoscopic procedures.

[0051] In one embodiment, laparoscopic sleeve 31 may have a rigid material composition with a straight cylindrical configuration as shown in FIG. 1A or a curved cylindrical configuration 31a as shown in FIG. 3A.

[0052] In a second embodiment, laparoscopic sleeve 31 may have a rigid material composition with a jointed cylindrical configuration 31b as shown in FIG. 3B for facilitating a manual pivoting of a distal end of laparoscopic sleeve 31.

[0053] In a third embodiment, laparoscopic sleeve 31 may have a semi-rigid material composition with a cylindrical configuration, such as, for example, laparoscopic sleeve 31 may be a catheter 31c as shown in FIG. 3C.

[0054] In a fourth embodiment, laparoscopic sleeve 31 may have a rigid material composition with a controllable cylindrical configuration, such as, for example, laparoscopic sleeve 31 may be a snake robot 31d as shown in FIG. 3D.

[0055] Referring back to FIG. 1A, adapter mount 32 has a mount channel for receiving flexible shaft 20 and/or laparoscopic sleeve 31 as symbolically shown by the dashed lines within laparoscopic sleeve 31.

[0056] In practice, adapter mount 32 may clamp onto flexible shaft 20 and/or laparoscopic sleeve 31 to maintain laparoscopic sleeve 31 at a fixed position relative to ultrasound transducer 23.

[0057] Still referring to FIG. 1A, probe handle 33a is affixed to adapter mount 32 to enable a user manipulation of a coarse alignment of ultrasound transducer 23 to a region of interest of a patient anatomy.

[0058] Probe handle 33a includes a user input device 34 (e.g., a joystick, a rollerball, etc.) for operating a probe controller 35a to generate a probe actuation signal indicating a delineated deflecting of distal end 22d of flexible shaft 22 via user input device 34.

[0059] In one embodiment as shown in FIG. 1B, probe controller 35a communicates (wired or wireless) a probe actuation signal 36 to a robot actuator controller 50 whereby robot actuator controller 50 communicates (wired or wireless) robot commands 51 to a robot actuator 40 to control actuation of a deflection of distal end 22d of flexible shaft 22 based on robot position data 41 communicated (wired or wireless) by robot actuator 40 to robot actuator controller 50 as will be further described in connection with FIGS. 7A-7D.

[0060] In practice, robot actuator 40 may have any embodiment suitable for actuating a deflection of distal end 22d of flexible shaft 22.

[0061] In one embodiment 40a of robot actuator 40 as shown in FIG. 2B, robotic actuator 40a employs a deflection actuator 41, an axial translation actuator 42, and an axial rotation actuator 43 for fine alignment of ultrasound transducer 23a to a region of interest of a patient anatomy.

[0062] Deflection actuator 41 is mechanically engaged as known in the art with dials 25 and 26 of TEE probe 20a. Robot actuator controller 50 provides robot commands 51 to motor controller(s) (not shown) of deflection actuator 41 for actuating dials 25 and 26 to actuate a deflection of a TEE

probe **20a** corresponding to a mapped motion of user input device (e.g., user input device **34** of probe handle **33a**).

[0063] Axial translation actuator **42** and axial rotation actuator **43** are mechanically coupled to deflection actuator **41**.

[0064] Axial translation actuator **42** as known in the art may be actuated to translate handle **21a** of 3D TEE probe **20a** along its longitudinal axis. Robot actuator controller **50** provides further robot commands **51** to a motor controller (not shown) of axial translation actuator **42** to actuate an axial translation of handle **21a**, which may correspond to a mapped motion of a user input device (e.g., user input device **34** of probe handle **33a**).

[0065] Axial rotation actuator **43** as known in the art may be actuated to rotate handle **21a** of 3D TEE probe **20a** along its longitudinal axis. Robot actuator controller **50** provides further robot commands **51** to a motor controller (not shown) of axial rotation actuator **43** to actuate an axial rotation of handle **21a** of 3D TEE probe **20a**, which may correspond to a mapped motion of a user input device (e.g., user input device **34** of probe handle **33a**).

[0066] Also in practice, the probe controller may be segregated from the probe handle. For example, as shown in FIGS. **4A** and **4B**, a probe controller **35b** may be segregated from a probe handle **33b** whereby probe controller **35b** is operated via a user input device integrated with probe handle **33b** (e.g., a joystick, a roller ball, etc.) or a user input device segregated from probe handle **33b** (e.g., an eye-tracker, a voice control, virtual reality control, gesture tracking, foot pedals, etc.).

[0067] To facilitate a further understanding of the inventions of the present disclosure, the following description of FIGS. **5A-5E** teaches a specific embodiment of an adaptation of a 3D transesophageal echocardiography (“TEE”) probe into a 3D laparoscopic ultrasound (“LUS”) probe. From the description of FIGS. **5A-5E**, those having ordinary skill in the art will further appreciate how to apply the inventive principles of the present disclosure to making and using numerous and varied embodiments of an adaption of a 3D echocardiography probe of any type into a 3D LUS probe of the present disclosure.

[0068] Referring to FIG. **5A**, a 3D LUS probe **100** of the present disclosure employs a rigid disposable laparoscopic sleeve **110**, a disposable handle mount **120** and a reusable probe handle **130**.

[0069] As shown in FIG. **5B**, laparoscopic sleeve **110** includes an upper semi-cylinder **111** having a shaft cover **111b**, a proximal mount coupler **111p** and a distal shaft coupler **111d**, and a lower semi-cylinder **112** having a shaft cover **112b**, a proximal mount coupler **112p** and a distal shaft coupler **112d**.

[0070] As shown in FIG. **5C**, handle mount **120** includes an upper mount **121** and a lower mount **122**.

[0071] As shown in FIG. **5D**, probe handle **130** is in the form of a remote probe controller including a handle **131**, an extension **132**, a joystick **133** and a probe controller (not shown) electrically connected to a cord **134**.

[0072] Prior to and/or during a laparoscopic procedure, a surgical personal attaches rigid disposable laparoscopic sleeve **110** to a flexible shaft of a US TEE probe by first attaching lower semi-cylinder **112** under the flexible shaft (e.g., distal shaft coupler **112d** being a collar) and then, by attaching upper semi-cylinder **111** over the flexible shaft above the lower semi-cylinder **112** (e.g., distal shaft coupler

111d being a flange slidable within a collar). Distal couplers **111d** and **112d** serve as a clamping mechanism for holding a position of semi-cylinders **111** and **112** on the flexible shaft.

[0073] Lower mount **122** is then placed under the flexible shaft and upper mount **122** is slide on lower mount **122** and fixes both the flexible shaft therebetween. Proximal mount couplers **111p** and **112p** are then friction fitted within upper mount **121** and lower mount **122** (e.g., proximal mount couplers **111p** and **112p** being flanges friction fitted within slots of upper mount **121** and lower mount **122** respectively).

[0074] Reusable remote probe controller **130** is attached to lower controller mount **122**, and wrapped with a sterile drape **140** as shown in FIG. **5** (e.g., lower controller mount **122** including a rail **123** slidable within a groove (not shown) of controller **130** to a stop **132**).

[0075] Upon adaption of the 3D TEE probe into a 3D LUS probe, the handle of 3D LUS probe is inserted into an actuator robot that controls its dials. Both a direction and a speed of a deflection of the 3D LUS probe are controlled by reusable remote probe controller **130**.

[0076] To facilitate a further understanding of the inventions of the present disclosure, the following description of FIGS. **6** and **7** teaches various deflection control schemes executed by a robot actuator controller of the present disclosure. From the description of FIGS. **5A-5E**, those having ordinary skill in the art will further appreciate how to apply the inventive principles of the present disclosure to making and using numerous and varied embodiments of deflection control schemes of the present disclosure.

[0077] Referring to FIG. **6A**, a laparoscopic adapter **31** of the present disclosure is tracked by an external position measurement system (PMS) **60** for generation an adapter pose signal estimating a 3D pose of laparoscopic adapter **31** using a tracked body **61** rigidly attached to handle mount **32** and pre-calibrated so that a position of laparoscopic adapter **31** with respect to PSM **60** is known. A registration between a pre-operative image volume **80** (e.g., a CT volume or a MRI volume) and 3D US volume **25** is provided by PSM **60** using registration techniques known in art of the present disclosure including, but not limited to, a point-based rigid registration based on anatomical landmarks (vessel’s bifurcations, calcifications, etc.).

[0078] A registration between 3D US volume **24** and tracked body **61** rigidly attached to handle mount **32** is calculated using registration techniques known in art of the present disclosure including, but not limited to, a registration technique utilizing a calibration tool made of ultrasound opaque features organized at a known geometry (hereinafter the “opaque registration”). An exemplary calibration tool **61a** is shown in FIG. **6B**.

[0079] For the opaque registration, ultrasound transducer **23** of 3D LUS probe must be stationary with respect to handle mount **32**. An orientation of 3D US transducer **23** is therefore tracked using an inertial measurement unit (IMU) **70** as known in art of the present disclosure including, but not limited to, a combination **70a** of an accelerometer, a gyroscope and a magnetometer as shown in FIG. **6B**. IMU **70** generates a transducer orientation signal **71** indicative any deflection of 3D US transducer **23**.

[0080] Robot actuator controller **50** processes adapter position signal **62** and transducer orientation signal **71** to control an actuation of a deflection of 3D US transducer **23**. Assuming a link between the tracked body **61** rigidly

attached to handle mount **32** and 3D US transducer **23** is not compressible, a position (i.e., a location and/or an orientation) of the US volume **24** with respect to pre-operative image volume **80** may be estimated using one of the mathematical models known in art of the present disclosure for single-link flexible manipulator based transducer orientation signal **71**.

[0081] Alternatively, as shown in FIG. 6C, an electromagnetic sensor array **61b** may be rigidly attached to handle mount **32** and an electromagnetic sensor array **70b** may be attached to 3D US transducer **23**.

[0082] Referring to FIG. 7A, a robot actuator control scheme executable by robot actuator controller **50** (FIGS. 1B and 4B). Basically, a stage **S41** involves a generation a desired actuation position P_D of 3D US transducer **23** (FIGS. 1B and 4B) derived from a mapping by robot actuator controller **50** of probe actuation signal **PAS** as previously described herein, and a position control stage **S52a** generates an actuation position P_A for 3D US transducer **23** in terms of a specific pitch and yaw achieved by corresponding angular positions of the gears/actuation dials.

[0083] A generation of motor commands **MC** for achieving actuation position P_A involves a minimization a position error between actuation position P_A and measured motor positions P_M .

[0084] Specifically, a motor controller of deflection actuator **41** (FIG. 41) continually communicates sensed motor positions P_S during a stage **S53** to robot actuator controller **50**. In response thereto, robot actuator controller **50** periodically measures sensed motor positions P_S and compares the measured motor positions P_M to motor positions associated with the desired actuation position P_D of 3D US transducer **23** and the resulting position error is an input for position control stage **S52a** designed to minimize the position error. In practice, robot actuator controller **50** may execute any control technique(s) as known in the art of the present disclosure for minimizing the position error (e.g., a PID control).

[0085] Robot actuator controller **50** continually loop through stages **S51-S53** during the laparoscopic procedure.

[0086] Referring to FIG. 7B, the robot actuator control scheme of FIG. 7A involves a input of a tracked US volume **25** for purposes of implementing an organ scanning technique. Specifically, robot actuator controller **50** is able to ascertain a spatial relation between 3D US transducer **23** and a surface of an organ whereby robot actuator controller **50** constrains a movement of 3D US transducer **23** as needed to maintain a parallel spatial relation between 3D US transducer **23** and the surface of an organ while minimizing a position error.

[0087] Referring to FIG. 7C, the robot actuator control scheme of FIG. 7A involves an implementation of a sensorless force control technique.

[0088] Specifically, a desired force F_D of 3D US transducer **23**, which is typically a constant value greater than zero to maintain contact with tissue and ensure acoustic coupling, is communicated to robot actuator controller **50** during a force control stage **S54** whereby robot actuator controller **50** generates a contact force correction F_C for actuation position P_A for 3D US transducer **23**.

[0089] The generation of motor commands **MC** involves an application of contact force correction F_C to actuation position P_A in view of minimizing a position error between actuation position P_A and measured motor positions P_M , and

a contract force error between contact force correction F_C and an expected contact force F_E .

[0090] Specifically, a motor controller of deflection actuator **41** continually communicates sensed motor positions P_S and sensed motor currents I_S during respective stages **S53** and **S56** to robot actuator controller **50**. In response thereto, robot actuator controller **50** periodically measures sensed motor positions P_S and compares the measured motor positions P_M to motor positions associated with a desired actuation position P_D of 3D US transducer **23** and the resulting position error is an input for position control stage **S52a** designed to minimize the position error. In practice, robot actuator controller **50** may execute any control technique(s) as known in the art for minimizing the position error (e.g., a PID control).

[0091] Robot actuator controller **50** also periodically in sync measures sensed motor currents I_S and combines the measured sensed motor currents I_S to an expected motor currents I_E , which is calculated by inputting measured motor positions P_M into the lookup table of stage **S57** computed by a calibrator as known in the art of the present disclosure. The lookup table takes two inputs of position of the two dials and returns two expected current values I_E for each degree-of-freedom. During stage **S55** expected current values I_E and the measured motor current values I_M are current fed to force curve ($C \rightarrow F$) computed by calibrator as known in the art of the present disclosure to estimate an expected contact force F_E on 3D US transducer **23**.

[0092] Force control stage **S54** receives contact force correction F_C from a comparison of desired contact force F_D and expected contract force F_E and adjusts a path generated by position control stage **S52** to limit the forces exerted by the head of 3D US transducer **23**. In one embodiment, a direct method to model this motion is to assume that contact surface acts as an ideal spring, in which case:

$$\Delta f = K(x - x_0)$$

[0093] where Δf is the force error signal, x is the position of the contact point, x_0 would be the position of 3D US transducer **23** if there was no obstacle, and K is elastic constant of the esophagus of the patient (values known in literature can be used). Since x_0 can be known from the kinematic model of 3D US transducer **23**, there is a direct link between motor commands and the force. Similarly to position control value:

$$x = \frac{\Delta f}{K} + x_0$$

[0094] Robot actuator controller **50** continually loop through stages **S51-S57** during the laparoscopic procedure.

[0095] Referring to FIG. 7D, the robot actuator control scheme of FIG. 7C involves a input of a tracked US volume **25** for purposes of implementing an organ scanning technique. As previously described, robot actuator controller **50** is able to ascertain a spatial relation between 3D US transducer **23** and a surface of an organ whereby robot actuator controller **50** constrains a movement of 3D US transducer **23** as needed to maintain a parallel spatial relation between 3D US transducer **23** and the surface of an organ while minimizing a position error.

[0096] Referring to FIGS. 1-7, those having ordinary skill in the art of the present disclosure will appreciate numerous

benefits of the inventions of the present disclosure including, but not limited to, an acquisition of volumetric information during a laparoscopic procedure.

[0097] Furthermore, as one having ordinary skill in the art will appreciate in view of the teachings provided herein, features, elements, components, etc. described in the present disclosure/specification and/or depicted in the Figures may be implemented in various combinations of electronic components/circuitry, hardware, executable software and executable firmware and provide functions which may be combined in a single element or multiple elements. For example, the functions of the various features, elements, components, etc. shown/illustrated/depicted in the Figures can be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions can be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which can be shared and/or multiplexed. Moreover, explicit use of the term “processor” should not be construed to refer exclusively to hardware capable of executing software, and can implicitly include, without limitation, digital signal processor (“DSP”) hardware, memory (e.g., read only memory (“ROM”) for storing software, random access memory (“RAM”), non-volatile storage, etc.) and virtually any means and/or machine (including hardware, software, firmware, circuitry, combinations thereof, etc.) which is capable of (and/or configurable) to perform and/or control a process.

[0098] Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future (e.g., any elements developed that can perform the same or substantially similar function, regardless of structure). Thus, for example, it will be appreciated by one having ordinary skill in the art in view of the teachings provided herein that any block diagrams presented herein can represent conceptual views of illustrative system components and/or circuitry embodying the principles of the invention. Similarly, one having ordinary skill in the art should appreciate in view of the teachings provided herein that any flow charts, flow diagrams and the like can represent various processes which can be substantially represented in computer readable storage media and so executed by a computer, processor or other device with processing capabilities, whether or not such computer or processor is explicitly shown.

[0099] Furthermore, exemplary embodiments of the present disclosure can take the form of a computer program product or application module accessible from a computer-usable and/or computer-readable storage medium providing program code and/or instructions for use by or in connection with, e.g., a computer or any instruction execution system. In accordance with the present disclosure, a computer-usable or computer readable storage medium can be any apparatus that can, e.g., include, store, communicate, propagate or transport the program for use by or in connection with the instruction execution system, apparatus or device. Such exemplary medium can be, e.g., an electronic, magnetic, optical, electromagnetic, infrared or semiconductor system (or apparatus or device) or a propagation medium.

Examples of a computer-readable medium include, e.g., a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), flash (drive), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W) and DVD. Further, it should be understood that any new computer-readable medium which may hereafter be developed should also be considered as computer-readable medium as may be used or referred to in accordance with exemplary embodiments of the present disclosure and disclosure.

[0100] Having described preferred and exemplary embodiments of novel and inventive adaptations of a 3D echocardiography probe of any type (e.g., a 3D TEE probe or a 3D ICE probe) into a 3D LUS probe of the present disclosure (which embodiments are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons having ordinary skill in the art in light of the teachings provided herein, including the Figures. It is therefore to be understood that changes can be made in/to the preferred and exemplary embodiments of the present disclosure which are within the scope of the embodiments disclosed herein.

[0101] Moreover, it is contemplated that corresponding and/or related systems incorporating and/or implementing the device or such as may be used/implemented in a device in accordance with the present disclosure are also contemplated and considered to be within the scope of the present disclosure. Further, corresponding and/or related method for manufacturing and/or using a device and/or system in accordance with the present disclosure are also contemplated and considered to be within the scope of the present disclosure.

1. A laparoscopic adapter for adapting a 3D echocardiography probe into a 3D laparoscopic ultrasound probe, the laparoscopic adapter comprising:

- a laparoscopic sleeve configured to at least partially encircle a portion of a flexible shaft of the 3D echocardiography probe; and
- a probe handle mountable to the laparoscopic sleeve.

2. The laparoscopic adapter of claim 1,

- wherein the laparoscopic sleeve includes a first semi-cylinder affixable to a second semi-cylinder; and
- wherein the first semi-cylinder and the second semi-cylinder are configured to enclose the portion of the flexible shaft.

3. The laparoscopic adapter of claim 1,

- wherein the laparoscopic sleeve is one of a rigid cylinder, a jointed cylinder, a catheter and a snake robot.

4. The laparoscopic adapter of claim 1, further comprising:

- a handle mount for mounting the probe handle to the laparoscopic sleeve, wherein the handle mount is configured to at least partially encircle a portion of the laparoscopic sleeve.

5. The laparoscopic adapter of claim 4,

- wherein the handle mount includes a first mount affixable to a second mount;
- wherein the first mount and the second mount are configured to enclose the portion of the laparoscopic sleeve; and
- wherein the probe handle is configured to be affixed to at least one the first mount and the second mount.

6. The laparoscopic adapter of claim 1, wherein the probe handle includes a probe controller configured to generate a probe actuation signal indicating a delineated deflecting of the flexible shaft.
7. The laparoscopic adapter of claim 6, wherein the probe handle further includes a user input device configured to operate the probe controller.
8. A 3D laparoscopic ultrasound probe for laparoscopic procedures, the 3D laparoscopic ultrasound probe comprising:
 - a 3D echocardiography probe including a flexible shaft; and
 - a laparoscopic adapter coupled to the flexible shaft, wherein the laparoscopic adapter adapts the 3D echocardiography probe into the 3D laparoscopic ultrasound probe.
9. The 3D laparoscopic ultrasound probe of claim 8, wherein the laparoscopic adapter includes a laparoscopic sleeve at least partially encircling a portion of the flexible shaft.
10. The 3D laparoscopic ultrasound probe of claim 9, wherein the laparoscopic sleeve includes a first semi-cylinder affixed to a second semi-cylinder; and wherein the first semi-cylinder and the second semi-cylinder enclose the portion of the flexible shaft.
11. The 3D laparoscopic ultrasound probe of claim 9, wherein the laparoscopic sleeve is one of a rigid cylinder, a jointed cylinder, a catheter and a snake robot.
12. The 3D laparoscopic ultrasound probe of claim 9, wherein the laparoscopic adapter further includes a probe handle and a handle mount for mounting the probe handle to the laparoscopic sleeve; and wherein the handle mount at least partially encircling a portion of the laparoscopic sleeve.
13. The 3D laparoscopic ultrasound probe of claim 12, wherein the handle mount includes a first mount affixed to a second mount; wherein the first mount and the second mount enclose the portion of the laparoscopic sleeve; and wherein the probe handle is configured to be affixed to at least one the first mount and the second mount.
14. The 3D laparoscopic ultrasound probe of claim 12, wherein the probe handle includes a probe controller configured to generate a probe actuation signal indicating a delineated deflecting of the flexible shaft.
15. The 3D laparoscopic ultrasound probe of claim 4, wherein the probe handle further includes a user input device configured to operate the probe controller.
16. A method for adapting a 3D echocardiography probe into a 3D laparoscopic ultrasound probe for laparoscopic procedures, the method comprising:
 - coupling a laparoscopic sleeve to a flexible shaft of the 3D echocardiography probe,
 - wherein the laparoscopic sleeve at least partially encircles a portion of the flexible shaft; and
 - mounting a probe handle to the laparoscopic sleeve.
17. The method of claim 16, wherein the laparoscopic sleeve includes a first semi-cylinder and a second semi-cylinder; and wherein the coupling of the laparoscopic sleeve to the flexible shaft of the 3D echocardiography probe includes:
 - positioning the portion of the flexible shaft within the first semi-cylinder;
 - affixing the second semi-cylinder onto the first semi-cylinder.
18. The method of claim 16, wherein the mounting of the probe handle to the laparoscopic sleeve includes:
 - affixing a handle mount to the laparoscopic sleeve,
 - wherein the handle mount partially encircles a portion of the laparoscopic sleeve; and
 - affixing the probe handle to the handle mount.
19. The method of claim 18, wherein the affixing of the handle mount to the laparoscopic sleeve includes:
 - positioning the portion of the laparoscopic sleeve within a first mount; and
 - affixing a second mount to the first mount.
20. The method of claim 16, further comprising:
 - draping the probe handle.

* * * * *

专利名称(译)	腹腔镜适配器，超声心动图探头以及将适配器耦合到探头的方法		
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摘要(译)

可以将3D超声心动图探头（20）（例如3D经食道超声心动图探头或3D心脏内超声心动图探头）适配到3D腹腔镜超声探头（10一个）中，以进行腹腔镜手术。。该3D超声心动图探头包括柔性轴（22 d，22 p），腹腔镜适配器（30 一个）可以与之连接。。腹腔镜适配器包括被配置为部分包围3D超声心动图探头的柔性轴的一部分的腹腔镜套管（31）和可安装到腹腔镜套管的探针手柄（33 一个）。（31）。

