

(12) STANDARD PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. **AU 2020204810 B2**

(54) Title
Surgical robot systems comprising robotic telemanipulators and integrated laparoscopy

(51) International Patent Classification(s)
A61B 34/37 (2016.01) **A61B 46/10** (2016.01)
A61B 34/00 (2016.01)

(21) Application No: **2020204810** (22) Date of Filing: **2020.01.04**

(87) WIPO No: **WO20/141487**

(30) Priority Data

(31) Number	(32) Date	(33) Country
PCT/IB2019/050961	2019.02.06	IB
62/788,781	2019.01.05	US
16/269,383	2019.02.06	US
16/505,585	2019.07.08	US

(43) Publication Date: **2020.07.09**

(44) Accepted Journal Date: **2025.05.08**

(71) Applicant(s)
Distalmotion SA

(72) Inventor(s)
CHASSOT, Julien;FRIEDRICH, Michael;SCHOENEICH, Patrick;SALEHIAN, Mehrnaz

(74) Agent / Attorney
RnB IP Pty Ltd, PO Box 9530, Deakin, ACT, 2600, AU

(56) Related Art
US 2010/0286712 A1



(51) International Patent Classification:

A61B 34/37 (2016.01) A61B 46/10 (2016.01)
A61B 34/00 (2016.01)

(21) International Application Number:

PCT/IB2020/050039

(22) International Filing Date:

04 January 2020 (04.01.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/788,781	05 January 2019 (05.01.2019)	US
PCT/IB2019/050961		
	06 February 2019 (06.02.2019)	IB
16/269,383	06 February 2019 (06.02.2019)	US
16/505,585	08 July 2019 (08.07.2019)	US

(71) Applicant: **DISTALMOTION SA** [CH/CH]; Route de la Corniche 3, Batiment SE-A, 1066 Epalinges (CH).

(72) Inventors: **CHASSOT, Julien**; Route de Fribourg 14, 1773 Lechelles (CH). **FRIEDRICH, Michael**; Freiburgstrasse 43, 3008 Bern (CH). **SCHOENEICH, Patrick**; Chemin de Beree 16a, 1010 Lausanne (CH). **SALEHIAN, Mehrnaz**; Avenue d'Echallens 31b, 1004 Lausanne (CH).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: SURGICAL ROBOT SYSTEMS COMPRISING ROBOTIC TELEMANIPULATORS AND INTEGRATED LAPAROSCOPY

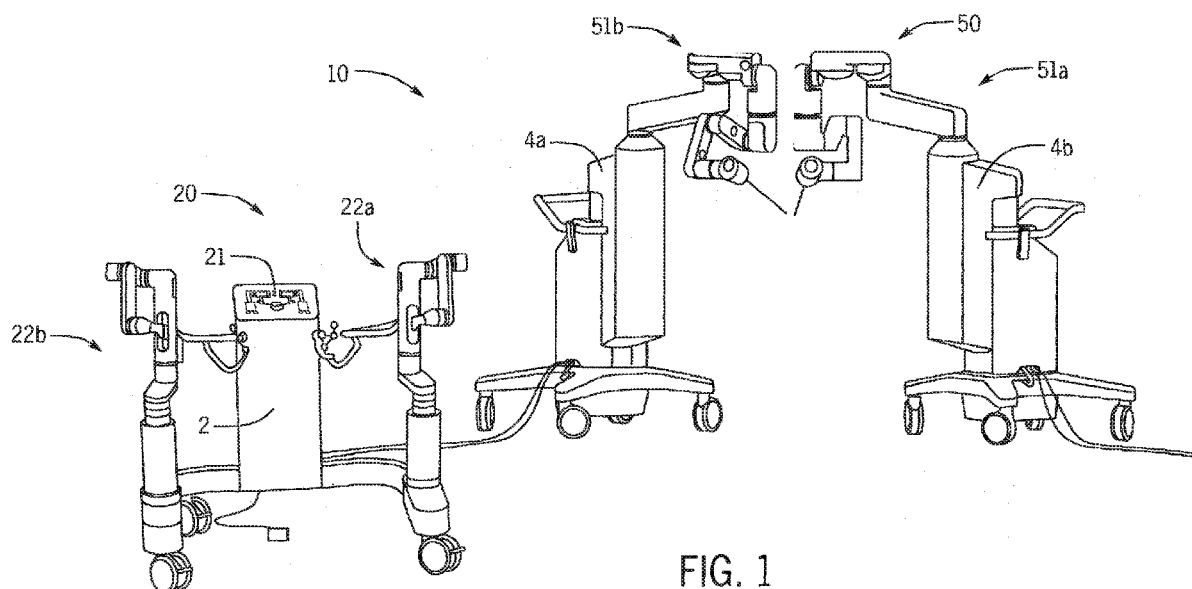


FIG. 1

(57) Abstract: Surgical robot systems for remote manipulation having robotic telemanipulators are provided. The surgical robot systems are well adapted for use by the surgeon, seamlessly integrateable into the operation room, allow for a surgeon to work between the robot and the patient throughout a surgery in a sterile manner, are relatively low cost, and/or permit integrated laparoscopy. The system preferably includes a master console having a plurality of master links interconnected by a plurality of master joints, and a handle coupled to the master console for operating the telemanipulator. The system further includes a slave console operatively coupled to the master console and having a plurality of slave links interconnected by a plurality of slave joints that move responsive to movement at the master console to permit an end-effector to perform surgery.



UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*
- *s1*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(88) Date of publication of the international search report:

20 August 2020 (20.08.2020)

SURGICAL ROBOT SYSTEMS COMPRISING ROBOTIC TELEMANIPULATORS AND INTEGRATED LAPAROSCOPY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of U.S. Patent Application Serial No. 16/505,585, filed July 8, 2019, which is a continuation of U.S. Patent Application Serial No. 16/269,383, filed February 6, 2019, now U.S. Patent No. 10,413,374, which claims the benefit of priority of U.S. Provisional Patent Application Serial No. 62/788,781, filed January 5, 2019, and U.S. Provisional Patent Application Serial No. 62/627,554, filed February 7, 2018, the entire contents of each of which are incorporated herein by reference. This application also claims the benefit of priority of PCT/IB2019/050961, filed February 6, 2019, published as WO 2019/155383, which claims the benefit of priority of U.S. Provisional Patent Application Serial No. 62/788,781, filed January 5, 2019, and U.S. Provisional Patent Application Serial No. 62/627,554, filed February 7, 2018, the entire contents of each of which are incorporated herein by reference.

FIELD OF USE

[0002] This application generally relates to remotely actuated surgical robot systems having robotic telemanipulators.

BACKGROUND

[0003] Numerous environments and applications call for remote actuation with teleoperated surgical devices. These applications include the ability to perform fine manipulation, to manipulate in confined spaces, manipulate in dangerous or contaminated environments, in clean-room or sterile environments and in surgical environments, whether open field or minimally invasive. While these applications vary, along with parameters such as precise tolerances and the level of skill of the end user, each demands many of the same features from a teleoperated system, such as the ability to carry out dexterous manipulation with high precision.

[0004] Surgical applications are discussed in the following disclosure in more detail as exemplary of applications for a teleoperated device system where known devices exist but significant shortcomings are evident in previously-known systems and methods.

[0005] Open surgery is still the preferred method for many surgical procedures. It has been used by the medical community for many decades and typically required making long incisions in the abdomen or other area of the body, through which traditional surgical tools are inserted. Due to such incisions, this extremely invasive approach results in substantial blood loss during surgery and, typically, long and painful recuperation periods in a hospital setting.

[0006] Laparoscopy, a minimally invasive technique, was developed to overcome some of the disadvantages of open surgery. Instead of large through-wall incisions, several small openings are made in the patient through which long and thin surgical instruments and endoscopic cameras are inserted. The minimally invasive nature of laparoscopic procedures reduces blood loss and pain and shortens hospital stays. When performed by experienced surgeons, a laparoscopic technique can attain clinical outcomes similar to open surgery. However, despite the above-mentioned advantages, laparoscopy requires a high degree of skill to successfully manipulate the rigid and long instrumentation used in such procedures. Typically, the entry incision acts as a point of rotation, decreasing the freedom for positioning and orientating the instruments inside the patient. The movements of the surgeon's hand about this incision point are inverted and scaled-up relative to the instrument tip ("fulcrum effect"), which reduces dexterity and sensitivity and magnifies any tremors of the surgeon's hands. In addition, the long and straight instruments force the surgeon to work in an uncomfortable posture for hands, arms and body, which can be tremendously tiring during a prolonged procedure. Therefore, due to these drawbacks of laparoscopic instrumentation, minimally invasive techniques are mainly limited to use in simple surgeries, while only a small minority of surgeons is able to use such instrumentation and methods in complex procedures.

[0007] To overcome the foregoing limitations of previously-known systems, surgical robotic systems were developed to provide an easier-to-use approach to complex minimally invasive surgeries. By means of a computerized robotic interface, those systems enable the performance of remote laparoscopy where the surgeon sits at a console manipulating two master manipulators

to perform the operation through several small incisions. Like laparoscopy, the robotic approach is also minimally invasive, providing the above-mentioned advantages over open surgery with respect to reduced pain, blood loss, and recuperation time. In addition, it also offers better ergonomics for the surgeon compared to open and laparoscopic techniques, improved dexterity, precision, and tremor suppression, and the removal of the fulcrum effect. Although being technically easier, robotic surgery still involves several drawbacks. One major disadvantage of previously-known robotic surgical systems relates to the extremely high complexity of such systems, which contain four to five robotic arms to replace the hands of both the surgeon and the assistant, integrated endoscopic imaging systems, as well as the ability to perform remote surgery, leading to huge capital costs for acquisition and maintenance, and limiting the affordability for the majority of surgical departments worldwide. Another drawback of these systems is the bulkiness of previously-known surgical robots, which compete for precious space within the operating room environment and significantly increasing preparation time. Access to the patient thus may be impaired, which raises safety concerns.

[0008] For example, the da Vinci® surgical systems (available by Intuitive Surgical, Inc., Sunnyvale, California, USA) is a robotic surgical system for allowing performance of remote laparoscopy by a surgeon. However, the da Vinci® surgical systems are very complex robotic systems, with each system costing around \$2,000,000 per robot, \$150,000 per year for servicing, and \$2,000 per surgery for surgical instruments. The da Vinci® surgical system also requires a lot of space in the operating room, making it hard to move around to a desired location within the operating room, and difficult to switch between forward and reverse surgical workspaces (also known as multi-quadrant surgery).

[0009] Moreover, as the surgeon's operating console is typically positioned away from the surgical site, the surgeon and the operating console are not in the sterile zone of the operating room. If the surgeon's operating console is not sterile, the surgeon is not permitted to attend to the patient if necessary without undergoing additional sterilization procedures. During certain surgical operations, a surgeon may need to intervene at a moment's notice, and current bulky robotic systems may prevent the surgeon from quickly accessing the surgical site on the patient in a timely, life-saving manner.

[0010] WO97/43942 to Madhani, WO98/25666 to Cooper, and U.S. Patent Application Publication No. 2010/0011900 to Burbank each discloses a robotic teleoperated surgical instrument designed to replicate a surgeon's hand movements inside the patient's body. By means of a computerized, robotic interface, the instrument enables the performance of remote laparoscopy, in which the surgeon, seated at a console and manipulating two joysticks, performs the operation through several small incisions. Those systems do not have autonomy or artificial intelligence, being essentially a sophisticated tool that is fully controlled by the surgeon. The control commands are transmitted between the robotic master and robotic slave by a complex computer-controlled mechatronic system, which is extremely costly to produce and maintain and requires considerable training for the hospital staff.

[0011] WO2013/014621 to Beira, the entire contents of which are incorporated herein by reference, describes a mechanical teleoperated device for remote manipulation which comprises master-slave configuration including a slave unit driven by a kinematically equivalent master unit, such that each part of the slave unit mimics the movement of a corresponding part of the master unit. A typical master-slave telemanipulator provides movement in seven degrees-of-freedom. Specifically, these degrees of freedom include three translational macro movements, e.g., inward/outward, upward/downward, and left/right degrees-of-freedom, and four micro movements including one rotational degree-of-freedom, e.g., pronosupination, two articulation degrees-of-freedom, e.g., yaw and pitch, and one actuation degree-of-freedom, e.g., open/close. Although the mechanical transmission system described in that publication is well adapted to the device, the low-friction routing of the cables from handles through the entire kinematic chain to the instruments is costly, complex, bulky, and requires precise calibration and careful handling and maintenance.

[0012] In addition, previously-known purely mechanical solutions do not offer wrist alignment, low device complexity, low mass and inertia, high surgical volume, and good haptic feedback. For example, with a purely mechanical teleoperated device, in order to perform a pure pronosupination/roll movement of the instrument, the surgeon typically has to perform a combined pronosupination/roll movement of his hand/forearm as well as a translational movement on a curved path with his wrist. Such movements are complex to execute properly,

and if not done properly, the end-effector pitches and yaws creating undesired parasitic movements.

[0013] Further, the routing of the articulation and actuation degrees-of-freedom cables through mechanical telemanipulators may limit the dexterity of the angular range of the various joints of the telemanipulator link-and-joint structure. This in turn limits the available surgical volume of the instruments accessible within the patient. During rapid movements of the mechanical telemanipulators, inertia of the telemanipulators also may be disturbing and result in over-shoot of the target and fatigue of the surgeon's hand. Part of this mass can be attributed to parts and components required to route the actuation and articulation degrees-of-freedom.

[0014] Accordingly, it would be desirable to provide remotely actuated surgical robot systems having robotic telemanipulators that are well adapted for use by the surgeon, seamlessly integrated into the operation room, allow for a surgeon to work between the robot and the patient in a sterile manner, are relatively low cost, and/or permit integrated laparoscopy.

[0015] It would further be desirable to provide a remotely actuated surgical robot having mechanical and/or electromechanical telemanipulators.

SUMMARY

[0016] The present invention overcomes the drawbacks of previously-known systems by providing remotely actuated surgical robot systems having robotic telemanipulators that are preferably well adapted for use by the surgeon, seamlessly integrateable into the operation room, allow for a surgeon to work between the robot and the patient throughout a surgery in a sterile manner, are relatively low cost, and/or permit integrated laparoscopy.

[0017] As will be understood by a person having ordinary skill in the art, the term "master" used herein refers to components controlled by the surgeon and may be referred to as "surgeon," and the term "slave" used herein refers to components that interact with the patient undergoing the surgery and may be referred to as "patient." For example, the terms "master console" and "surgeon console" are interchangeable and the terms "slave console" and "patient console" are interchangeable, etc. The surgical robot system for remote manipulation includes a master console having a plurality of master links, and a handle coupled to the master console such that

movement applied at the handle moves at least one of the plurality of master links. The master console may be designed to remain sterile during the surgery. In accordance with one aspect, the handle may be removably coupled to the master console such that the handle is sterile during the surgery and sterilizable while removed for additional surgeries. For example, the handle may be removably coupled to the master console via, e.g., a clip attachment or a screw attachment. The removable handle may be purely mechanical without electronics such as circuits, sensors, or electrically coupled buttons to facilitate sterilization between surgeries while the handle is removed from the master console. In this manner, the master console may be sterile (e.g., covered with a sterile drape except at the handles) during the surgery while permitting the surgeon to have the tactile feedback available from direct contact with the robot's handles.

[0018] The surgical robot system further includes a slave console having a plurality of slave links. In accordance with one aspect, the distal end of the slave console may be rotatable about an alpha-axis of an angulation slave link of the plurality slave links such that the distal end of the slave console is positionable in a manner to permit a user to move from the master console to manually perform a laparoscopic procedure on a patient undergoing the surgery.

[0019] In addition, the system includes an end-effector coupled to the slave console, wherein the end-effector moves responsive to movement applied at the handle and responsive to movement at the slave console to perform the surgery. For example, the slave console may include a plurality of actuators, e.g., motors, operatively coupled to the end-effector that, when activated responsive to actuation at the handle, apply translational macro-movements to the plurality of slave links during a macro-synchronization state, but not in an unsynchronized macro state, and apply micro-movements to the end-effector during a micro-synchronization state, but not in an unsynchronized micro state. Moreover, the surgical robot system may include an instrument having a proximal end and a distal end, the proximal end having an instrument hub designed to be coupled to the distal end of the slave console, and the distal end having the end-effector.

[0020] The handle may include a retractable piston that moves responsive to actuation of the handle. Thus, at least one sensor of the master console is designed to sense movement of the retractable piston to cause the plurality of actuators to make corresponding micro-movements at

the end-effector. In accordance with one aspect of the present invention, the slave console does not respond to movement at the master console unless the at least one sensor senses at least a predetermined amount of the retractable piston. Further, at least one sensor coupled to the handle may be designed to sense an actuation pattern of the handle that transitions the robot from an unsynchronized micro state to the micro-synchronized state. For example, in the unsynchronized micro state, movement at the handle sensed by the plurality of sensors does not cause corresponding micro-movement by the end-effector until the robot is transitioned to the micro-synchronized state because the at least one sensor senses the actuation pattern of the handle.

[0021] The master console may include a mechanical constraint designed to constrain movement of at least one master link of the plurality of master links, and may further include a clutch that when actuated prevents translational macro-movement of the plurality of master links. The surgical robot system further may include a display coupled to the master console that permits a user to visualize the end-effector during operation of the telemanipulator. Additionally, the system may include a removable incision pointer that permits alignment of the distal end of the slave console with a trocar positioned within a patient undergoing the surgery.

[0022] Moreover, the base of the slave console may be coupled to a proximal slave link of the plurality of slave links via a proximal slave joint of a plurality of slave joints such that the plurality of slave links and joints are moveable about the proximal slave joint to position the distal end of the slave console at a desired horizontal location prior to performing the surgery while the base of the slave console remains stationary. In addition, the base of the slave console may include an adjustable vertical column coupled to the proximal slave link of the plurality of slave links. The adjustable vertical column may adjust a height of the plurality of slave links and joints to position the distal end of the slave console at a desired vertical location prior to operation of the telemanipulator.

[0023] In accordance with one aspect of the present application, slave links and joints of the pluralities of slave links and joints distal to a beta joint of the plurality of slave joints are designed to move relative to the beta joint to flip the distal end of the slave console between a

forward surgical workspace and a reverse surgical workspace while slave links of the plurality of slave links proximal to the beta joint, and a base of the slave console, remain stationary.

[0024] The surgical robot system also may include a controller operatively coupled to the plurality of actuators such that the plurality of actuators apply movement to the plurality of slave links of the slave console responsive to instructions executed by the controller. For example, the controller may execute instructions to cause the plurality of actuators to move the plurality of slave links of the slave console to a home configuration where, in the home configuration, the plurality of slave links are retracted such that the end-effector is positionable within a trocar inserted in a patient undergoing the surgery. In addition, the controller may execute instructions to cause the plurality of actuators to move an angulation slave link of the plurality slave links to an angle such that the angulation slave link and the slave links of the slave console proximal to the angulation slave link remain stationary during operation of the telemanipulator. Accordingly, at the angle of the angulation slave link, the distal end of the slave console permits the end-effector to perform the surgery in a semi-spherical surgical workspace tilted at an angle essentially parallel to the angle of the angulation slave link.

[0025] In accordance with another aspect of the present invention, the master console has a master controller and the slave console has a slave controller, such that the master controller may execute instructions based on movement sensed at the handle and transmit signals to the slave controller based on the movement. Accordingly, the slave controller may receive the signals and execute instructions to move at least one of the plurality of slave links or the end-effector, or both, based on the signals transmitted from the master controller. For example, the slave console may include a right slave telemanipulator, a right slave controller, a left slave telemanipulator, and a left slave controller, and the master console may include a right master telemanipulator, a left master telemanipulator, and master controller, such that, in a forward surgical workspace configuration, the master controller communicates with the right slave controller to cause the right slave telemanipulator to move responsive to movement at the right master telemanipulator and the master controller communicates with the left slave controller to cause the left slave telemanipulator to move responsive to movement at the left master telemanipulator. Additionally, in accordance with some embodiments, in a reverse surgical workspace configuration, the master controller communicates with the left slave controller to cause the left

slave telemanipulator to move responsive to movement at the right master telemanipulator and the master controller communicates with the right slave controller to cause the right slave telemanipulator to move responsive to movement at the left master telemanipulator.

[0026] Accordingly, a distal end of the right slave telemanipulator may be rotatable about the alpha-axis of a right angulation slave link of the plurality of right slave links, and a distal end of the left slave telemanipulator may be rotatable about the alpha-axis of a left angulation slave link of the plurality of left slave links such that the distal ends of the right and left slave telemanipulators are positionable in a manner to permit a user to move from the master console to manually perform a laparoscopic procedure on a patient undergoing the surgery. In addition, the right handle may be removably coupled to the right master telemanipulator and the left handle may be removably coupled to the left master telemanipulator.

[0027] In accordance with yet another aspect of the present invention, a system for remote manipulation to perform surgery is provided. The system includes a patient console having a plurality of patient links coupled to a base, and a surgical instrument coupled to the patient console. A distal region of the surgical instrument may be inserted into a patient at a surgical site for performing robotic surgery. The system further includes a controller that executes instructions to: cause, in a surgical mode, at least one of the plurality of patient links to move responsive to movement applied at a handle of a surgeon console operatively coupled to the patient console to thereby move the surgical instrument to perform the robotic surgery, and to cause the patient console to transition from the surgical mode to a laparoscopic mode where the plurality of patient links are retracted away from the patient while the base of the patient console remains stationary to expose the surgical site to permit a surgeon to perform non-robotic surgery at the surgical site without interference from the plurality of patient links.

[0028] In addition, the controller further may execute instructions to determine that the surgical instrument has been removed from the patient at the surgical site, such that the controller only cause the patient console to transition from the surgical mode to the laparoscopic mode if the surgical instrument has been removed. For example, the controller may determine that the surgical instrument has been removed from the patient by determining that the surgical instrument has been decoupled from the patient console. Moreover, the controller may cause the

patient console to transition from the surgical mode to the laparoscopic mode responsive to user input received at the patient console. In addition, the handle may be removably coupled to the surgeon console such that the handle is sterile during the surgery and sterilizable while removed for additional surgeries. The system further may include a display coupled to the surgeon console to permit the surgeon to visualize the surgical instrument during operation of the system.

[0029] Further, the controller further may execute instructions to cause, in the surgical mode, the at least one of the plurality of patient links to move responsive to movement applied at the handle of the surgeon console at a scaled degree. For example, the controller may execute instructions to cause, in the surgical mode, scaled micro movements at the surgical instrument in a micro degree-of-freedom responsive to corresponding movement applied at the handle of the surgeon console. Micro movements applied at the surgical instrument may be independently scalable for each of the micro degrees-of-freedom such that the scaled micro movements in the micro degree-of-freedom are at a different scale than second scaled micro movement at the surgical instrument in a second micro degree-of-freedom. Moreover, the surgeon console may include a clutch for preventing micro-movements at the surgical instrument responsive to micro-movements applied at the handle of the surgeon console when the clutch is actuated.

[0030] In accordance with another aspect of the present invention, a method for remotely performing a surgery is provided. The method may include: coupling a surgical instrument to a patient console comprising a plurality of patient links coupled to a base; inserting a distal region of the surgical instrument into a patient at a surgical site for performing robotic surgery; moving, in a surgical mode, at least one of the plurality of patient links responsive to movement applied at a handle of a surgeon console operatively coupled to the patient console to thereby move the surgical instrument to perform the robotic surgery; and transitioning the patient console from the surgical mode to a laparoscopic mode where the plurality of patient links are retracted away from the patient while the base of the patient console remains stationary to expose the surgical site to permit a surgeon to perform non-robotic surgery at the surgical site without interference from the plurality of patient links.

[0031] In accordance with yet another aspect of the present invention, another system for remote manipulation to perform surgery is provided. The system may include a patient console

having an alignment joint and a plurality of patient links coupled to a base, and a surgical instrument coupled to the patient console. A distal region of the surgical instrument may be inserted into a patient at a surgical site for performing robotic surgery. The system further may include a controller that executes instructions to: set a virtual center-of-motion based on an alignment of the alignment joint and the surgical site; and cause at least one of the plurality of patient links to move responsive to movement applied at a handle of a surgeon console operatively coupled to the patient console to thereby move the surgical instrument to perform the robotic surgery, wherein movement of the surgical instrument is restricted about the virtual remote center-of-motion to maintain alignment of the patient joint with the surgical site during the surgery.

[0032] The system further may include an incision pointer that may be removably coupled to the alignment joint to permit alignment of the alignment joint and the surgical site. For example, the incision pointer may be removably coupled to the alignment joint via a magnetic attachment. In addition, the system may include a trocar positioned within the patient at the surgical site, such that the virtual center-of-motion is set based on the alignment of the alignment joint and the trocar.

[0033] In accordance with another aspect of the present invention, another method for remotely performing a surgery is provided. The method may include: aligning a patient joint of a plurality of patient joints of a patient console with a trocar insertion site, the plurality of patient joints interconnected by a plurality of patient links, the patient console operatively coupled to a surgeon console and configured to move responsive to movement applied at a handle of the surgeon console; setting a virtual remote center-of-motion based on the alignment of the patient joint with the trocar insertion site; and moving at least one of the plurality of patient links responsive to movement applied at the handle to move a surgical instrument coupled to the patient console to perform the surgery, wherein movement of the surgical instrument is restricted about the virtual remote center-of-motion to maintain alignment of the patient joint with the trocar insertion site during the surgery.

[0034] In accordance with yet another aspect of the present invention, another system for remote manipulation to perform surgery is provided. The system may include a patient console

having an alignment joint and a plurality of patient links coupled to a base, and a surgical instrument coupled to the patient console. A distal region of the surgical instrument may be inserted into a patient at a surgical site for performing robotic surgery. The system further may include a controller that executes instructions to cause, in the surgical mode, scaled micro movements at the surgical instrument in micro degrees-of-freedom responsive to corresponding movement applied at the handle of the surgeon console, wherein the scaled micro movements at the surgical instrument in the micro degrees-of-freedom are greater than the corresponding movements applied at the handle of the surgeon console. Micro movements applied at the surgical instrument may be independently scalable for each of the micro degrees-of-freedom such that the scaled micro movements in a first micro degree-of-freedom are at a different scale than second scaled micro movement at the surgical instrument in a second micro degree-of-freedom.

[0035] Moreover, the surgeon console may include a clutch for preventing micro-movements at the surgical instrument responsive to micro-movements applied at the handle of the surgeon console when the clutch is actuated. For example, the surgeon may articulate the instrument end-effector into a certain position (e.g. using the roll, pitch, and/or yaw degrees-of-freedom of the end-effector) via the handle, then actuate the clutch, move the handle back into a more ergonomic position while the instrument end-effector remains stationary, and then release the clutch to continue relative micro-movements from the handle to the instrument end-effector.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] FIG. 1 shows an exemplary remotely actuated surgical robot system having robotic telemanipulators constructed in accordance with the principles of the present invention.

[0037] FIG. 2A shows an exemplary master console constructed in accordance with the principles of the present invention.

[0038] FIG. 2B shows an exemplary display constructed in accordance with the principles of the present invention.

[0039] FIG. 2C shows another exemplary master console constructed in accordance with the principles of the present invention.

[0040] FIG. 3A shows the master console of FIG. 2A in a seated configuration, and FIGS. 3B and 3C show the master console of FIG. 2A in a standing configuration.

[0041] FIG. 4 shows an exemplary master console handle constructed in accordance with the principles of the present invention.

[0042] FIG. 5A shows an exemplary handle grip constructed in accordance with the principles of the present invention. FIGS. 5B and 5C show the handle grip of FIG. 5A removably coupling with the master console handle of FIG. 4A in accordance with the principles of the present invention.

[0043] FIGS. 5D-5F show an exemplary handle grip removably coupling with a master console handle via a clip attachment in accordance with the principles of the present invention.

[0044] FIG. 5G shows an exemplary sterile drape cap coupled to the master console handle in accordance with the principles of the present invention.

[0045] FIG. 6 shows an exemplary handle grip removably coupling with a master console handle via a screw attachment in accordance with the principles of the present invention.

[0046] FIGS. 7A-7C show actuation steps of the handle grip of FIG. 5A in accordance with the principles of the present invention.

[0047] FIGS. 7D and 7E are cross-sectional views of the handle grip of FIG. 5A coupled to the master console handle.

[0048] FIG. 8A shows another exemplary master console handle constructed in accordance with the principles of the present invention.

[0049] FIGS. 8B and 8C show movement of the handle grips of the master console handle of FIG. 8A in accordance with the principles of the present invention.

[0050] FIGS. 8D and 8E are interior views of the master console handle of FIG. 8A.

[0051] FIGS. 8F and 8G show an exemplary sterile drape interface in accordance with the principles of the present invention.

[0052] FIGS. 9A-9C show the handle grip of FIG. 8A removably coupling with the master console handle of FIG. 8A in accordance with the principles of the present invention.

[0053] FIGS. 9D-9F show the handle grip of FIG. 8A decoupling with the master console handle of FIG. 8A in accordance with the principles of the present invention.

[0054] FIGS. 10A-10C show yet another exemplary master console handle constructed in accordance with the principles of the present invention.

[0055] FIGS. 11A and 11B show an exemplary slave console constructed in accordance with the principles of the present invention.

[0056] FIG. 12 shows a left slave console constructed in accordance with the principles of the present invention.

[0057] FIG. 13A shows an exemplary controller of the remotely actuated surgical robot system.

[0058] FIG. 13B shows another exemplary controller of the remotely actuated surgical robot system.

[0059] FIGS. 14A-14E show Scara movement of the slave console in accordance with the principles of the present invention.

[0060] FIGS. 15A-15C show vertical adjustment of the slave console in accordance with the principles of the present invention.

[0061] FIG. 16 shows the slave console in a home configuration in accordance with the principles of the present invention.

[0062] FIGS. 17A-17D show movement of an exemplary translational instrument interface coupled to the slave console in a forward configuration during zero-degree angulation of the slave console.

[0063] FIGS. 18A-18D illustrates the forward surgical workspace of FIGS. 17A-17D.

[0064] FIG. 18E is a back view of the forward surgical workspace of the slave console of FIGS. 18A-18D.

[0065] FIGS. 19A-19C show the forward surgical workspace of an exemplary instrument coupled to the slave console in a forward configuration during twenty-degree angulation of the slave console.

[0066] FIGS. 20A-20C show the forward surgical workspace of an exemplary instrument coupled to the slave console in a forward configuration during forty-degree angulation of the slave console.

[0067] FIGS. 21A-21J show flipping of the slave console between a forward configuration and a reverse configuration in accordance with the principles of the present invention.

[0068] FIGS. 21K and 21L are a schematic of the master console and slave console during the forward configuration and the reverse configuration, respectively, in accordance with the principles of the present invention.

[0069] FIGS. 22A-22C show an exemplary translational instrument interface coupled to the slave console in a reverse configuration during zero, twenty, and forty-degree angulation, respectively, of the slave console.

[0070] FIGS. 23A-23C illustrates the reverse surgical workspaces of FIGS. 22A-22C.

[0071] FIGS. 24A-24D show adjustment of the slave console for integrated laparoscopy in accordance with the principles of the present invention.

[0072] FIG. 25 is a flow chart illustrating use of the remotely actuated surgical robot system of FIG. 1 in accordance with the principles of the present invention.

[0073] FIG. 26 is a flow chart illustrating the surgeon console positioning step of FIG. 25 in accordance with the principles of the present invention.

[0074] FIG. 27 is a flow chart illustrating the preparation step of FIG. 25 in accordance with the principles of the present invention.

[0075] FIG. 28 is a flow chart illustrating the ready for instrument step of FIG. 25 in accordance with the principles of the present invention.

[0076] FIG. 29 is a flow chart illustrating the ready for operation step of FIG. 25 in accordance with the principles of the present invention.

[0077] FIG. 30 is a flow chart illustrating the operating step of FIG. 25 in accordance with the principles of the present invention.

[0078] FIGS. 31A and 31B show an exemplary remotely actuated surgical robot system having hybrid telemanipulators constructed in accordance with the principles of the present invention.

[0079] FIGS. 32A and 32B show partially exploded perspective views of the surgical robot system of FIGS. 31A and 31B.

[0080] FIG. 33 shows a top view, partially exploded, of an exemplary mechanical transmission system constructed in accordance with the principles of the present invention.

[0081] FIGS. 34A and 34B show side perspective views of an exemplary master unit constructed in accordance with the principles of the present invention.

[0082] FIGS. 34C and 34D show alternative embodiments of a handle suitable for use with the master unit depicted in FIGS. 34A and 34B.

[0083] FIGS. 35A and 35B show side perspective views of an exemplary slave unit constructed in accordance with the principles of the present invention.

[0084] FIGS. 36A and 36B show, respectively, an end sectional and side interior perspective view of an exemplary slave hub.

[0085] FIGS. 36C and 36D are, respectively, a perspective side view of a slave instrument and a detailed interior view of an end-effector constructed in accordance with the principles of the present invention.

[0086] FIG. 36E is a detailed view of an alternative embodiment of an exemplary end-effector.

[0087] FIG. 37 shows a flow chart illustrating exemplary method steps for identifying the kinematics of a selected end-effector.

[0088] FIG. 38 shows an alternative exemplary embodiment of a remotely actuated surgical robot system of the present invention.

[0089] FIG. 39 shows interior side perspective view of the master unit of the remotely actuated surgical robot system of FIG. 38.

[0090] FIGS. 40A and 40B are forward and rearward perspective views of the slave unit of the remotely actuated surgical robot system of FIG. 38.

[0091] FIGS. 40C and 40D show another exemplary incision pointer constructed in accordance with the principles of the present invention.

[0092] FIGS. 41A and 41B are alternative schematic illustrations of a control system suitable for use in the surgical robot system of the present invention.

[0093] FIGS. 42A and 42B are side perspective views of alternative embodiments of telemanipulators constructed in accordance with the principles of the present invention.

[0094] FIG. 43 shows another exemplary master console constructed in accordance with the principles of the present invention.

DETAILED DESCRIPTION

[0095] A remotely actuated surgical robot system having robotic telemanipulators and integrated laparoscopy, which may be used in minimally invasive surgical procedures or in other applications, constructed in accordance with the principles of the present invention, is described herein. The surgical robot system provides the value of robotics for long and difficult surgical tasks such as suturing and dissection, and permits a user, e.g., a surgeon, to efficiently switch to integrated laparoscopy for short and specialized surgical tasks such as vessel sealing and

stapling. The fully articulated instruments simplify complex surgical tasks, and replication of hand movements increase precision. The user may be seated or standing in a relaxed ergonomic working position to improve surgeon focus and performance.

[0096] Referring to FIG. 1, exemplary remotely actuated surgical robot system 10 having robotic telemanipulators is described. Surgical robot system 10 includes master console 20 electrically and operatively coupled to slave console 50 via, e.g., electrical cables. As described in further detail below, surgical robot system 10 includes a macro-synchronization state where a plurality of actuators, e.g., preferably motors, coupled to slave console 50 applies translational macro-movements to an end-effector of slave console 50 responsive to movement applied at master console 20 via a processor-driven control system, and a micro-synchronization state where a plurality of actuators, e.g., preferably motors, coupled to slave console 50 applies micro-movements to an end-effector of slave console 50 responsive to movement applied at a handle of master console 20 via the processor-driven control system.

[0097] The control system may include master controller 2 operatively coupled to right master telemanipulator 22a and left master telemanipulator 22b of master console 20, and slave controllers 4a and 4b operatively coupled to right slave telemanipulator 51a and left slave telemanipulator 51b of slave console 50, respectively. For example, master controller 2 may include non-transitory computer readable media, e.g., memory, having instructions stored thereon that, when executed by one or more processors of master controller 2, allow operation of master console 20. Similarly, slave controllers 4a and 4b may each include non-transitory computer readable media, e.g., memory, having instructions stored thereon that, when executed by one or more processors of respective slave controllers 4a, 4b, allow operation of slave console 50. Master controller 2 is operatively coupled to slave controller 4a and slave controller 4b via communication links such as cables (as illustrated) or via wireless communication components.

[0098] Master controller 2 may be operatively coupled to one or more sensors of master console 20, and slave controllers 4a, 4b may be operatively coupled to one or more actuators of slave console 50 such that master controller 2 may receive signals indicative of movement applied at master console 20 by the one or more sensors of master console 20, and execute instructions stored thereon to perform coordinate transforms necessary to activate the one or

more actuators of slave console 50, send the processed signals to respective slave controllers 4a, 4b that execute instructions stored thereon to move slave console 50 in a manner corresponding to movement of master console 20 based on the processed signals. For example, the one or more actuators may include one or more motors. Alternatively, master controller 2 may receive the signals from the one or more sensors of master console 20, process the signals, and transmit the processed signals to respective slave controllers 4a, 4b which execute instructions stored thereon to perform the coordinate transforms based on the processed signals, and execute instructions to activate the one or more actuators of slave console 50 to move slave console 50 in a manner corresponding to movement of master console 20 based on the transformed, processed signals. Preferably, the slave links and joints of slave console 50 move in a manner such that the end-effector/instrument tip replicates the movement applied at the handle of master console 20, without deviating, during operation of surgical robot system 10, from a remote center-of-motion, as described in further detail below. Thus, translation degrees-of-freedom, e.g., left/right, upward/downward, inward/outward, the articulation degrees-of-freedom, e.g., pitch and yaw, the actuation degrees-of-freedom, e.g., open/close, and the rotation degree-of-freedom, e.g., pronosupination, are electromechanically replicated via sensors, actuators, and a control system as described in further detail below.

[0099] In accordance with one aspect of the present invention, the slave links and joints of slave console 50 may move in a manner responsive to movement applied at the handle of master console 20 such that the surgical instrument reproduces the movement applied at the handle of master console 20 at a scaled degree. For example, master controller 2 may receive the signals from the one or more sensors of master console 20, process the signals, and transmit the processed signals to respective slave controllers 4a, 4b which execute instructions stored thereon to perform the coordinate transforms based on the processed signals to generate signals indicative of corresponding scaled movements, and execute instructions to activate the one or more actuators of slave console 50 to move slave console 50 in a scaled manner corresponding to movement of master console 20 based on the transformed, scaled processed signals. Accordingly, the surgeon may apply a micro roll movement of, e.g., 30 degrees, to the handle of master console 20, such that the actuators of slave console 50 cause the surgical instrument of slave console 50 to perform a micro roll movement at a scaled degree of, e.g., 60 degrees, thereby resulting in a scaled ratio movement (e.g., 1:2) by slave console 50 in response to

movement at master console 20. Preferably, the micro-scaling causes greater micro movements at the end-effector than occurred at the handle. Each of the macro degrees-of-freedom, e.g., translation, and each of the micro degrees-of-freedom, e.g., articulation, actuation, and rotation, may be independently scaled such that corresponding movement at slave console 50 in an assigned degree-of-freedom is selectively scaled in comparison to the movement applied at master console 20 by the surgeon. For example, the rotation micro degree-of-freedom may be programmed to have corresponding scaled movements between the master and slave at a first scale (1:2), whereas the actuation and/or articulation micro degrees-of-freedom may be programmed to have corresponding scaled movements between the master and slave at a second scale (2:3), different than the first scale. A third scale may be used for the third micro degree-of-freedom. As will be understood by a person having ordinary skill in the art, the scale ratios may be, e.g., 3:1, 2.5:1, 2:1, 1.5:1, 1:1.5, 1:2, 1:2.5, or 1:3, and may vary across the degrees-of-freedom. Advantageously, when micro-scaling calls for greater scaled movements at the end-effector than at the handle, the surgeon need not apply a large movement on the handle of master console 20 to achieve a desired large movement by the surgical instrument of slave console 50. This allows for more efficient aspects of robotic surgery (e.g., suturing) with reduced strain on the surgeon's hand/wrist/arm.

[00100] Master console 20 may be positioned within the operating room where a user, e.g., surgeon, may be situated, and in close proximity to slave console 50 where a patient undergoing surgery may be situated, e.g., the sterile zone, so that the user may move quickly between master console 20 and slave console 50 to manually perform laparoscopy during the surgery if necessary. Accordingly, slave console 50 is designed to efficiently retract to a configuration to permit the surgeon to access the surgical site on the patient as described in further detail below. Master console 20 may be covered with a sterile drape, and may include removable handles that may be removed and sterilizable between surgeries such that the handles are sterile during the surgery and there are no physical barriers between the handles and the surgeon's hands, thereby improving control and performance by the surgeon. The removable handle may be purely mechanical without electronics such as circuits, sensors, or electrically coupled buttons so that the removable handle is easily sterilizable between surgeries. In this manner, the master console may be sterile during the surgery while permitting the surgeon to have the tactile feedback available from direct contact with the robot's handles.

[00101] As illustrated in FIG. 1, master console 20 includes right master telemanipulator 22a and left master telemanipulator 22b. Right master telemanipulator 22a and left master telemanipulator 22b may be positioned on a single master console such that right master telemanipulator 22a may be manipulated by the surgeon's right hand and left master telemanipulator 22b may be manipulated by the surgeon's left hand when the surgeon is situated at master console 20. Accordingly, master console 20 may include wheels for mobility within the operating room, and wheel locks that may be actuated to lock the telemanipulators in position, e.g., during storage or during use by the surgeon during the surgery. In addition, right master telemanipulator 22a and left master telemanipulator 22b may be operated simultaneously and independently from the other, e.g., by the surgeon's right and left hands. Preferably, surgical robot system 10 is optimized for use in surgical procedures.

[00102] As further illustrated in FIG. 1, slave console 50 includes right slave telemanipulator 51a operatively coupled to right master telemanipulator 22a, and left slave telemanipulator 51b operatively coupled to left master telemanipulator 22b. Right and left slave telemanipulators 51a and 51b may be positioned on separate consoles such that right slave telemanipulator 51a may be positioned on the right side of the patient undergoing surgery and left slave telemanipulator may be positioned on the left side of the patient. Accordingly, right and left slave telemanipulators 51a and 51b each may include wheels for mobility within the operating room, and floor locks that may be actuated to lock the telemanipulators in position, e.g., during storage or adjacent the patient during the surgery. In addition, right and left slave telemanipulators 51a and 51b each may include a pull bar for pushing and pulling the telemanipulators within the operating room.

[00103] Moreover, a camera system may be used with surgical robot system 10. For example, a camera e.g., an endoscope, that is manipulated by the assistant situated at slave console 50 may be operated and/or held in position at slave console 50. Accordingly, the camera system may include display 21 mounted on master console 20 in a position that is easily observable by the surgeon during a surgical procedure. Display 21 may display status information on the surgical robot system 10, and/or display the surgical site captured by the endoscopic camera to surgeon in real-time.

[00104] Referring now to FIG. 2A, exemplary master console 20 is described. As described above, master console 20 includes right master telemanipulator 22a and left master telemanipulator 22b. As left master telemanipulator 22b may be a structurally mirrored version of right master telemanipulator 22a as illustrated, the description below of right master telemanipulator 22a applies also to left master telemanipulator 22b.

[00105] Master telemanipulator 22a includes a plurality of master links, e.g., first master link 26, second master link 28, third master link 30, and fourth master link, e.g., guided master link 32, interconnected by a plurality of master joints, e.g., first master joint 25, second master joint 27, third master joint 29, fourth master joint 31, and fifth master joint 34. As shown in FIG. 1, handle portion 35 is connected to master telemanipulator 22a via joint 34, and includes a plurality of handles links interconnected by a plurality of handle joints for operating master telemanipulator 22a. In addition, master telemanipulator 22a includes a base portion having telescoping bases 23a and 23b, and base cap 24 fixed atop telescoping bases 23a and 23b. Link 26 is rotatably coupled to base cap 24 via joint 25. Thus, link 26, and accordingly all the master joints and links distal to link 26, may rotate relative to base cap 24 about axis δ_1 at joint 25. As shown in FIG. 1, link 28, and accordingly all the master joints and links distal to link 28, may rotate relative to link 26 about axis δ_2 at joint 27, link 30, and accordingly all the master joints and links distal to link 30, may rotate relative to link 28 about axis δ_3 at joint 29, and guide master link 32, and accordingly all the master joints and links distal to guided master link 32, may rotate relative to link 30 about axis δ_4 at joint 31.

[00106] Master console 20 includes a plurality of sensors positioned within master telemanipulator 22a such that any movement applied to any master links and joints may be sensed and transmitted to the control system, which will then execute instructions to cause one or more actuators coupled to slave console 50 to replicate the movement on corresponding slave link and joints of slave telemanipulator 51a, as described in further detail below with reference to FIG. 12.

[00107] Still referring to FIG. 2A, master telemanipulator 22a includes mechanical constraint 33, which includes an opening within link 26 sized and shaped to permit guided master link 32 to be positioned therethrough, thereby constraining movements of master telemanipulator 22a about

a pivot point at master telemanipulator 22a. For example, mechanical constraint 33 ensures that, when master telemanipulator 22a is actuated, guided master link 32 translates along longitudinal axis δ_5 . In addition, mechanical constraint 33 enables guided master link 32 to rotate about axes δ_1 and δ_6 that are perpendicular to each other, creating a plane that intersects longitudinal axis δ_5 at stationary pivot point P independently of the orientation of guided master link 32. As a result, the slave telemanipulator produces corresponding movements, thereby virtually maintaining the pivot point of the master telemanipulator, for example, at the fixed incision point on a patient where a trocar passes into a patient's abdomen.

[00108] When surgical robot system 10 is positioned such that remote center-of-motion V is aligned with the patient incision, translational movement applied to handle portion 35 is replicated by the end-effector disposed inside the patient. Because the end-effector replicates the movement applied to handle portion 35, this arrangement advantageously eliminates the fulcrum effect between the handle and end-effector.

[00109] In addition, master console 20 may include arm support 12, e.g., coupled to base cap 24, sized and shaped to permit the surgeon to rest the surgeon's arms against the arm support during operation of master console 20. Accordingly, arm support 12 remains static during operation of master telemanipulator 22a. Master console 20 further may include clutch 11, e.g., a foot pedal, that when actuated prevents macro-synchronization and/or micro-synchronization of surgical robot system 10, as described in further detail below. As such, master console 20 permits macro-clutching and micro-clutching.

[00110] Referring now to FIG. 2B, display 21 is described. Display 21 may have a simplistic design without text, utilizing only visible graphical elements and LEDs, e.g., white, yellow, and red lights. For example, white light conveys that the component is functioning properly, yellow light conveys that the surgeon has conducted an inappropriate action, and red conveys that there is an error with the component. As shown in FIG. 2B, display 21 graphically displays various components of slave console 50 and the status thereof. Icon 21a corresponds with the booting of the system, icon 21b corresponds with a system warning, icon 21h corresponds with the work limit being reached, and icon 21j corresponds with whether the respective slave telemanipulators of slave console 50 are in a forward surgical workspace or a reverse surgical workspace, all of

which may be invisible when not lit up, whereas all other icons have a visible graphical element even when not lit up. Icon 21c corresponds with homing, e.g., home configuration, of slave console 50, icon 21d corresponds with the status of instrument 82, icon 21e corresponds with the sterile interface of translation instrument interface 81, icon 21f corresponds with macro-synchronization, icon 21g corresponds with micro-synchronization, and icon 21i corresponds with whether the wheels of slave console 50 are locked or unlocked, the functionality of all of which will be described in further detail below. As will be understood by a person having ordinary skill in the art, display 21 may be any display known in the art that may convey information to the surgeon.

[00111] FIG. 2C shows another exemplary master console similar to that shown in FIG. 2A except master console 20 in FIG. 2C further includes an additional clutch 11', e.g., an additional foot pedal. In this manner, actuation of clutch 11 allows the master/slave to transition between one type of synchronization/desynchronization (e.g., for macro movements) and actuation of clutch 11' allows the master/slave to transition between another type of synchronization/desynchronization (e.g., for micro movements, for both micro and macro movements), as described in further detail below. As such, independently actuatable macro-clutching and micro-clutching is permitted. Alternatively or additionally, different predetermined actuation patterns (e.g., multiple presses at the pedal within a predetermined time versus one press at the pedal within the predetermined time) at clutch 11 and/or clutch 11' may be used for independently actuatable macro-clutching and micro-clutching.

[00112] Referring now to FIGS. 3A-3C, master console 20 may be adjusted between a seated configuration and a standing configuration via telescoping bases 23a and 23b. For example, as illustrated in FIG. 3A, master console 20 may be adjusted to a seated configuration such that telescoping bases 23a and 23b have a vertical height D_1 . In this seated configuration, the surgeon may be seated during operation of master console 20. As illustrated in FIGS. 3B and 3C, master console 20 may be adjusted to a standing configuration such that telescoping bases 23a and 23b have a vertical height D_2 . In this configuration, the surgeon may be standing during operation of master console 20. In addition, the vertical height of telescoping bases 23a and 23b may be adjusted via an actuator positioned on master console 20, e.g., on master link 26. For example, the actuator may include up and down buttons that when actuated, cause the vertical

height of telescoping bases 23a and 23b to increase or decrease, respectively. As will be understood by a person having ordinary skill in the art, the vertical height of telescoping bases 23a and 23b may be adjusted to any vertical height between D_1 and D_2 , as desired by the surgeon.

[00113] Referring now to FIG. 4, master console handle portion 35 is described. Master console handle portion 35 includes a plurality of handle links, e.g., handle link 36 and handle link 38, interconnected by a plurality of handle joints, e.g., handle joint 37 and handle joint 39. As illustrated in FIG. 4, handle link 36 is rotatably coupled to guided master link 32 via joint 34, and accordingly may rotate relative to guided master link 32 about axis δ_7 . In addition, handle link 38 is rotatably coupled to handle link 36 via handle joint 37, and accordingly may rotate relative to handle link 36 about axis δ_8 . Moreover, handle grip 40 may be removably coupled to master console handle portion 35 at joint 39, such that handle grip 40 may rotate relative to handle link 37 about axis δ_9 . As shown in FIG. 4, handle grip 40 may include finger strap 41 for engagement with the surgeon's fingers, e.g., thumb and index finger.

[00114] Inward/outward movement of handle portion 35 causes guided master link 32 to move inward/outward along longitudinal axis δ_5 , the movement of which is sensed by one or more sensors coupled to master telemanipulator 22a and transmitted to the control system, which then executes instructions to cause one or more actuators coupled to slave telemanipulator 51a to cause the corresponding slave link to replicate the inward/outward movement about virtual longitudinal axis ω_9 . Similarly, upward/downward movement of handle portion 35 causes guided master link to move upward/downward along longitudinal axis δ_6 , the movement of which is sensed by one or more sensors coupled to master telemanipulator 22a and transmitted to the control system, which then executes instructions to cause one or more actuators coupled to slave telemanipulator 51a to cause the corresponding slave link to replicate the upward/downward movement about virtual longitudinal axis ω_{10} . Finally, left/right movement of handle portion 35 causes guided master link to move left/right along longitudinal axis δ_1 , the movement of which is sensed by one or more sensors coupled to master telemanipulator 22a and transmitted to the control system, which then executes instructions to cause one or more actuators coupled to slave telemanipulator 51a to cause the corresponding slave link to replicate the left/right movement about virtual longitudinal axis ω_5 .

[00115] Still referring to FIG. 4, movement applied at handle portion 35 of master telemanipulator 22a actuates the articulation degrees-of-freedom, e.g., pitch and yaw, the actuation degree-of-freedom, e.g., open/close, and the rotation degree-of-freedom, e.g., pronosupination, electromechanically via sensors, actuators, and the control system. Master telemanipulator 22a preferably includes one or more sensors coupled to handle portion 35 for detecting motion of handle portion 35. As will be understood, the sensors may be any sensor designed to detect rotational movement, such as magnetic-based rotational sensors that includes a magnet on one side and a sensor on another side to measure rotation by measuring angle and position. The sensors are coupled to a control system for generating signals indicative of the rotation measured by the sensors and transmitting the signals to one or more actuators coupled to slave console 50, which may reproduce movements applied on handle portion 35 to the end effector. For example, electrical cables may extend from handle portion 35 to the control system, e.g., a unit containing control electronics, and additional electrical cables may extend from the control system to the one or more actuators coupled to slave console 50.

[00116] As illustrated in FIG. 5A, handle grip 40 includes triggers 41a, 41b that are biased toward an open configuration. Accordingly, triggers 41a, 41b may be actuated to generate a signal that is transmitted via the control system, which executes instructions that causes the actuators coupled to slave console 50 to actuate the end-effector to open/close.

[00117] Referring back to FIG. 4, handle grip 40 may be rotatable about handle axis δ_9 , such that rotation of the handle grip 40 is detected by a sensor that generates and transmits a signal via the control system, which executes instructions that causes the actuators coupled to slave console 50 to cause rotation of the end-effector in the pronosupination degree-of-freedom.

[00118] Handle portion 35 also is rotatable about handle axis δ_8 , such that the rotation about handle axis δ_8 is detected by a sensor, which generates and transmits a signal via the control system, which executes instructions that causes the actuators coupled to slave console 50 to cause movement of the end-effector in the yaw degree-of-freedom. In addition, handle portion 35 may be rotatable about handle axis δ_7 , such that the rotation of handle portion 35 about handle axis δ_7 is detected by a sensor, which generates and transmits a signal via the control system,

which executes instructions that causes the actuators coupled to slave console 50 to cause movement of the end-effector in the pitch degree-of-freedom.

[00119] As illustrated in FIGS. 5B and 5C, handle grip 40 may be removably coupled to handle portion 35 of master telemanipulator 22a via joint 39. Accordingly, handle grip 40 may be removed between surgeries to be sterilized, and reconnected to master telemanipulator 22a just before a surgery. Thus, as the entirety of master console 20 may be covered with a sterile drape during operation of surgical robot system 10, handle grip 40 will be sterile and may be connected to master console 20 outside of the sterile drape. This permits the surgeon to directly contact handle grip 40 without a physical barrier therebetween, thereby improving tactile feedback and overall performance.

[00120] Referring now to FIGS. 5D-5F, handle grip 40 may be removably coupled to handle portion 35 of master console 20 via a clip attachment. As shown in FIGS. 5D-5F, spring 43 may be connected to joint 39 of handle portion 35 and clip portion 42 of handle grip 40 to preload the attachment to eliminate fixation backlash.

[00121] As shown in FIG. 5G sterile drape cap 13 may be removably coupled to master console handle portion 35 in accordance with the principles of the present invention. As described above, master console 20 may be covered with sterile drape 14 during the surgery while permitting the surgeon to have the tactile feedback available from direct contact with the robot's handles. Sterile drape interface 14 includes sterile drape ring 14a defining opening 14b within sterile drape interface 14, and sterile drape 14c coupled to sterile drape ring 14a. While the handle grip is not attached to master console 20, e.g., during sterilization and/or cleaning, sterile drape cap 13 may be temporarily coupled to sterile drape ring 14a and to master console handle portion 35 to avoid accidental contact with the interior of the master console handle interface by the clinician. For example, sterile drape cap 13 may be fitted over master console handle portion 35 and held in place via methods known in the art including, but not limited to, a system of magnets, friction forces, Velcro surfaces, matching geometries, hooks, etc. When the handle grip is ready to be coupled to master console handle portion 35, sterile drape cap 13 may be removed and disposed of. Sterile drape ring 14a is preferably formed of a rigid material, e.g., metal, and is designed to be sandwiched between master console 20 (e.g., at master console

handle portion 35) and the handle grip when the handle grip is coupled to the master console. This provides secure coupling of sterile drape 14c to the master console using the removable handle. In addition, sterile drape interface 14 may be easily removed from the master console when the handle grip is removed for sterilization for further surgeries. Opening 14b of sterile drape interface 14 allows components of the handle to move into the master console responsive to actuation by the surgeon through opening 14b of sterile drape interface 14 without interference of sterile drape 14c. This ensures a sterile surgery while allowing interaction between the removable handle and the master console.

[00122] In accordance with another aspect of the present invention, as shown in FIG. 6, handle grip 40' may be removably coupled to handle portion 35' of master console 20 via a screw attachment. As shown in FIG. 6, screw portion 42' of handle grip 40' having inner threaded portion 44a may engage with outer threaded portion 44b at joint 39' of handle portion 35', such that handle grip 40' is screwed onto handle portion 35'.

[00123] Referring now to FIGS. 7A-7C, actuation steps of handle grip 40 are described. As illustrated in FIGS. 7B and 7C, handle grip 40 includes retractable piston 45 positioned within a central lumen of handle grip 40. Retractable piston 45 is mechanically coupled to triggers 41a, 41b of handle grip 40 via connectors 46a, 46b, respectively. As shown in FIG. 7A, when triggers 41a, 41b are in a relaxed state, e.g., biased toward an open configuration, retractable piston 45 is completely within the central lumen of handle grip 40. As shown in FIGS. 7B and 7C, as handle grip 40 is actuated, e.g., triggers 41a, 41b are pressed toward each other, connectors 46a, 46b cause retractable piston 45 to protrude out of the central lumen of handle grip 40. The movement of retractable piston 45 beyond the central lumen of handle grip 40 may be sensed by sensors within handle portion 35.

[00124] For example, as shown in FIGS. 7D and 7E, the portion of master console adjacent to where handle grip 40 is removably coupled to handle portion 35 may include one or more sensors 47 for sensing movement at handle portion 35. Accordingly, one or more sensors 47 may transmit a signal to the control system indicating movement of retractable piston 45, and the control system may execute instructions to cause one or more actuators to cause movement by the end-effector. This may serve as a fail-safe because the control system will not instruct the

actuators to cause movement by the end-effector without sensors 47 sensing movement of retractable piston 45. For example, when triggers 41a, 41b of handle grip 40 are in a relaxed state, no movement will be sensed due to small incidental movements of triggers 41a, 41b until triggers 41a, 41b are purposefully actuated by the surgeon. Thus, triggers 41a, 41b may have to be actuated at least a pre-specified amount in order for retractable piston 45 to protrude beyond the central lumen of handle grip 40. In addition, as illustrated in FIGS. 7D and 7E, handle portion 35 may include spring 48 for pushing against retractable piston 45 to bias triggers 41a, 41b in an open configuration via connectors 46a, 46b.

[00125] Referring now to FIG. 8A-8G, another exemplary handle grip is provided. Handle grip 71 is constructed to be coupled to master console handle portion 35 at sterile drape interface 14 (e.g., by sandwiching sterile drape ring 14a between master console handle portion 35 and the movable outer flange to clip the components together). Handle grip 71 includes triggers 72a and 72b, which are biased in an open configuration. For example, as shown in FIG. 8B, when the clinician does not apply any force to triggers 72a, 72b, triggers 72a, 72b may be biased to, e.g., 150 – 160 degrees, or preferably 155 degrees, apart. At any time, when the clinician releases triggers 72a, 72b, triggers 72a, 72b will return to the predetermined open configuration. Triggers 72a, 72b may be biased to an open configuration via springs as described above with reference to triggers 41a, 41b. Like handle grip 40, triggers 72a, 72b of handle grip 71 may have to be pressed to be a first predetermined angle from one another before the control system executes instructions to cause one or more actuators to cause movement at the surgical instrument. For example, as shown in FIG. 8C, the actuators will not cause movement by the plurality of slave links and slave joints or the end-effector until triggers 72a, 72b are pressed such that triggers 71a, 72b are within the first predetermined angle, e.g., 90 degrees apart or less. This may serve as a fail-safe to prevent small incidental movements of triggers 72a, 72b from being replicated by the end-effector until triggers 72a, 72b are purposefully actuated by the surgeon. For example, triggers 72a, 72b must be pressed to within 90 degrees apart (or another preset angle), before the plurality of slave links and slave joints move responsive to movement of at least one of the plurality of master links and master joints. If triggers 72a, 72b are released by the surgeon, the slave console will cease movement responsive to movements at the master console. In this manner, a surgeon can readjust the plurality of master links and master joints to a different desirable configuration without causing corresponding movements at any of the slave links or

joints. This allows the surgeon to readjust the master console to a more comfortable position without moving the slave console. Once triggers 72a, 72b are reengaged to the first predetermined angle, or less, the controller will then cause corresponding movements at the slave console responsive to movement at the handle. Handle grip 71 further includes palm extension 72c that extends from the triggers in the direction of a surgeon's palm so that the surgeon's palm can contact palm extension 72c while performing surgery for ergonomic purposes.

[00126] In addition, while the controller will not cause movement at the slave console unless the surgeon engages the handle in a predetermined manner (e.g., triggers 72a, 72b are moved toward one another to within the first predetermined angle or less), the controller also will not cause micro-movements at the end-effector unless the surgeon engages the handle in a second predetermined manner. For example, the second predetermined manner may be to move triggers 72a, 72b toward one another a second predetermined angle (e.g., 30 degrees apart) or less, where the second predetermined angle is less than the first predetermined angle. In this manner, the slave console will not move responsive to movement at the handle/master console unless a first actuation pattern is sensed at the handle by the controller (e.g., triggers 72a, 72b are moved toward one another to within the first predetermined angle or less) and the end effector will not open/close unless a second actuation pattern is sensed at the handle by the controller (e.g., triggers 72a, 72b are moved toward one another to within the second predetermined angle or less).

[00127] Referring now to FIGS. 8D and 8E, the internal components of handle grip 71 are described. As shown in FIGS. 8D and 8E, handle grip 71 has release grip 76, which is coupled to coaxial retraction tube 74, such that retraction of release grip 76 causes retraction tube 74 to retract. Retraction tube 74 has a number of apertures 75 corresponding with a number of hooks 73, such that each of hooks 73 protrudes through each of apertures 75 when release grip 76 and retraction tube 74 are in a relaxed state. For example, handle grip 71 may have one, two, three, or four hooks. Hooks 73 have an angled surface, e.g., angling away from the direction where handle grip 71 is coupled to the master console, so that as retraction tube 74 is retracted via release grip 76, the edge of apertures 75 is moved over the angled surface of hooks 73 causing hooks 73 to bend radially inward toward the center axis of retraction tube 74. When release grip 76 is released, both release grip 76 and retraction tube 74 returns to their relaxed

state allowing apertures 75 to realign with hooks 73 such that hooks 73 protrude through apertures 75.

[00128] Master console handle portion 35 includes angular orientation constraint 80b, which has a geometry that corresponds with angular orientation constraint 80a of handle grip 71 such that retraction tube 74 may be inserted within a lumen of angular orientation constraint 80b at a specific rotational orientation. As shown in FIG. 8E, angular orientation constraint 80b includes one or more grooves 77 on its inner surface having a geometry that corresponds with hooks 73 such that when retraction tube is inserted within the lumen of angular orientation constraint 80b and hooks 73 are protruding through apertures 75, hooks 73 will engage with groove 77. There may be a number of grooves corresponding with the number of hooks 73, or groove 77 may fully extend circumferentially along the inner surface of angular orientation constraint 80b. Moreover, handle grip 71 may include actuation rod 78 which is sized to fit within the lumen of preload spacer 86 and interact with actuation rod 79 of the master console. For example, actuation rod 79 may extend a predetermine distance within preload spacer 86 to push against actuation rod 78 of handle grip 71 for biasing triggers 72a, 72b in the open configuration as described above.

[00129] Preload spacer 86 may be coupled to preload spring 85, such that preload spacer pushes against handle grip 71 when handle grip 71 is engaged with master console handle portion 35. Accordingly, when hooks 73 are engaged with grooves 77, preload spacer 86 pushes against handle grip 71 to keep hooks 73 positioned within grooves 77 and cancel any backlash. Specifically, the trailing edge of hooks 73 is pushed against the trailing edge of grooves 77 to prevent lateral movement of handle grip 71 relative to master console handle portion 35 when handle grip 71 is engaged.

[00130] As shown in FIG. 8F, release grip 76 may have a textured surface for ease of retraction of release grip 76 by the clinician when coupling and decoupling handle grip 71 with master console handle portion 35. As shown in FIGS. 8F and 8G, release grip 76 engages with sterile drape interface 14 when handle grip 71 is engaged with master console handle portion 35 such that handle grip 71 may still rotate freely. As shown in FIG. 8F, sterile drape ring 14a of sterile drape interface 14 having sterile drape 14c coupled thereto snaps onto master console

handle portion 35, such that sterile drape 14c maintains sterility of the master console during operation.

[00131] Referring now to FIGS. 9A-9C, the steps of coupling handle grip 71 to the master console are illustrated. FIG. 9A shows release grip 76 of handle grip 71 in a relaxed state, with hooks 73 protruding through apertures 75 of retraction tube 74. FIG. 9B illustrates retraction of release grip 76, when the edge of apertures 75 causes hooks 73 to move radially inward such that retraction tube 74 may be inserted within the lumen of angular orientation constraint 80b. When retraction tube 74 is fully inserted within the lumen of angular orientation constraint 80b, release grip 76 may be released as shown in FIG. 9C to permit hooks 73 to protrude through apertures 75 of retraction tube 74 and to engage with grooves 77 in the relaxed state. FIG. 9C illustrated handle grip 71 coupled to master console handle portion 35.

[00132] Referring now to FIGS. 9D-F, the steps of decoupling handle grip 71 from the master console are illustrated. FIG. 9D shows release grip 76 being retracted such that the edge of apertures 75 causes hooks 73 to move radially inward and disengage with grooves 77. Once disengaged, handle grip 71 may be removed from the master console as shown in FIG. 9E. When handle grip 71 is decoupled from the master console, release grip 71 may be released and returned to its relaxed state, with hooks 73 protruding through apertures 75 of retraction tube 74.

[00133] In accordance with another aspect of the present invention, as illustrated in FIGS. 10A-10C, handle grip 40" may be removably coupled to handle portion 35 of master telemanipulator 22a. For example, handle grip 40" may have a pistol shape including a handle and trigger 49 for performing a desired surgical task. As will be understood by a person having ordinary skill in the art, various shaped handle grips may be removably coupled to the master telemanipulator to actuate a desired movement by the end-effector of the slave telemanipulator. Accordingly, the handle grips may have an integrated identifier element, e.g., an RFID tag, such that the control system detects the identifier element and identifies whether the handle grip is authorized for use with surgical robot system 10.

[00134] Referring now to FIGS. 11A and 11B, slave console 50 is described. As shown in FIG. 11A, slave console 50 includes right slave telemanipulator 51a and left slave telemanipulator 51b. As left slave telemanipulator 51b may be a structurally mirrored version of

right slave telemanipulator 51a as illustrated, the description below of right slave telemanipulator 51a applies also to left slave telemanipulator 51b.

[00135] As illustrated in FIG. 12, slave telemanipulator 51a includes a plurality of slave links, e.g., first slave link 55, second slave link 57, third slave link 59, fourth slave link, e.g., angulation link 61, fifth slave link 63, sixth slave link 65, seventh slave link 67, and eighth slave link, e.g., slave hub 69, interconnected by a plurality of slave joints, e.g., first slave joint, e.g., proximal Scara joint 54, second slave joint, e.g., median Scara joint 56, third slave joint, e.g., distal Scara joint 58, fourth slave joint, e.g., angulation joint 60, fifth slave joint, e.g., alpha joint 62, sixth slave joint, e.g., beta joint 64, seventh slave joint, e.g., gamma joint 66, and eighth slave joint, e.g., theta joint 68. As shown in FIG. 12, translational instrument interface 81 is coupled to slave telemanipulator 51a via theta joint 68.

[00136] Translational instrument interface 81 may be constructed as described in U.S. Patent Application Publication No. 2018/0353252 to Chassot, assigned to the assignee of the instant application, the entire contents of which are incorporated by reference herein. For example, translational instrument interface 81 includes slave hub 69 and a surgical instrument. As shown in FIG. 11B, slave hub 69 may be affixed to link 67 of slave telemanipulator 51a. The surgical instrument includes the end-effector disposed at the distal end of the shaft of the surgical instrument, and may be coupled to slave hub 69. For example, the end-effector may be removably coupled to slave hub 69. A sterile interface may be positioned between slave hub 69 and the surgical instrument. In addition, translational instrument interface 81 includes a translation transmission system that extends from one or more actuators positioned within slave hub 69 to the components of the end-effector. For example, the end-effector includes a plurality of end-effector links interconnected by a plurality of end-effector joints coupled to the translation transmission system of translational instrument interface 81, such that actuation of the translation transmission system by the one or more actuators causes movement of the end-effector via the plurality of end-effector links and joints.

[00137] In addition, slave telemanipulator 51a includes base portion 52 having and adjustable column, and slave support 53 fixed atop the adjustable column. Link 55 is rotatably coupled to slave support 53 via proximal Scara joint 54. Thus, link 55, and accordingly all the slave joints

and links distal to link 55, may rotate relative to slave support 53 about axis ω_1 at proximal Scara joint 54. As shown in FIG. 12, link 57, and accordingly all the slave joints and links distal to link 57, may rotate relative to link 55 about axis ω_2 at median Scara joint 56, link 59, and accordingly all the slave joints and links distal to link 59, may rotate relative to link 57 about axis ω_3 at distal Scara joint 58, angulation link 61, and according all the slave joints and links distal to angulation link 61, may rotate relative to link 59 about axis ω_4 at angulation joint 60, link 63, and accordingly all the slave joints and links distal to link 63, may rotate relative to angulation link 61 about alpha axis ω_5 at alpha joint 62, link 65, and accordingly all the slave joints and links distal to link 65, may rotate relative to link 63 about beta axis ω_6 at beta joint 64, link 67, and accordingly all the slave joints and links distal to link 67, may rotate relative to link 65 about gamma axis ω_7 at gamma joint 66, and slave hub 69, and accordingly translational instrument interface 81 when translational instrument interface 81 is coupled to slave hub 69, may rotate relative to link 67 about theta axis ω_8 at theta joint 68.

[00138] The column integrated into slave support 53 contains an actuator, e.g., an electric motor, that allows for extending and retracting the column, thereby adjusting the height of all links distal to slave support 53 relative to the ground. Alternatively, instead of a column integrated into slave support 53, slave support 53 may include a mechanical linear guidance system having a counter-balance system based on a counter-weight, and an electric brake to block the vertical movement. Accordingly, when the electric brake is released, the vertical height of all links distal to slave support 53 may be adjusted relative to the ground. Proximal Scara joint 54, median Scara joint 56, and distal Scara joint 58 each contain an electric brake that may block the movement of the corresponding joint when the respective brake is engaged and permit manual movement of the respective joint when the respective brake is released. Angulation joint 60 contains an actuator, e.g., an electromagnetic motor, that allows for adjustment of the angular position of link 61 about link 59. Alpha joint 62, beta joint 64, gamma joint 66, and theta joint 68 are each linked to a dedicated electromagnetic motor and brake pair such that the control system may adjust the angular position of each joint by applying a position command to the respective motor, and stop any movement of the joint by activating the respective brake.

[00139] As will be understood by a person having ordinary skill in the art, slave console 50 may include a plurality of sensors and master console 20 may include a plurality of actuators such that movement applied at slave console 50 may cause movement to be applied at master console 20, thereby providing tactile feedback.

[00140] Referring now to FIG. 13A, controller 70 is described. Controller 70 may be a remote controller or a graphical user interface operatively coupled to the control system of surgical robot system 10, or a series of actuators integrated into the left and right telemanipulator 51a and 51b, respectively. Accordingly, controller 70 may include a plurality of actuators, e.g., buttons, or a touchscreen interface whereby a user may select a plurality of options via touch. For example, controller 70 may provide a user with the option to select at least one of the following commands: Scara brake engagement and release 70a, park position configuration 70b, flipping from forward to reverse gear or from reverse gear to forward gear 70c, vertical adjustment of slave console 70d, vertical column brake release 70e, laparoscopic configuration 70f, home configuration 70g, and increase and decrease the forward angulation 70h. Controller 70 is operatively coupled to one or both slave controllers and/or the master controller. As shown in FIG. 13A, controller 70 may be integrated into a link of the slave console itself. For example, controller 70 is integrated into third slave link 59' of left slave telemanipulator 51b to control certain functionality of that slave telemanipulator responsive to user input and a second controller with the same functionality is integrated into a slave link (e.g., third slave link) to control certain functionality of that slave telemanipulator, e.g., right slave telemanipulator 51a, responsive to user input.

[00141] For example, when the user actuates Scara brake engagement and release 70a interface, the controller will cause Scara brake to transition from engaged to released or vice versa. When the user actuates park position configuration 70b interface, the controller will cause the slave telemanipulator to move into a position suitable for transportation and storage. When the user actuates flipping from forward to reverse gear or from reverse gear to forward gear 70c, the controller will cause the slave telemanipulator to move between a forward surgical workspace and a reverse surgical workspace. When the user actuates vertical adjustment of slave console 70d, the controller will cause vertical adjustment of the slave telemanipulator. When the user actuates vertical column brake release 70e, the controller will cause the vertical

column brake to transition from engaged to released or vice versa, to prevent or permit, respectively, vertical adjustment of the slave telemanipulator. When the user actuates laparoscopic configuration 70f, home configuration 70g, the controller will cause the slave hub to move away from the patient undergoing surgery so that the surgeon may quickly and safely move from the master console to the surgical site on the patient to manually perform laparoscopic procedures on the patient. When the user actuates increase and decrease the forward angulation 70h, the controller will cause adjustment in the forward angulation of the slave telemanipulator. Responsive to user input at controller 70, the respective slave controller executes instructions stored thereon to execute the command(s) explained below inputted by the user. Each slave console may include its own dedicated controller 70 or a common controller 70 may be used for both slave consoles.

[00142] Referring now to FIG. 13B, controller 70' is described. Controller 70' is constructed similar to controller 70, except that controller 70' is a remote controller separate from the slave console and powered by a wired or wireless connection. Accordingly, controller 70' may be removed and operated at a distance away from the slave console for convenience of the clinician and/or operator.

[00143] For example, as illustrated in FIGS. 14A-14E, controller 70 may permit a user to release the brakes in proximal Scara joint 54, median Scara joint 56, and distal Scara joint 56 so that the surgeon may manually reposition the slave arm horizontally by grabbing, holding and pushing/pulling the slave arm links distal to proximal Scara joint 54 while slave support 53 of the slave telemanipulator remains stationary. Specifically, during Scara movement, slave links 55, 57, 59 are permitted to move about axes ω_1 , ω_2 , ω_3 , at joints 54, 56, and 58, while slave support 53 of the slave telemanipulator remains stationary, and while the slave joints and link distal to slave link 59 are fixed relative to slave link 59. Accordingly, the user may adjust the distal end of the slave telemanipulator, e.g., slave hub 69, to a desired position over the patient undergoing surgery.

[00144] As illustrated in FIGS. 15A-15C, controller 70 may permit a user to select a vertical adjustment of slave console command whereby the control system will execute instructions to cause the actuator, e.g., motor, coupled to the column in slave support 53 to extend or retract.

Specifically, during vertical adjustment of the slave telemanipulator, the relative distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator may be adjusted. For example, as shown in FIG. 15A, the vertical distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator is H_1 , as shown in FIG. 15B, the vertical distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator is H_2 , and as shown in FIG. 15C, the vertical distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator is H_3 . Accordingly, the user may adjust the relative distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator to a desired height over the patient undergoing surgery. In the embodiment where the slave console includes a mechanical linear guidance system having a counter-balance system based on a counter-weight, controller 70 may permit a user to select a vertical adjustment of slave console command whereby the control system will execute instructions to cause an electric brake in the column to be released so that the mechanically counter-balanced linear guidance system may move up or down, thereby adjusting the relative distance between slave link 55 and the top surface of base portion 52 of the slave telemanipulator to a desired height over the patient undergoing surgery.

[00145] As illustrated in FIG. 16, controller 70 may permit a user to select a home configuration command whereby the control system will execute instructions to cause the actuators coupled to beta joint 64, gamma joint 66, and theta joint 68 to move the slave links and joints to a retracted position such that slave hub 69 of the slave telemanipulator is in a desirable position for positioning the shaft of translational instrument interface 81 within a trocar within the patient undergoing surgery. In the home position, slave hub 69 will be positioned relative to the trocar within the patient such that an instrument 82 may be inserted through and coupled to slave hub 69, such that instrument tip 84 will slide into, but not pass through the trocar, hence permitting the surgeon to insert the instrument safely and without the need for supervising the distal end of the trocar with the help of an endoscope.

[00146] In addition, controller 70 may permit a user to select an angulation command whereby the control system will execute instructions to cause the actuator coupled to angulation joint 60 to adjust the angulation of angulation link 61 about axis ω_4 at angulation joint 60 to a desired angulation angle, e.g., between zero and 45-degrees relative to base 52 of slave

telemanipulator 51a. Specifically, when the angulation command is actuated, angulation link 61, and accordingly all the slave links and joints distal to angulation link 61, will rotated about axis ω_4 at angulation joint 60, while slave link 59 and all the slave links and joints proximal to slave link 59, and base portion 52 of the slave telemanipulator remains stationary. By adjusting the angulation angle of the slave telemanipulator, the angle of the surgical workspace of the slave telemanipulator will be adjusted, providing more access by the surgeon to the patient via translational instrument interface 81.

[00147] For example, FIGS. 17A-17D illustrate movement of translational instrument interface 81 coupled to slave telemanipulator 51a during zero-degree angulation of the slave console. As shown in FIGS. 17A-17D, angulation link 61, and accordingly angulation axis ω_5 , are parallel with the longitudinal axis of base 52 of slave telemanipulator 51a, and perpendicular with the ground floor. During operation of slave telemanipulator 51a, the control system only executes instructions to cause the actuators coupled to slave console 20 to apply movement to the slave links and joints distal to angulation link 61. Accordingly, as shown in FIGS. 18A-18D, translational instrument interface 81 of slave telemanipulator 51a has forward surgical workspace FSW, e.g., the extent to which translational instrument interface 81 can reach in a forward configuration during zero-degree angulation of the slave console. FIG. 18E is a back view of forward surgical workspace FSW of the slave console of FIGS. 18A-18D.

[00148] FIGS. 19A-19C illustrate movement of translational instrument interface 81 coupled to slave telemanipulator 51a during 20-degree angulation of the slave console. As shown in FIGS. 19A, angulation link 61, and accordingly angulation axis ω_5 , is adjusted to a 20-degree angle relative to the longitudinal axis of base 52 of slave telemanipulator 51a. During operation of slave telemanipulator 51a, the control system only executes instructions to cause the actuators coupled to slave console 20 to apply movement to the slave links and joints distal to angulation link 61. Accordingly, as shown in FIGS. 19B, translational instrument interface 81 of slave telemanipulator 51a has forward surgical workspace FSW, e.g., the extent to which translational instrument interface 81 can reach in a forward configuration during 20-degree angulation of the slave console. FIG. 19C is a back view of forward surgical workspace FSW of the slave console of FIG. 19B during 20-degree angulation of the slave console.

[00149] FIGS. 20A-20C illustrate movement of translational instrument interface 81 coupled to slave telemanipulator 51a during 40-degree angulation of the slave console. As shown in FIGS. 20A, angulation link 61, and accordingly angulation axis ω_5 , is adjusted to a 40-degree angle relative to the longitudinal axis of base 52 of slave telemanipulator 51a. During operation of slave telemanipulator 51a, the control system only executes instructions to cause the actuators coupled to slave console 20 to apply movement to the slave links and joints distal to angulation link 61. Accordingly, as shown in FIGS. 20B, translational instrument interface 81 of slave telemanipulator 51a has forward surgical workspace FSW, e.g., the extent to which translational instrument interface 81 can reach in a forward configuration during 40-degree angulation of the slave console. FIG. 20C is a back view of forward surgical workspace FSW of the slave console of FIG. 19B during 40-degree angulation of the slave console.

[00150] As illustrated in FIGS. 21A-21J, controller 70 may permit a user to select a flipping command whereby the control system will execute instructions to cause the plurality of actuators coupled to the slave console to move slave telemanipulator 51a between a forward surgical workspace and a reverse surgical workspace. For example, the control system may cause the plurality of actuators coupled to the slave console to invert slave telemanipulator 51a from a forward surgical workspace to a reverse surgical workspace, and vice versa. Specifically, during actuation of the flipping command, link 65, and accordingly all slave links and slave joints distal to link 65, are rotated about beta joint 64 of slave telemanipulator 51a. In addition, as link 65 rotates about beta joint 64, link 67 rotates relative to link 65 at gamma joint 66, and slave hub 69 rotates relative to link 67 about theta joint 68, until slave telemanipulator 51a is in a reverse surgical workspace configuration. As illustrated in FIGS. 22B-22H, translational instrument interface 81 is removed from slave hub 69 prior to actuation of the flipping command to prevent translational instrument interface 81 from injury the patient. As slave telemanipulator 51a is able to flip between a forward surgical workspace and a reverse surgical workspace by simply removing translational instrument interface 81 and actuating the flipping command without having to unlock slave telemanipulator 51a and move it about the operating room, and without having to actuate the Scara brake release command or the vertical adjustment of slave console command, the user will save a lot of time and be able to quickly continue operating on the patient in a different surgical workspace.

[00151] Referring now to FIGS. 21K and 21L, a schematic of the master console and slave console having a forward surgical workspace and a reverse surgical workspace, respectively, is provided. As shown in FIG. 21K, when the telemanipulators of slave console 50 have a forward surgical workspace, master controller 2 of master console 20 is programmed such that right master telemanipulator 22a communicates with right slave telemanipulator 51a, and left master telemanipulator 22b communicates with left slave telemanipulator 51b. Accordingly, master controller 2 may receive signals indicative of movement applied at right master telemanipulator 22a by the one or more sensors of master console 20, and execute instructions stored thereon to perform coordinate transforms necessary to activate the one or more actuators of slave console 50, send the processed signals to respective slave controllers 4a that execute instructions stored thereon to move right slave telemanipulator 51a in a manner corresponding to movement of right master telemanipulator 22a based on the processed signals. Similarly, master controller 2 may receive signals indicative of movement applied at left master telemanipulator 22b by the one or more sensors of master console 20, and execute instructions stored thereon to perform coordinate transforms necessary to activate the one or more actuators of slave console 50, send the processed signals to respective slave controllers 4b that execute instructions stored thereon to move left slave telemanipulator 51b in a manner corresponding to movement of left master telemanipulator 22b based on the processed signals.

[00152] As shown in FIG. 21L, when the telemanipulators of slave console 50 have a reverse surgical workspace, master controller 2 of master console 20 behaves as a switch board and is programmed such that right master telemanipulator 22a communicates with left slave telemanipulator 51b, and left master telemanipulator 22b communicates with right slave telemanipulator 51a. This is necessary so that the surgeon positioned at master console 20 and viewing the surgery site via display 21 may operate what appears to the surgeon as the “right” slave telemanipulator (left slave telemanipulator 51b in the reverse surgical workspace) with right master telemanipulator 22a and what appears to the surgeon as the “left” slave telemanipulator (right slave telemanipulator 51a in the reverse surgical workspace) with left master telemanipulator 22a. Accordingly, master controller 2 may receive signals indicative of movement applied at right master telemanipulator 22a by the one or more sensors of master console 20, and execute instructions stored thereon to perform coordinate transforms necessary to activate the one or more actuators of slave console 50, send the processed signals to respective

slave controllers 4b that execute instructions stored thereon to move left slave telemanipulator 51b in a manner corresponding to movement of right master telemanipulator 22a based on the processed signals. Similarly, master controller 2 may receive signals indicative of movement applied at left master telemanipulator 22b by the one or more sensors of master console 20, and execute instructions stored thereon to perform coordinate transforms necessary to activate the one or more actuators of slave console 50, send the processed signals to respective slave controllers 4a that execute instructions stored thereon to move right slave telemanipulator 51a in a manner corresponding to movement of left master telemanipulator 22b based on the processed signals.

[00153] Thus, in the forward surgical workspace configuration, master controller 2 communicates with right slave controller 4a to cause right slave telemanipulator 51a to move responsive to movement at right master telemanipulator 22a and master controller 2 communicates with left slave controller 4b to cause left slave telemanipulator 51b to move responsive to movement at left master telemanipulator 22b. Additionally, in the reverse surgical workspace configuration, master controller 2 communicates with left slave controller 4b to cause left slave telemanipulator 51b to move responsive to movement at right master telemanipulator 22a and master controller 2 communicates with right slave controller 4a to cause right slave telemanipulator 51a to move responsive to movement at left master telemanipulator 22b.

[00154] FIG. 22A illustrates slave telemanipulator 51a in a reverse configuration during zero-degree angulation of the slave console, FIGS. 22B illustrates slave telemanipulator 51a in a reverse configuration during 20-degree angulation of the slave console, and FIG. 22C illustrates slave telemanipulator 51a in a reverse configuration during 40-degree angulation of the slave console. In addition, as shown in FIGS. 23A-23C, translational instrument interface 81 of slave telemanipulator 51a has reverse surgical workspace RSW, e.g., the extent to which translational instrument interface 81 can reach in a reverse configuration during zero-degree angulation, 20-degree angulation, and 40-degree angulation, respectively, of the slave console.

[00155] As illustrated in FIGS. 24A-24D, controller 70 may permit a user to select a laparoscopic configuration command whereby the control system will execute instructions to cause the plurality of actuators coupled to the slave console to move slave hub 69 from a surgical

mode where a plurality of slave links move responsive to movement applied at handle of master console to thereby move the surgical instrument to perform the robotic surgery, to a laparoscopic mode where slave hub 69 is positioned away from the patient undergoing surgery so that the surgeon may quickly and safely move from master console 20 to the surgical site on the patient to manually perform laparoscopic tasks on the patient. Accordingly, in the laparoscopic mode, the plurality of slave links proximal to slave hub 69 are retracted away from the patient while base 52 of slave console 50 remains stationary to expose the surgical site to permit a surgeon to perform non-robotic surgery at the surgical site without interference from the plurality of slave links and slave hub 69. Specifically, actuation of the laparoscopic configuration command causes link 63, and accordingly all the slave links and joints distal to link 63, to rotate about alpha axis ω_5 at joint 62 while angulation link 61, and accordingly all the slave links and joints proximal to angulation link 61 including base 52 of slave telemanipulator 51a remain stationary, until slave hub 69 is facing away from the patient as shown in FIG. 24D.

[00156] Accordingly, in a preferred embodiment, the longitudinal axis of at least one link of the slave console (e.g., angulation link 61 and/or link 63) remains aligned with the remote center-of-motion in both the surgical and laparoscopic modes to allow for seamless transition back-and-forth between the modes. For example, alpha axis ω_5 may remain aligned with the remote center-of-motion of slave console 50 during the transition from the surgical mode to the laparoscopic mode. Advantageously, this allows the surgeon to move slave console 50 between the surgical mode and the laparoscopic mode without having to realign angulation link 61 and alpha axis ω_5 with the remote center-of-motion of slave console 50, and accordingly, the incision point on the patient's body, when transitioning back to the surgical mode. In accordance with another aspect of the present invention, upon actuation of the laparoscopic configuration command, the distal slave links of slave console 50 may be retracted away from the patient about an axis other than alpha axis ω_5 while base 52 of slave console 50 remains stationary to expose the surgical site, such that alpha axis ω_5 does not remain aligned with the remote center-of-motion of slave console 50 during the transition from the surgical mode to the laparoscopic mode. For example, the distal slave links of slave console 50 may rotate about, e.g., axis ω_4 , axis ω_3 , axis ω_2 , or axis ω_1 , while base 52 of slave console 50 remains stationary to expose the surgical site.

[00157] In addition, the control system will execute instructions to determine whether translational instrument interface 81 has been decoupled from slave hub 69 of slave console 50, and accordingly from the patient at the surgical site, such that the laparoscopic configuration command cannot be actuated unless the control system determines that translational instrument interface 81 is not coupled to slave hub 69. Accordingly, translational instrument interface 81 must be removed from slave hub 69 prior to actuation of the laparoscopic configuration command by the user to transition the slave console from the surgical mode to the laparoscopic mode.

[00158] Referring now to FIGS. 25-30, exemplary method 90 for using of surgical robot system 10 via the control system is described. As will be understood by one skilled in the art, the steps of the methods described herein may be executed by one or more processors of the control system (e.g., at the master controller, the first slave controller, and/or the second slave controller) that execute instructions stored in one or more memory components responsive to user input. As shown in FIG. 25, at step 91, system 10 is powered on. At step 92, slave console 50 is prepared to be ready for operating on the patient undergoing surgery as further illustrated in FIG. 27, and at step 93, master console 20 is positioned to the surgeon's desired configuration during operation as further illustrated in FIG. 26.

[00159] For example, FIG. 26 illustrates step 93 of positioning master console 20 to the surgeon's desired configuration. Master console 20 may be moved about the operating room via the wheels at its base while the wheels are unlocked. Upon reaching the desired location within the operating room, the wheel locks are activated to keep master console 20 in place. As shown in FIG. 26, at step 93A, the master telemanipulators are stationary and telescoping bases 23a, 23b have an initial height. A controller operatively coupled to master console 20, e.g., a button, may then be actuated to adjust the height of telescoping bases 23a, 23b, e.g., to increase or decrease the height of telescoping bases 23a, 23b, until master console 20 is at the surgeon's desired height at step 93B. For example, master console 20 may be adjusted to a seated configuration where the surgeon may be seated during operation of master console 20, or a standing configuration where the surgeon may be standing during operation of master console 20. Accordingly, the controller may be actuated to return master console 20 to the initial height, e.g., for storage purposes.

[00160] Referring now to FIG. 27, step 92 of preparation of slave console 50 is described. As shown in FIG. 27, at step 92A, the wheel locks of the slave telemanipulator are disengaged such that slave console 50 may be moved about the operating room to the desired location relative to the patient. The wheel locks can only be disengaged when no instrument 82 is inserted into slave hub 69 so as to avoid injuring the patient. As multiple slave telemanipulators may be used, each slave telemanipulator is positioned during step 92A. When slave console 50 is in the desired position within the operating room adjacent the patient undergoing surgery, the wheel locks of slave console 50 are activated at step 92B such that slave console 50 is prevented from further movement about the operating room via its wheels. Accordingly, the wheel locks may be disengaged again at step 92A if slave console 50 needs to be moved to a different desired position.

[00161] At step 92C, the Scara brake release command has not been actuated and Scara brakes of slave console 50 are on. At step 92D, the Scara brake release command may be actuated by the user to position the distal end of the slave telemanipulator, e.g., the slave links distal to link 59, at a desired position over the patient undergoing surgery. Specifically, upon actuation of the Scara brake release command, slave links 55, 57, 59 are permitted to move about axes ω_1 , ω_2 , ω_3 , at joints 54, 56, and 58, while slave support 53 of the slave telemanipulator remains stationary, and while the slave joints and link distal to slave link 59 are fixed relative to slave link 59. When the distal end of the slave telemanipulator is in the desired position over the patient, actuation of the Scara brake release command ceases at step 92C. In addition, as described above with reference to FIGS. 15A-15C, the vertical height of the slave telemanipulators may be adjusted such that the distal end of the slave telemanipulator is at a desired height relative to the trocar within the patient. The Scara brake release command can only be enabled when no instrument 82 is present in slave hub 69 so as to avoid injuring the patient.

[00162] Referring again to FIG. 27, at step 92E, angulation link 61 of the slave telemanipulator is stationary relative to slave link 59. For example, the slave telemanipulator may initially have an angulation angle of zero degrees. At step 92F, the angulation command may be actuated to adjust the angulation of angulation link 61 about axis ω_4 at angulation joint 60 to a desired angulation angle, e.g., between zero and 45-degrees relative to base 52 of slave

telemanipulator 51a. Specifically, upon actuation of the angulation command, angulation link 61, and accordingly all the slave links and joints distal to angulation link 61, will rotate about axis ω_4 at angulation joint 60, while slave link 59 and all the slave links and joints proximal to slave link 59, and base portion 52 of the slave telemanipulator remains stationary. When the desired angle of angulation of the slave telemanipulator is achieved, actuation of the angulation command ceases at step 92E such that angulation link 61 of the slave telemanipulator is stationary relative to slave link 59. The angulation command may have two buttons, one to increase and another one to decrease the angulation.

[00163] At step 92G, the slave telemanipulator has a forward surgical workspace, or alternatively, at step 92H, the slave telemanipulator has a reverse surgical workspace. During both steps 92G and 92H, instrument 82 cannot be in slave hub 69. If the slave telemanipulator has a forward surgical workspace at step 92G, and the user desires a reverse surgical workspace, the flipping command may be actuated to invert slave telemanipulator 51a from a forward surgical workspace to a reverse surgical workspace. Specifically, upon actuation of the flipping command, link 65, and accordingly all slave links and slave joints distal to link 65, are rotated about beta joint 64 of slave telemanipulator 51a. In addition, as link 65 rotates about beta joint 64, link 67 rotates relative to link 65 at gamma joint 66, and slave hub 69 rotates relative to link 67 about theta joint 68, until slave telemanipulator 51a is in a reverse surgical workspace configuration. Similarly, if the slave telemanipulator has a reverse surgical workspace at step 92H, and the user desires a forward surgical workspace, the flipping command may be actuated to invert slave telemanipulator 51a from a forward surgical workspace to a reverse surgical workspace.

[00164] At step 92I, translational instrument interface 81 is not coupled to slave hub 69 of the slave telemanipulator. At step 92J, a temporary incision pointer may be removably coupled to the slave telemanipulator. For example, the temporary incision pointer is removably coupled to the slave telemanipulator such that it points to virtual remote center-of-motion V located at a predetermined point on axis ω_5 , such that virtual remote center-of-motion V may be brought in coincidence with the surgical incision point, reducing trauma to the patient and improving cosmetic outcomes of the surgery. The temporary incision pointer may be removed prior to installation of the translational instrument interface 81 if necessary. During preparation step 92,

instrument 82 should not be coupled to slave hub 69 of the slave telemanipulator. Thus, if instrument 82 is coupled to slave hub 69 of the slave telemanipulator, at step 92K, the control system will prevent further actions until translational instrument interface 81 is removed.

[00165] At step 92L, the slave links and joints distal to link 61 of the slave telemanipulator may be in any position. Accordingly, at step 92M, the home configuration command may be actuated to move the slave links and joints to a retracted position such that slave hub 69 of the slave telemanipulator is in a desirable position for positioning instrument tip 84 within a trocar within the patient undergoing surgery. At step 92N, the slave telemanipulator is in the home position, wherein slave hub 69 is positioned relative to the trocar within the patient such that instrument 82 may be inserted through and coupled to slave hub 69, and the instrument tip 84 will slide into, but not pass through the trocar.

[00166] At step 92O, the laparoscopic configuration command may be actuated to move slave hub 69 away from the patient undergoing surgery so that the surgeon may quickly and safely move from master console 20 to the surgical site on the patient to manually perform laparoscopic tasks on the patient. Specifically, upon actuation of the laparoscopic configuration command, link 63, and accordingly all the slave links and joints distal to link 63, to rotate about alpha axis ω_5 at joint 62 while angulation link 61, and accordingly all the slave links and joints proximal to angulation link 61 including base 52 of slave telemanipulator 51a remain stationary, until slave hub 69 is facing away from the patient. At step 92P, slave hub 69 is in the retracted position.

[00167] At step 92Q, the sterile interface of translational instrument interface 81 is not coupled to slave hub 69 of the slave telemanipulator. At step 92R, the sterile interface is coupled to the slave hub, and the control system determines whether the sterile interface is identified, e.g., by reading an RFID tag integrated into the sterile interface. If the sterile interface is not identified, at step 92S, the control system awaits removal of the sterile interface until the sterile interface is decoupled from slave hub 69 at step 92Q. If the sterile interface is identified, the sterile interface is successfully installed at step 92T.

[00168] At step 92U, the park position command may be actuated to move slave telemanipulator 51b into a position suitable for transportation and storage. Specifically, upon actuation of the park position command, the vertical column in slave support 53 retracts to a

minimum height, the Scara brakes release to fold the Scara arm into a folded position, the angulation returns to zero-degree angulation, and the joints distal to joint 62 move to fold the slave arm into a compact position. Surgical robot system 10 may be powered off if necessary after step 92.

[00169] If surgical robot system 10 is not powered off after step 92, at step 94, the control system determines whether the sterile interface has been successfully installed and whether the floor lock is activated. If it is determined that either the sterile interface has not been successfully installed or that the floor lock is disengaged, surgical robot system 10 must return to preparation step 92 to rectify the above. If it is determined at step 94 that the sterile interface has been successfully installed and that the floor lock is activated, surgical robot system 10 may proceed to step 95.

[00170] At step 95, surgical robot system is ready for instrument 82 as shown in FIG. 28. For example, at step 95A, the control system of slave console 50 waits for instrument 82 until instrument 82 is coupled to slave hub 69 of the slave telemanipulator. Accordingly, an instrument 82 is selected and inserted within slave hub 69. To ensure that the instrument doesn't fall out of the slave hub, the user may mechanically lock the instrument into slave hub 69 by rotating the proximal end of the instrument. Slave hub 69 has an integrated sensor to detect whether the instrument is locked. At step 95B, sensors positioned within slave hub 69 read out an identifier element integrated with the selected instrument, e.g., an RFID tag, where the RFID tag contains identification information of the selected instrument. At step 95C, the control system determines whether the selected instrument is authorized based on the detection of the RFID tag. If the selected instrument is not authorized, the control system waits until it is removed at step 95D. When the unauthorized instrument is removed, step 95D returns to step 95A. If the selected instrument is authorized and locked within slave hub 69 of the slave telemanipulator at step 95E, method 90 may proceed to step 96. If at any time during step 95 the sterile interface is removed, the floor lock is disengaged, the flipping command is actuated, the Scara brake release command is actuated, the home configuration command is actuated, or the incision pointer is inserted, method 90 may return to preparation step 92.

[00171] At step 96, surgical robot system 10 is ready for operation. As shown in FIG. 29, at step 96A, the control system verifies that instrument 82 is coupled to slave hub 69 of the slave telemanipulator. At step 96B, the control system detects when the surgeon grabs handle grip 40 of handle portion 35. As shown in FIG. 9A and 9B, sensors within the handle may detect that the surgeon has grabbed the handle. At step 96C, clutch 11 is actuated to prepare the control system for macro-synchronization as described in step 97A.

[00172] As shown in FIG. 30, surgical robot system 10 may now be operated. For example, at step 97A, surgical robot system 10 is in a macro-synchronization state, but not in a micro-synchronization state. In the macro-synchronization state, translational macro-movements applied at master console 20 will be sensed and transmitted to the control system, which instructs the actuators coupled to slave console 50 to cause the corresponding slave links and joints to move in a manner so that the macro-movements (i.e. up/down, left/right, in/out) of instrument tip 84 corresponds to the macro-movements of the handle at the master console 20. However, in the unsynchronized macro state, the control system does not cause macro-movements applied at master console 20 to be made in a corresponding manner at slave console 50. For example, in the unsynchronized macro state, macro-movements at master console 20, whether intentional or unintentional, will permit the master links of master console 20 to move, but will not result in any corresponding movement at slave console 50.

[00173] In the micro-synchronization state, micro-movements applied at handle portion 35 of master console 20 will be sensed and transmitted to the control system, which instructs the actuators coupled to slave console 50 to cause the instrument tip 84 move in a manner corresponding to those micro-movements applied at handle portion 35 of master console 20. However, in the unsynchronized micro state, the control system does not cause micro-movements applied at master console 20/handle portion 35 to be made in a corresponding manner at slave console 50/end-effector. Thus, at step 97A, translational macro-movements are replicated, but micro-movements are unsynchronized. Clutch 11 may be actuated to transition surgical robot system 10 to unsynchronized macro state at step 97B where translation macro-movements may be prevented by master console 20, and thus not replicated by slave console 50. For example, clutch 11 may be a foot pedal that when stepped on, maintains surgical robot system 10 in the unsynchronized macro state. Upon release of clutch 11, surgical robot system

10 returns to the macro-synchronization state at step 97A. Accordingly, for example, the surgeon may apply a macro-movement to handle portion 35 in the synchronized macro state, e.g., move handle portion 35 inward/outward thereby causing inward/outward movement on the surgical instrument, then actuate clutch 11 to transition the surgical system from the synchronized macro state to the unsynchronized macro state, move handle portion back to its original or another more comfortable position, which will not result in macro-movement of the surgical instrument, release clutch 11 to transition the surgical system from the unsynchronized macro state to the synchronized macro state, and proceed with applying additional macro-movements to handle portion 35, which will result in corresponding macro-movement at the surgical instrument. Advantageously, this will permit the surgeon to readjust master console 20 for comfort, while slave console 50 remains in a desired position. In a further example, actuation of clutch 11 transitions the surgical system between the synchronized and unsynchronized states for both macro movements and micro movements.

[00174] In addition, the control system may be programmed to detect an actuation pattern by handle portion 35 such that micro-movements at handle portion 35 are not replicated by the end-effector unless the control system detects the actuation pattern. For example, the actuation pattern may include a quick, double actuation of handle grip 40. Thus, when the user presses handle grip 40 twice repeatedly at step 97C, the control system detects the actuation pattern, and surgical robot system 10 is in a micro-synchronization state where micro-movements at handle portion 35 will be replicated by the end-effector. When transitioning from an unsynchronized micro state to a micro-synchronization state, the control system executes instructions to cause the micro-position of instrument tip 84 to have the same spatial orientation relative to the instrument shaft 82 as the spatial orientation of handle portion 35 relative to corresponding link 32 of master telemanipulator 22a. At step 97D, surgical robot system 10 is fully in both a macro-synchronization state and a micro-synchronization state, e.g., when the end-effector is in the target position for the operation, and the surgeon can use surgical robot system 10 to perform surgical tasks. Upon actuating clutch 11, at step 97E, surgical robot system 10 is in a micro-synchronization state, but in the unsynchronized macro state.

[00175] In accordance with another aspect of the present invention, as shown in FIG. 2C, master console 20 may have second clutch 11' for use in conjunction with clutch 11 to actuate

the macro-synchronization state and/or the micro-synchronization state of surgical robot system 10. For example, actuation of clutch 11 may cause surgical robot system 10 to transition between a synchronized and unsynchronized macro state, and actuation of clutch 11' may cause surgical robot system 10 to transition between a synchronized and unsynchronized micro state. Accordingly, for example, the surgeon may apply a micro-movement to handle portion 35 in the synchronized macro state, e.g., roll handle portion 35 thereby causing roll movement on the surgical instrument, then actuate clutch 11' to transition the surgical system from the synchronized micro state to the unsynchronized micro state, move handle portion back to its original or another more comfortable position, which will not result in micro-movement of the surgical instrument though may result in macro-movement of the surgical instrument if the surgical system is in a synchronized macro state, release clutch 11' to transition the surgical system from the unsynchronized micro state to the synchronized micro state, and proceed with applying additional micro-movements to handle portion 35, which will result in corresponding micro-movement at the surgical instrument. Advantageously, this will permit the surgeon to readjust master console 20 for comfort, while slave console 50 remains in a desired position.

[00176] The surgeon may selectively choose any combination of synchronized and unsynchronized macro and micro states of surgical robot system 10. In accordance with yet another aspect of the present invention, actuation of clutch 11 may cause surgical robot system 10 to transition between both unsynchronized macro and micro states and synchronized macro and micro states; whereas, actuation of clutch 11' only causes surgical robot system 10 to transition between an unsynchronized and synchronized micro state. Alternatively, actuation of clutch 11 may cause surgical robot system 10 to transition between both unsynchronized macro and micro states and synchronized macro and micro states; whereas, actuation of clutch 11' only causes surgical robot system 10 to transition between an unsynchronized and synchronized macro state.

[00177] In accordance with another aspect of the present invention, a remotely actuated surgical robot system having hybrid telemanipulators, which may be used in minimally invasive surgical procedures or in other applications, constructed in accordance with the principles of the present invention, is described herein.

[00178] Referring to FIGS. 31A and 31B, exemplary remotely actuated surgical robot system 100 having hybrid telemanipulators is described. Surgical robot system 100 illustratively is affixed atop moveable cart 101, to which the hybrid telemanipulators also may be mounted for mobility and ease of transport within an operating room. Surgical robot system 100 includes master region 400, where a surgeon may be situated to operate system 100, and remote slave region 500 in proximity to the sterile zone, where a patient to be operated upon may be positioned. As shown in FIG. 31B, the operating surgeon preferably is seated with ready access to master region 400, while another surgeon or assistant may be situated near slave region 500, which is positioned over a patient. In the embodiment of FIGS. 31A and 31B, master region 400 is situated laterally adjacent to slave region 500. In addition, camera system 102 may be used with surgical robot system 100, e.g., an endoscope that is manipulated by the assistant situated at slave region 500 may be operate and/or held in position as shown in FIG. 31B. Camera system 102 also may include display 103 for displaying the surgical site captured by camera 102 to the surgeon in real-time. Display 103 may be mounted to master region 400, or anywhere in proximity to master region 400 that is easily observable by the surgeon during a surgical procedure.

[00179] Referring again to FIG. 31A, system 100 includes two hybrid telemanipulators 104 and 105, including left hybrid telemanipulator 104 that is manipulated by the surgeon's left hand, and right hybrid telemanipulator 105 that is manipulated by the surgeon's right hand. Hybrid telemanipulators 104 and 105 may be operated simultaneously and independently from the other, e.g., by the surgeon's left and right hands. Preferably, the teleoperated remotely actuated surgical robot system 100 is optimized for use in surgical procedures.

[00180] Each hybrid telemanipulator provides input to a master-slave configuration, in which a slave unit, made of a plurality of rigid slave links and slave joints, is driven kinematically by a master unit, made of a plurality of rigid master links and master joints. For example, left hybrid telemanipulator 104 includes master unit 401 and corresponding slave unit 501, and right hybrid telemanipulator 105 includes master unit 402 and corresponding slave unit 502. Master units 401 and 402 are disposed within master region 400 of system 100, while slave units 501 and 502 are within slave region 500 of system 100. Preferably, slave units 501 and 502 mimics the movement of the corresponding portions of master units 401 and 402, respectively, without

deviating, during operation of the device, from a remote center-of-motion, as described in further detail below.

[00181] Still referring to FIG. 31A, teleoperated surgical instrument 106, e.g., translational instrument interface, having end effector 107 is coupled to the distal end of slave unit 501, and a handle is coupled to the distal end of master unit 401 such that movement applied to the handle induces a corresponding micro-movement of end-effector 107 via a processor-driven control system. For example, the control system may receive a signal indicative of movement applied at the handle by one or more sensors coupled to the handle, and perform coordinate transforms necessary to activate one or more actuators operatively coupled to end-effector 107 to replicate a corresponding movement of the end effector. Slave instrument 106 of the translational instrument interface may be removably attached to and operated by slave unit 501, such that the translation degrees-of-freedom, e.g., left/right, upward/downward, inward/outward, are actuated by direct mechanical coupling, whereas the articulation degrees-of-freedom, e.g., pitch and yaw, the actuation degrees-of-freedom, e.g., open/close, and the rotation degree-of-freedom, e.g., pronosupination, are electromechanically replicated via sensors, actuators, and a control system as described in further detail below.

[00182] Referring now to FIGS. 32A and 32B, the mechanisms of exemplary remotely actuated surgical robot system 100 having hybrid telemanipulators are illustrated, in which the external covers depicted in FIGS. 31 are omitted for clarity. In FIGS. 32A and 32B, mechanical transmission 300 is arranged to directly couple slave unit 501 with master unit 401, such that translational macro-movement applied to the plurality of master joints of master unit 401 is replicated by corresponding respective joints of the plurality of slave joints of slave unit 501. Likewise, mechanical transmission 300 also directly couples slave unit 502 with master unit 402, such that translational macro-movement applied to the plurality of master joints of master unit 402 is replicated by corresponding respective joints of the plurality of slave joints of slave unit 502. Transmission 300 illustratively includes one or more cables 301 routed via one or more pulleys from master unit 401 to slave unit 501, and one or more cables 303 routed via one or more pulleys from master unit 402 to slave unit 502, for controlling one of four degrees-of-freedom of slave unit 501 and 502. Mechanical constraint 200 of master unit 401 constrains movement of master unit 401 by removing a degree-of-freedom of motion, thereby limiting

movement in three translational degrees-of-freedom, e.g., left/right, upward/downward, inward/outward.

[00183] For example, one or more cables 301 may form one or more closed loops beginning at pulley P1 coupled to master unit 401, and extending through pulleys P2, P3, P4, P5, P6, tensioning system 302, pulley P7, and around pulley P8 coupled to slave unit 501, and extending back through pulley P7, tensioning system 302, pulleys P6, P5, P4, P3, P2, and ending at pulley P1. Thus, rotation of pulley P1 clockwise or counter-clockwise causes a cable of one or more cables 301 to rotate pulley P8, thereby actuating a slave unit 501 in one of four degrees-of-freedom. Mechanical constraint 200 of master unit 401, however, constrains movement of master unit 401 by removing one degree-of-freedom of motion, thereby limiting movement of slave unit 501 to three translational degrees-of-freedom, e.g., left/right, upward/downward, inward/outward. Each of pulleys P1, P2, P3, P4, P5, P6, P7, and P8 may include a number of individual pulleys corresponding to the number of degrees-of-freedom of motion actuatable of slave unit 501 by master unit 401. Similarly, one or more cables 301 may include a number of closed cable loops corresponding to the number of degrees-of-freedom of motion actuatable of slave unit 501 by master unit 401.

[00184] Similarly, one or more cables 303 may form one or more corresponding closed loops beginning at pulley P9, coupled to master unit 402, and extending through tensioning system 304, pulleys P10, P11, P12, P13, P14, and around pulley P15 coupled to slave unit 502, and extending back through pulleys P14, P13, P12, P11, P10, tensioning system 304, and ending at pulley P9. In this manner, rotation of pulley P9 clockwise or counter-clockwise may cause a cable of one or more cables 303 to rotate pulley P15, thereby actuating a slave unit 502 in one of four degrees-of-freedom. Mechanical constraint 201 of master unit 402 (see FIG. 32A) likewise constrains movement of master unit 402 by removing a degree-of-freedom of motion, thereby limiting movement of slave unit 502 to three translational degrees-of-freedom, e.g., left/right, upward/downward, inward/outward. Each of pulleys P9, P10, P11, P12, P13, P14, and P15 may include a number of individual pulleys corresponding to the number of degrees-of-freedom of motion actuatable of slave unit 502 by master unit 402. Similarly, one or more cables 303 may include a number of closed cable loops corresponding to the number of degrees-of-freedom of motion actuatable of slave unit 502 by master unit 402.

[00185] As will be understood by a person having ordinary skill in the art, the number of pulleys P2-P7 employed to route cables 301 between pulleys P1 and P8, and the number of pulleys P10-P14 employed to route cables 303 between pulleys P9 and P15 will depend on the construction of the right and left hybrid telemanipulators, respectively.

[00186] Referring now to FIG. 33, one or more cables 301 of mechanical transmission 300 pass through tensioning system 302, and one or more cables 303 passes through tensioning system 304. Tensioning system 302 is designed to apply a predetermined tension force to cables 301, while tensioning system 304 is designed to apply a predetermined tension force to cables 303. For example, tensioning system 302 may include pulley P16 coupled to pulley P17 via tension link 305, and pulley P18 coupled to pulley P19 via tension link 306. Tension link 305 is adjustably and rotatably coupled to tension link 306 about a vertical axis running through axle 307, such that a predetermined tension force is applied to cables 301 by pulleys P16, P17, P18, and P19. In addition, tensioning system 302 may be used to calibrate mechanical transmission 300, thereby ensuring that the angles of corresponding master and slave joints are identical. Tensioning system 304 may be identical in structure to tensioning system 302.

[00187] Also in FIG. 33, pulleys P11, P12, and P13 of the mechanical transmission of the right hybrid telemanipulator are coupled to slave link 308, which is rotatably coupled to positioning system 310 via slave link 309. Positioning system 310 may be, e.g., a hydraulic device, that restricts movement of slave unit 502 with respect to slave unit 501 along a single plane. For example, the position of pulley P8 may be fixed, such that the position of P15 is moveable relative to P8 along the horizontal plane (x- and y-direction).

[00188] Referring now to FIGS. 34A and 34B, components of an exemplary master unit of system 100 is described. As master unit 401 is identical in structure to master unit 402, respectively, the description below of master unit 401 applies also to master unit 402.

[00189] Master unit 401 includes a plurality of master links, e.g., first master link 405a, second master link 405b, third master link 405c, and fourth master link, e.g., guided master link 404, interconnected by a plurality of master joints. Handle 403 is connected to a distal end of master unit 401 via guided master link 404, e.g., master rod, and includes a plurality of handle links interconnected by a plurality of handle joints for operating the hybrid telemanipulator. For

example, translational macro-movement applied on handle 403 causes corresponding movement of the plurality of master joints via the plurality of master links, which is transmitted to the corresponding slave joints of slave unit 501 via mechanical transmission 300, thereby replicating the translational macro-movement at slave unit 501. Translational movement of handle 403 causes guided master link 404 to transmit motion to pulley P1 via first master link 405a, second master link 405b, and third master link 405c, thereby causing slave unit 501 to mimic the translational movement via mechanical transmission 300. First master link 405a, second master link 405b, third master link 405c, and guided master link 404 are coupled to pulley P1 via a transmission system including, e.g., one or more toothed belts 406 routed via one or more pulleys 407. Alternatively, the transmission system coupling pulley P1 and the plurality of master links and joints of master unit 501 may include a system of cables and pulleys, and/or rigid transmission links.

[00190] In FIGS. 34A and 34B, mechanical constraint 408 on master unit 401 includes a yoke pivotally coupled to a sleeve that slides on guided master link 404 and constrains movements of the distal end of slave unit 501 in correspondence with a remote center of motion that is aligned with the incision point on a patient, e.g., the point at which a trocar passes into a patient's abdomen. For example, mechanical constraint 408 ensures that, when the hybrid telemanipulator is actuated, guided master link 404 of master unit 401 translates along longitudinal axis θ_1 so that the corresponding slave link of slave unit 501, e.g., translational instrument interface coupled to the distal end of slave unit 501, also translates along virtual axis θ_4 parallel to longitudinal axis θ_1 of guided master link 404 in the vicinity of the remote manipulation, as depicted in FIGS. 35A and 35B. In addition, mechanical constraint 408 enables guided master link 404 to rotate about second and third axes θ_2 , θ_3 that are perpendicular to each other. Referring still to FIGS. 34A and 34B, axis θ_3 is coaxial to the axis of pulley P1. The plane defined by longitudinal axis θ_1 of guided master link 404 and second axis θ_2 intersects third axis θ_3 at stationary single point 409 independently of the orientation of master link 404. This configuration allows the corresponding slave link of slave unit 501 to rotate about fifth and sixth virtual axes θ_5 , θ_6 that are perpendicular to each other. Longitudinal axis θ_4 of the corresponding slave link and fifth and sixth virtual axes θ_5 , θ_6 always intersect each other at virtual stationary single point 509, e.g., the remote center-of-motion, in the vicinity of the patient incision.

[00191] When surgical robot system 100 is positioned such that remote center-of-motion 509 is aligned with the patient incision, translational movement applied to handle 403 is replicated by the end-effector disposed inside the patient. Because the end-effector perfectly replicates the movement applied to handle 403, this arrangement advantageously eliminates the fulcrum effect between the handle and end-effector, and ensures that the instrument always passes through the remote center-of-motion. Whereas in previously-known surgical robots, maintaining a fixed point of movement of the surgical instrument as it passes through the patient incision requires complex control electronics, in the system of the present invention, mechanical constraint 408 provides translational replication between master unit 401 and slave unit 501 that ensures that the instrument always passes through remote center-of-motion 509.

[00192] Inward/outward movement of handle 403 of the embodiments of FIGS. 34A and 34B causes first master link 405a, second master link 405b, third master link 405c, and guided master link 404 to move inward/outward along longitudinal axis θ_1 of guided master link 404. That motion is transmitted to pulley P1 via the plurality of master links, causing slave unit 501 to replicate the inward/outward movement about longitudinal axis θ_4 via mechanical transmission 300 and the plurality of slave links, joints, and timing belts. Similarly, movement of handle 403 upward/downward causes first master link 405a, second master link 405b, third master link 405c, and guided master link 404 to rotate upward/downward about second axis θ_2 . That motion is transmitted to pulley P1 via the plurality of master links, in turn causing slave unit 501 to replicate the upward/downward movement about fifth axis θ_5 via mechanical transmission 300 and the plurality of slave links, joints, and timing belts. Finally, movement of handle 403 left/right causes first master link 405a, second master link 405b, third master link 405c, and guided master link 404 to rotate left/right about third axis θ_3 . That motion is transmitted to pulley P1 via the plurality of master links, causing slave unit 501 to replicate the left/right movement about sixth axis θ_6 via mechanical transmission 300 and the plurality of slave links, joints, and timing belts.

[00193] Still referring to FIGS. 34A and 34B, movement applied at handle 403 of master unit 401 actuates the articulation degrees-of-freedom, e.g., pitch and yaw, the actuation degree-of-freedom, e.g., open/close, and the rotation degree-of-freedom, e.g., pronosupination, electromechanically via sensors, motors, and a control system. Master unit 401 preferably

includes one or more sensors 410 coupled to handle 403 via circuit board 411 for detecting motion of handle 403. As will be understood, sensor 410 may be any sensor designed to detect rotational movement, such as magnetic-based rotational sensors that includes a magnet on one side and a sensor on another side to measure rotation by measuring angle and position. Circuit board 411 is coupled to a control system for generating signals indicative of the rotation measured by sensor 410 and transmitting the signals to one or more motors coupled to slave unit 501, which may reproduce movements applied on handle 403 to the end effector. For example, electrical cables may extend from handle 403 to the control system, e.g., a unit containing control electronics, and additional electrical cables may extend from the control system to the one or more motors coupled to slave unit 501.

[00194] Actuation of trigger 412 of handle 403 generates a signal that is transmitted via the control system to the motors coupled to slave unit 501, thereby causing actuation of a translation transmission system of the translational instrument interface coupled to slave unit 501, in turn causing actuation of the end-effector of the translational instrument interface to open/close.

[00195] Handle 403 also may include ball 413 designed to be easily gripped by the surgeon and which aligns the surgeon's wrist with master unit 401. Ball 413 may be rotatable about handle axis θ_7 , such that the rotation of ball 413 is detected by a sensor that generates and transmits a signal via the control system to a motor coupled to slave unit 501. The signal received from the control system at the slave unit causes rotation of the translational instrument interface coupled to slave unit 501, thus rotating the end-effector of the translational instrument interface in the pronosupination degree-of-freedom.

[00196] Handle 403 also is rotatable about handle axis θ_8 , such that the rotation about handle axis θ_8 is detected by a sensor, which generates and transmits a signal via the control system to the motors of slave unit 501. That signal causes actuation of the translation transmission system of the translational instrument interface coupled to slave unit 501, which in turn causes movement of the end-effector of the translational instrument interface in the yaw degree-of-freedom. In addition, handle 403 may be rotatable about handle axis θ_9 , such that the rotation of handle 403 about handle axis θ_9 is detected by a sensor, which generates and transmits a signal via the control system to the motors of slave unit 501. That signal causes actuation of the

translation transmission system of the translational instrument interface coupled to slave unit 501, which causes movement of the end-effector of the translational instrument interface in the pitch degree-of-freedom.

[00197] Referring now to FIGS. 34C and 34D, alternative embodiments of the handle of master unit 401 are described. In FIG. 34C, handle 403' is rotatable about handle axis θ_7 , handle axis θ_8 , and handle axis θ_9 , such that rotation of handle 403' about the handle axes is detected by one or more sensors 410, which generate and transmit a signal via the control system to motors of slave unit 501. That signal actuates the translation transmission system of the translational instrument interface coupled to slave unit 501, causing movement of the end-effector of the translational instrument interface in the pronosupination, yaw, and pitch degrees-of-freedom, respectively.

[00198] Similarly, handle 403'' of FIG. 34D is rotatable about handle axis θ_7 , handle axis θ_8 , and handle axis θ_9 , such that rotation of handle 403'' about the handle axes is detected by one or more sensors 410, which generates and transmits a signal via the control system to the one or more motors coupled to slave unit 501. That signal actuates the translation transmission system of the translational instrument interface coupled to slave unit 501, causing movement of the end-effector of the translational instrument interface in the pronosupination, yaw, and pitch degrees-of-freedom, respectively.

[00199] Referring now to FIGS. 35A and 35B, an exemplary slave unit of system 100 is described. As slave unit 501 is identical in structure to slave unit 502, respectively, the description below of slave unit 501 applies also to slave unit 502.

[00200] As described above, master unit 401 includes a plurality of master links interconnected by a plurality of master joints. Slave unit 501 includes a corresponding plurality of slave links, e.g., first slave link 505a, second slave link 505b, third slave link 505c, and fourth slave link, e.g., translational instrument interface 503, interconnected by a plurality of slave joints, such that a direct mechanical coupling is formed by the plurality of slave links and corresponding plurality of slave joints of slave unit 501, which is identical to the kinematic model formed by the corresponding plurality of master links and corresponding plurality of master joints of master unit 401. For example, first slave link 505a always remains parallel to

first master link 405a, second slave link 505b always remains parallel to second master link 405b, third slave link 505c always remains parallel to third master link 405c, and translational instrument interface 503 always remains parallel to guided master link 404 during operation of the hybrid telemanipulator. Thus, each translational macro-movement applied to the plurality of master joints of master unit 401 is replicated by a corresponding respective joint of the plurality of slave joints of slave unit 501 via mechanical transmission 300 and the plurality of slave links.

[00201] In FIGS. 35A and 35B, translational instrument interface 503 is coupled to distal end 504 of slave unit 501. Translational movement of handle 403 is transmitted to pulley P9 via mechanical transmission 300. More specifically, translational actuation of handle 403 causes pulley P9 to transmit motion to end-effector 512 via first slave link 505a, second slave link 505b, third slave link 505c, and translational instrument interface 503, thereby causing slave unit 501 to replicate the translational movement. First slave link 505a, second slave link 505b, third slave link 505c, and translational instrument interface 503 are coupled to pulley P9 via a transmission system including, e.g., one or more timing belts 506 routed via one or more pulleys 507. Thus, each of the four pulleys of P9 is operatively coupled to and controls movement of first slave link 505a, second slave link 505b, third slave link 505c, and translational instrument interface 503. Alternatively, the transmission system coupling pulley P9 and the plurality of slave links and joints of slave unit 501 may include a system of cables and pulleys, and/or rigid transmission links.

[00202] Mechanical constraint 408 of master unit 401 ensures that, when the hybrid telemanipulator is in operation, first slave link 505a, second slave link 505b, third slave link 505c, and translational instrument interface 503 always rotate about virtual stationary point 509. For example, end-effector 512 of translational instrument interface 503 coupled to slave unit 501 always translates along longitudinal axis θ_4 corresponding to the longitudinal axis θ_1 of master link 404 in the vicinity of the remote manipulation. In addition, mechanical constraint 408 allows end-effector 512 to rotate about fifth and a sixth virtual axis θ_5 , θ_6 that are perpendicular to each other. Longitudinal axis θ_4 of translational instrument interface 503 coupled to slave unit 501, and fifth and sixth virtual axes θ_5 , θ_6 always intersect each other at virtual stationary single point 509 in the vicinity of the remote manipulation. During a minimally invasive surgical

procedure, virtual stationary point 509 is aligned with the surgical incision point, reducing trauma to the patient and improving cosmetic outcomes of the surgery.

[00203] Movement of handle 403 in the inward/outward directions causes end effector 512 coupled to slave unit 501 to replicate the inward/outward movement about longitudinal axis θ_4 via mechanical transmission 300 and the transmission system coupling pulley P9 and the plurality of slave links and joints of slave unit 501. Movement of handle 403 upward/downward causes end effector 512 coupled to slave unit 501 to replicate the upward/downward movement about longitudinal axis θ_5 via mechanical transmission 300 and the transmission system coupling pulley P9 and the plurality of slave links and joints of slave unit 501. Movement of handle 403 left/right causes end effector 512 coupled to slave unit 501 to replicate the left/right movement about longitudinal axis θ_6 via mechanical transmission 300 and the transmission system coupling pulley P9 and the plurality of slave links and joints of slave unit 501.

[00204] In addition, movement applied at handle 403 of master unit 401 actuates the articulation degrees-of-freedom, e.g., pitch and yaw, the actuation degree-of-freedom, e.g., open/close, and the rotation degree-of-freedom, e.g., pronosupination of the end-effector of translational instrument interface 503, electromechanically via sensors, motors, and a control system. Translational instrument interface 503 may be constructed as described in U.S. Patent Publication No. 2018/0353252 to Chassot, assigned to the assignee of the instant application, the entire contents of which are incorporated by reference herein. For example, translational instrument interface 503 includes slave hub 510 and surgical instrument 511. Slave hub 510 may be affixed to distal end 504 of slave unit 501. Surgical instrument 511 includes end-effector 512 disposed at the distal end of the shaft of surgical instrument 511, and may be removably coupled to slave hub 510. A sterile interface may be positioned between slave hub 510 and surgical instrument 511. In addition, translational instrument interface 503 includes a translation transmission system that extends from one or more motors positioned within slave hub 510 to the components of end-effector 512. For example, end-effector 512 includes a plurality of end-effector links interconnected by a plurality of end-effector joints coupled to the translation transmission system of translational instrument interface 503, such that actuation of the translation transmission system by the one or more motors causes movement of end-effector 512 via the plurality of end-effector links and joints.

[00205] Further details regarding the components and operation of slave hub 510 are described with respect to FIGS. 36A and 36B. Slave hub 510 of translational instrument interface 503 affixed to slave unit 501 includes one or more motors, e.g., first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d, operatively coupled, e.g., via electrical wiring, with the control system via circuit board 602. Motors 601a-601d receive signals indicative of measured movements and trigger actuation of handle 403, as measured by one or more sensors 410 coupled to handle 403. Those signals are processed by the control system, which in turn provides signals to the motors that actuate translational instrument interface 503 to thereby replicate the micro-movements corresponding to those input at handle 403. First motor 601a, second motor 601b, and third motor 601c are coupled directly to translation transmission system 603 of translational instrument interface 503 for actuating end-effector 512 in the open/close, pitch, and yaw degrees-of-freedom. Translation transmission system 603 includes a plurality of transmission elements, e.g., cables and/or lead screws, such that each of the plurality of transmission elements are coupled to first motor 601a, second motor 601b, and third motor 601c at one end, and to the first, second, and third end-effector links at the opposite end, to move the end-effector in the open/close, pitch, and yaw degrees-of-freedom. Translation transmission system 603 may include a plurality of lead screws and/or closed cable loops. Fourth motor 601d actuates rotation of slave instrument 503 via pronosupination timing belt 513. As will be understood by a person having ordinary skill in the art, slave hub 510 may include any combination of motors 601a-601d, e.g., only the one or more motors for actuating end-effector 512 in the open/close degree-of-freedom and the motor for rotating end-effector 512 in the pronosupination degree-of-freedom when a non-articulated instrument is used.

[00206] Circuit board 602 also may include one or more sensors designed to detect undesired movement of translational instrument interface 503, and electrically communicate with first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d to resist such undesired movement.

[00207] In accordance with one aspect of the present invention, the control system may identify the kinematics of end-effector 512 of translational instrument interface 503 by reading out identifier element 516, e.g., RFID token integrated with the instrument, as shown in FIG. 36C, wherein the RFID token contains information on the kinematic configuration of the

instrument. In particular, the control system, based on the information read from identifier element 516, may configure operation of the one or more motors that interface with translational instrument interface 503 to operate differently (e.g. to turn simultaneously clockwise or one clockwise and the other counterclockwise) to cause actuations of the end-effector elements. For example, in FIG. 36D, a forceps-type end-effector having parallel-serial instrument kinematics is described. For this configuration, first motor 601a may be operatively coupled to a first link of end-effector 512', e.g., a first blade, via transmission element 514a of the translation transmission system, such that first motor 601a causes the first link of end-effector 512' to move outward/inward. Second motor 601b may be operatively coupled to a second link of end-effector 512', e.g., second blade, via transmission element 514b of the translation transmission system, such that second motor 601b causes the second link of end-effector 512' to move outward/inward. Thus, the control system may instruct first motor 601a to move the first link of end-effector 512' outward via transmission element 514a, while simultaneously instructing second motor 601b to move the second link of end-effector 512' outward via transmission element 514b, thereby causing end-effector 512' to open based on actuation of trigger 412 of handle 403. Conversely, the control system may instruct first motor 601a to move the first link of end-effector 512' inward via transmission element 514a, while simultaneously instructing second motor 601b to move the second link of end-effector 512' inward via transmission element 514b, thereby causing end-effector 512' to close based on actuation of trigger 412 of handle 403. Therefore, first motor 601a and second motor 601b may cause end-effector 512' to move in the open/close degree-of-freedom.

[00208] The control system may instruct first motor 601a to move the first link of end-effector 512' outward via transmission element 514a, while simultaneously instructing second motor 601b to move the second link of end-effector 512' inward via transmission element 514b, thereby causing end-effector 512' to pitch upward based on rotation of handle 403 about handle axis θ_9 . Conversely, the control system may instruct first motor 601a to move the first link of end-effector 512' inward via transmission element 514a, while simultaneously instructing second motor 601b to move the second link of end-effector 512' outward via transmission element 514b, thereby causing end-effector 512' to pitch downward based on rotation of handle 403 about handle axis θ_9 . Therefore, first motor 601a and second motor 601b may cause end-effector 512' to move in the pitch degree-of-freedom.

[00209] Third motor 601c may be operatively coupled to a third link of end-effector 512' via transmission element 514c of the translation transmission system such that third motor 601c causes end-effector 512' to move in the yaw degree-of-freedom based on rotation of handle 403 about handle axis θ_8 . Fourth motor 601d may be operatively coupled to first motor 601a, second motor 601b, third motor 601c, and surgical instrument 511 via a rotatable pronosupination timing belt 513 such that fourth motor 601d causes first motor 601a, second motor 601b, third motor 601c, and surgical instrument 511, and thereby end-effector 512', to rotate in the pronosupination degree-of-freedom based on rotation of ball 413 of handle 403.

[00210] Referring now to FIG. 36E, an end-effector having serial-serial instrument kinematics is described. For example, first motor 601a may be operatively coupled to a first link of end-effector 512'' via transmission element 515a of the translation transmission system such that first motor 601a causes end-effector 512'' to move in the open/close degree-of-freedom based on actuation of trigger 412 of handle 403. Second motor 601b may be operatively coupled to a second link of end-effector 512'' via transmission element 515b of the translation transmission system such that second motor 601b causes end-effector 512'' to move in the pitch degree-of-freedom based on rotation of handle 403 about handle axis θ_9 . Third motor 601c may be operatively coupled to a third link end-effector 512'' via transmission element 515c of the translation transmission system such that third motor 601c causes end-effector 512'' to move in the yaw degree-of-freedom based on rotation of handle 403 about handle axis θ_8 . Fourth motor 601d may be operatively coupled to first motor 601a, second motor 601b, third motor 601c, and surgical instrument 511 via a rotatable pronosupination timing belt 513 such that fourth motor 601d causes first motor 601a, second motor 601b, third motor 601c, and surgical instrument 511, and thereby end-effector 512'', to rotate in the pronosupination degree-of-freedom based on rotation of ball 413 of handle 403.

[00211] In accordance with one aspect of the invention, the control system may read information stored on identifier element 516, e.g., an RFID token, that is integrated with the instrument to identify the kinematics of end-effector 512 of translational instrument interface 503, as outlined in method steps 700 enumerated in FIG. 37. At step 701, the user selects a surgical instrument having an end-effector to be used with the hybrid telemanipulator. For example, the surgical instrument may have an end-effector having parallel-serial instrument

kinematics as shown in FIG. 36D or serial-serial instrument kinematics as shown in FIG. 36E. The surgical instrument then may be coupled to the slave unit of the hybrid telemanipulator. At step 702, the control system detects information for the kinematic configuration of the selected end-effector. For example, the control system may read out an RFID token integrated with surgical instrument 511, which contains information on the kinematic configuration of the selected end-effector, e.g., whether the selected end-effector has parallel-serial instrument kinematics or serial-serial instrument kinematics. The RFID token may be, for example, an inductively-read microchip that contains identification information that may be scanned by a reader disposed on the slave hub and operatively coupled to the control system. Alternatively, the function of identifier element 516 may be provided by, e.g., an optical tag such as a bar code, QR code, Datamatrix, Aztec code, or Semacode, disposed on the surgical instrument 511 that is read by the slave hub. If the surgical instrument has not yet been coupled to the slave unit of the hybrid telemanipulator, surgical instrument may be coupled to the slave unit of the hybrid telemanipulator after step 702.

[00212] At step 703, the control system identifies the kinematics of the selected end-effector based on the information detected at step 702 to determine which type of end-effector is coupled to the slave unit of the hybrid telemanipulator. At step 704, the control system adjusts its parameters based on the identity of the selected end-effector so that the hybrid telemanipulator may be properly actuated. For example, if the end-effector has parallel-serial instrument kinematics, the control system will include parameters that instruct first motor 601a and second motor 601b to simultaneously actuate the first and second end-effector links to move the end-effector in the open/close and pitch degrees-of-freedom as described above. If the end-effector has serial-serial instrument kinematics, the control system will include parameters that instruct first motor 601a to actuate the end-effector in the open/close degree-of-freedom, and second motor 601b to actuate the end-effector in the pitch degree-of-freedom as described above.

[00213] Referring to FIG. 38, an alternative exemplary embodiment of a remotely actuated surgical robot system wherein all degrees-of-freedom are controlled electromechanically is described. Although all seven of the degrees-of-freedom, e.g., inward/outward, upward/downward, left/right, yaw, pitch, open/close, and pronosupination, are controlled electromechanically via a system of sensors, motors, and a control system, system 800 retains a

mechanical constraint element as described above at the master unit, thereby creating a single virtual stationary point, e.g., remote center-of-motion, at the slave unit. Therefore, system 800 does not require coordinate transform and complex control system to align slave unit 1001 with an incision. The mechanical constraint and the corresponding remote-center-of-motion ensure that this design, is much simpler and safer than when using generic robotic arms.

[00214] Referring now to FIG. 39, master unit 901 is constructed similarly to master unit 401 of FIGS. 34A and 34B, except that instead of a plurality of cables and pulleys of the mechanical transmission coupled to pulley P1, master unit 901 includes one or more sensors, e.g., sensor 902a, sensor 902b, sensor 902c, and sensor 902d, operatively coupled to each of the four pulleys of pulley P1. Sensors 902a-902d measure rotational movement by measuring angle and position of pulley P1 in response to movement applied to handle 903 of master unit 901 via a plurality of master links, joints, and cables. Each of the four sensors measures movement of a joint of master unit 901 via each of the four pulleys of pulley P1, thereby measuring movement of master unit 901 in four degrees-of-motion. However, the mechanical constraint constrains movement of master unit 901 by removing one degree-of-freedom of motion, thereby resulting in movement of slave unit 1001 in three degrees-of-freedom of motion, e.g., inward/outward, upward/downward, and left/right.

[00215] Handle 903 is constructed similarly to handle 403 of FIGS. 34A and 34B. For example, handle 903 includes one or more sensors 410 and circuit board 411, such that micro movements applied at handle 903 may be transmitted to the end-effector of slave unit 1001 via one or more sensors 410 and the one or more motors coupled to the end-effector of slave unit 1001 to move the end-effector in the open/close, pitch, yaw, and pronosupination degrees-of-freedom.

[00216] Regarding transmission of macro-movements, sensor 902a, sensor 902b, sensor 902c, and sensor 902d generate signals indicative of the measured rotation of pulley P1 by the respective sensors, and transmit the signals to one or more motors coupled to slave unit 1001 via a control system, to thereby replicate the translational macro-movements applied at handle 903 coupled to master unit 901. For example, electrical cables may extend from master unit 901 to

the control system, e.g., unit containing control electronics, and additional electrical cables may extend from the control system to the one or more motors coupled to slave unit 1001.

[00217] With respect to FIGS. 40A and 40B, slave unit 1001 is constructed similarly to slave unit 501 of FIGS. 35A and 35B. For example, slave unit 1001 includes first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d operatively coupled to the end-effector of slave unit 1001, such that micro-movements applied at handle 903 may be transmitted to the end-effector of slave unit 1001 via one or more sensors 410, and first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d to move the end-effector in the open/close, pitch, yaw, and pronosupination degrees-of-freedom. Slave unit 1001 differs from slave unit 501 in that instead of a plurality of cables and pulleys of the mechanical transmission coupled to pulley P8, slave unit 1001 includes one or more motors, e.g., first motor 1002a, second motor 1002b, third motor 1002c, and fourth motor 1002d, operatively coupled to each of the four pulleys of pulley P8. The one or more motors are coupled to a circuit board for receiving signals indicative of the measured rotation of pulley P1 by sensor 902a, sensor 902b, sensor 902c, and sensor 902d in response to movement applied to handle 903 of master unit 901, to thereby actuate pulley P8 to replicate the translational macro-movements applied on handle 903 coupled to master unit 901 at slave unit 1001 via a plurality of slave links, joints, timing belts, and/or a system of cables and pulleys. For example, first motor 1002a is operatively coupled to and controls movement of first slave link 505a, second motor 1002b is operatively coupled and controls movement of to second slave link 505b, third motor 1002c is operatively coupled to and controls movement of third slave link 505c, and fourth motor 1002d is operatively coupled to and controls movement of translational instrument interface 503 via pulley P8 and the plurality of slave joints, timing belts, and/or system of cables and pulleys.

[00218] As the mechanical constraint of master unit 901 constrains movement of master unit 901 to movement in three degrees-of-freedom, e.g., inward/outward, upward/downward, and left/right, movement of first slave link 505a, second slave link 505b, third slave link 505c, and translational instrument interface 503 of slave unit 1001 by first motor 1002a, second motor 1002b, third motor 1002c, and fourth motor 1002d, respectively, is constrained to movement in three degrees-of-freedom, e.g., inward/outward, upward/downward, and left/right, about virtual stationary point 1005, e.g., remote center-of-motion.

[00219] Slave unit 1001 may include temporary incision pointer 1004 which points to virtual stationary point 1005, e.g., remote center-of-motion, created by the mechanical restraint at master unit 1001, such that virtual stationary point 1005 may be brought in coincidence with the surgical incision point, reducing trauma to the patient and improving cosmetic outcomes of the surgery. Temporary incision pointer 1004 is removably coupled to a joint of slave unit 1001 such that temporary incision pointer 1004 points to virtual stationary point 1005, and may be removed prior to operation of surgical robot system 800.

[00220] Referring now to FIGS. 40C and 40D, an alternative exemplary embodiment of the incision pointer is provided that is utilized with the systems shown in and described in FIGS. 1-30 herein. Like incision pointer 1004, incision pointer 1004' may be removably coupled to a joint of slave unit 1001 (e.g., the distal end of link 63 described above) such that temporary incision pointer 1004 points to a virtual center-of-motion, e.g., virtual stationary point 1005, thereby identifying the remote center-of-motion of the surgical instrument. For example, incision point 1004' may be removable coupled to the slave console using structures including, but not limited to, magnets, friction forces, Velcro surfaces, matching geometries, hooks, etc. Incision pointer 1004' may be made of ferritic stainless steel, and illustratively include magnetic head 1006 at a proximal end of the incision pointer for magnetically coupling with a corresponding surface at the slave console (e.g., the receptacle at the joint of slave unit 1001).

[00221] As shown in FIG. 40C, magnetic head 1006 may have a convex spherical surface with its center aligned with the distal tip of incision pointer 1004'. Accordingly, the receptacle at the joint of slave unit 1001 may have a corresponding concave spherical surface for engaging with the convex spherical surface of incision pointer 1004'. As will be understood by a person having ordinary skill in the art, magnetic head 1006 of incision pointer 1004' may have a concave spherical surface, and the receptacle at the joint of slave unit 1001 may have a convex spherical surface. Incision point 1004' may function with or without a sterile drape installed over slave unit 1001. FIG. 40E shows incision pointer 1004' inserted within trocar 1007 such that the distal tip of incision pointer 1004' is aligned with the body wall of the patient, e.g., virtual stationary point 1005, about which the instrument will rotate. Incision pointer 1004' may be removed from the receptacle at the joint of slave unit 1001 after the surgical instrument is inserted, prior to operation of the surgical robot system.

[00222] In accordance with one aspect of the present invention, incision pointer 1004' may be removably coupled to the joint of slave unit 1001, e.g., at link 63, and a clinician may move the joint of slave unit 1001, and accordingly, the neighboring plurality of slave links and slave joints, until the distal tip of incision pointer 1004' is aligned with and points to a desired location on the patient's body, e.g., the incision site on the patient's body. Once the joint of slave unit 1001 and incision pointer 1004' are pointing at the desired location, the clinician may set the desired location as virtual stationary point 1005 via the control system based on the alignment of the joint of slave unit 1001. Accordingly, all movement of the surgical instrument by the slave console during operation of the surgical robot system will always rotate about virtual stationary point 1005, even without a mechanical constraint at the master console as described in further detail below with reference to FIG. 43. In this manner, the controller of the system ensures that the surgical instrument does not cause translational movements away from the virtual stationary point 1005 for safe surgery through a trocar. The aligned link (e.g., link 63) preferably always points at the surgical site (e.g., opening through the trocar) during the surgery such that movement of the surgical instrument is restricted about the virtual stationary point.

[00223] Accordingly, the controller of the system may execute instructions to set virtual stationary point 1005 based on the alignment of link 63 and the desired location on the patient's body at the surgical site, such that movement of the surgical instrument is restricted about virtual stationary point 1005 to maintain alignment of link 63 (and its longitudinal axis ω_5) with the incision site during the surgery.

[00224] Referring now to FIGS. 41A and 41B, alternative embodiments of the control system of the surgical robot system are described. Control system 1100 of FIG. 41A, which may be integrated with system 100, includes non-transitory computer readable media, e.g., memory 1101, having instructions stored thereon that, when executed by processor 1102 of control system 1100 allow operation of the hybrid telemanipulators. In addition, control system 1100 may communicate with identifier element reader 517 of slave unit 501, either wirelessly or using an electric cable, so that memory 1101 may store the identity of the kinematic configuration of the end-effector read from identifier element 516, such that the instructions, when executed by processor 1102, cause the motors for controlling the end-effector in the open/close and pitch degrees-of-freedom to behave in accordance to the type of end-effector selected. Control system

1100 is electrically coupled, either wirelessly or using an electric cable, to the circuit boards of master unit 401 and, thereby, to one or more sensors 410 for receiving signals indicative of micro movements applied at handle 403. In addition, control system 1100 is electrically coupled, either wirelessly or using an electric cable, to the circuit boards of slave unit 501 and, thereby, to first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d for actuating the micro movements of the end-effector, e.g., in the open/close, pitch, yaw, and pronosupination degrees-of-freedom.

[00225] Control system 1110 of FIG. 41B, which may be integrated with system 800, includes non-transitory computer readable media, e.g., memory 1111, having instructions stored thereon that, when executed by processor 1112 of control system 1110 allow operation of the hybrid telemanipulators. In addition, control system 1110 may communicate with identifier element reader 517 of slave unit 1001, either wirelessly or using an electric cable, and memory 1111 may store the identity of the kinematic configuration of the end-effector read from identifier element 516, such that the instructions, when executed by processor 1112, cause the motors for controlling the end-effector in the open/close and pitch degrees-of-freedom to behave in accordance to the type of end-effector selected. Control system 1110 is electrically coupled, either wirelessly or using an electric cable, to the circuit boards of master unit 901 and, thereby, to one or more sensors 410 for receiving signals indicative of micro movements applied at handle 903, and to sensor 902a, sensor 902b, sensor 902c, and sensor 902d for receiving signals indicative of macro movements applied at handle 903. In addition, control system 1110 is electrically coupled, either wirelessly or using an electric cable, to the circuit boards of slave unit 1001 and, thereby, to first motor 601a, second motor 601b, third motor 601c, and fourth motor 601d for actuating the micro movements of the end-effector, e.g., in the open/close, pitch, yaw, and pronosupination degrees-of-freedom, and to first motor 1002a, second motor 1002b, third motor 1002c, and fourth motor 1002d for actuating the macro-movements of the end-effector, e.g., in the inward/outward, upward/downward, and left/right degrees-of-freedom.

[00226] Referring now to FIGS. 42A and 42B, alternative applications of the principles of the present invention may be applied to alternative telemanipulator designs. For example, a telemanipulator constructed as described in U.S. Patent No. 9,696,700 to Beira, depicted in FIG. 42A, may be modified to include handles and translational instrument interfaces for

electromechanically controlling the micro movements of the end-effector, e.g., open/close, pitch, yaw, and pronosupination degrees-of-freedom, while the translational macro movements of the end effector, e.g., upward/downward, inward/outward, and left/right degrees-of-freedom, are controlled mechanically by a mechanical transmission system. Remotely actuated surgical robot system 1200 includes master unit 1201 directly mechanically coupled to slave unit 1202, handle 1203 coupled to master unit 1201, translational instrument interface 1204 coupled to slave unit 1202, and mechanical constraint 1205. Handle 1203 may be constructed similarly to handle 403 of FIGS. 34A and 34B, and translational instrument interface 1204 likewise may be constructed similarly to translational instrument interface 503 of FIGS. 35A and 35B. For example, handle 1203 includes one or more sensors, such that micro-movements applied at handle 1203 may be transmitted to the end-effector of translational instrument interface 1204 via the one or more sensors and one or more motors coupled to the end-effector of slave unit 1202 to move the end-effector in the open/close, pitch, yaw, and pronosupination degrees-of-freedom. Accordingly, the translational macro-movements applied at handle 1201 will be replicated by translational instrument interface 1204 in three degrees-of-freedom, e.g., inward/outward, upward/downward, and left/right, due to mechanical constraint 1203. Alternatively, remotely actuated surgical robot system 1200 may have seven degrees-of-freedom actuated electromechanically.

[00227] With respect to FIG. 42B, an alternative telemanipulator is described. For example, a telemanipulator constructed as described in U.S. Patent Pub. No. 2017/0245954 to Beira, may be modified to include handles and translational instrument interfaces for electromechanically controlling the micro-movements of the end-effector, e.g., open/close, pitch, yaw, and pronosupination degrees-of-freedom, while the translational macro-movements of the end effector, e.g., upward/downward, inward/outward, and left/right degrees-of-freedom, are controlled mechanically by a mechanical transmission system. Remotely actuated surgical robot system 1210 includes master unit 1211 mechanically coupled to slave unit 1212, handle 1213 coupled to master unit 1211, translational instrument interface 1214 coupled to slave unit 1212, and mechanical constraint 1215. Handle 1213 is constructed similarly to handle 403 of FIGS. 34A and 34B, and translational instrument interface 1214 is constructed similarly to translational instrument interface 503 of FIGS. 35A and 35B. For example, handle 1213 includes one or more sensors, such that micro-movements applied at handle 1213 may be transmitted to the end-effector of translational instrument interface 1214 via the one or more sensors and one or more

motors coupled to the end-effector of slave unit 1212 to move the end-effector in the open/close, pitch, yaw, and pronosupination degrees-of-freedom. Accordingly, the translational macro-movements applied at handle 1213 will be replicated by the end-effector of translational instrument interface 1214 in three degrees-of-freedom, e.g., inward/outward, upward/downward, and left/right, due to mechanical constraint 1213. Alternatively, remotely actuated surgical robot system 1210 may have seven degrees-of-freedom actuated electromechanically.

[00228] Referring now to FIG. 43, another exemplary master console constructed in accordance with the principles of the present invention is provided. Master console 20' is constructed similar to master console 20 of FIG. 2A, except that the master telemanipulator of master console 20' does not include a mechanical constraint designed to constrain movement of at least one master link of the plurality of master links as described above. For example, a master telemanipulator of master console 20' includes a base portion having telescoping bases 1008 and 1009 for adjusting the vertical height of the master telemanipulator, and base cap 1010 fixed atop telescoping bases 1008 and 1009 and rotatably coupled to link 26 via joint 25.

[00229] Unlike master console 20 of FIG. 2A, the master telemanipulator of master console 20' includes link 1014 coupled to link 1012 via joint 1013, and link 1016 coupled to link 1014 via link 1015 and further coupled to handle portion 1018 via joint 1017. As shown in FIG. 43, none of links 1014 or 1016 passes through link 1012. Instead, once the virtual stationary point, e.g., remote center-of-motion, is set by the control system as described above with reference to FIG. 40C-40E, movements applied to the master telemanipulator by the surgeon will be made by slave links and slave joints of the slave console in a corresponding manner about the virtual stationary point.

[00230] Advantageously, master console 20 permits the surgeon to approach the handle grip of handle portion 1018 from top-down (instead of bottom-up or horizontally as with other surgical robots). In addition, master console 20 shares the same orientation as the surgeon's arms such that the base of the master arms is positioned on the side of the surgeon's body, and not in front in the area of the central pillar of master console 20. As the sterile master arms of master console 20 are positioned further from the ground in this configuration, sterility of master

console 20 is better maintained during use of the surgical system. Moreover, this configuration reduces the depth of the surgeon console, thereby saving valuable operating room floor space.

[00231] Further, as shown in FIG. 43, master console 20' may include master arm break release button 1019 and height adjustment button 1020. For example, actuation of master arm break release button 1019 will permit the user to readjust the plurality of master links and master joints until the master telemanipulator is in a desired configured for use by the surgeon, and actuation of height adjustment button 1020 will permit the user to adjust the vertical height, e.g., up or down, of the master telemanipulator via telescoping bases 1008 and 1009.

[00232] While various illustrative embodiments of the invention are described above, it will be apparent to one skilled in the art that various changes and modifications may be made therein without departing from the invention. The appended claims are intended to cover all such changes and modifications that fall within the true scope of the invention.

CLAIMS

1. A system for remote manipulation to perform surgery, the system comprising:
 - a slave console comprising a slave hub, an alignment joint disposed proximal of the slave hub, and a plurality of slave links coupled to a base;
 - a surgical instrument configured to be received in the slave hub and coupled to the slave console, a distal region of the surgical instrument configured to be inserted into a patient at a surgical site for performing robotic surgery;
 - an incision pointer configured to be removably coupled to the alignment joint to facilitate an alignment of the alignment joint and the surgical site; and
 - a controller configured to execute instructions to:
 - set a virtual remote center-of-motion based on the alignment of the alignment joint and the surgical site; and
 - cause at least one of the plurality of slave links distal to the alignment joint to move responsive to movement applied at a handle of a master console operatively coupled to the slave console to thereby move the surgical instrument to perform the robotic surgery,
 - wherein movement of the surgical instrument is restricted about the virtual remote center-of-motion to maintain alignment of the alignment joint with the surgical site during the surgery.
2. The system of claim 1, wherein the incision pointer is configured to be removably coupled to the alignment joint via a magnetic attachment.
3. The system of claim 1, wherein the virtual center-of-motion is set based on the alignment of the alignment joint and a trocar positioned within the patient at the surgical site.
4. The system of claim 1, wherein the handle is removably coupled to the master console such that the handle is sterile during the surgery and sterilizable while removed for additional surgeries.
5. A method for remotely performing a surgery, the method comprising:
 - aligning a slave joint of a plurality of slave joints of a slave console with a trocar insertion site, the plurality of slave joints interconnected by a plurality of slave links, the slave console operatively coupled to a master console and configured to move responsive to movement applied at a handle of the master

console, the slave console comprising a slave hub and an alignment joint disposed proximal of the slave hub;

coupling an incision pointer to the alignment joint to facilitate an alignment of the alignment joint and the trocar insertion site;

setting a virtual remote center-of-motion based on the alignment of the alignment joint with the trocar insertion site; and

moving at least one of the plurality of slave links distal to the alignment joint responsive to movement applied at the handle to move a surgical instrument coupled to the slave console to perform the surgery,

wherein movement of the surgical instrument is restricted about the virtual remote center-of-motion to maintain alignment of the alignment joint with the trocar insertion site during the surgery.

6. The method of claim 5, wherein aligning the slave joint of the plurality of slave joints of the slave console with the trocar insertion site comprises aligning the incision pointer with the trocar insertion site.

7. The method of claim 6, wherein coupling the incision pointer to the alignment joint comprises coupling the incision pointer to the alignment joint via a magnetic attachment.

8. The method of claim 5, further comprising removing the handle for sterilization in-between surgeries.

9. The system of claim 1, wherein the controller is configured to execute instructions to prevent movement of slave links proximal to the alignment joint.

10. The system of claim 1, wherein the incision pointer comprises a head configured to couple to the alignment joint and a shaft extending from the head.

11. The system of claim 4, further comprising:
a sterile drape interface coupled to a sterile drape configured to cover non-sterile portions of the master console, the sterile drape interface configured to couple to the master console and define an opening configured to receive a portion of the handle,
the handle configured to couple to the master console by having the portion inserted through the opening and into engagement with the master console.

12. The system of claim 11, further comprising a cap configured to cover the opening to avoid accidental contact of a user with an interior of the master console, the cap configured to be removed prior to coupling the handle to the master console.

13. The system of claim 11, wherein the sterile drape interface includes a rigid ring.

14. The system of claim 4, wherein the handle includes extensions that are configured to engage with a groove in the master console when the handle is coupled to the master console, the engagement of the extensions with the groove configured to prevent lateral movement of the handle relative to the master console while allowing the handle to rotate relative to the master console.

15. The system of claim 14, wherein the handle is configured to be released from the master console via retraction of a release grip that causes the extensions to move radially inward and disengage from the groove.

16. The system of claim 1, wherein the controller is further configured to execute instructions to cause, in response to an input at the slave console, the plurality of slave links to move from a first configuration to a second configuration by retracting away from the patient to expose the surgical site such that a user can perform non-robotic surgery at the surgical site.

17. The system of claim 16, wherein the controller is further configured to execute instructions to determine that the surgical instrument has been removed from the patient at the surgical site,

the controller configured to cause the plurality of slave links to move to the second configuration in response to the input at the slave console and determining that the surgical instrument has been removed from the patient.

18. The system of claim 17, wherein the controller is further configured to execute instructions to cause, in response to a second input at the slave console, the plurality of slave links to move from the second configuration back to the first configuration.

19. The system of claim 18, wherein the plurality of slave links in the first configuration is configured to enable the surgical instrument to be coupled to the slave console and positioned at the trocar insertion site.

20. The system of claim 16, wherein the alignment joint remains aligned with the virtual remote center-of-motion in the second configuration.

21. The system of claim 1, wherein the controller is disposed in a slave link of the plurality of slave links.

22. The system of claim 1, wherein the controller is configured to cause at least one of the plurality of slave links to move responsive to movement applied at the handle of the master console by:

generating signals indicative of scaled movements corresponding to the movement applied at the handle; and

causing the at least one of the plurality of slave links to move at a scaled degree corresponding to the movement applied at the handle based on the signals.

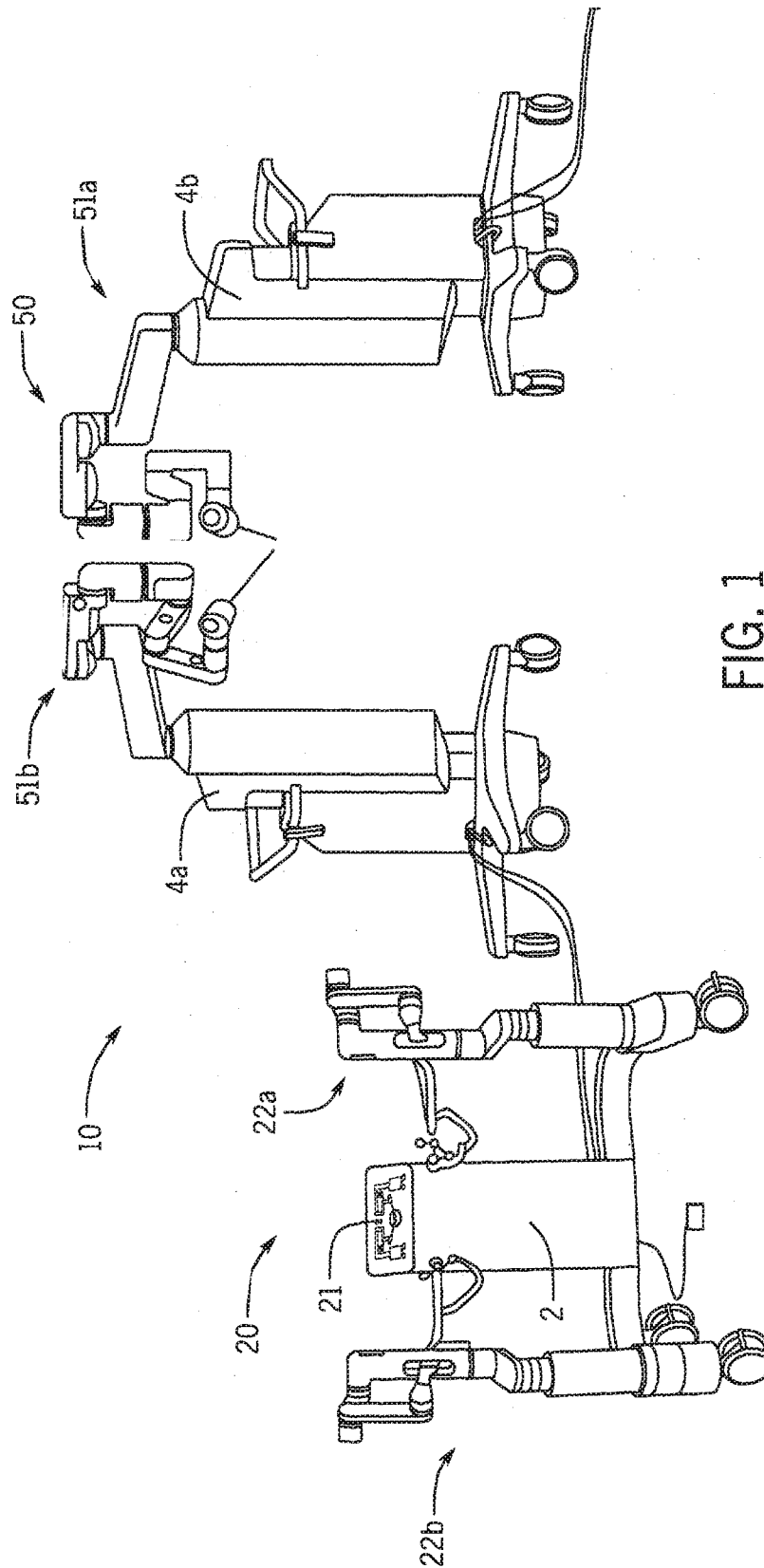
23. The system of claim 1, wherein the surgical instrument includes an end effector configured to move in a plurality of degrees-of-freedom, and the controller is further configured to execute instructions to cause the end effector to move in at least one of the plurality of degrees-of-freedom responsive to movement applied at the handle.

24. The system of claim 23, wherein the controller is configured to execute instructions to cause the end effector to move by:

causing the end effector to move in a first degree-of-freedom of the plurality of degrees-of-freedom at a first scaled degree based on a corresponding movement applied at the handle; and

causing the end effector to move in a second degree-of-freedom of the plurality of degrees-of-freedom at a second scaled degree based on a corresponding movement applied at the handle.

25. The system of claim 1, further comprising first and second foot pedals, wherein at least one of the first and second foot pedals, when actuated, is configured to prevent the plurality of slave links from moving responsive to the movement applied at the handle.



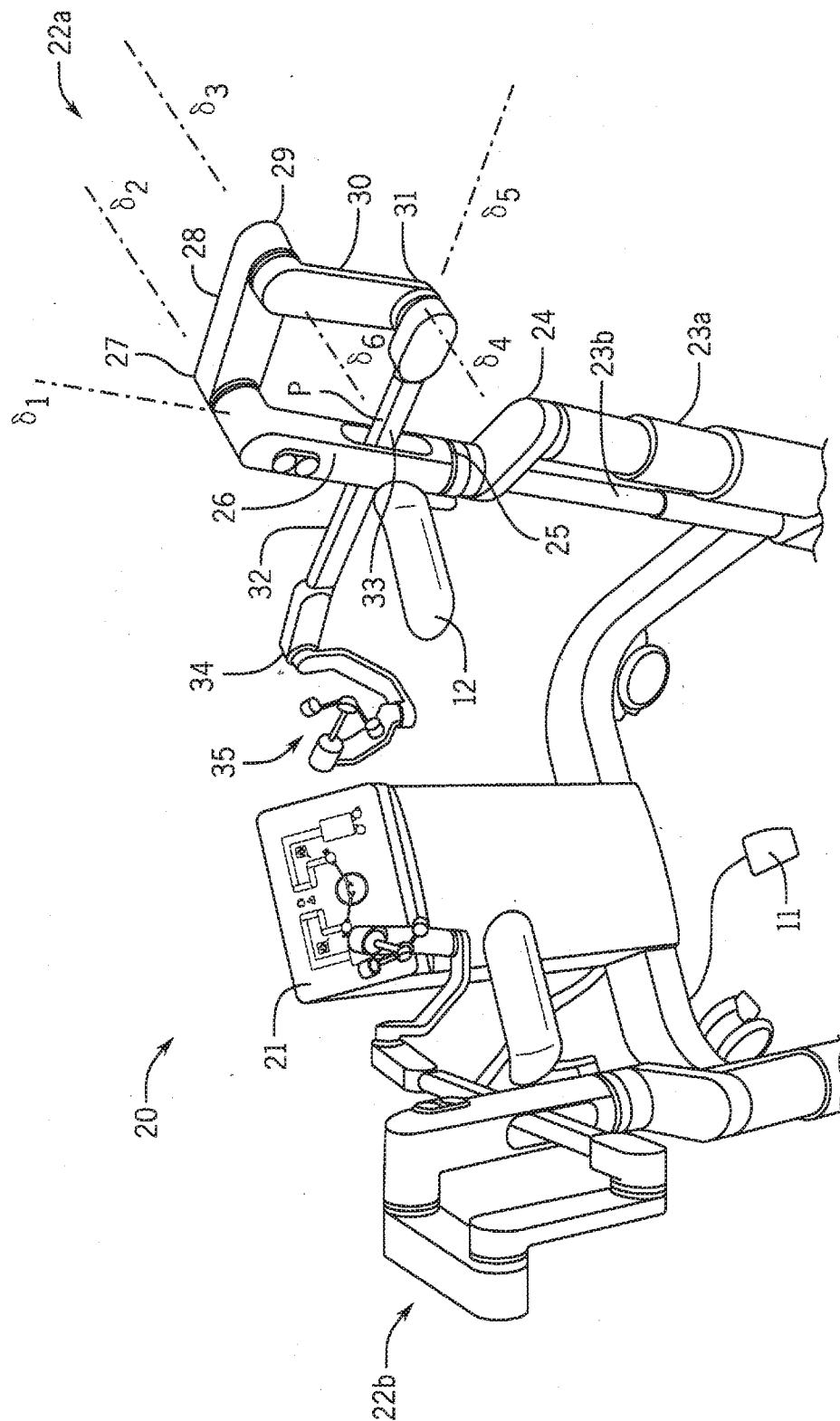


FIG. 2A

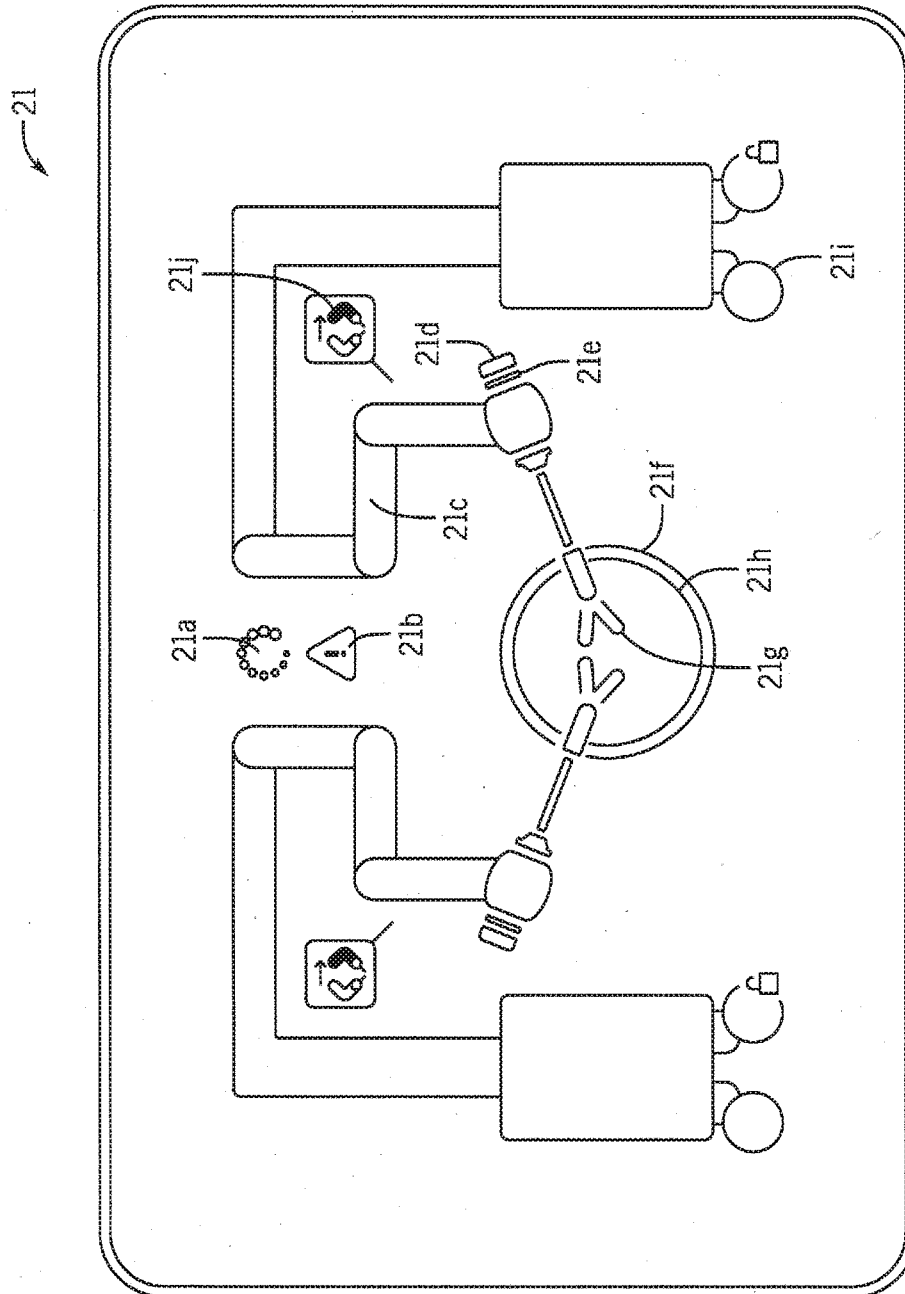


FIG. 2B

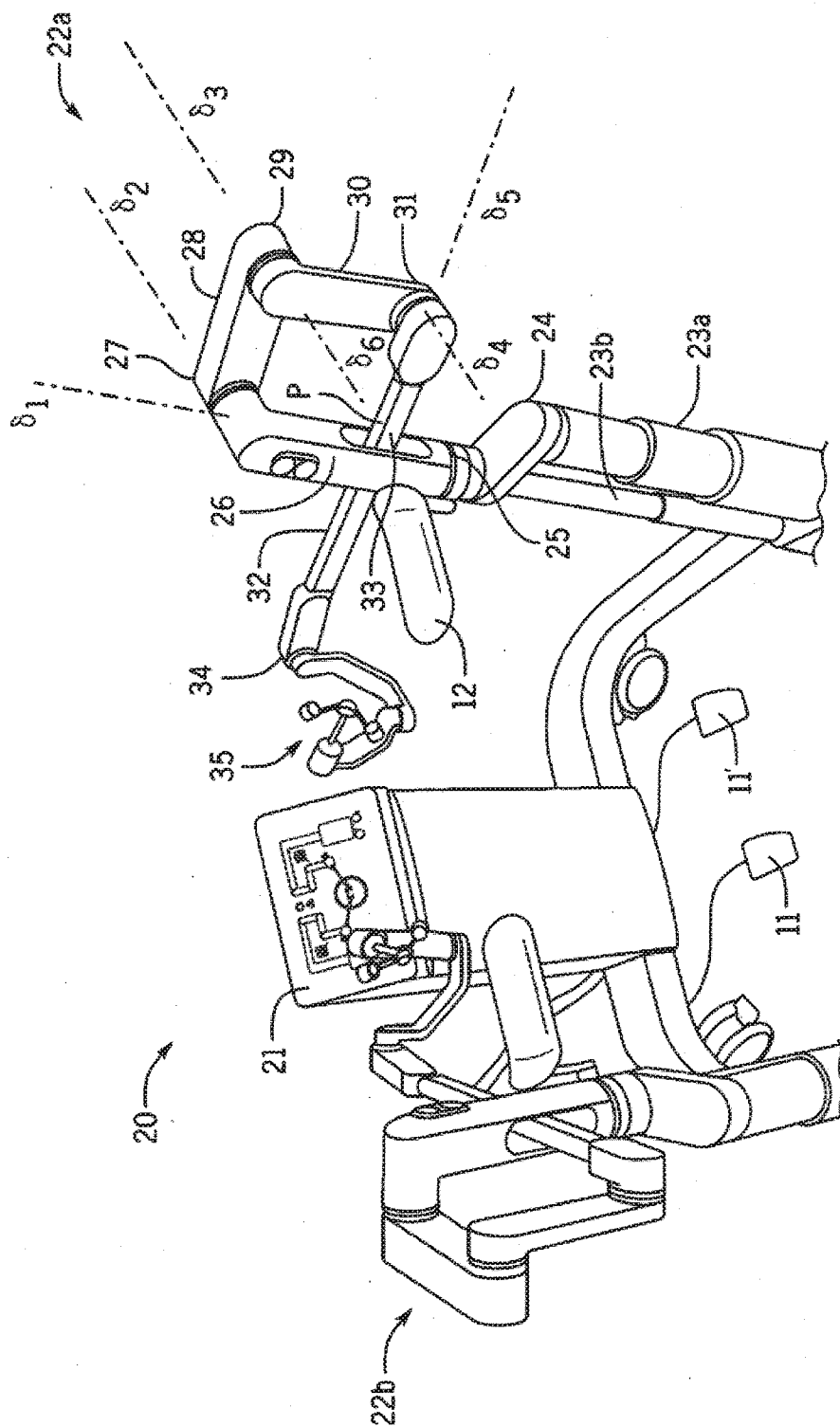


FIG. 2C

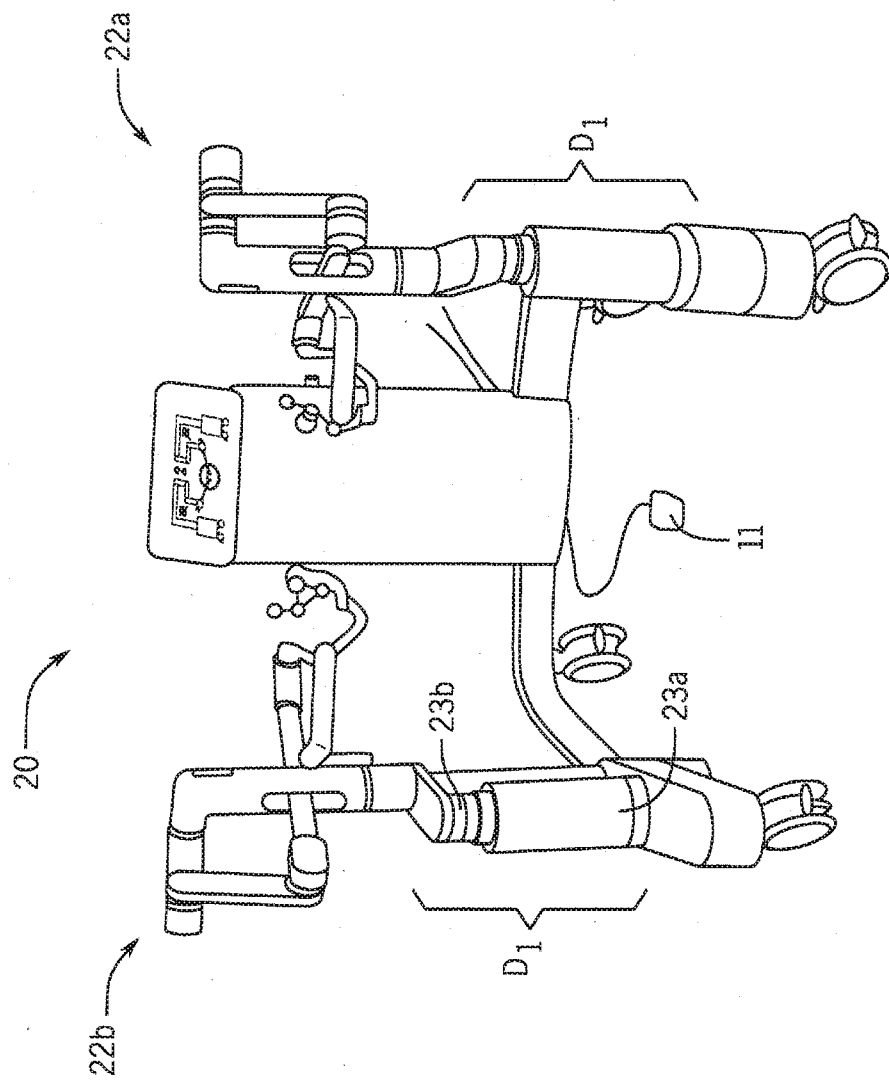
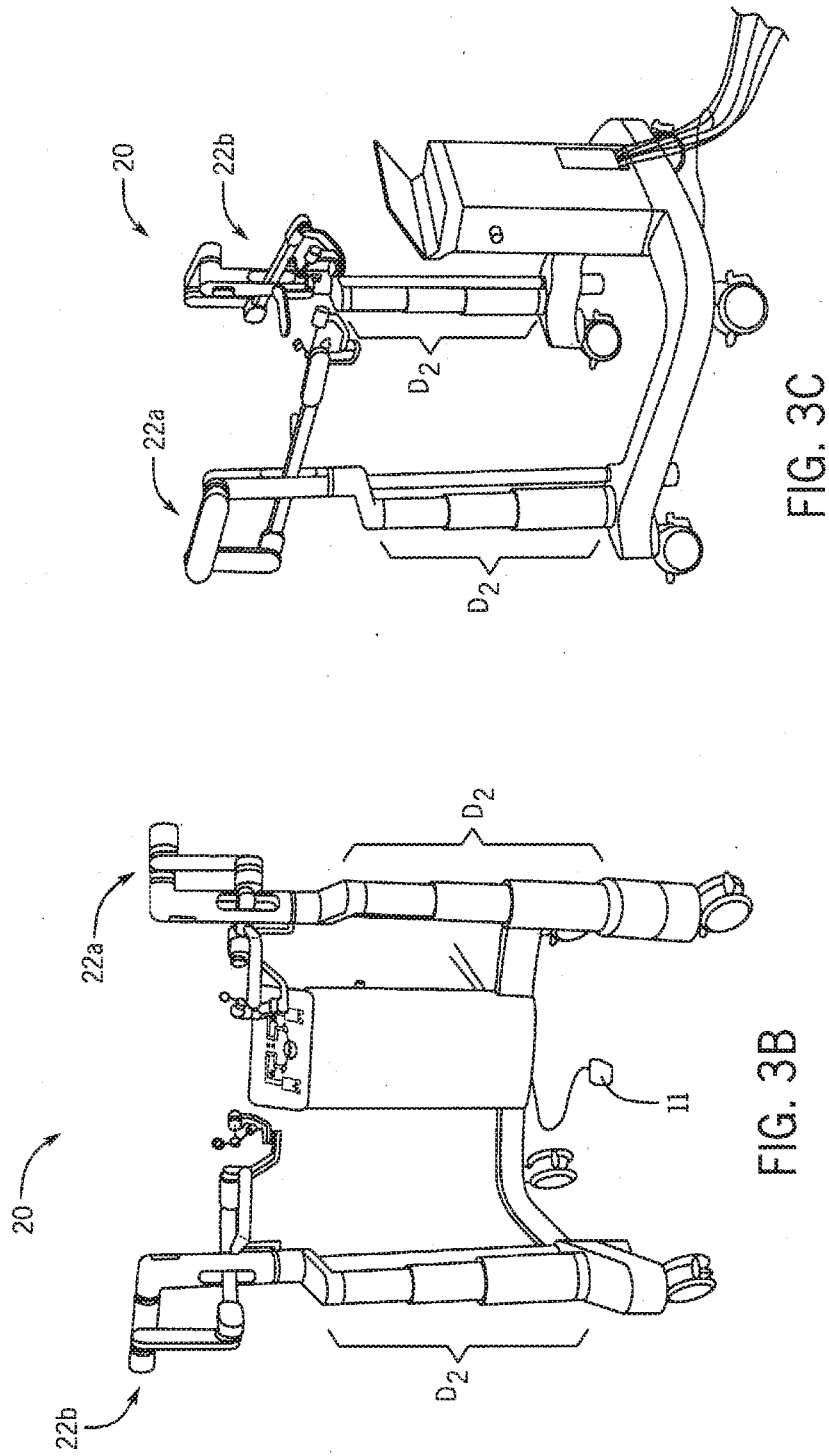


FIG. 3A



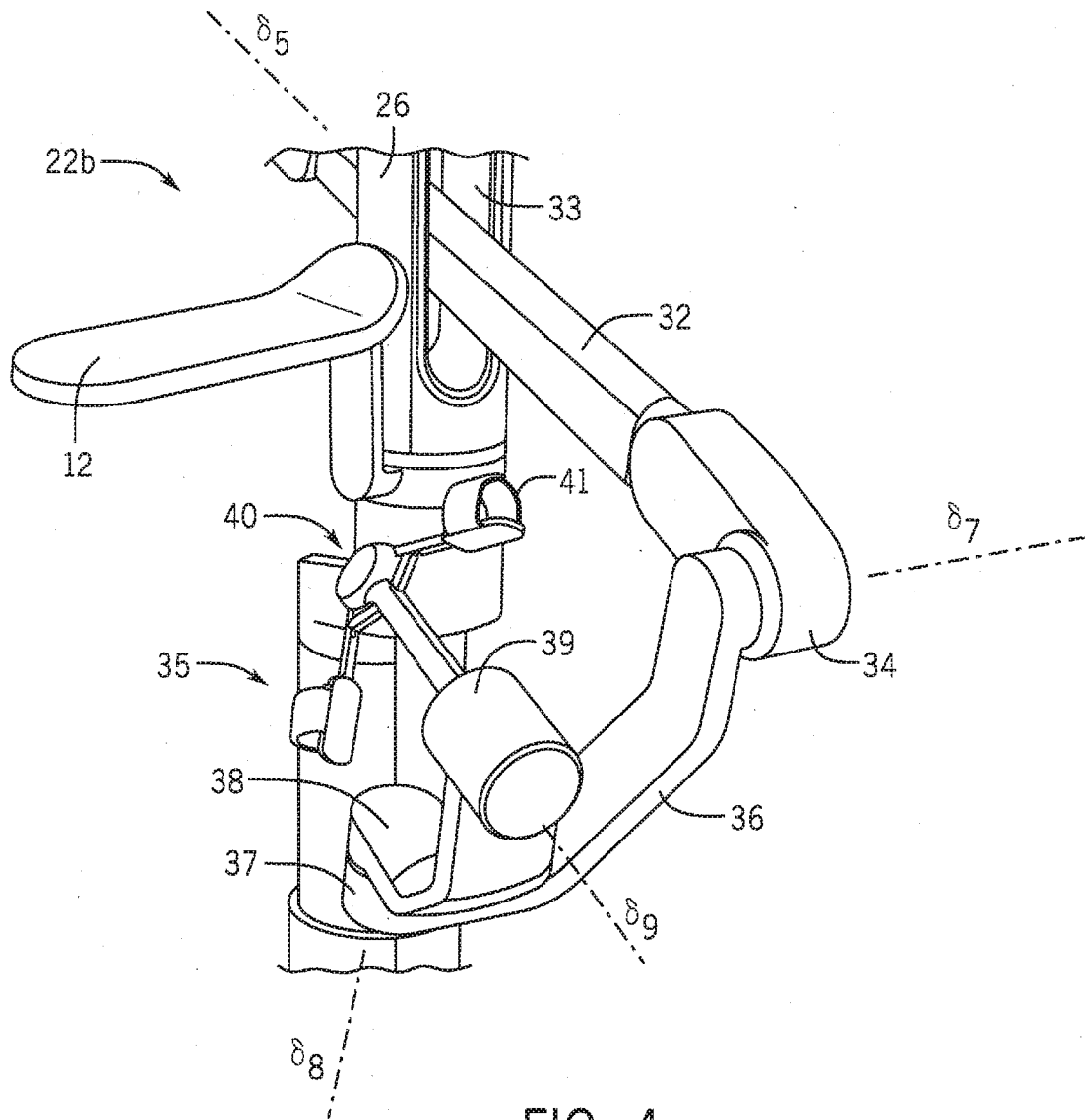


FIG. 4

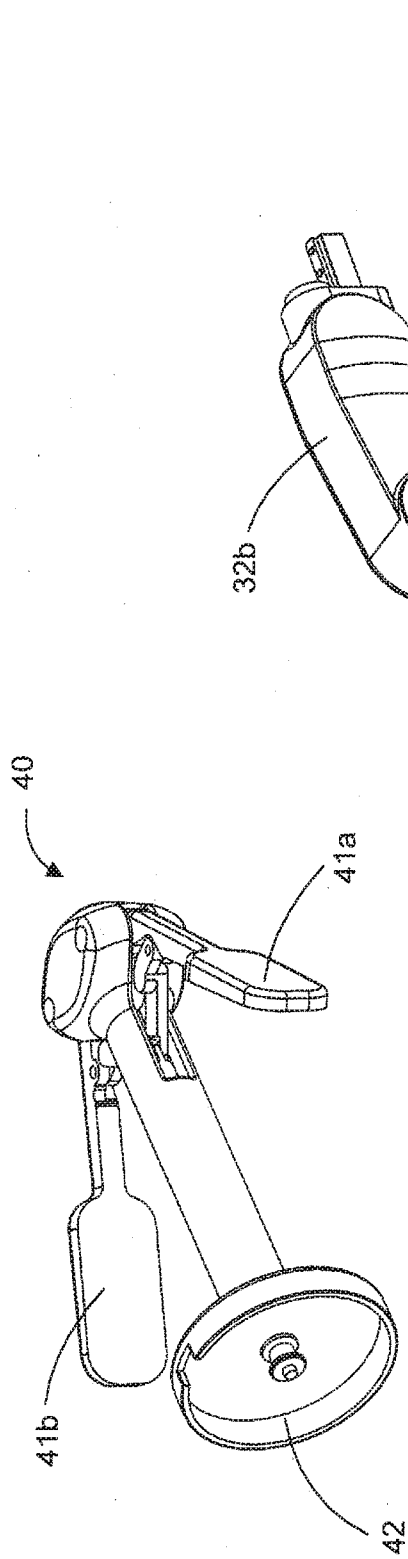


FIG. 5A

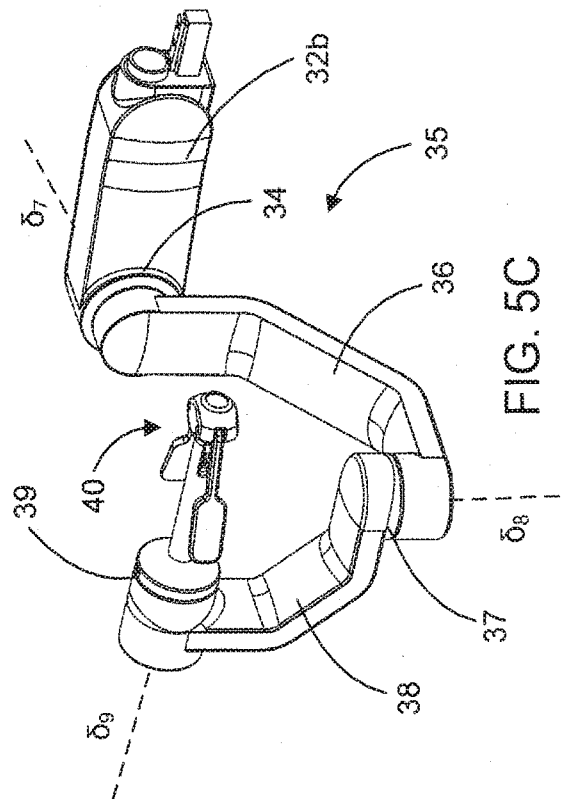


FIG. 5C

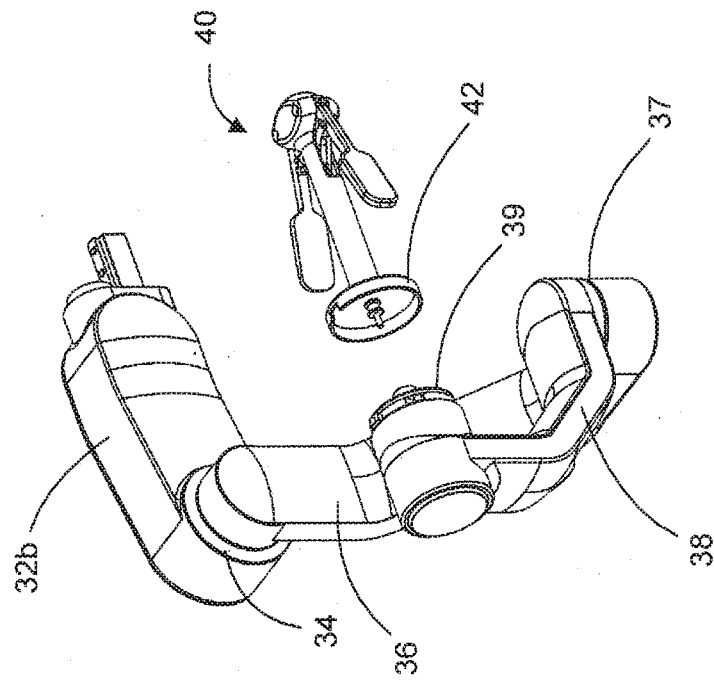


FIG. 5B

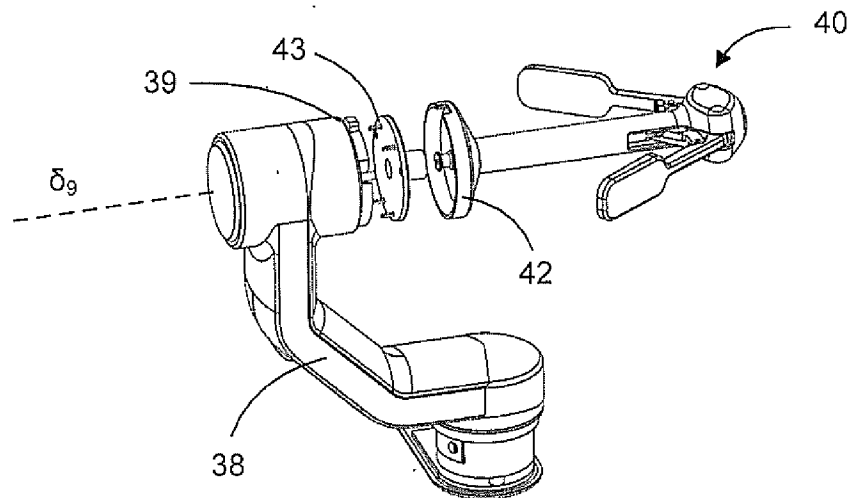


FIG. 5D

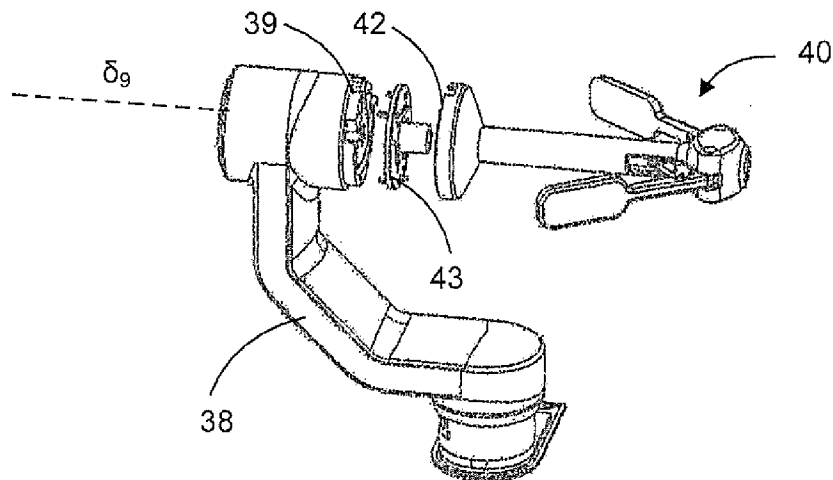


FIG. 5E

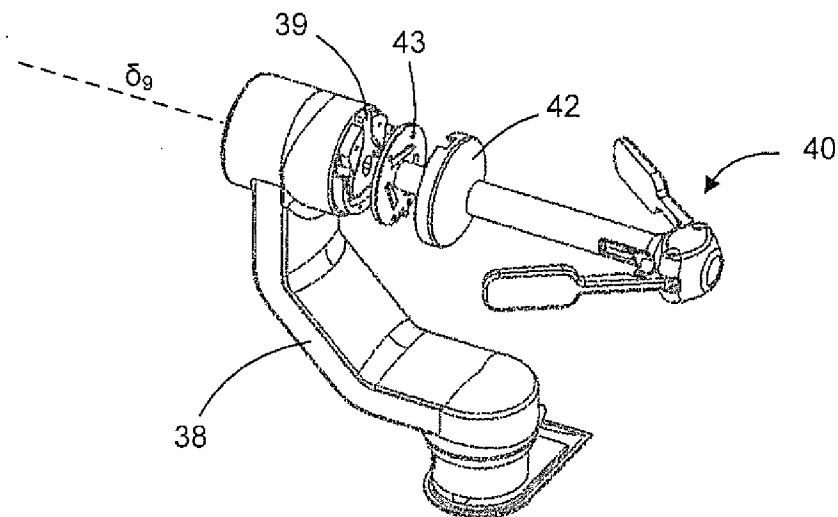


FIG. 5F

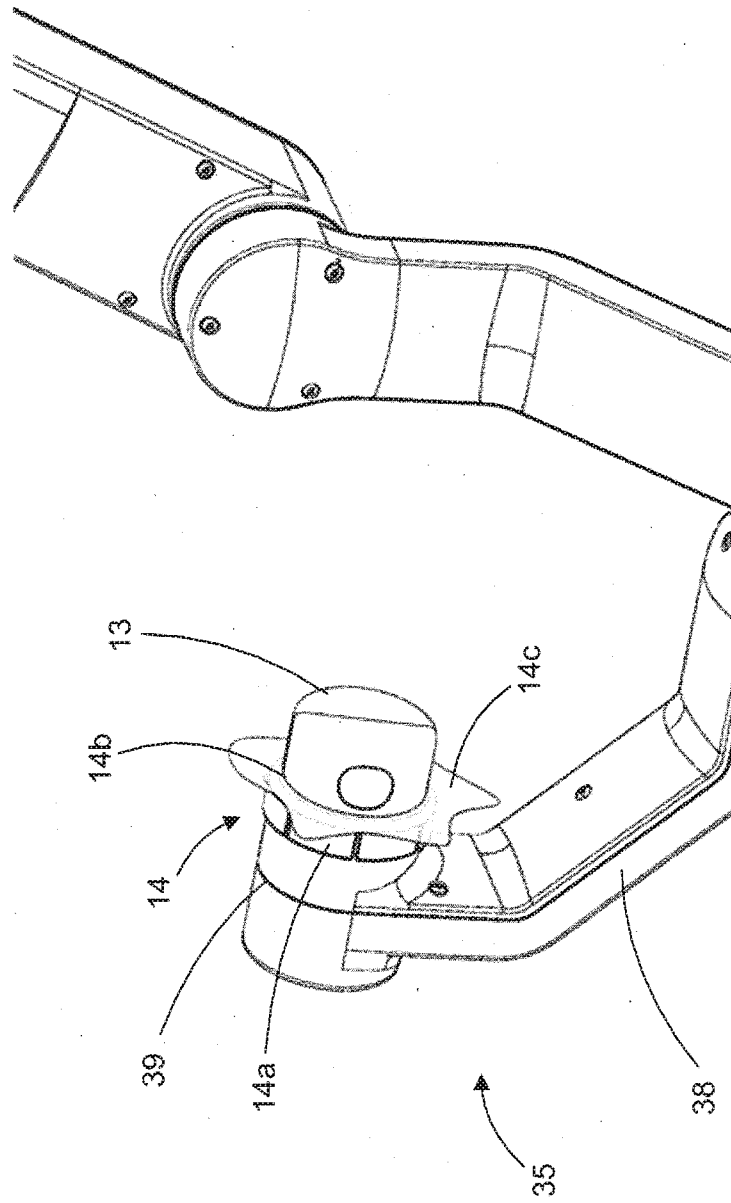


FIG. 5G

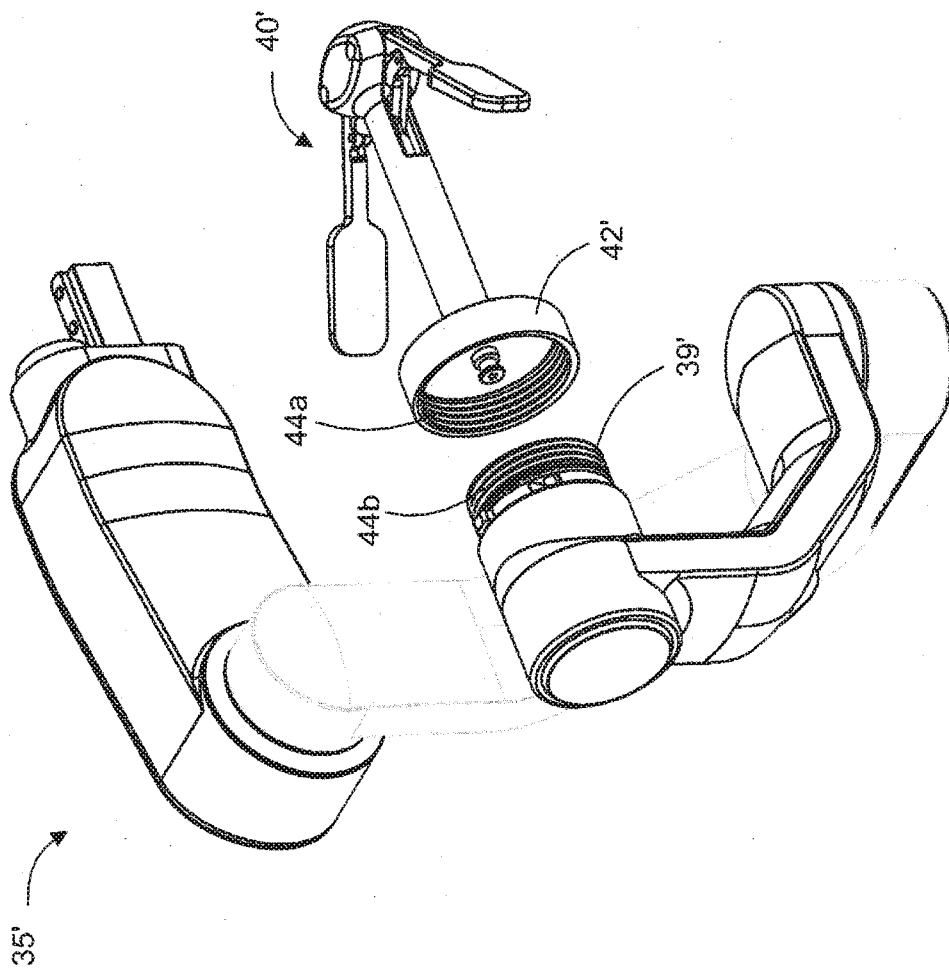


FIG. 6

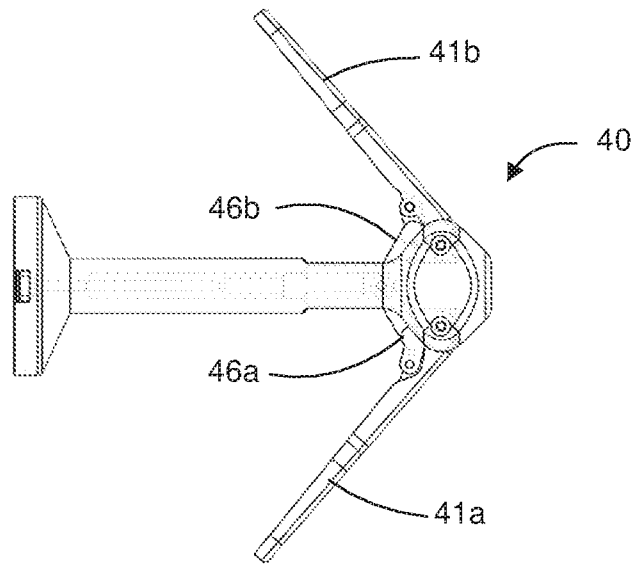


FIG. 7A

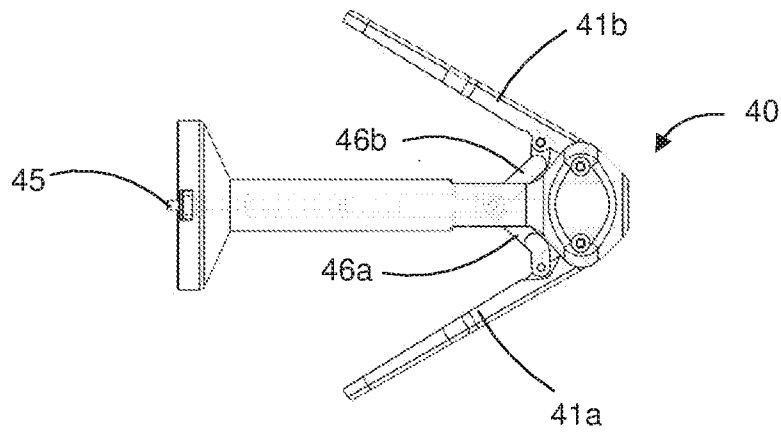


FIG. 7B

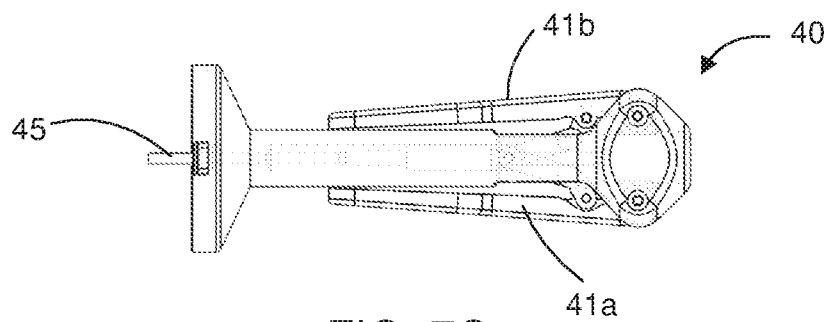


FIG. 7C

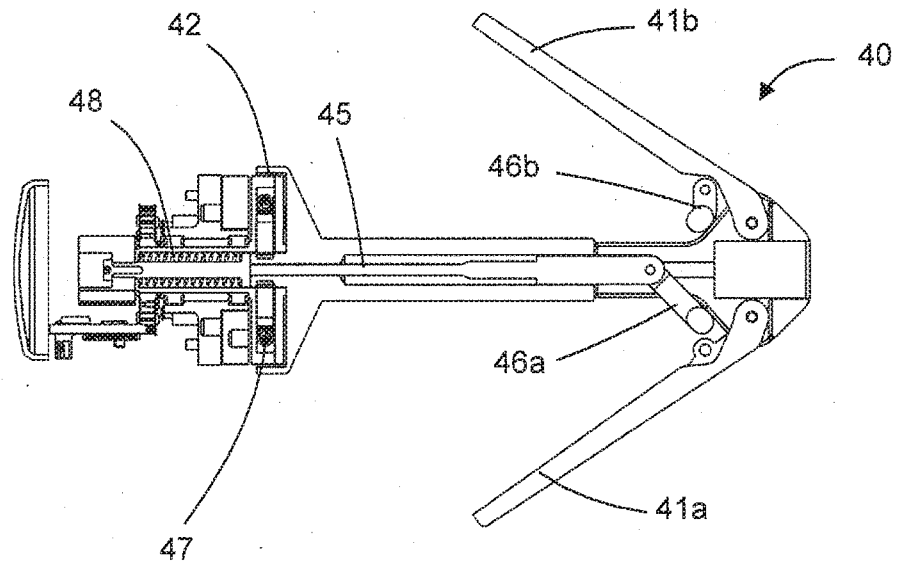


FIG. 7D

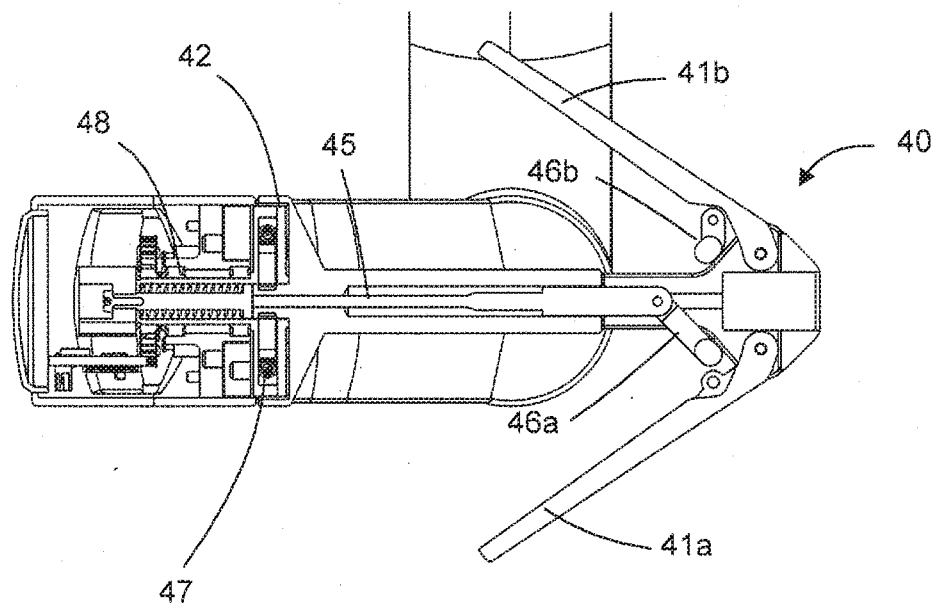


FIG. 7E

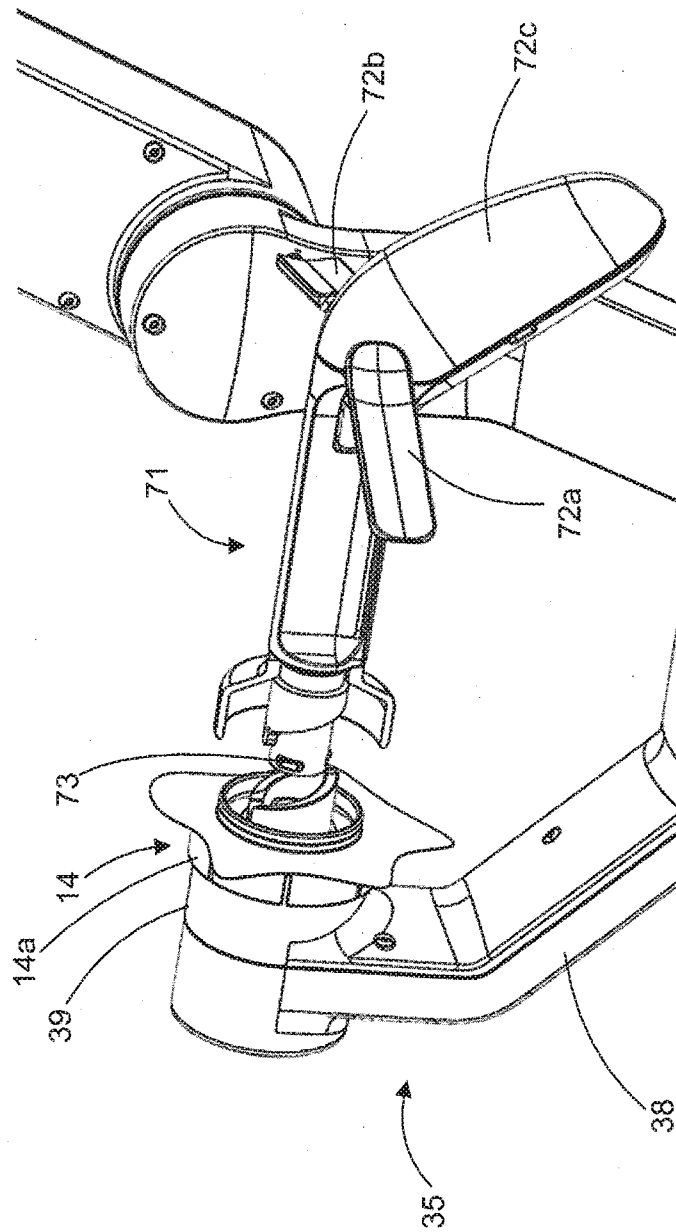


FIG. 8A

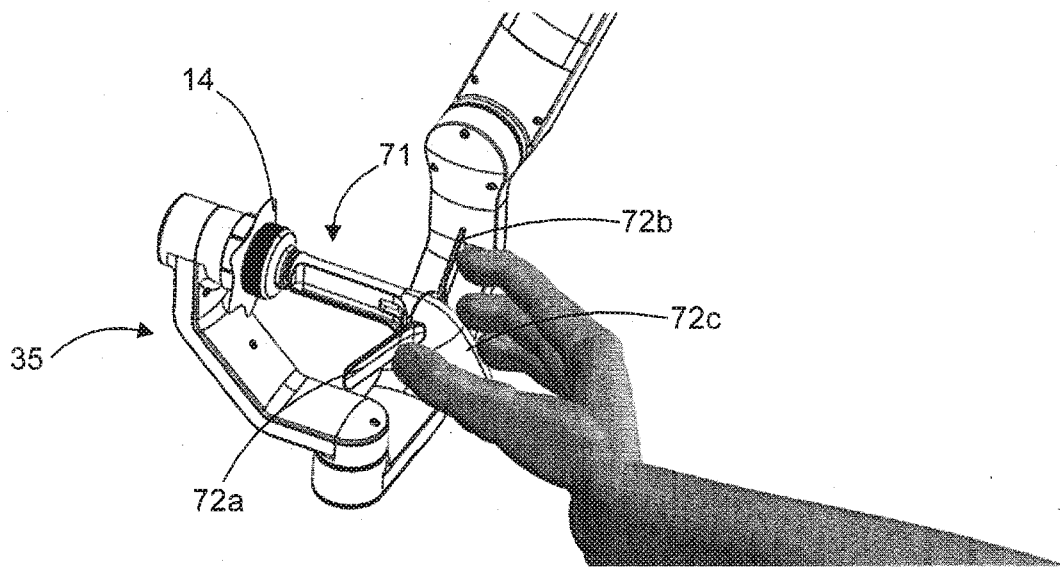


FIG. 8B

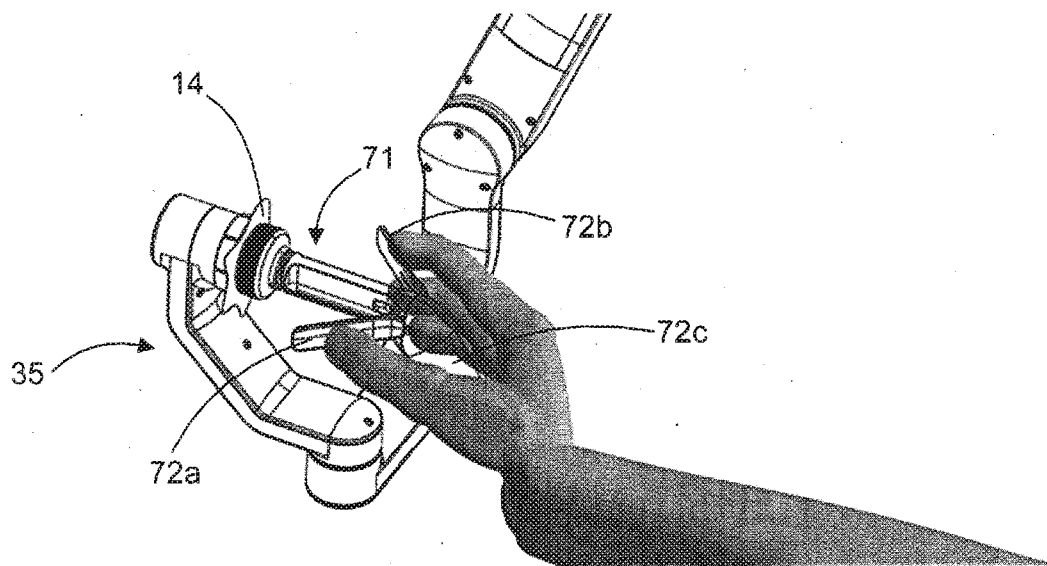


FIG. 8C

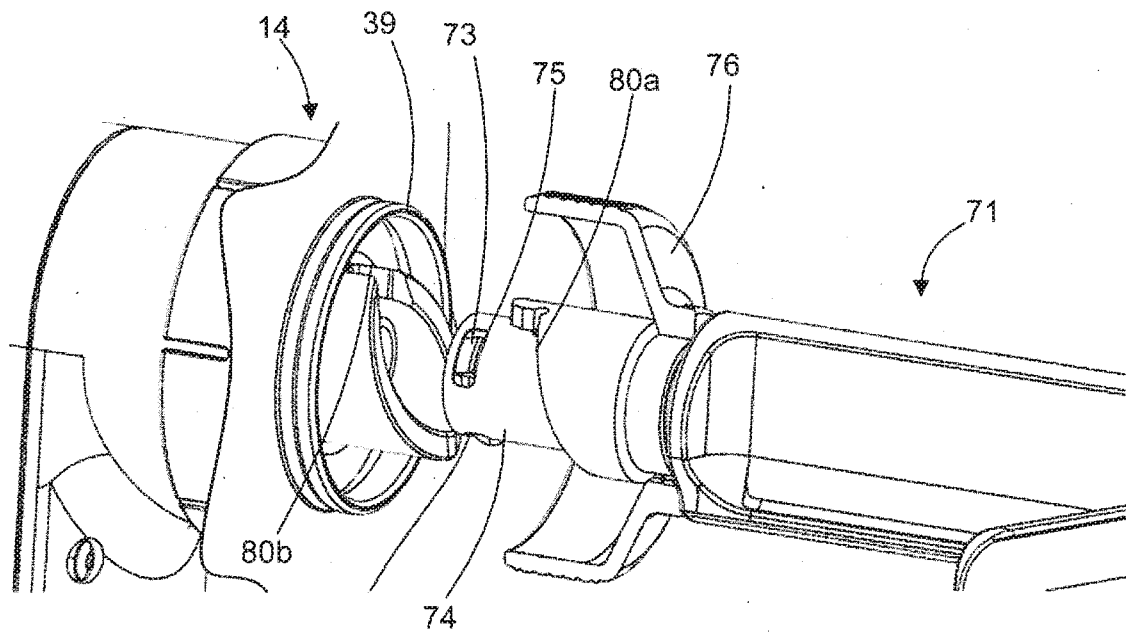


FIG. 8D

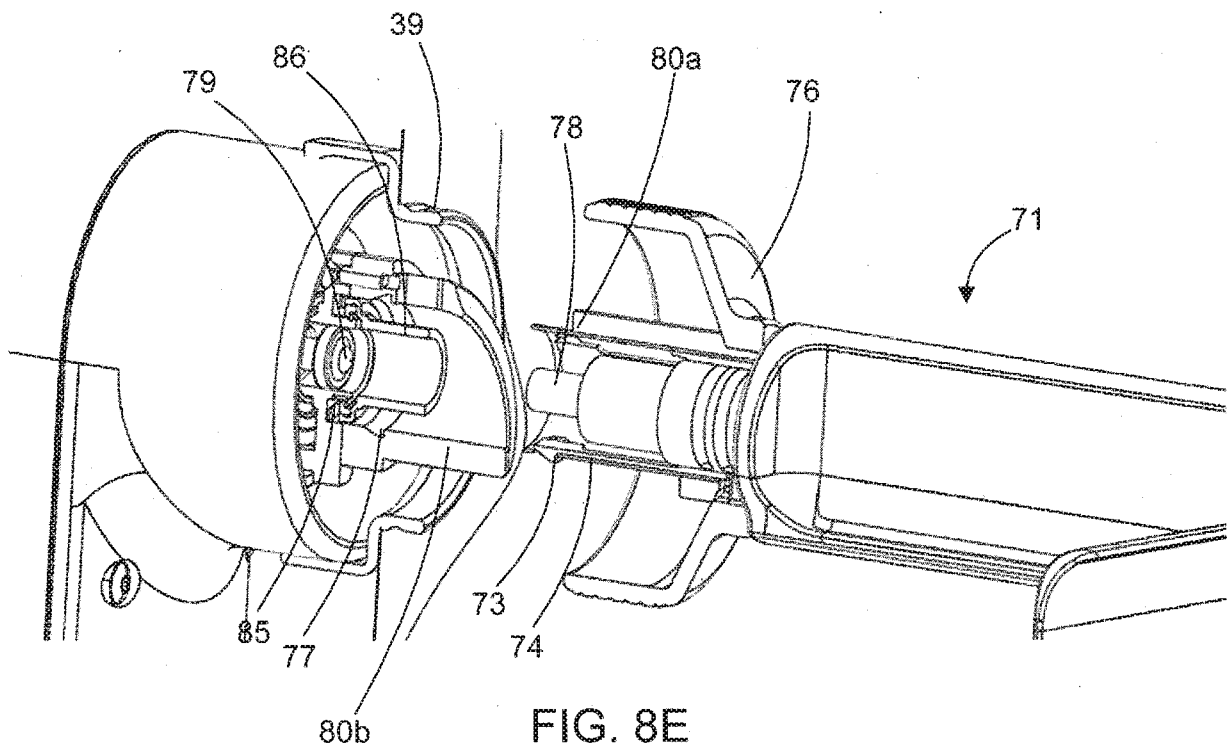


FIG. 8E

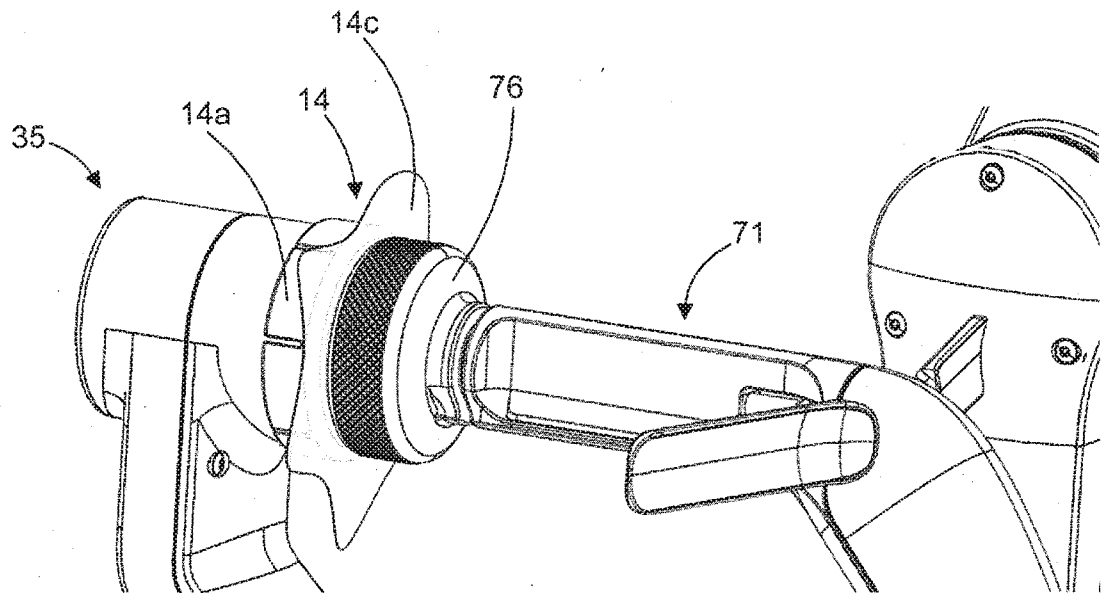


FIG. 8F

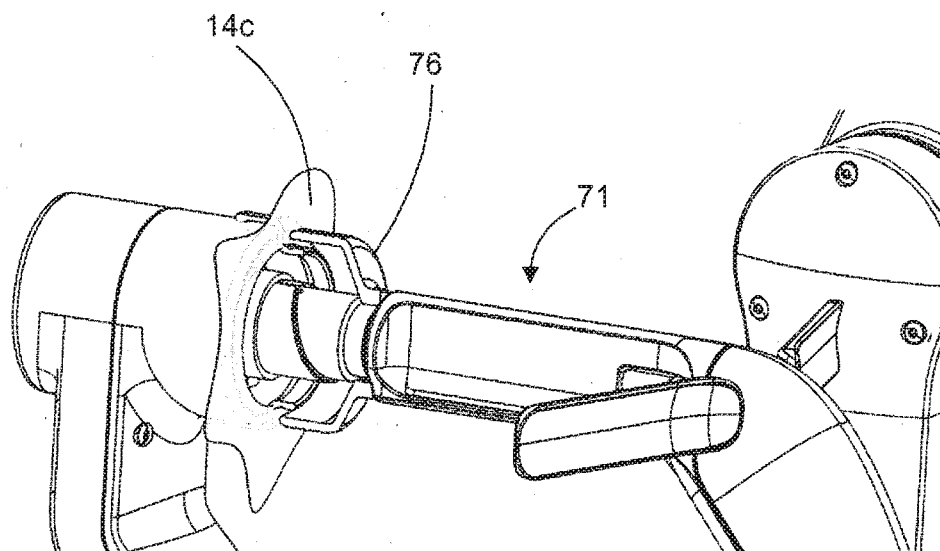


FIG. 8G

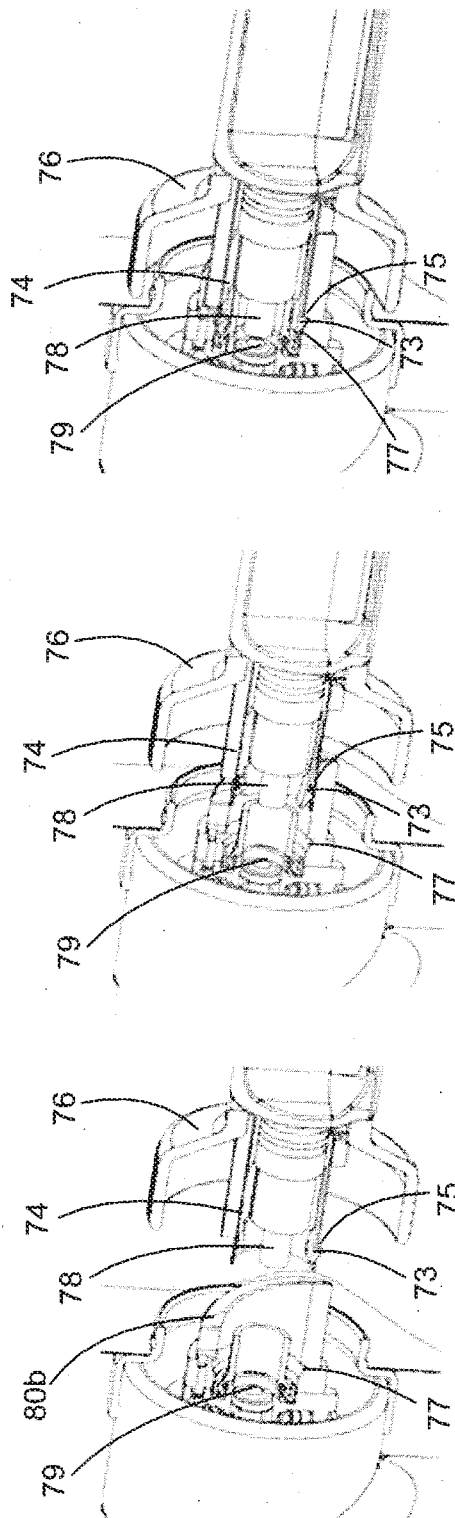


FIG. 9A

FIG. 9B

FIG. 9C

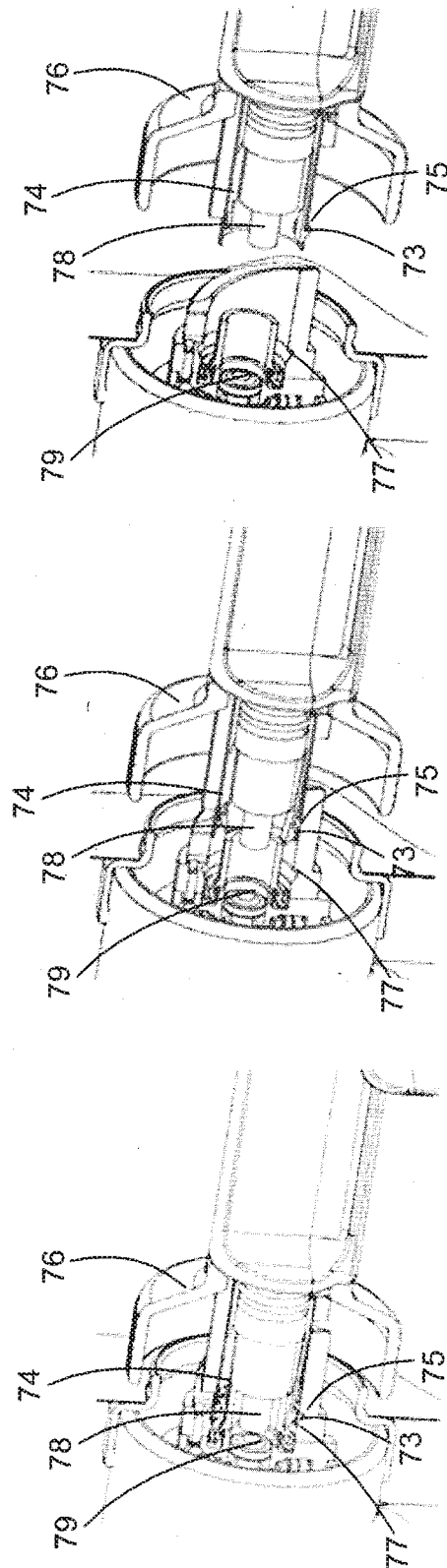


FIG. 9D

FIG. 9E

FIG. 9F

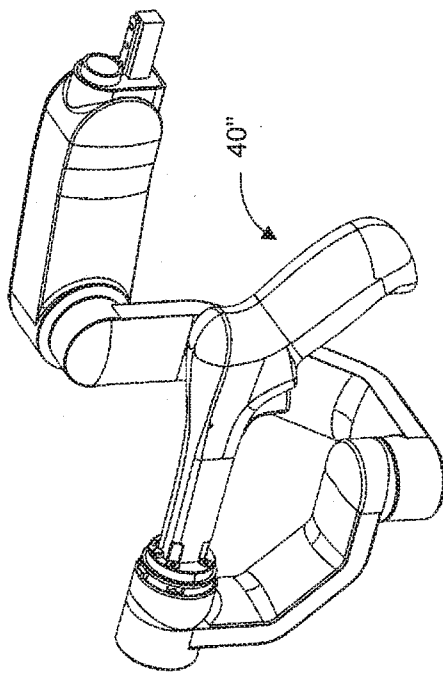


FIG. 10A

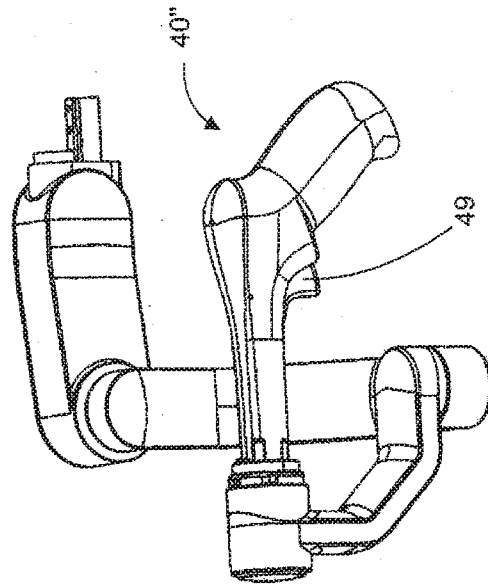


FIG. 10B

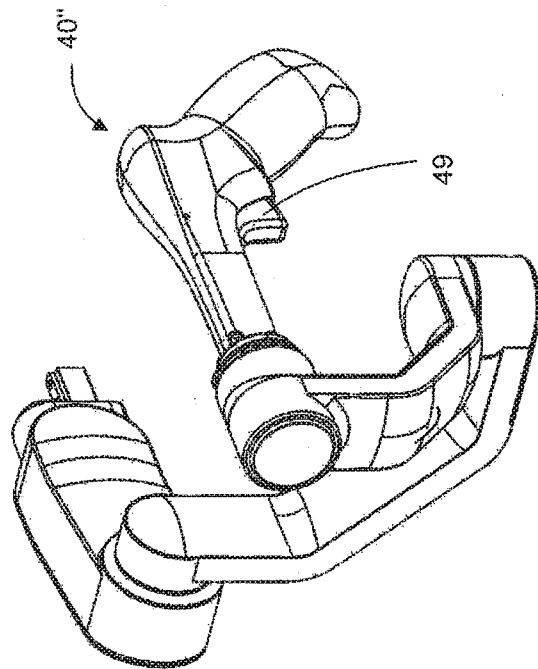


FIG. 10C

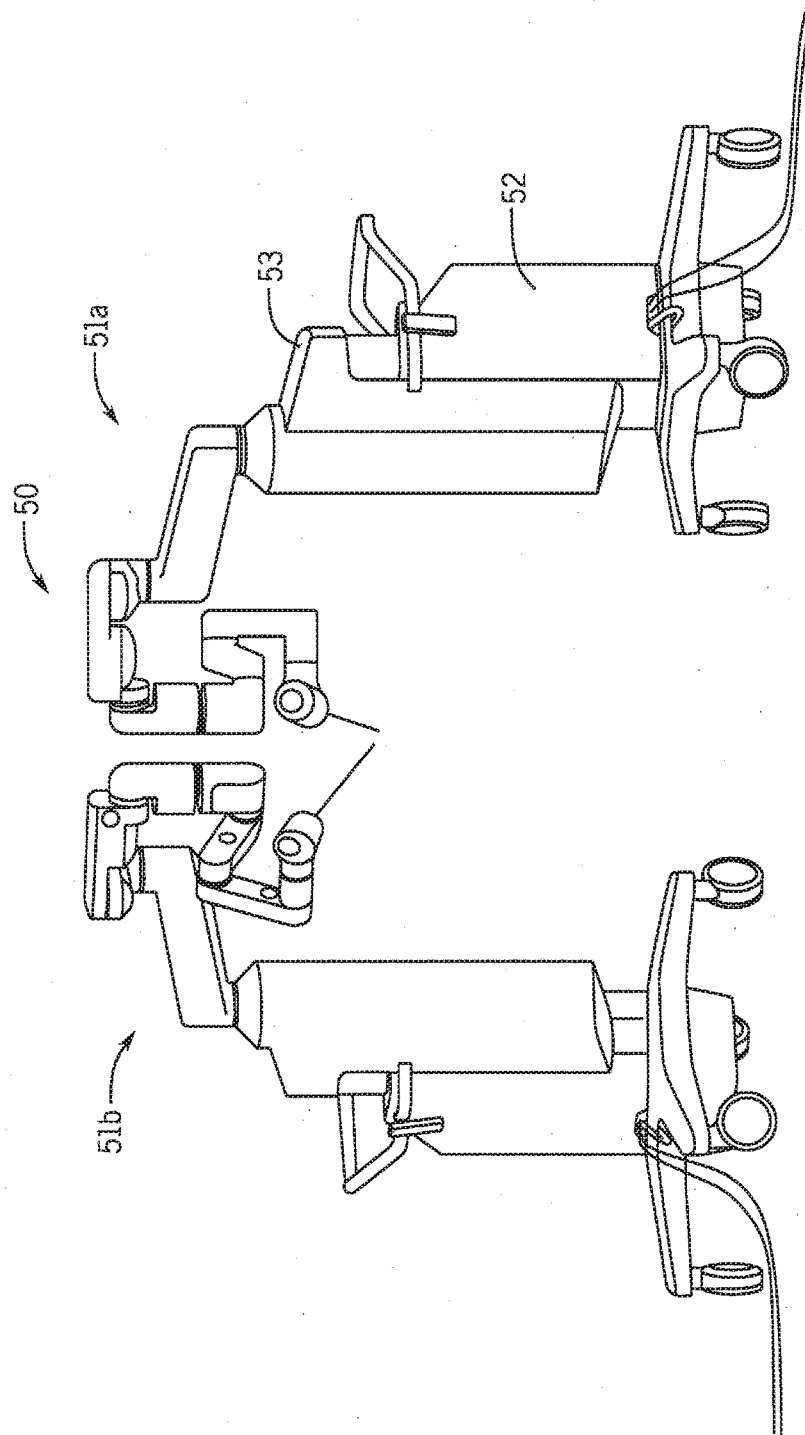
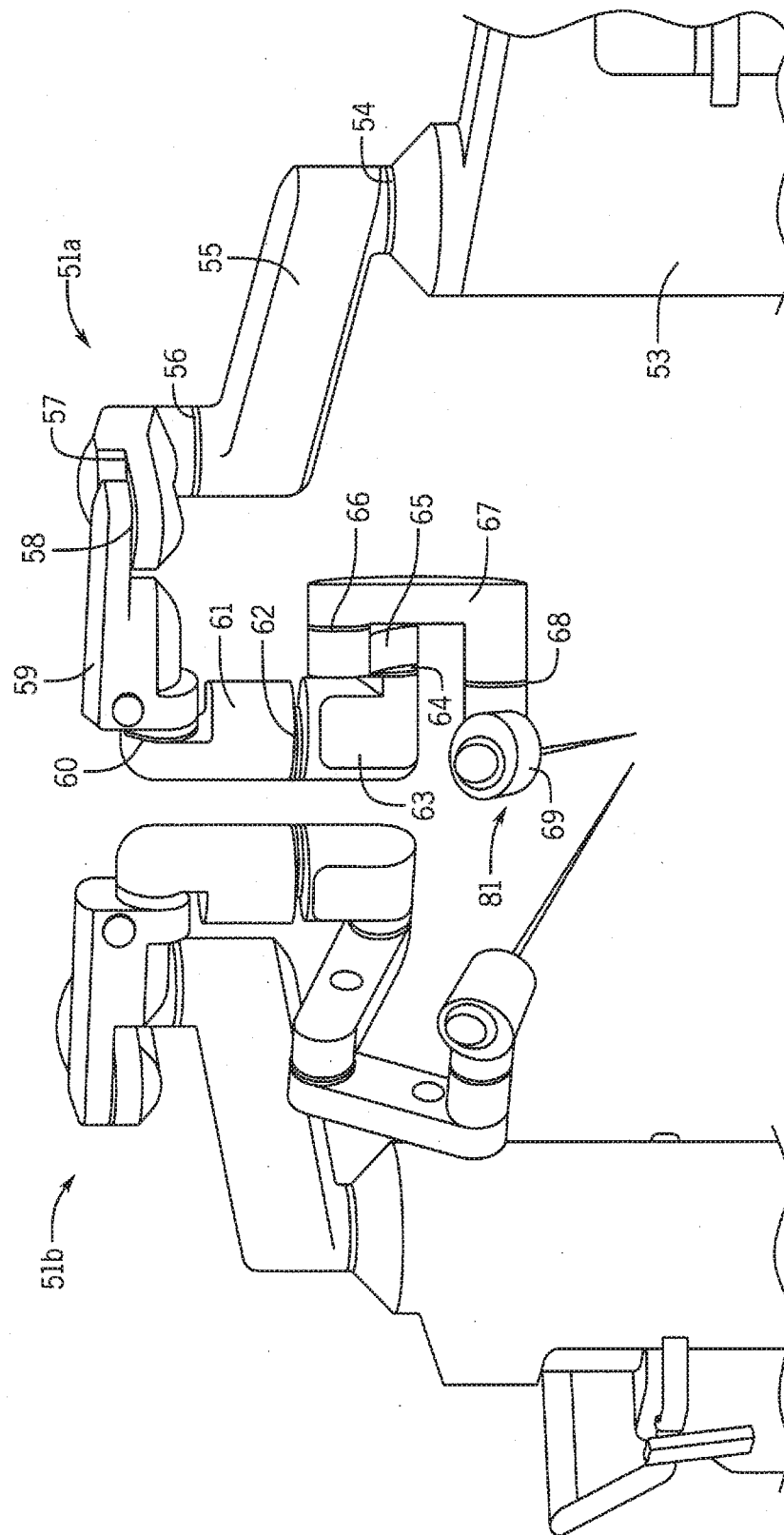


FIG. 11A



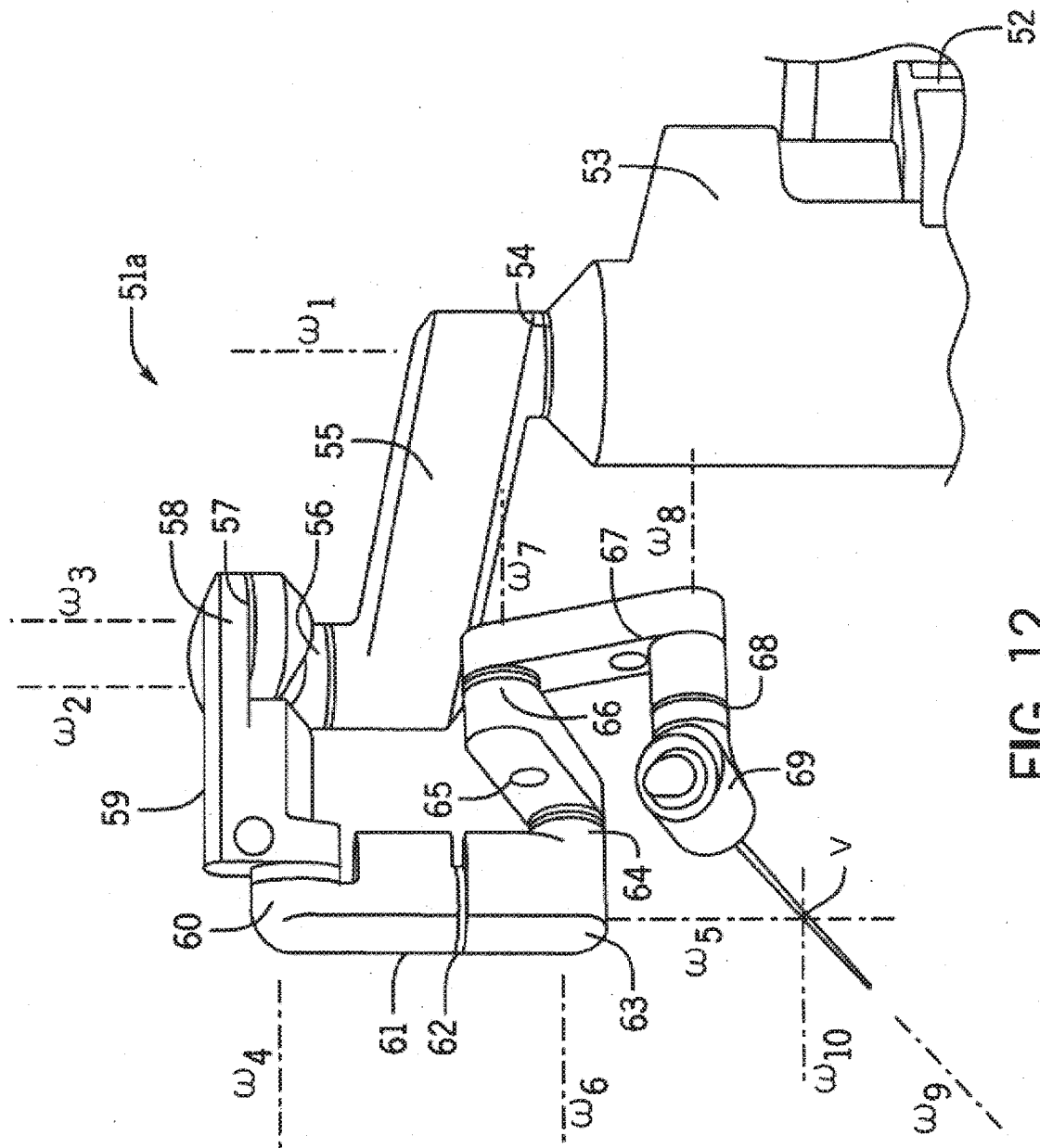


FIG. 12

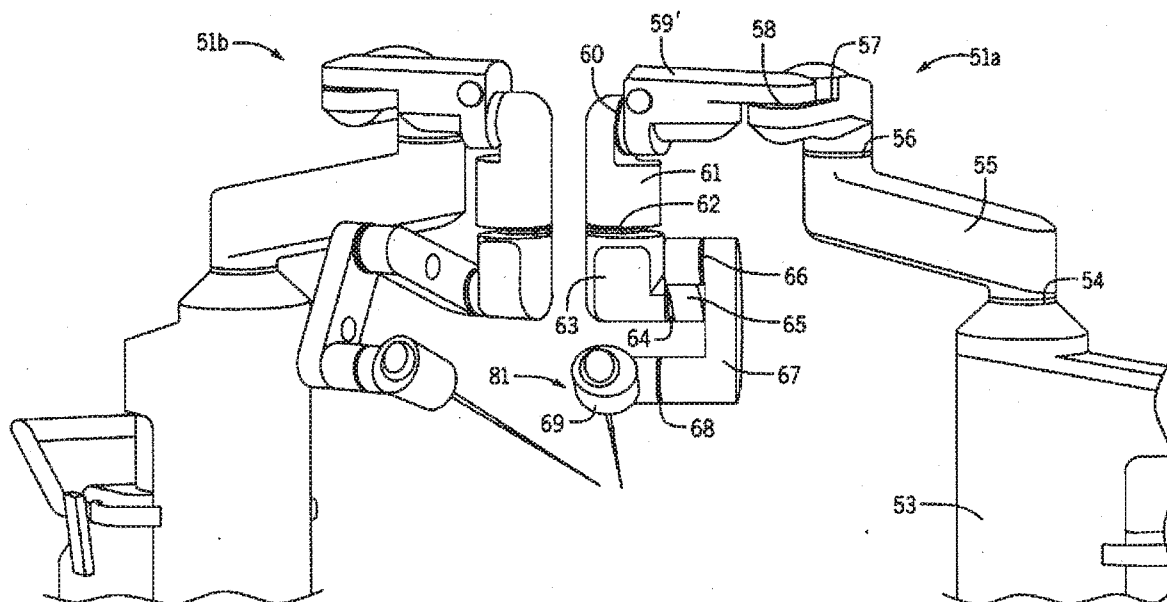
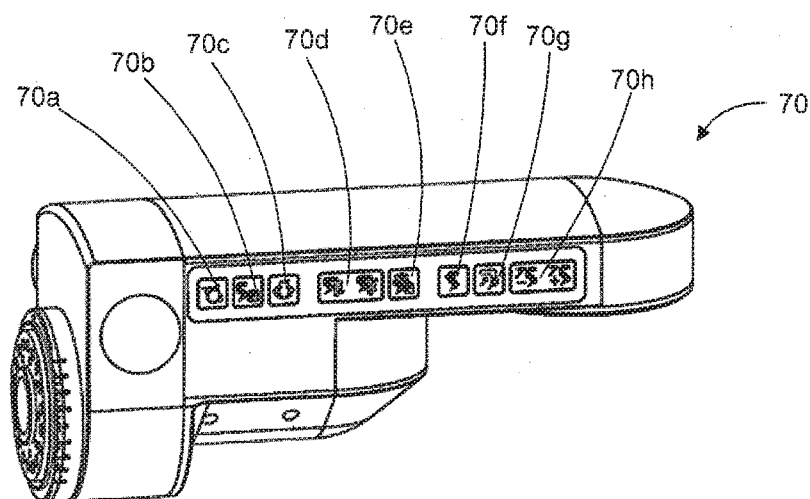


FIG. 13A

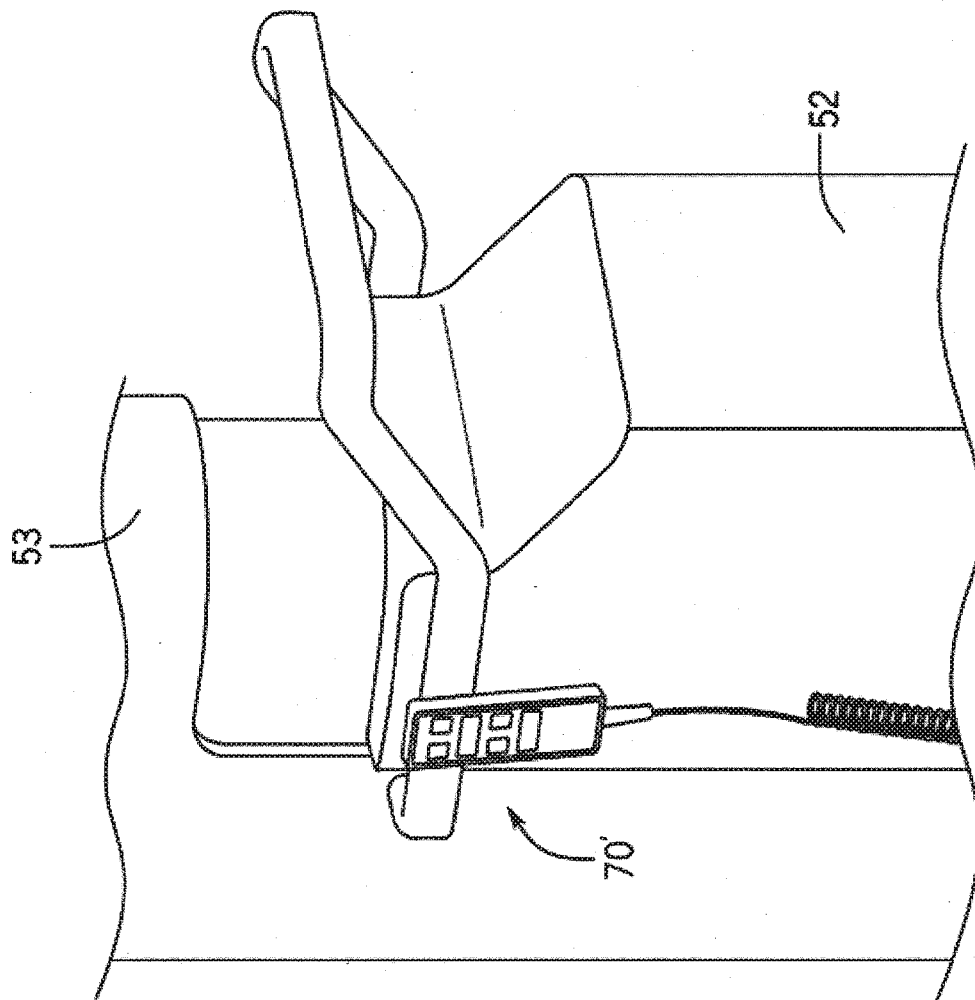


FIG. 13B

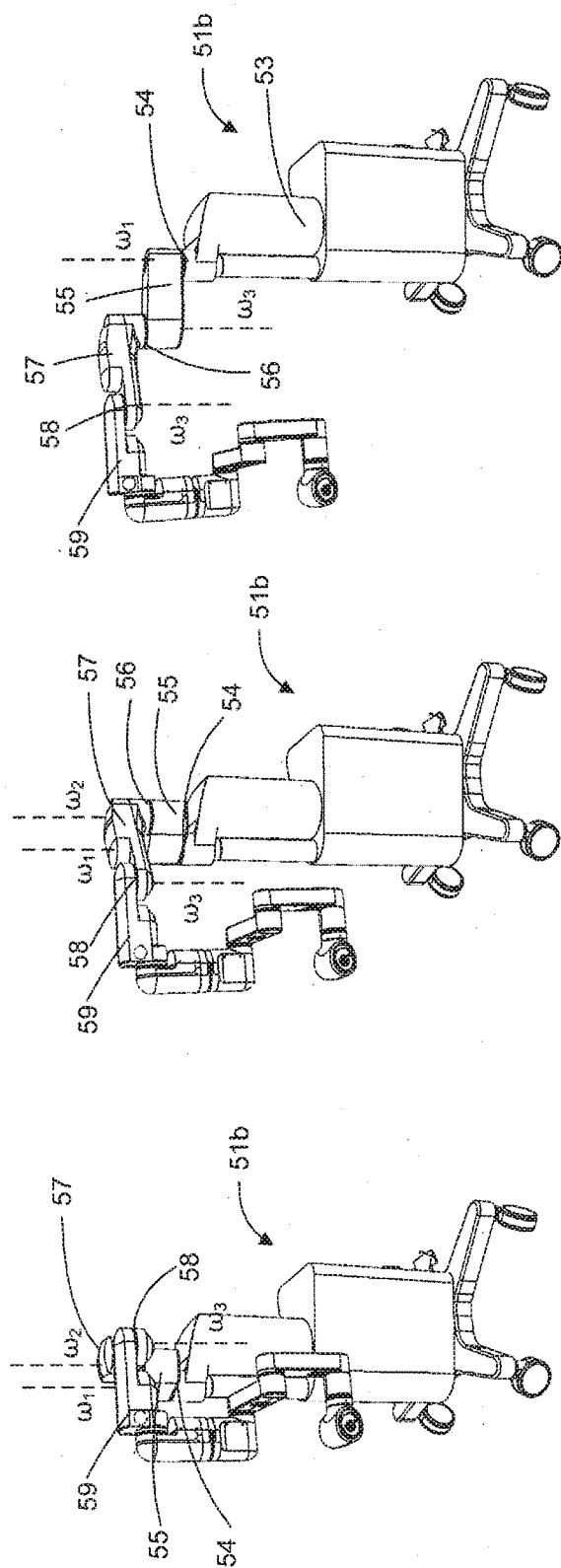


FIG. 14A

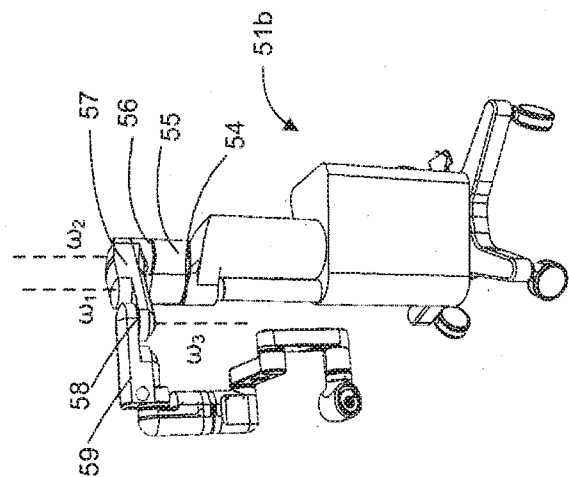


FIG. 14B

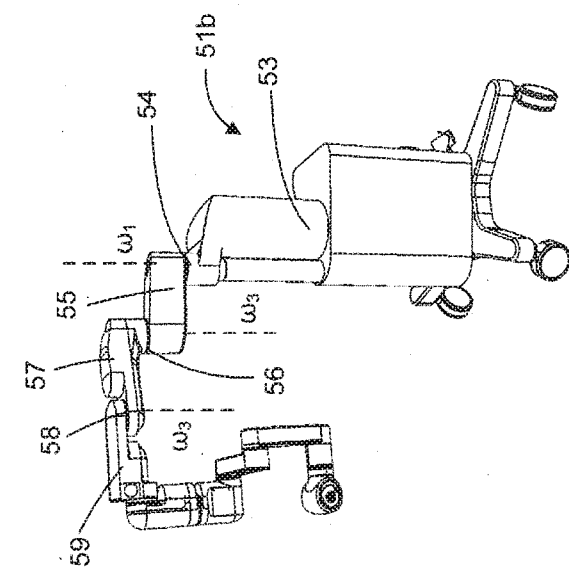


FIG. 14C

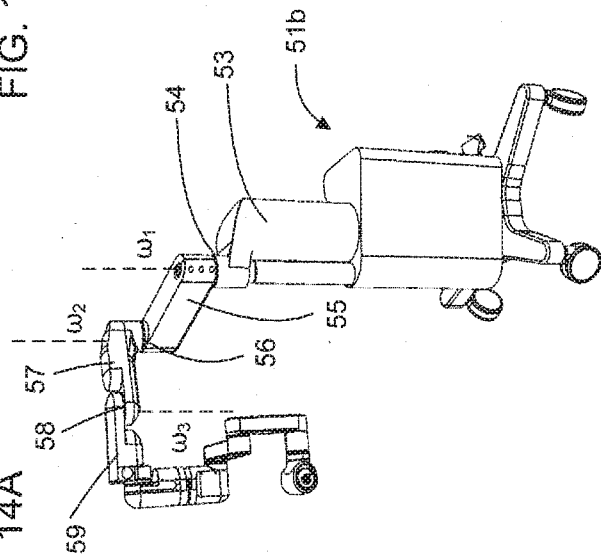


FIG. 14D

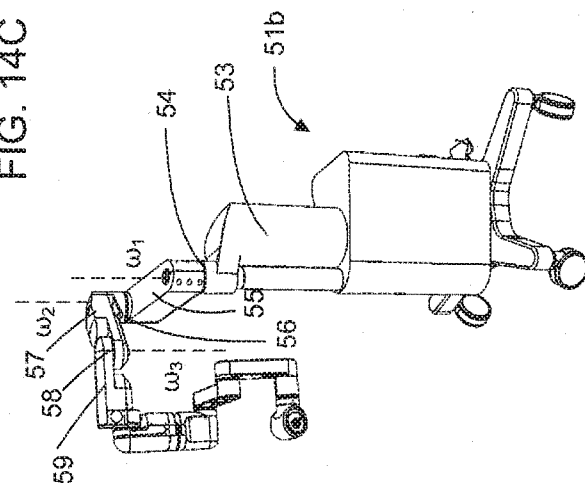


FIG. 14E

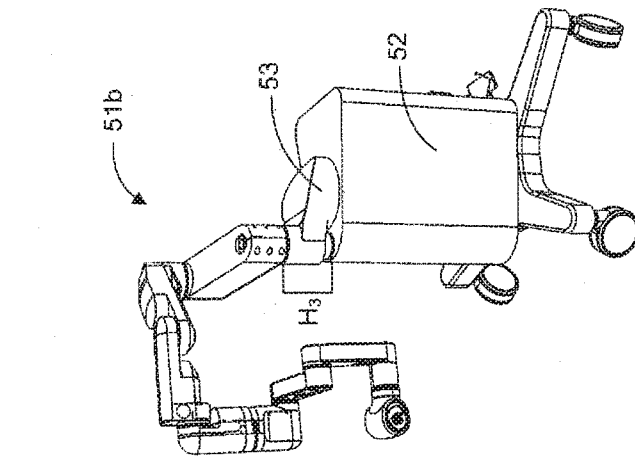


FIG. 15A

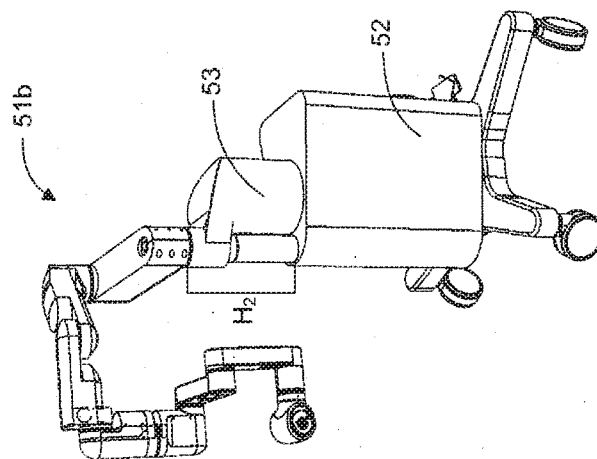


FIG. 15B

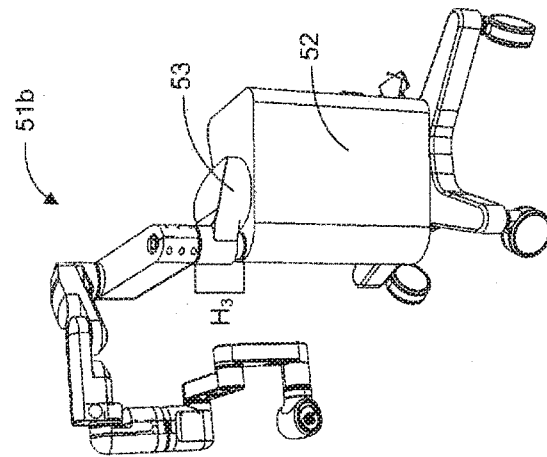


FIG. 15C

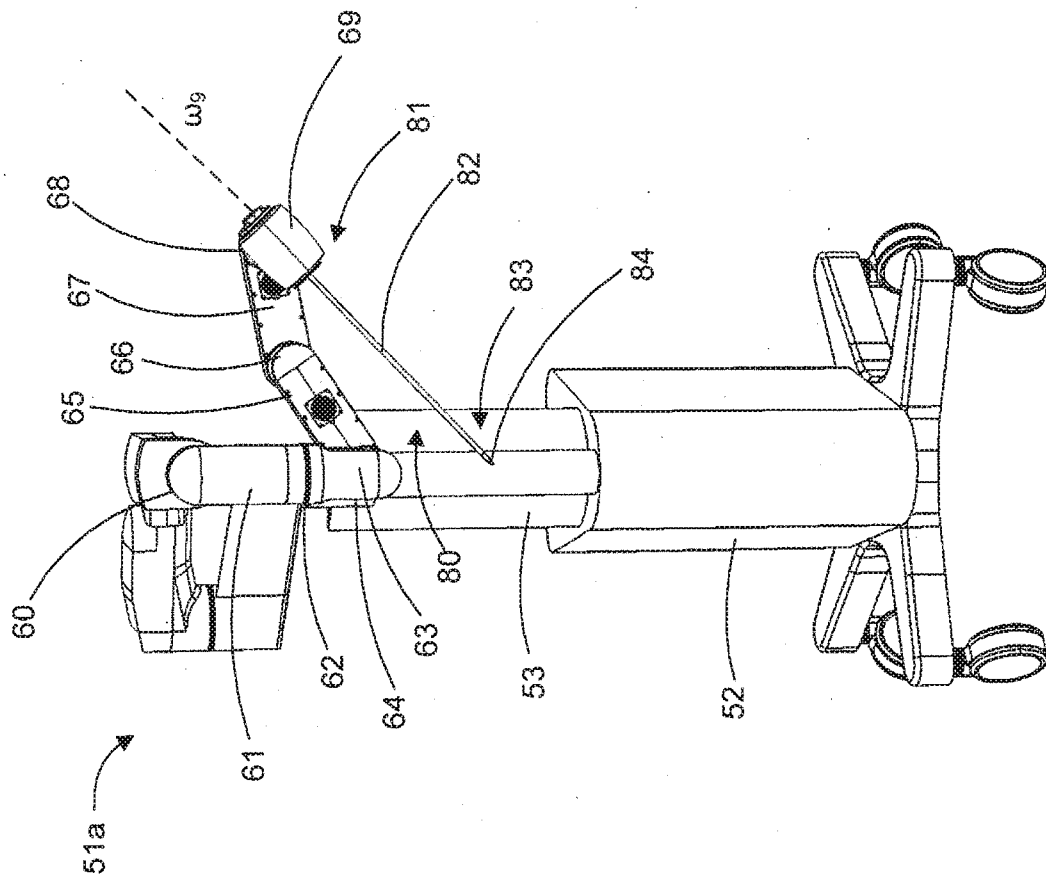
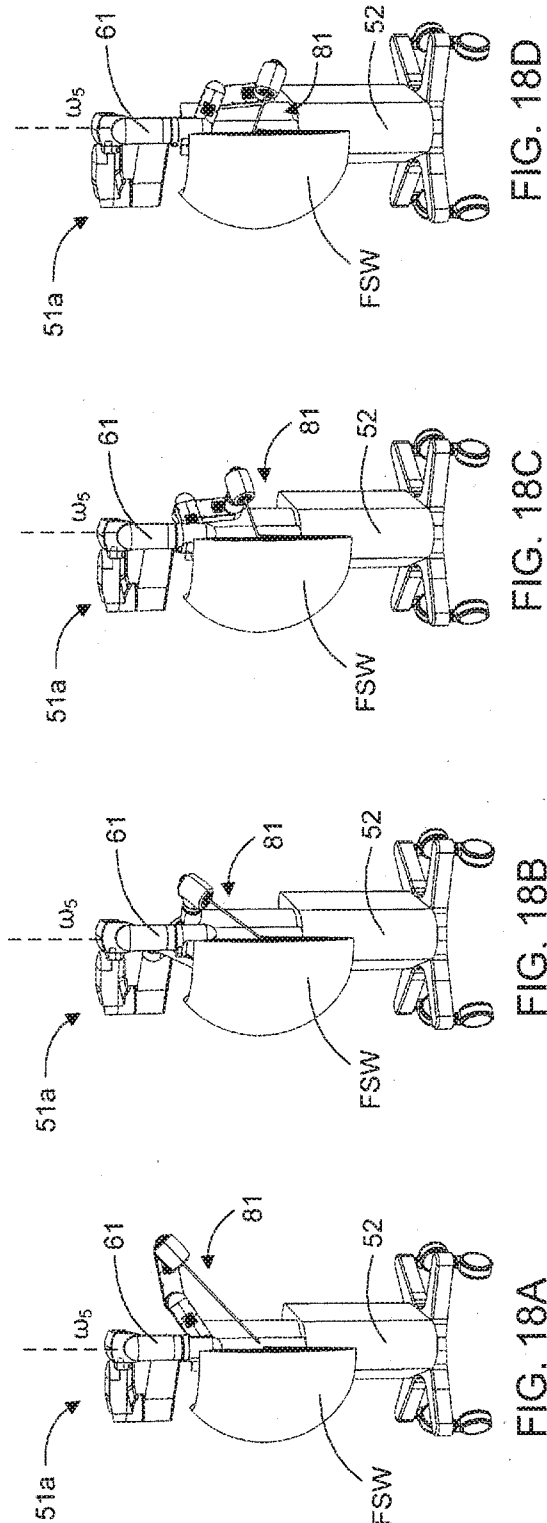
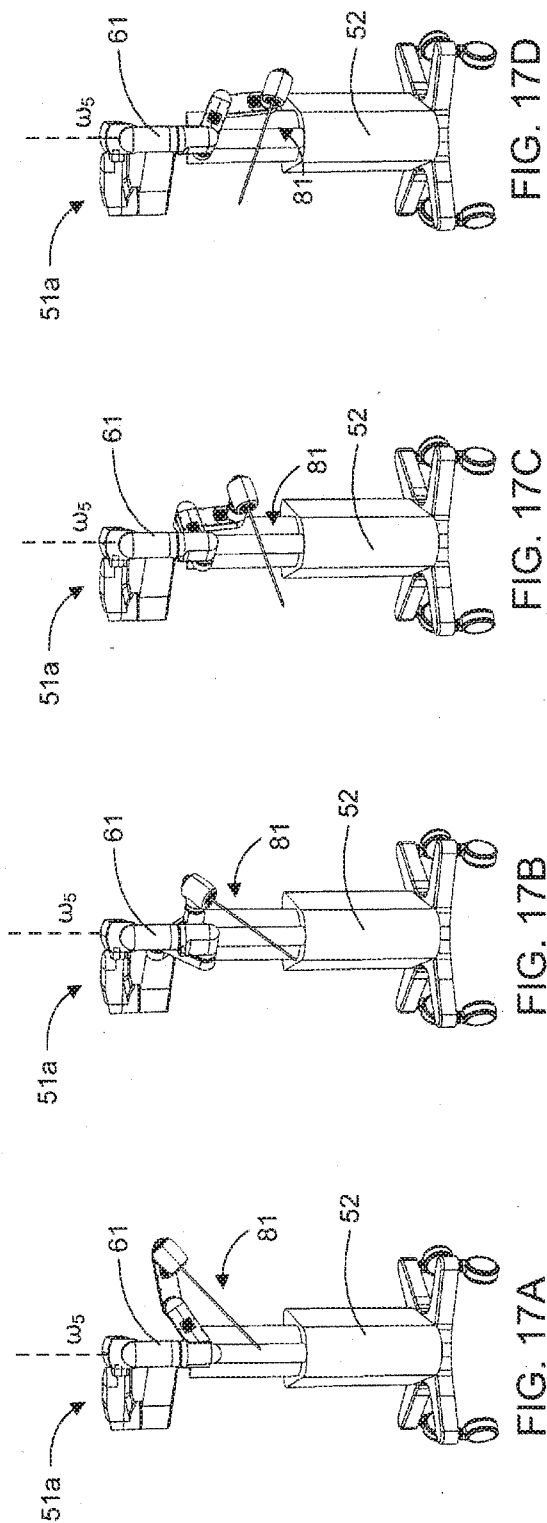


FIG. 16



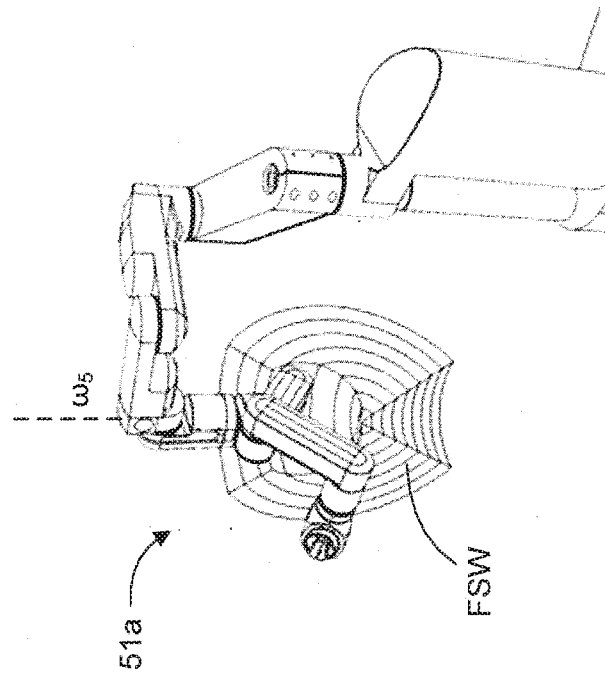
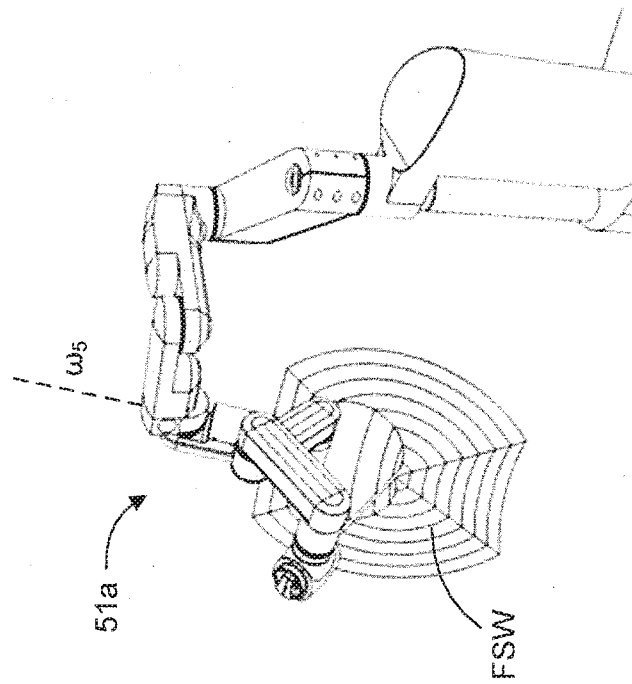
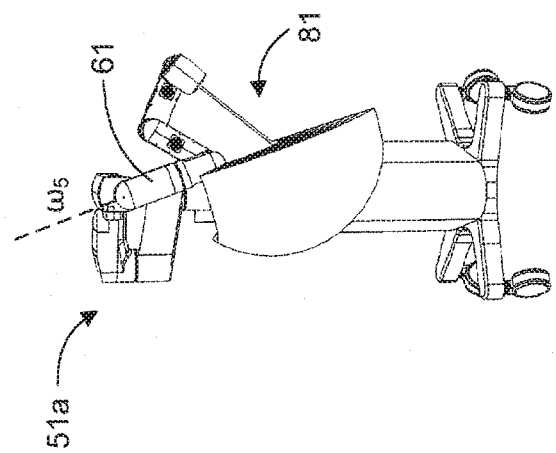
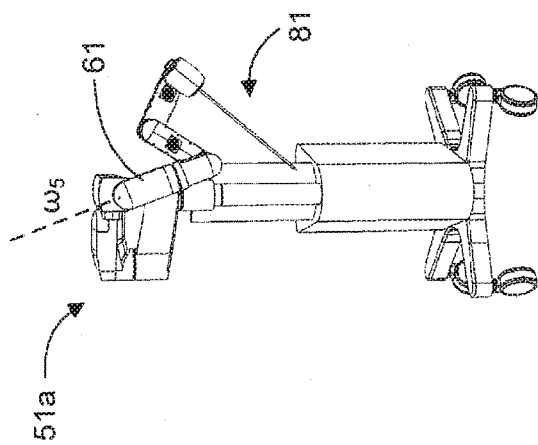


FIG. 18E



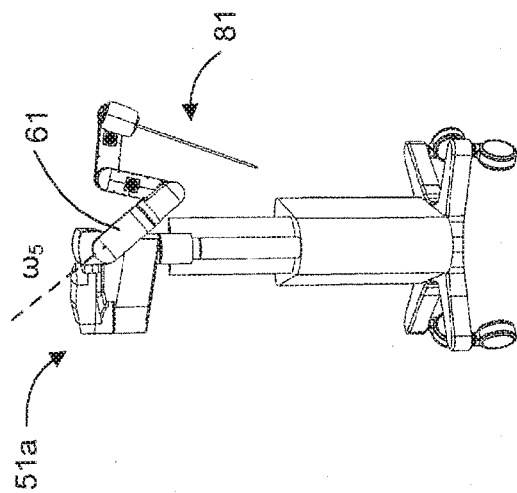


FIG. 20A

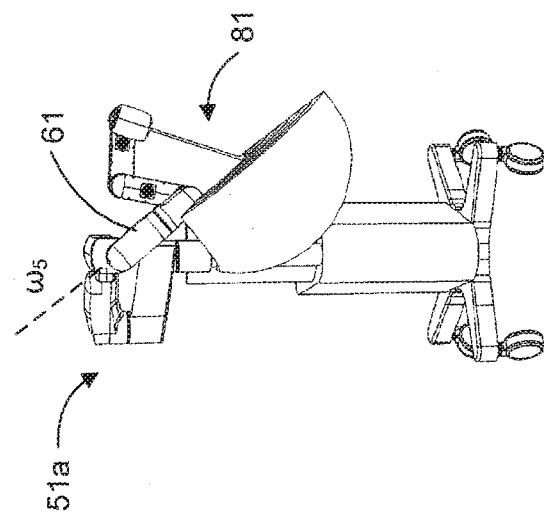


FIG. 20B

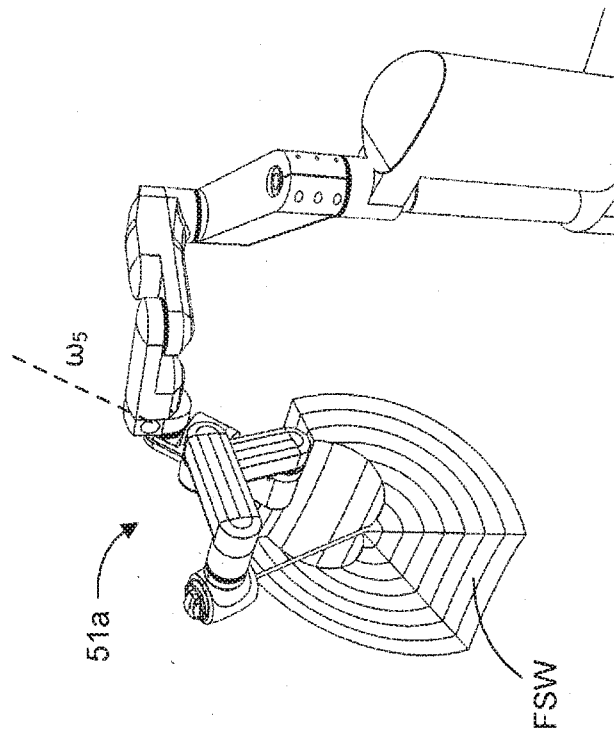


FIG. 20C

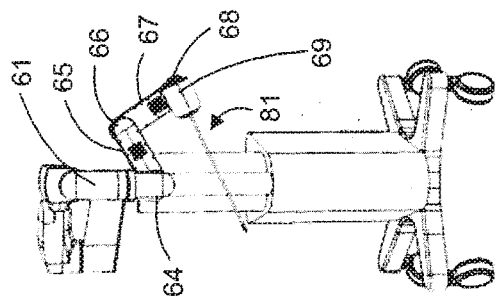


FIG. 21A

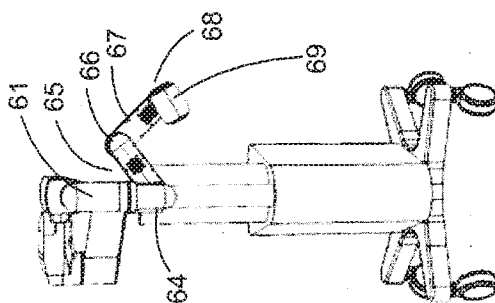


FIG. 21B

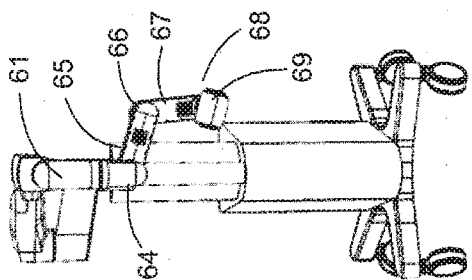


FIG. 21C

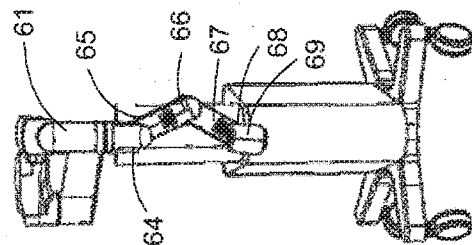


FIG. 21D

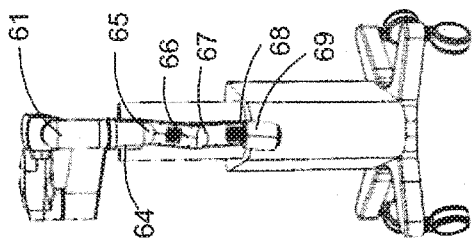


FIG. 21E

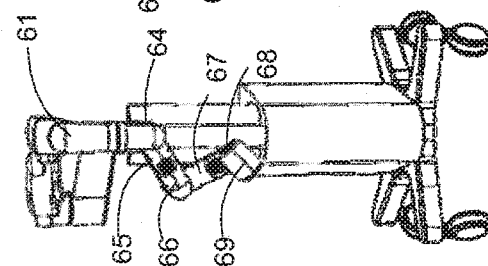


FIG. 21F

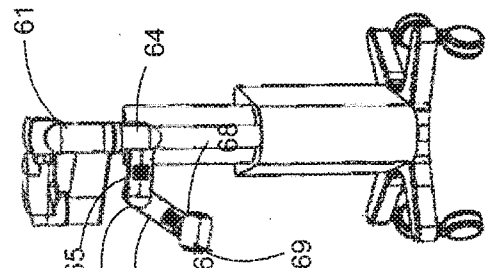


FIG. 21G

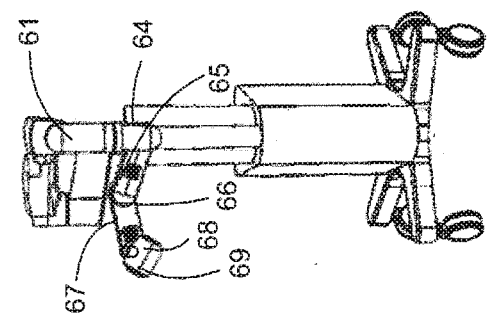


FIG. 21H

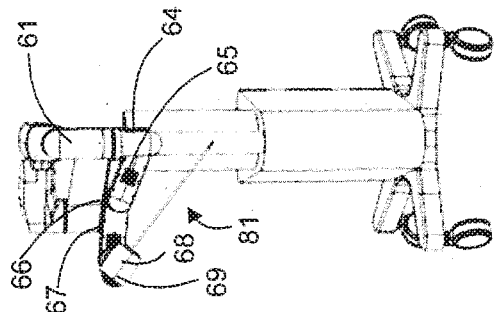


FIG. 21I

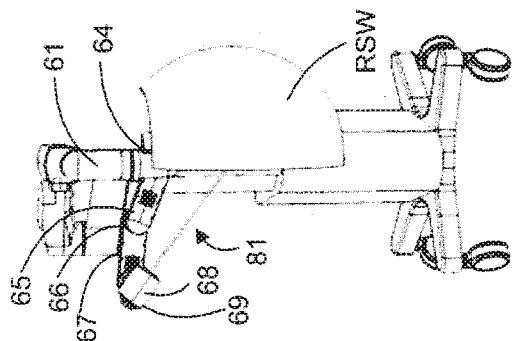


FIG. 21J

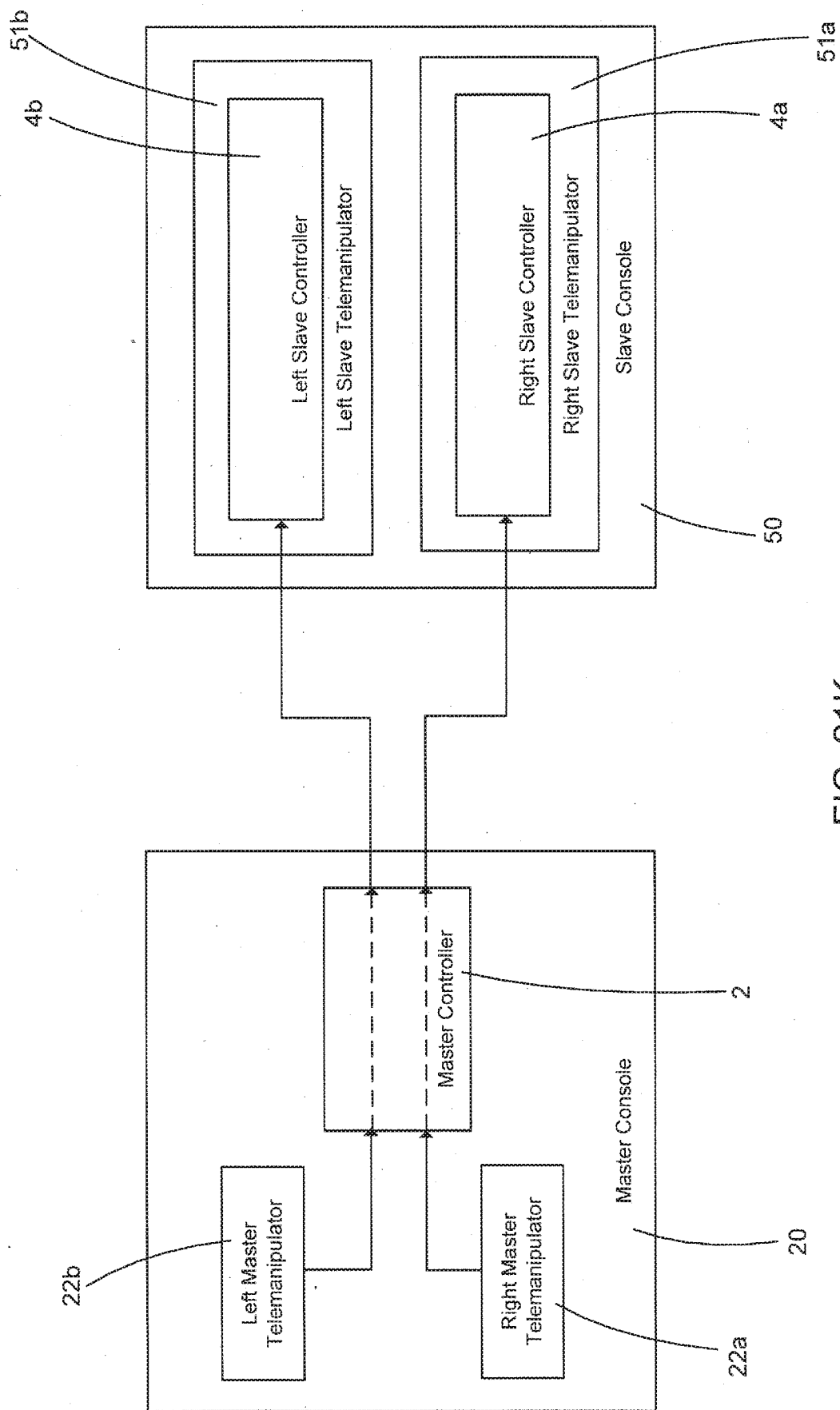
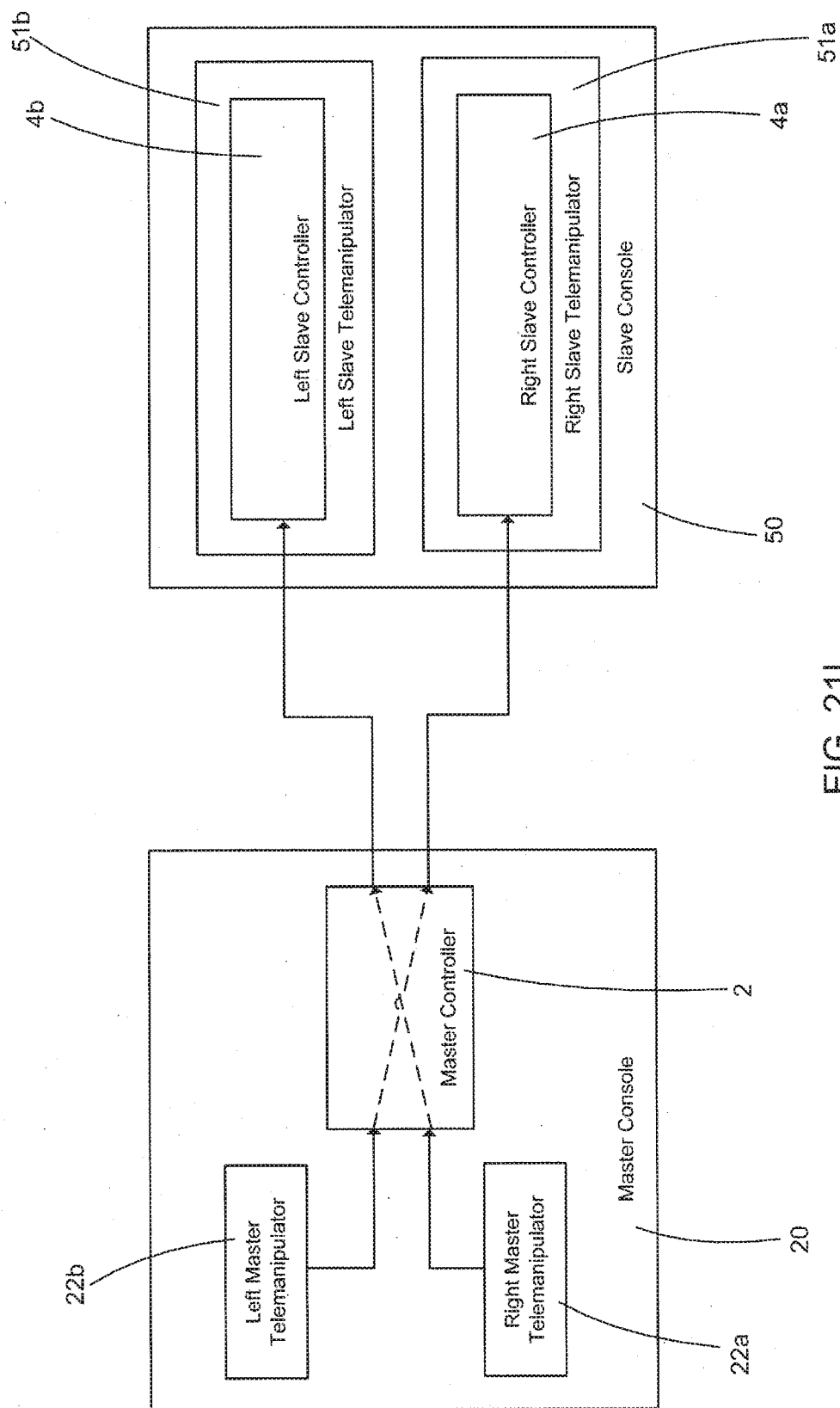
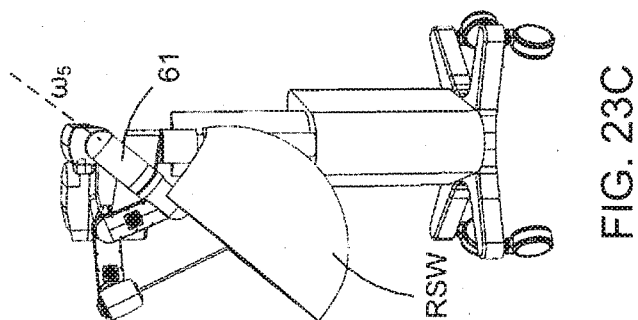
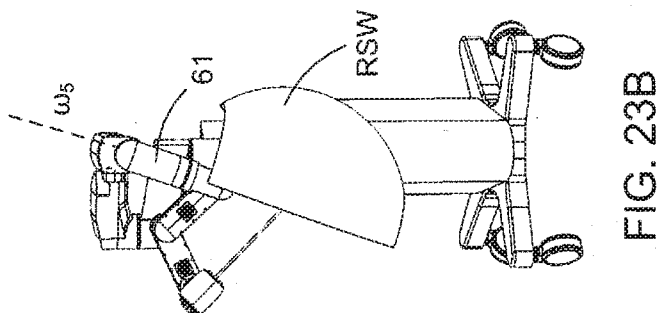
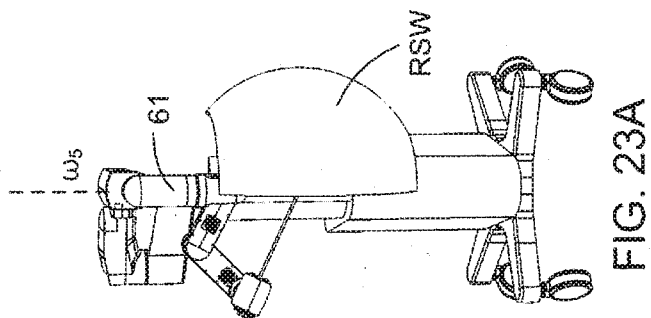
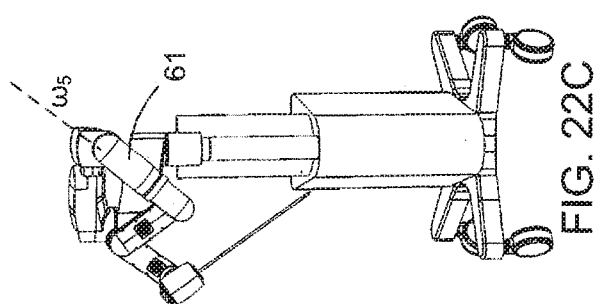
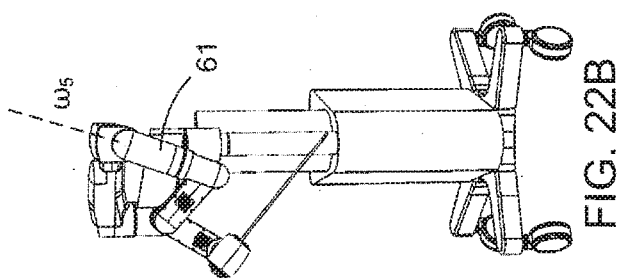
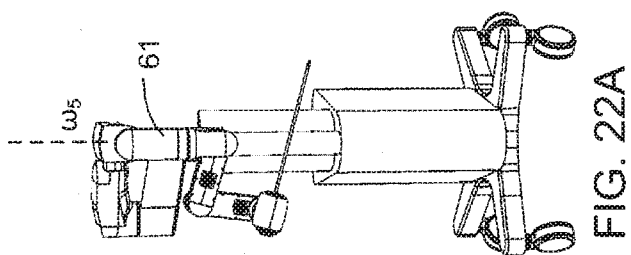


FIG. 21K





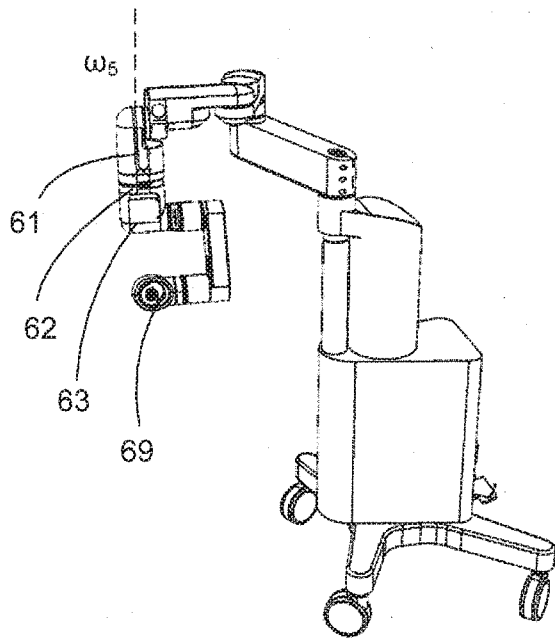


FIG. 24A

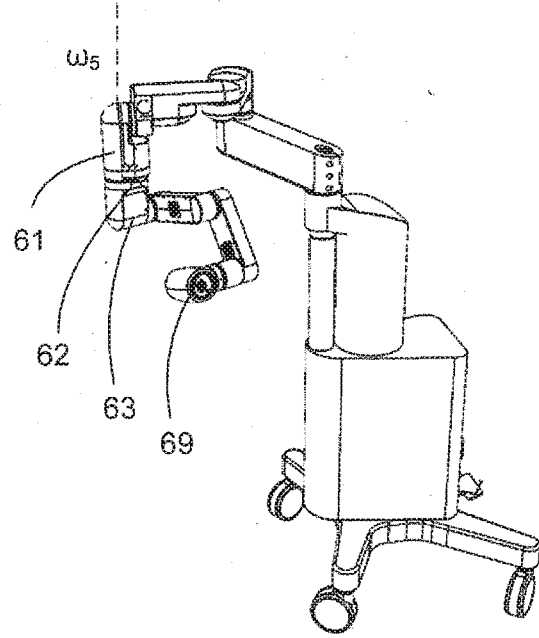


FIG. 24B

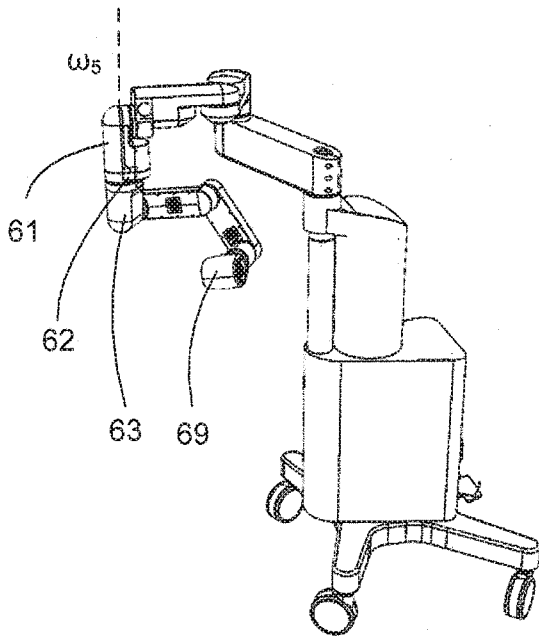


FIG. 24C

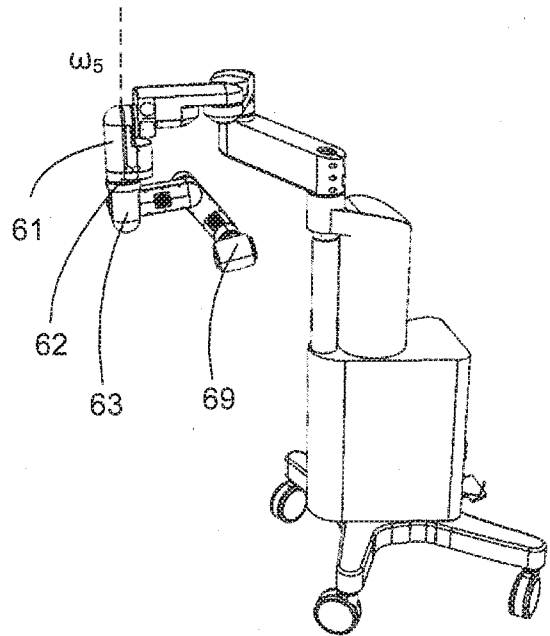


FIG. 24D

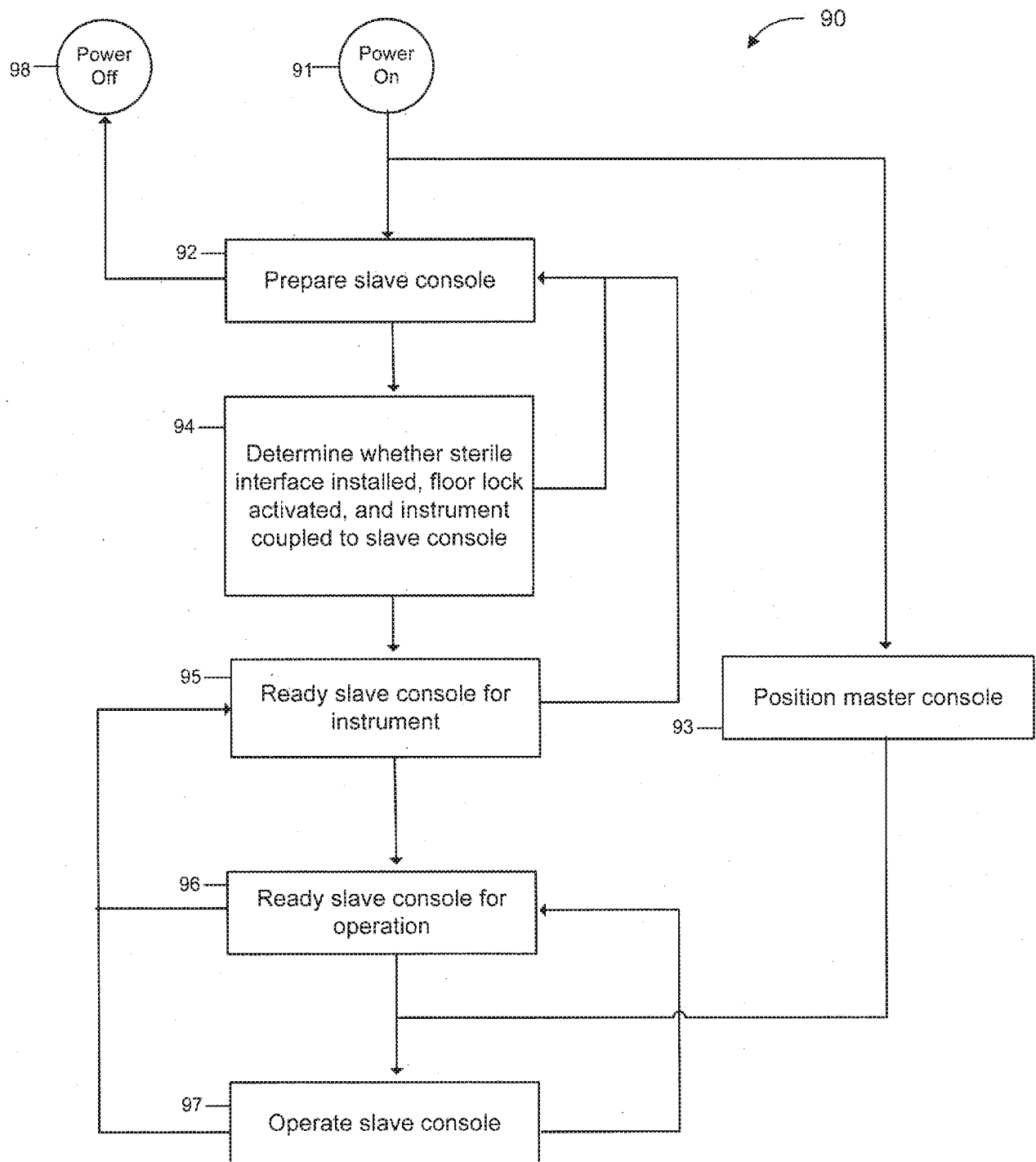


FIG. 25

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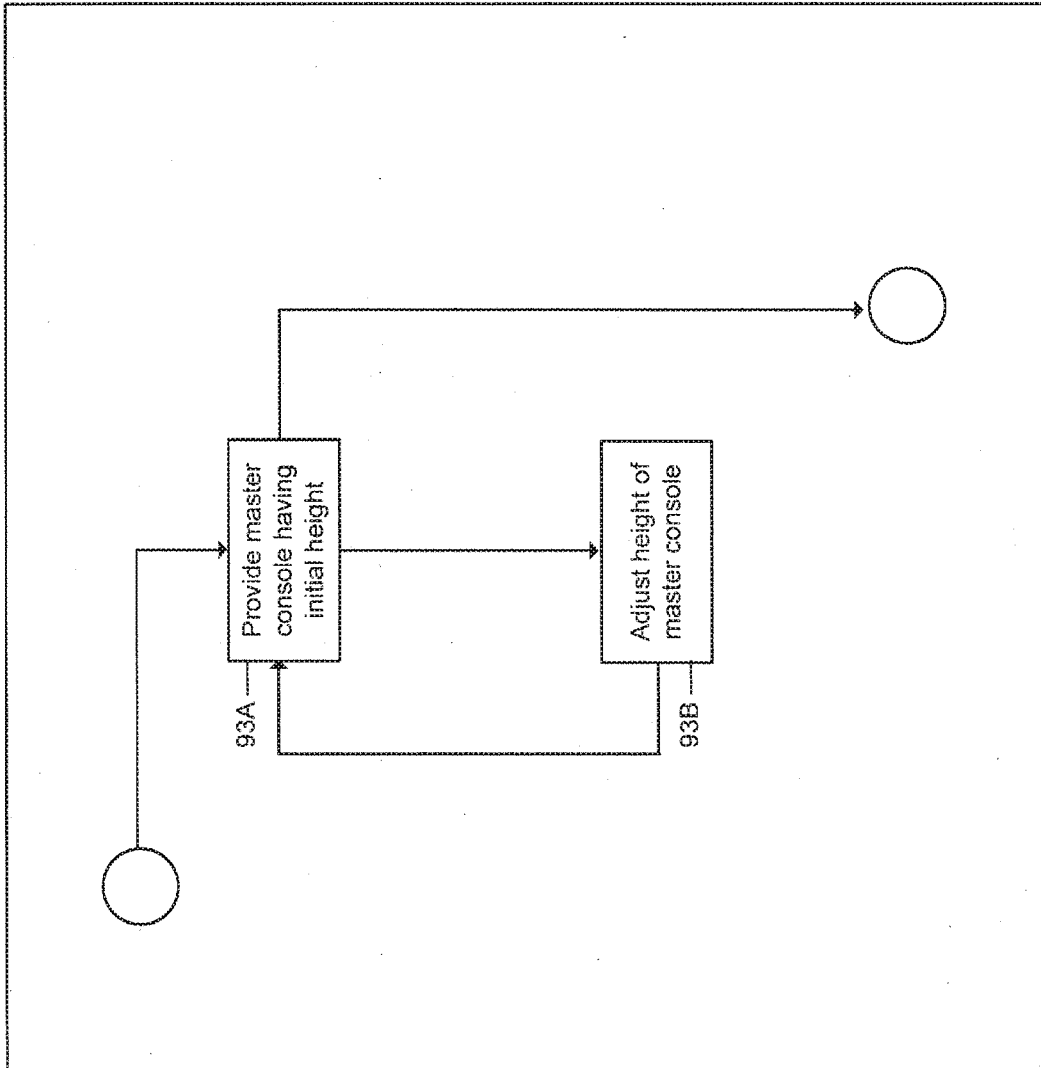
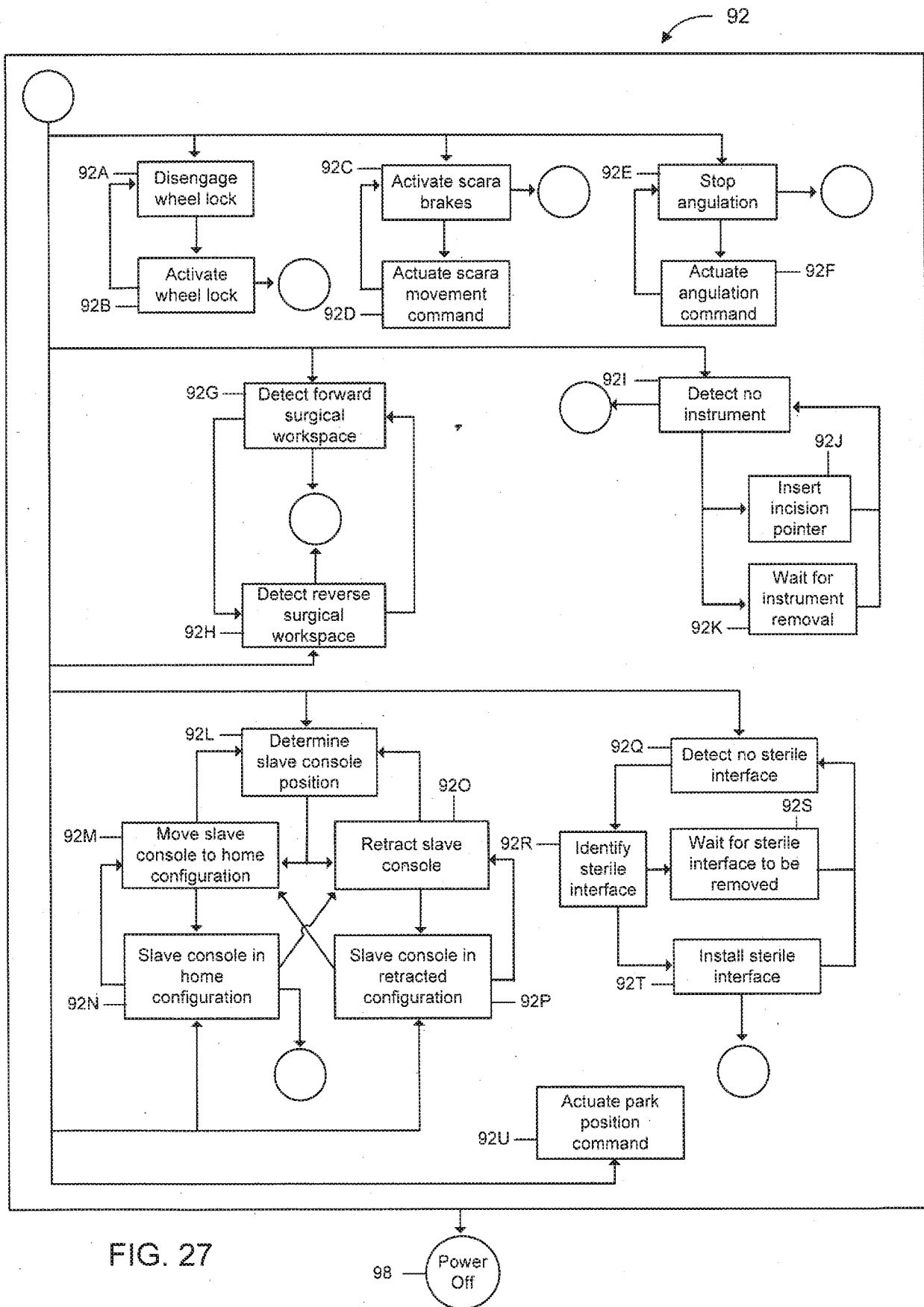


FIG. 26



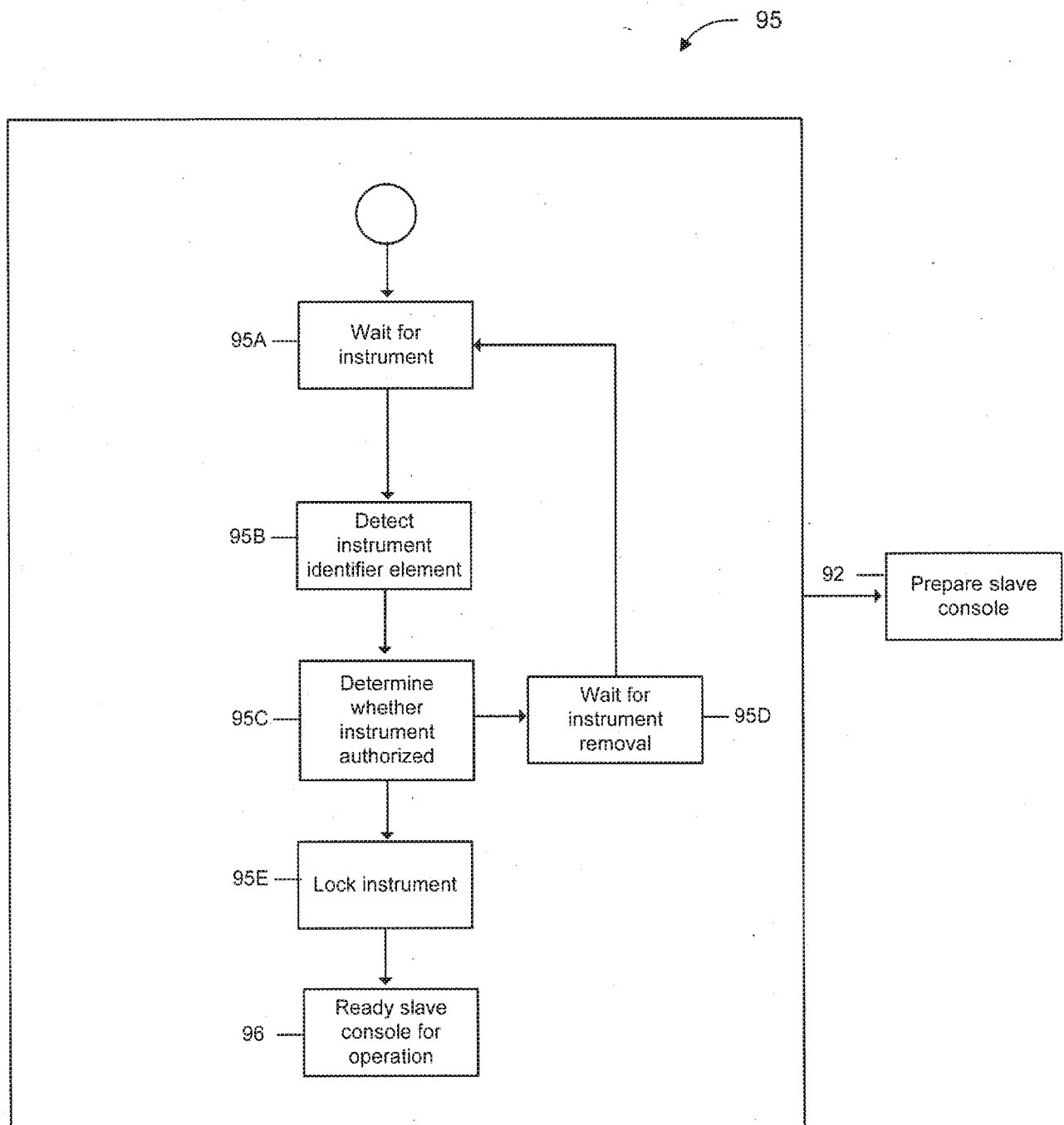


FIG. 28

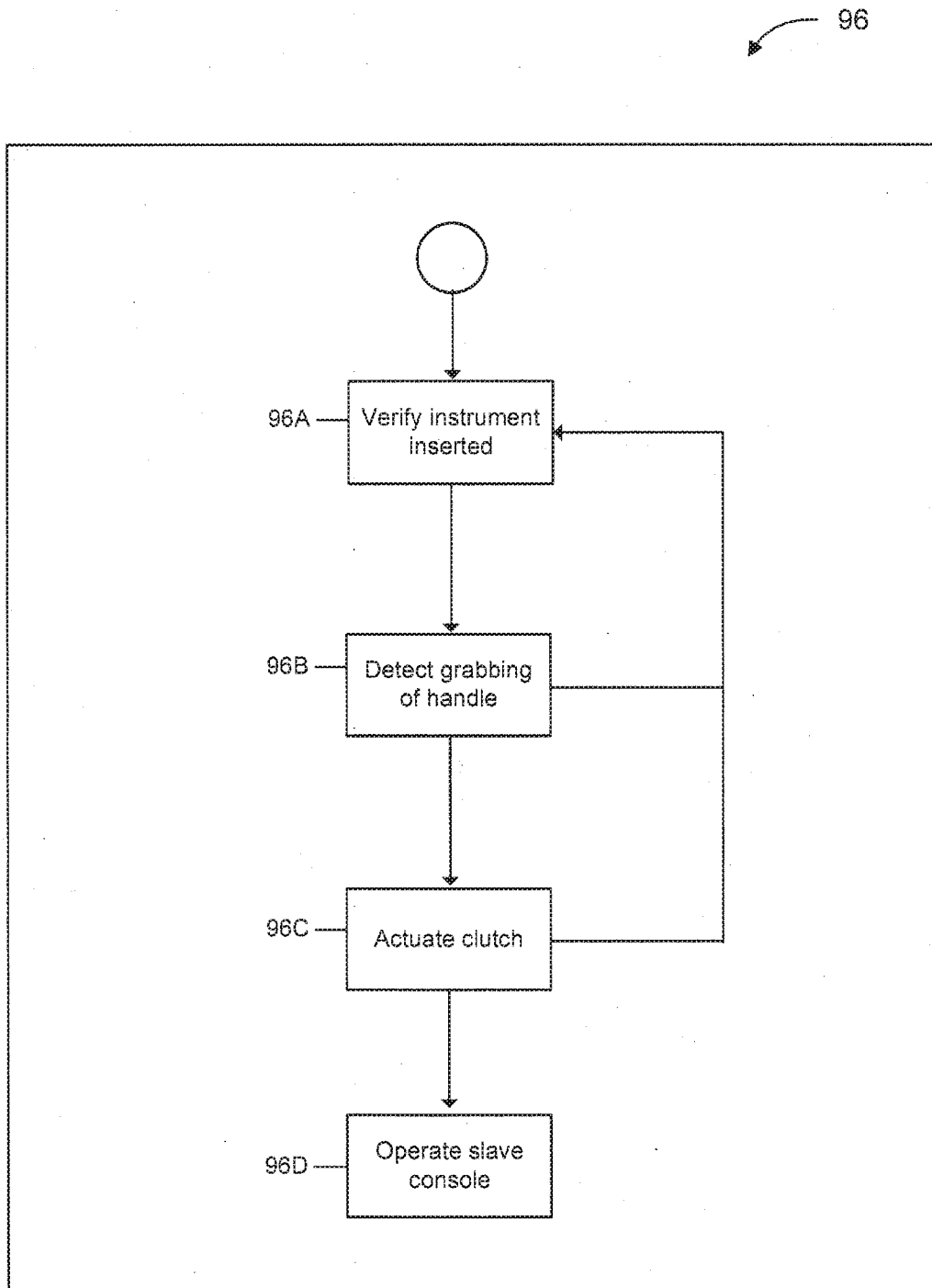


FIG. 29

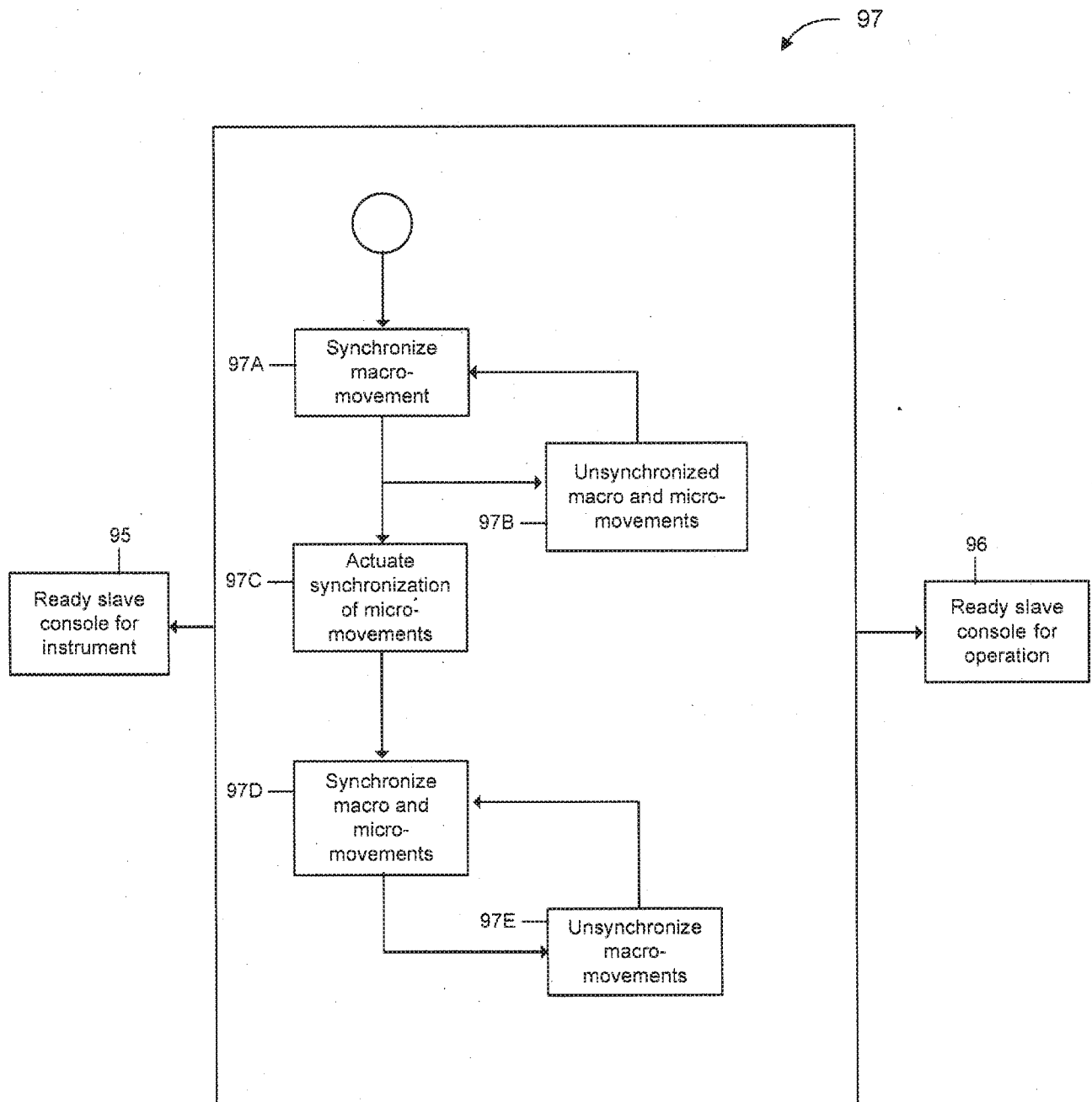
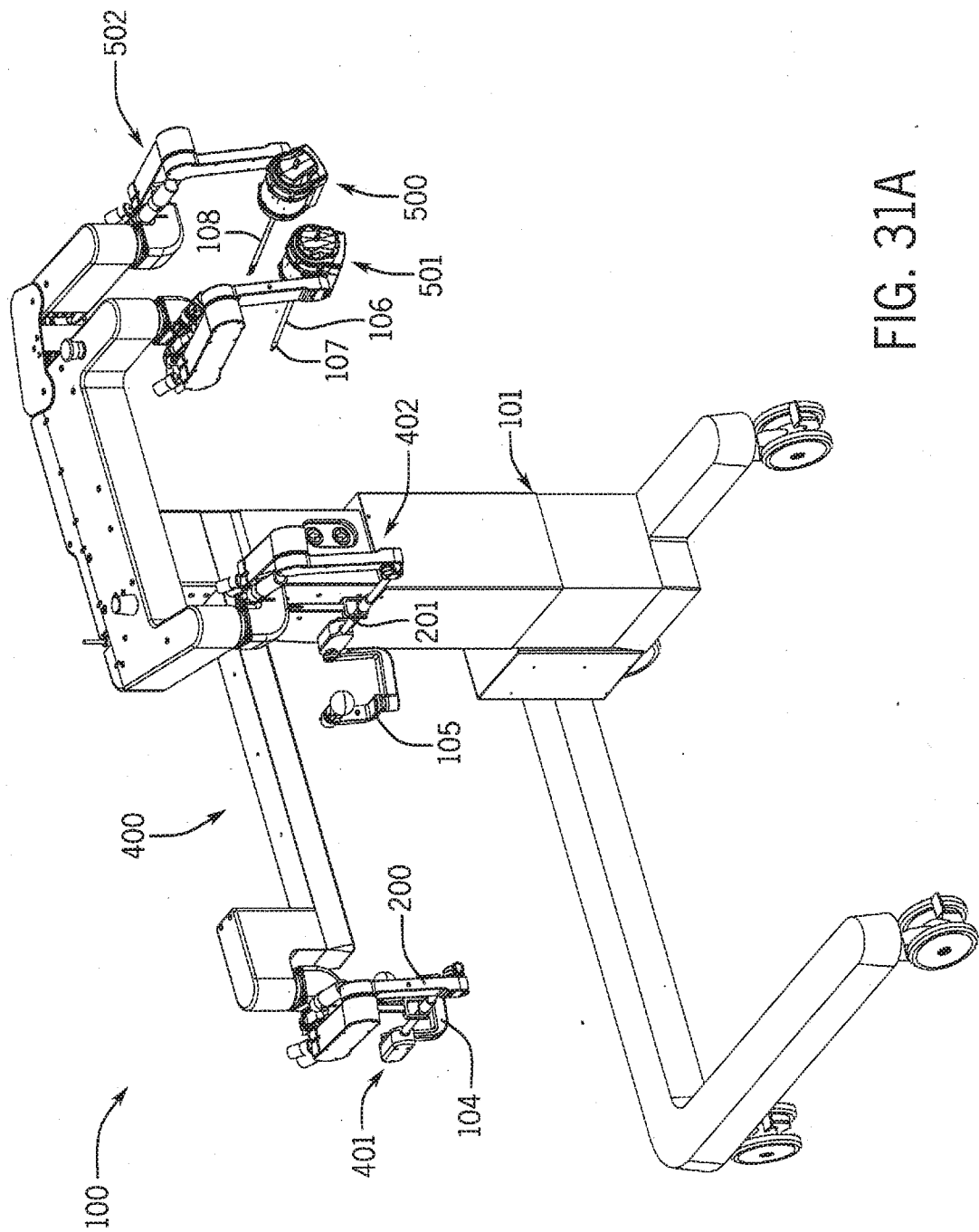


FIG. 30



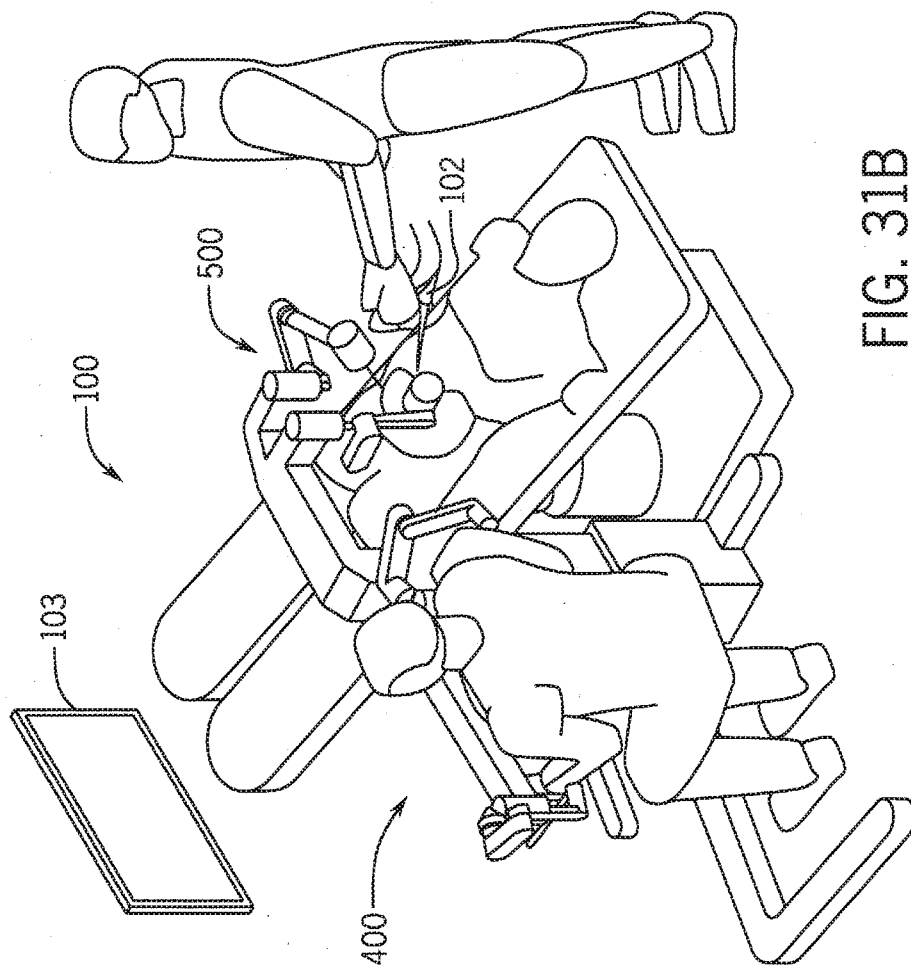
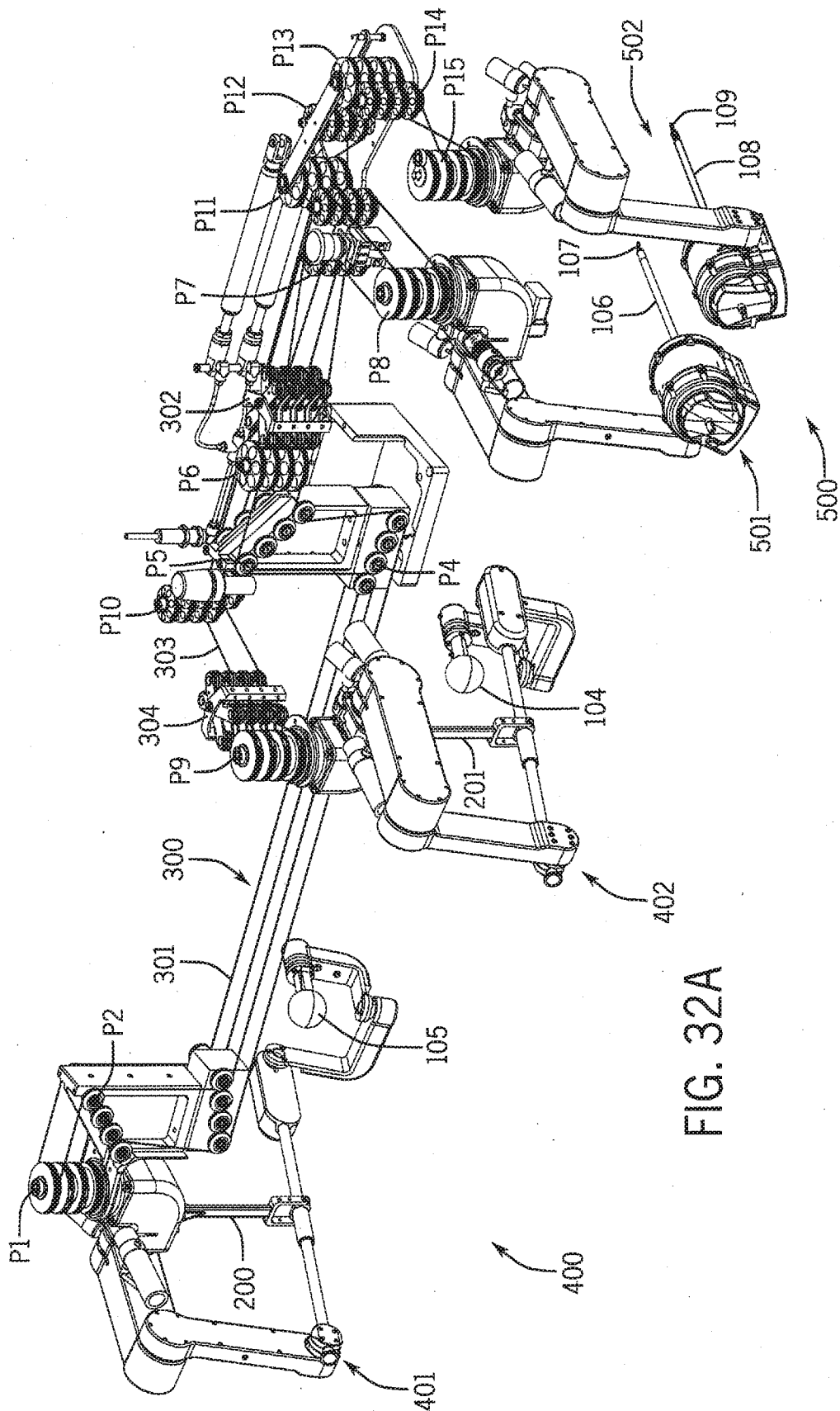
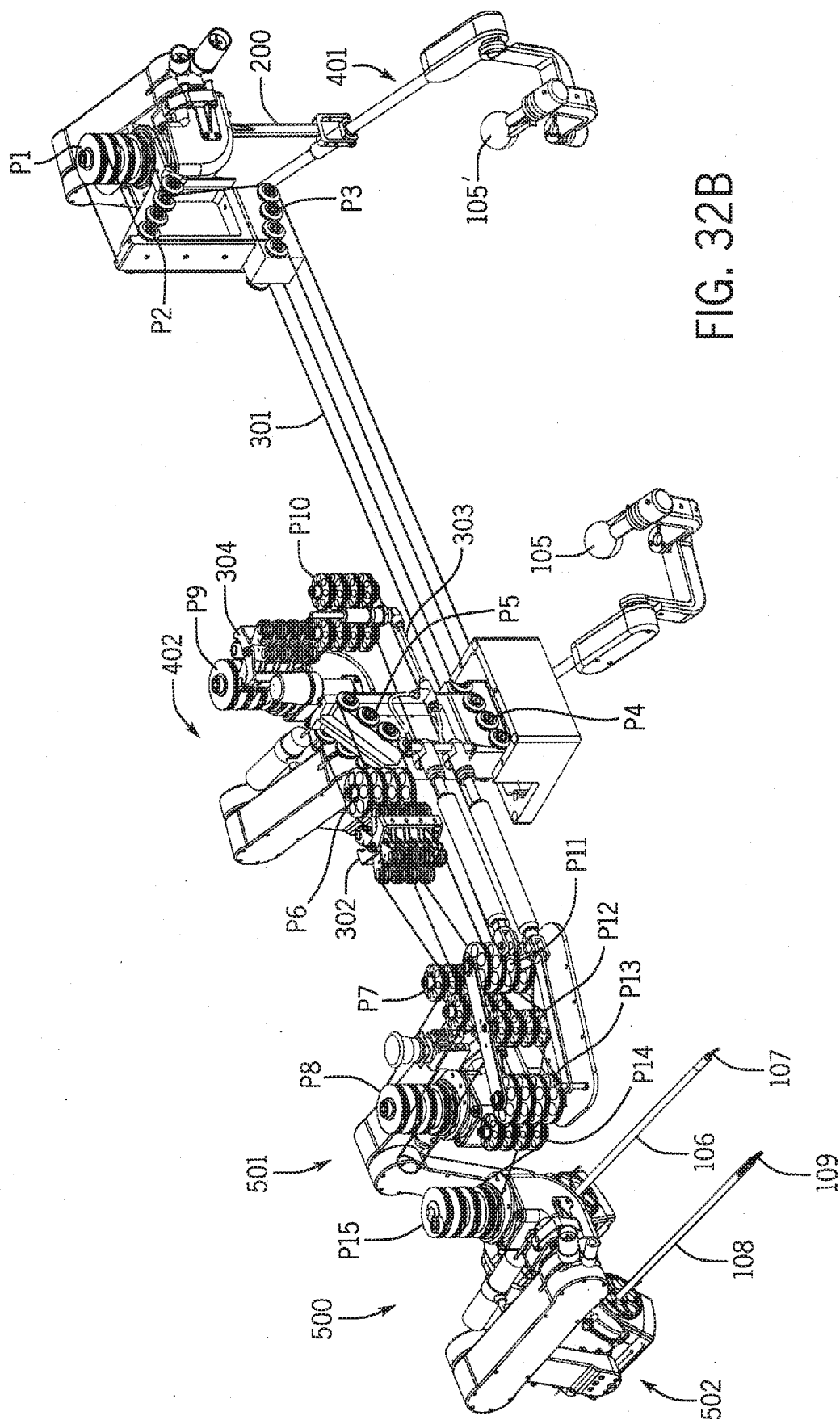


FIG. 31B





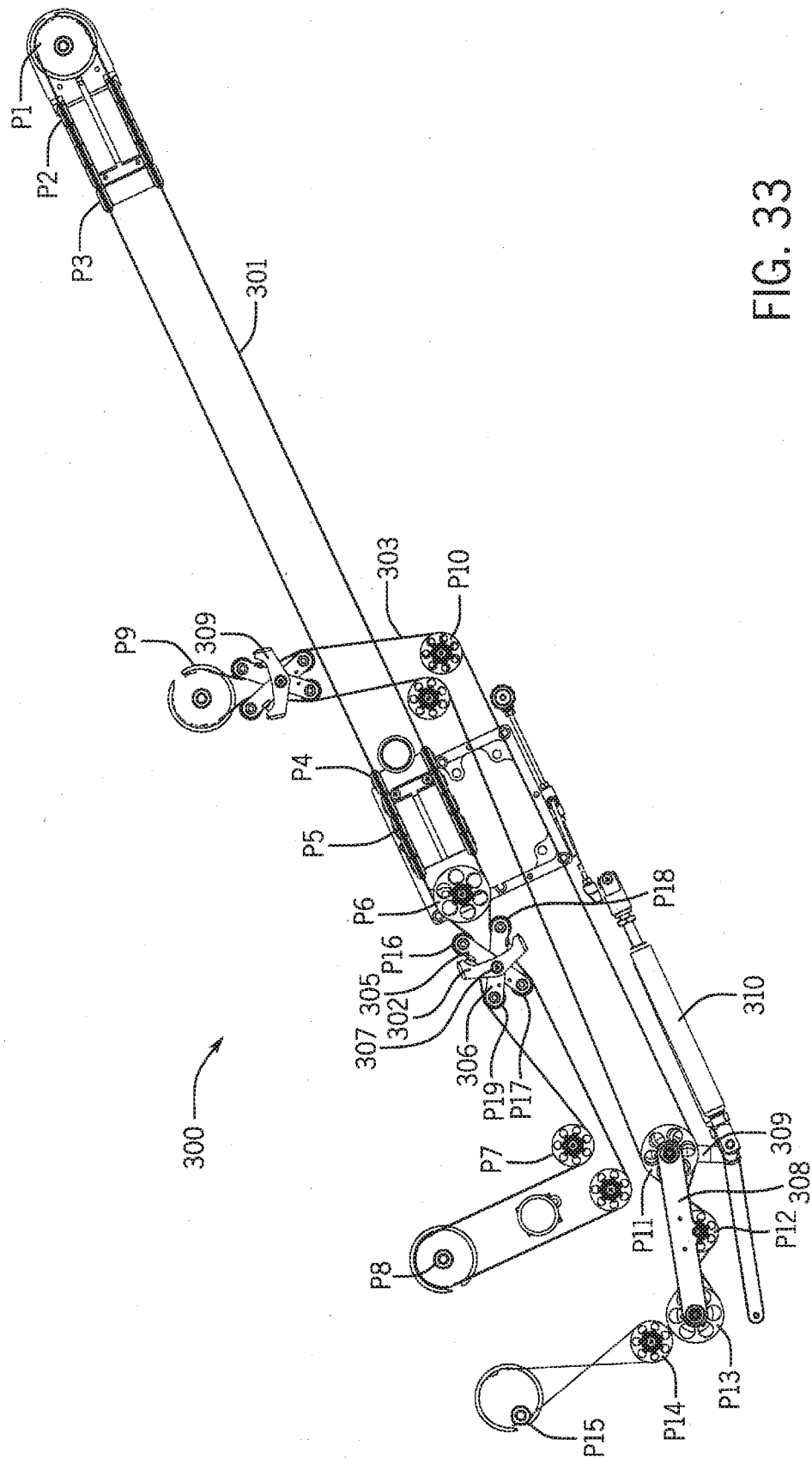
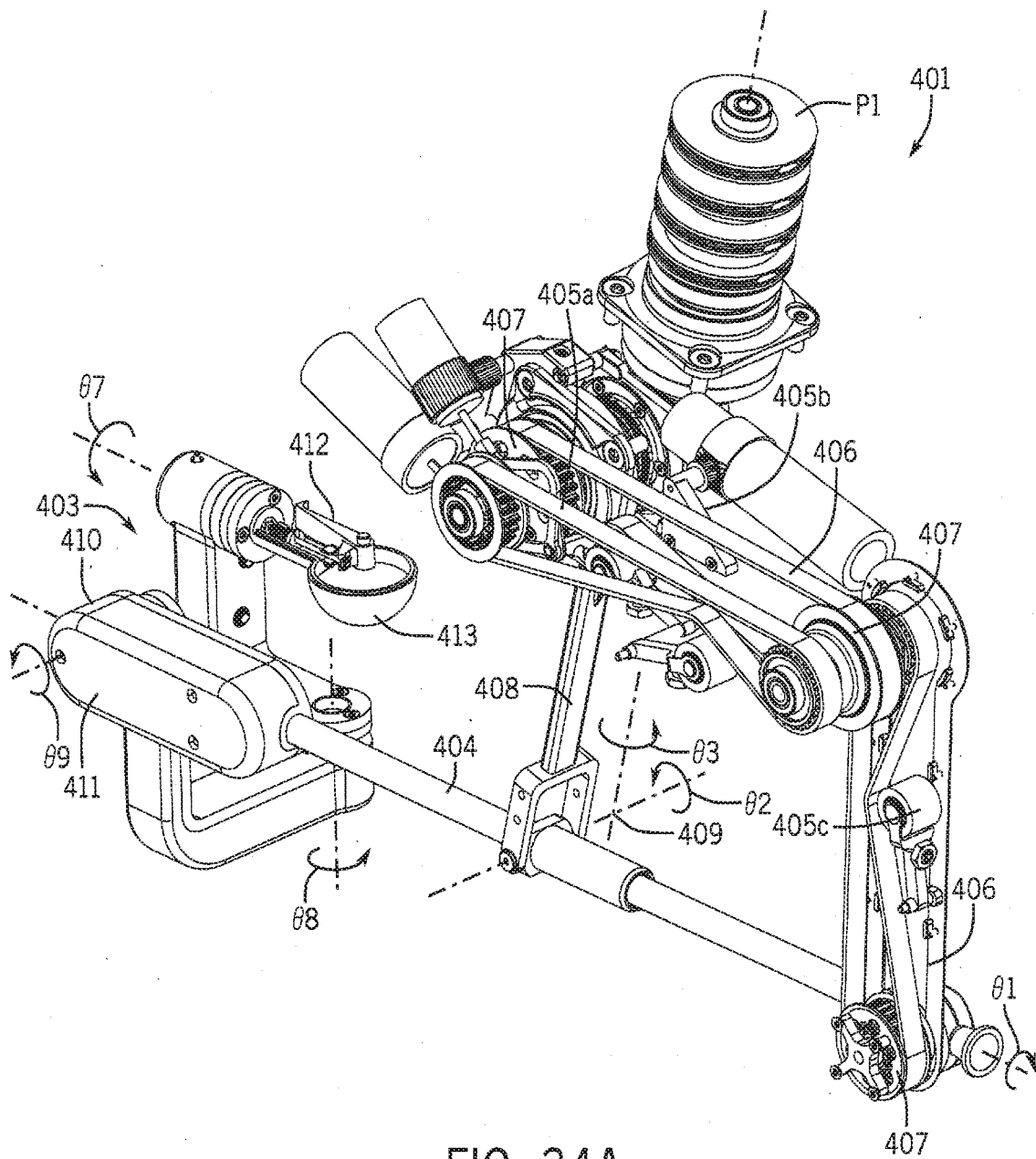
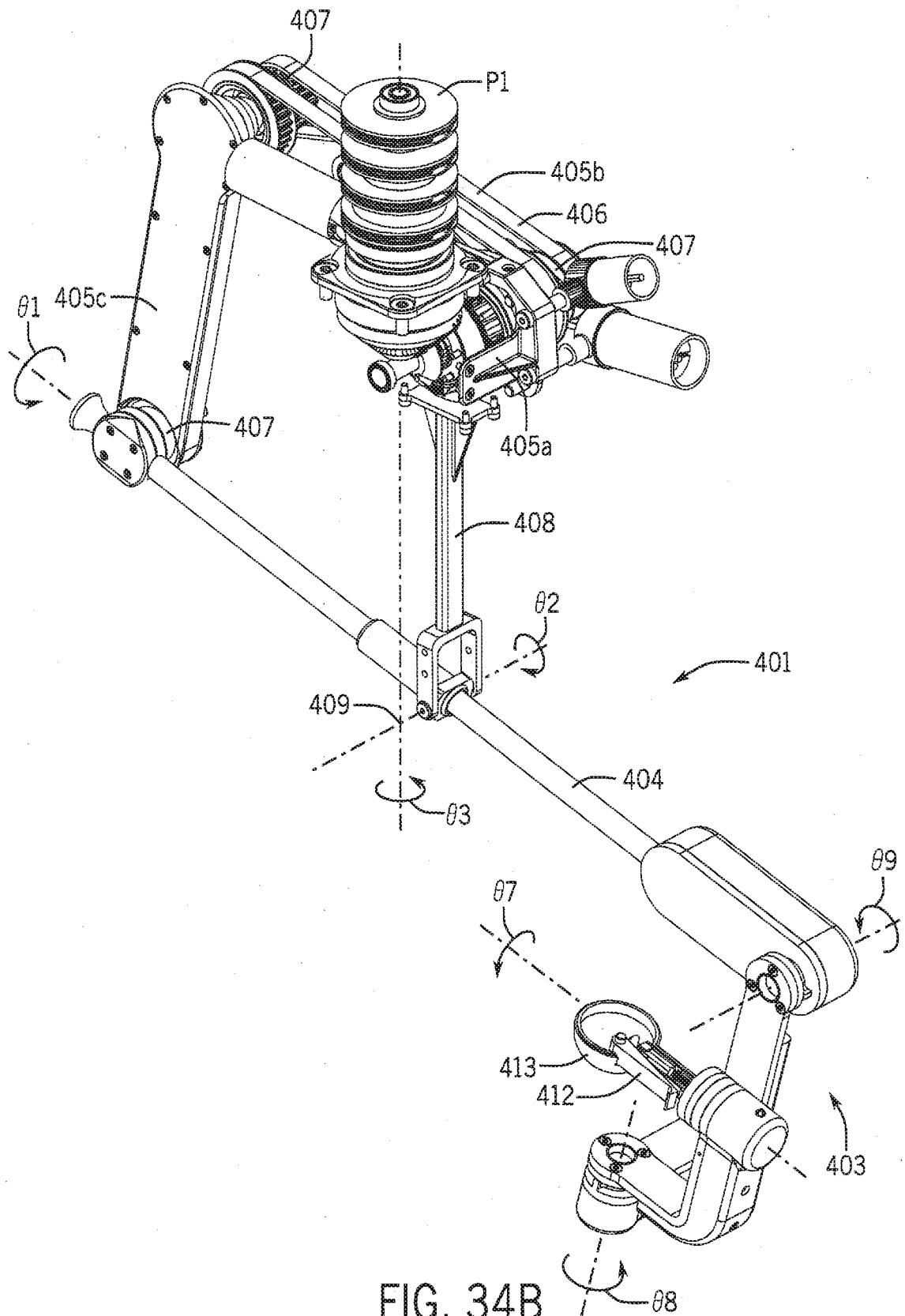


FIG. 33





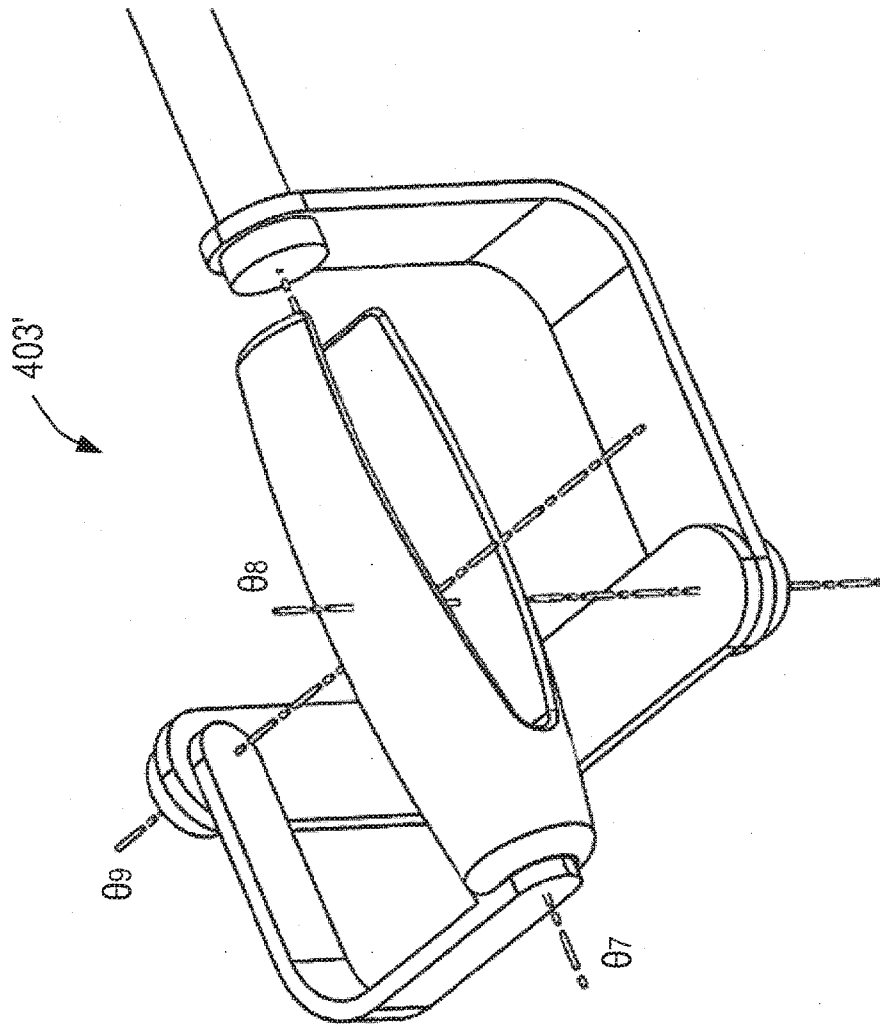


FIG. 34C

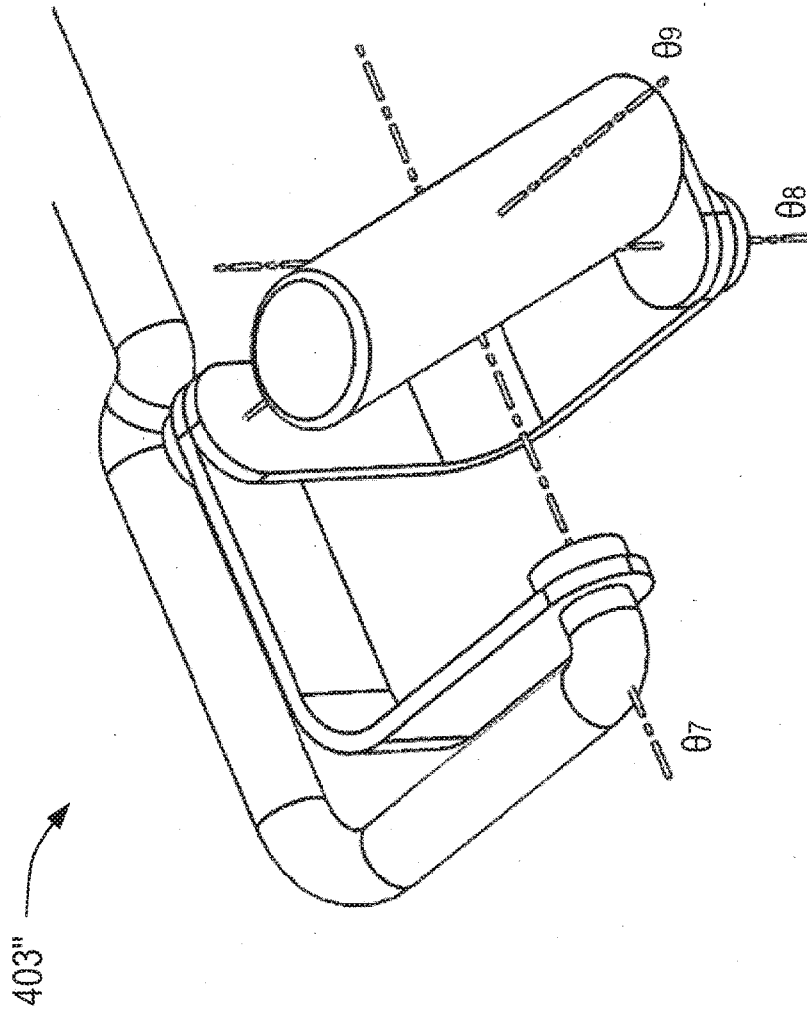


FIG. 34D

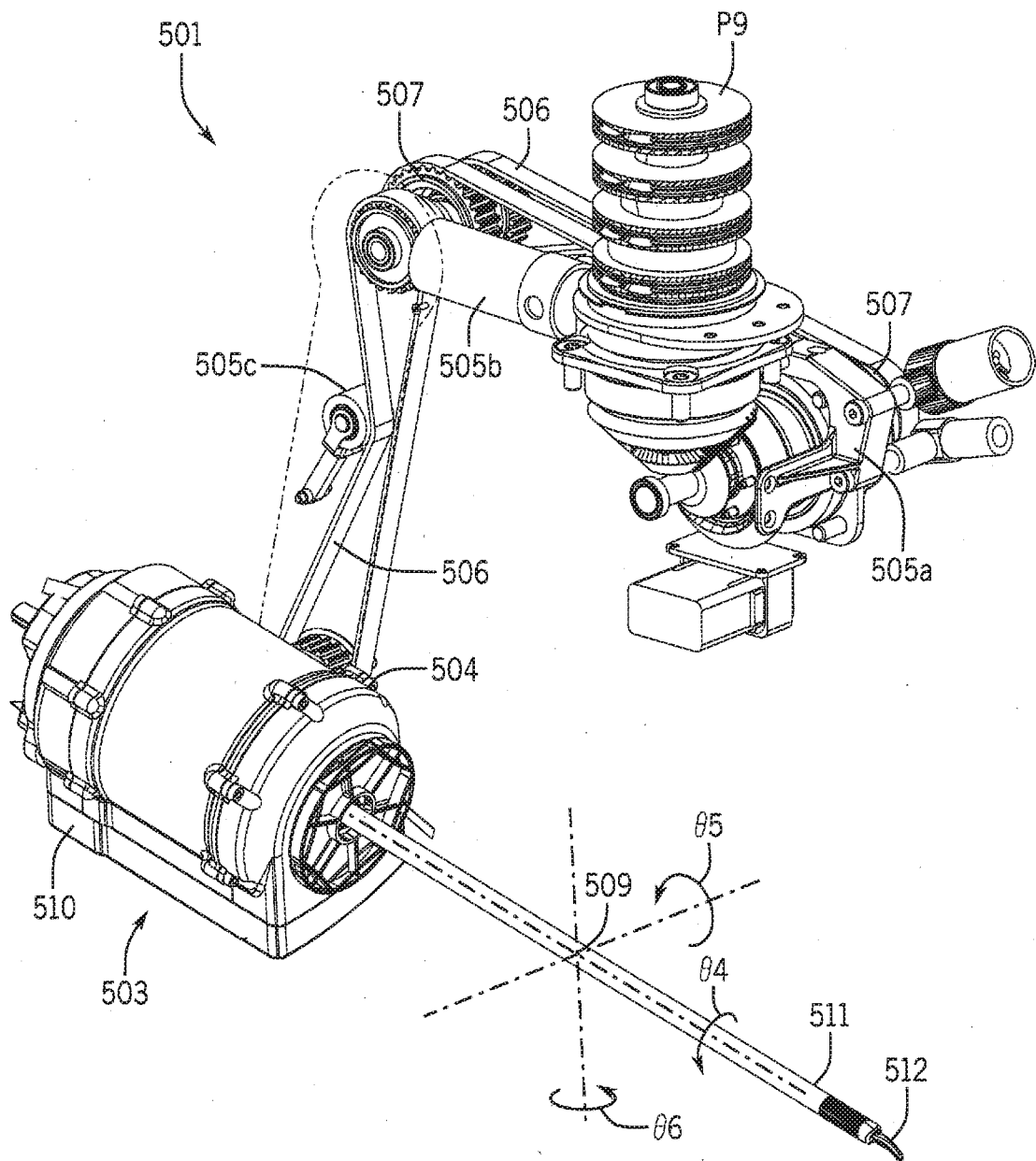


FIG. 35B

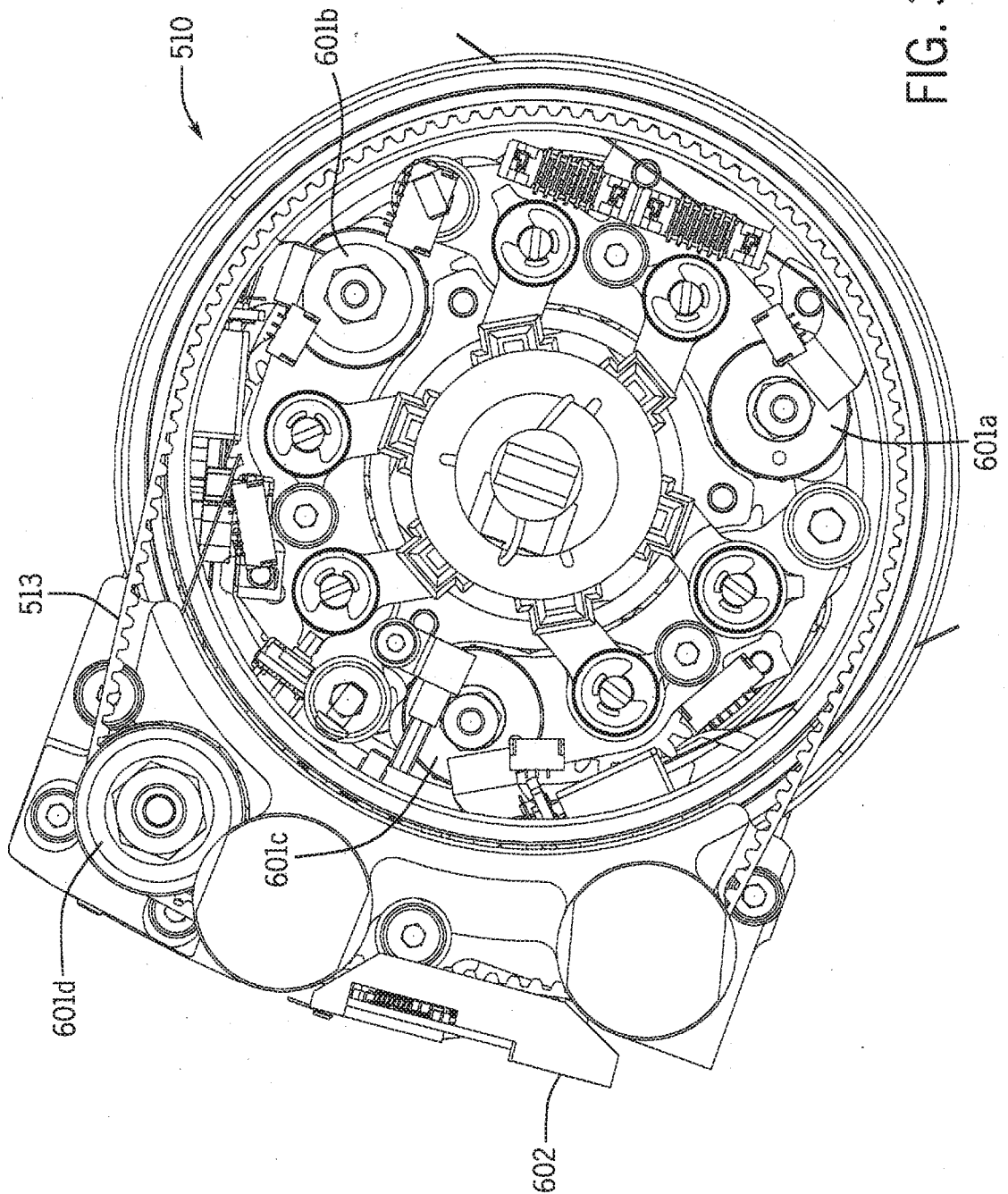
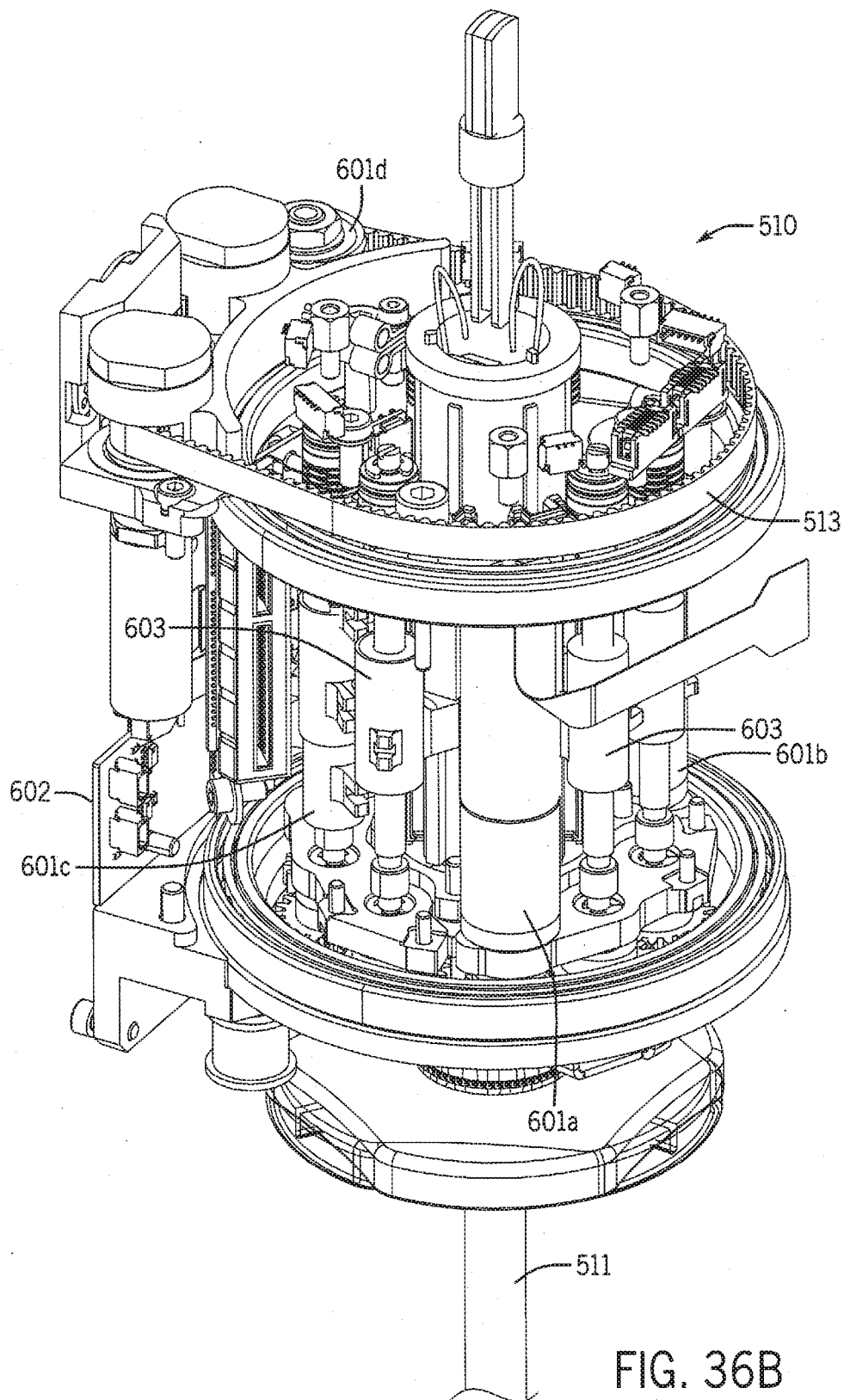


FIG. 36A



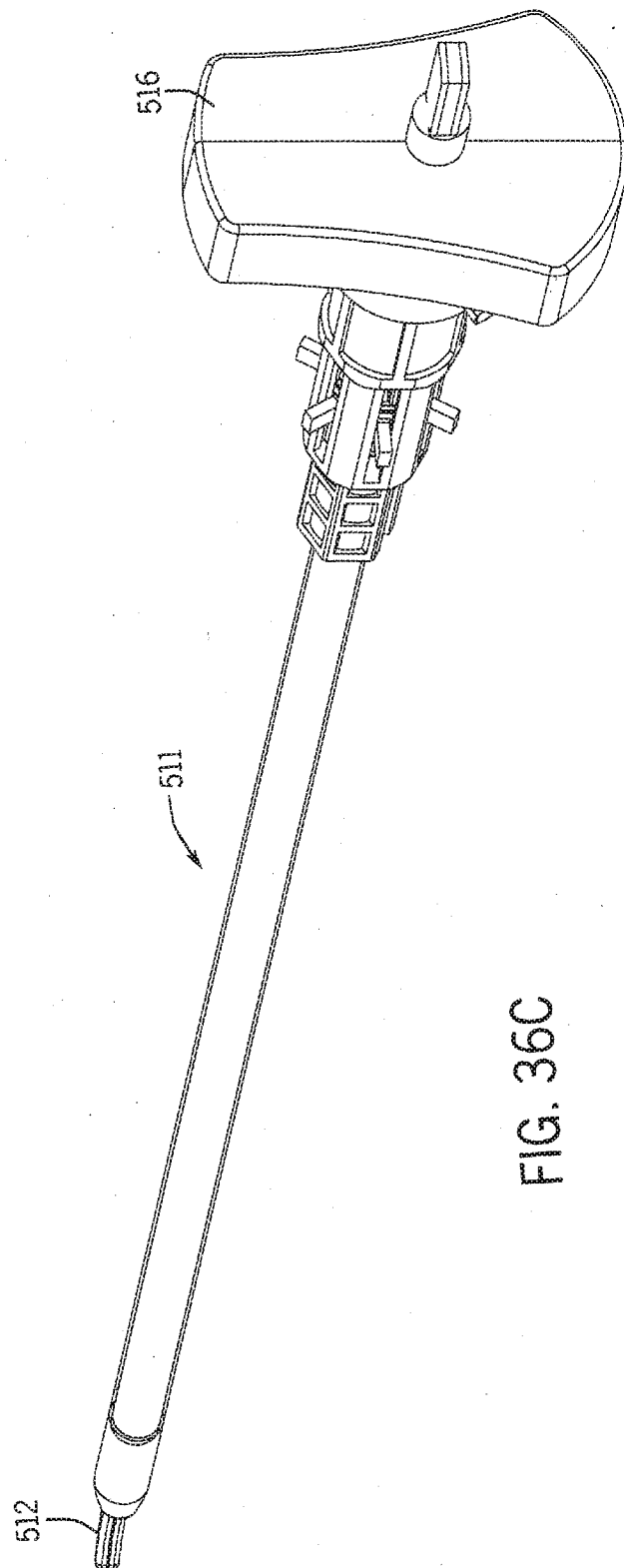


FIG. 36C

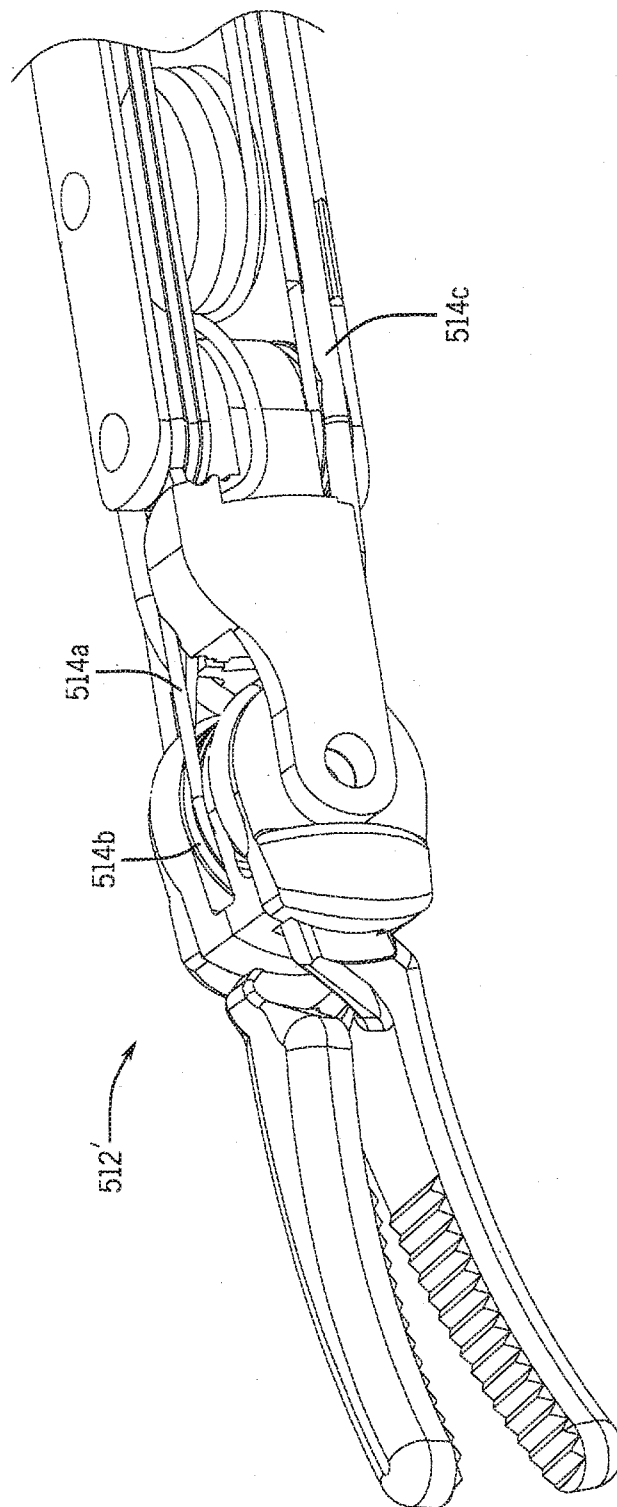


FIG. 36D

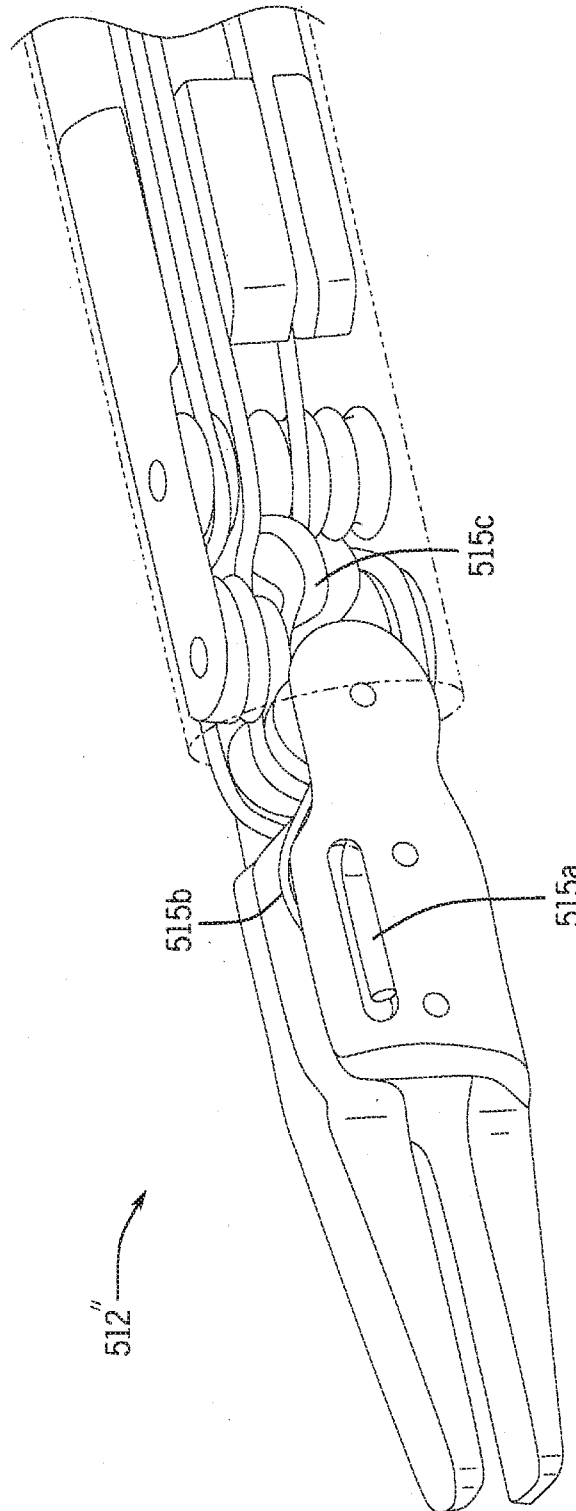


FIG. 36E

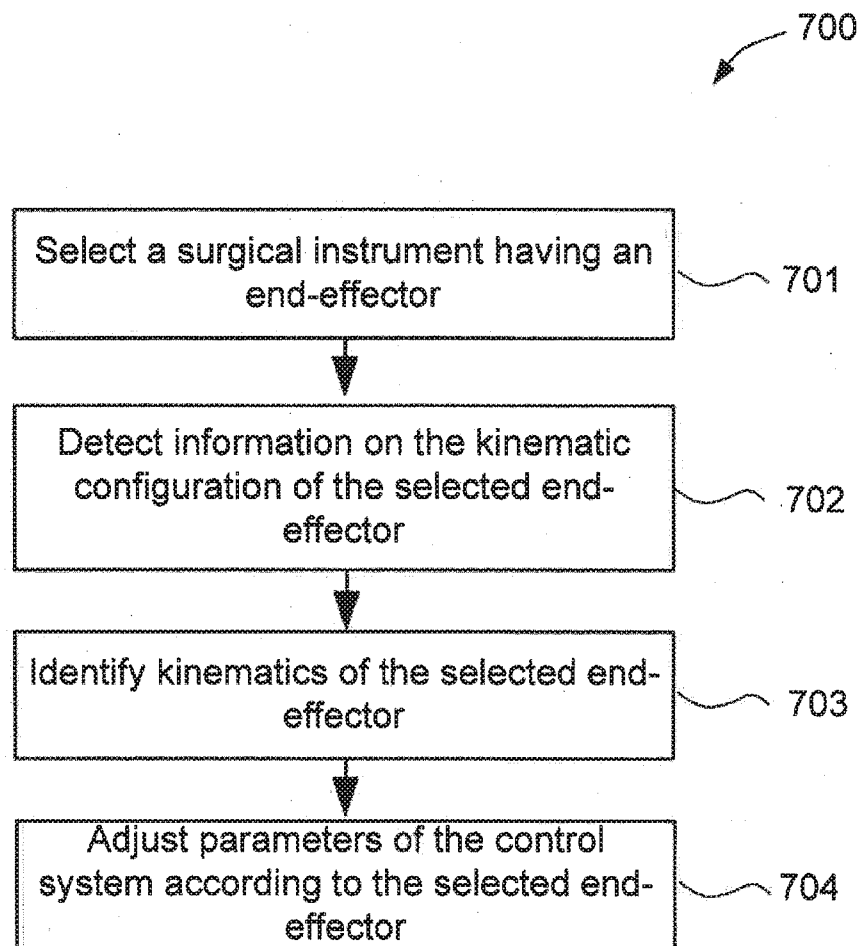


FIG. 37

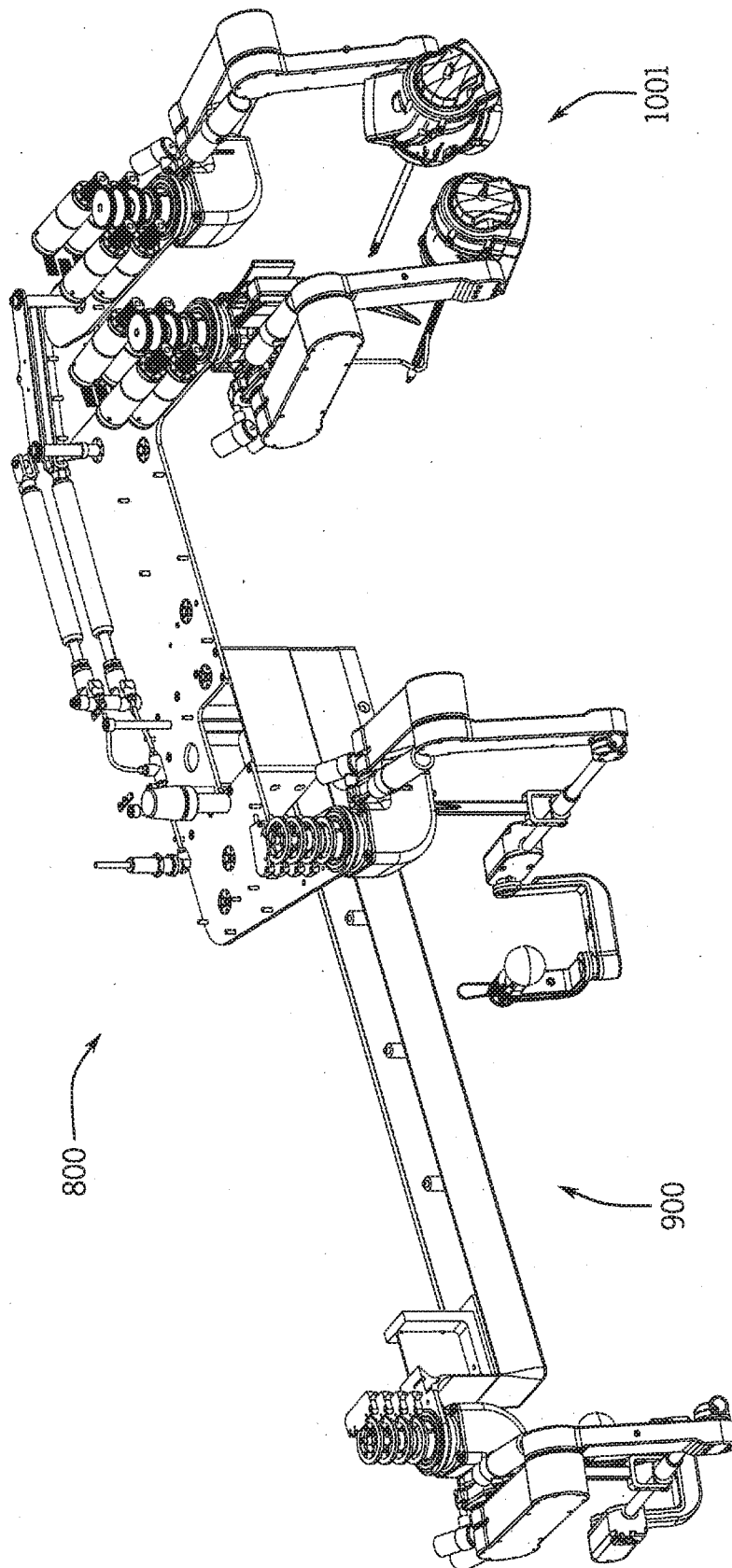


FIG. 38

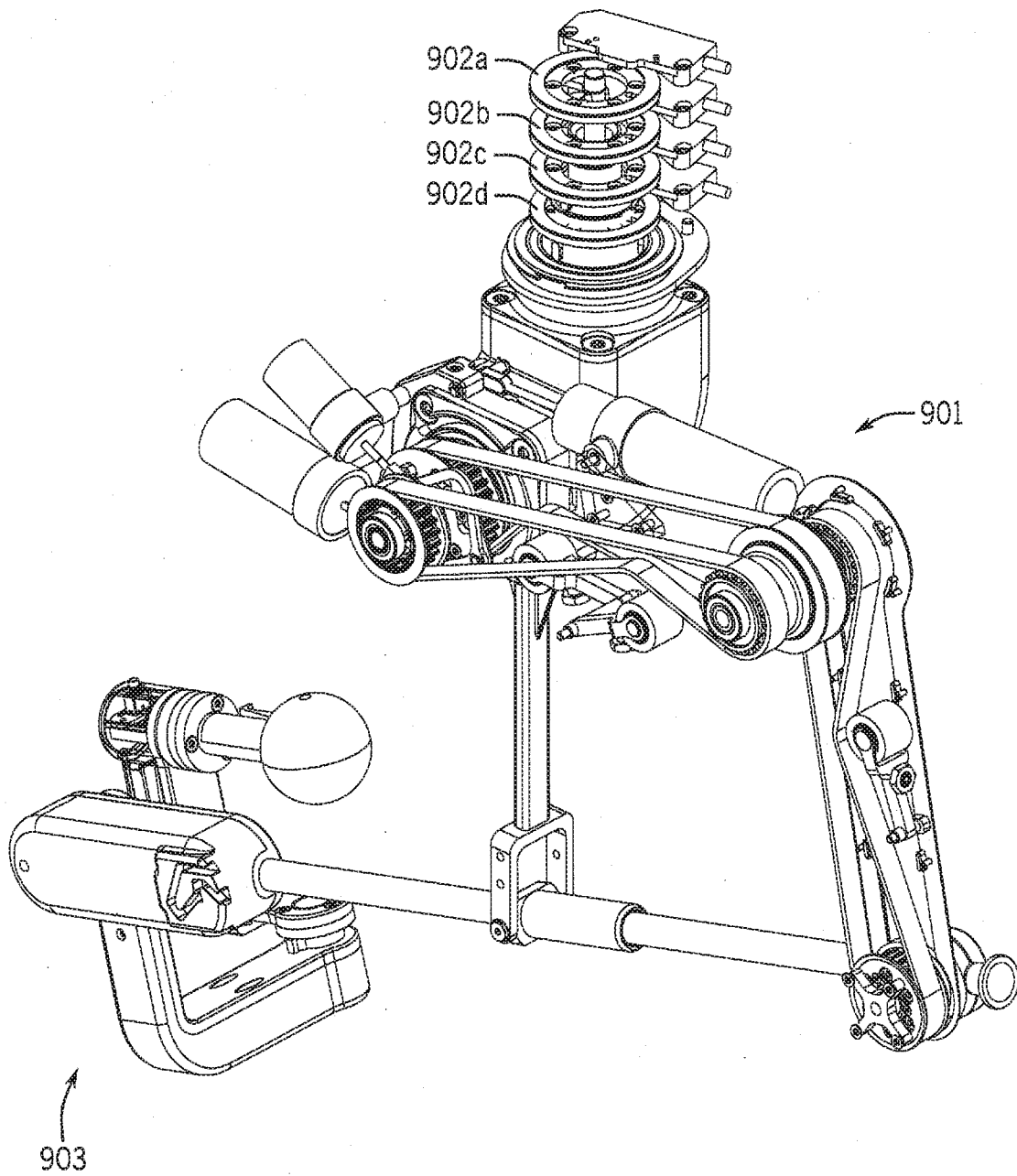


FIG. 39

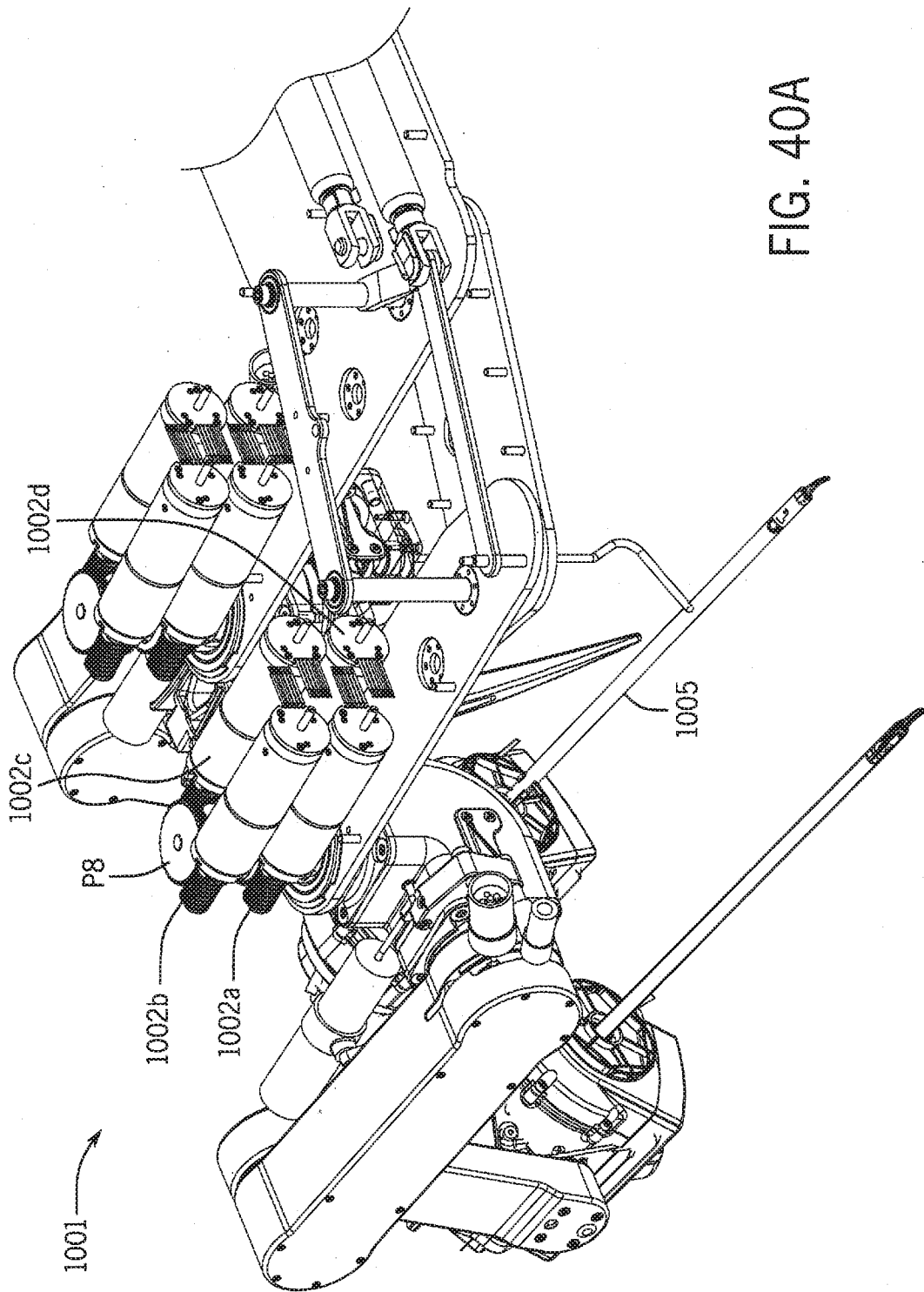
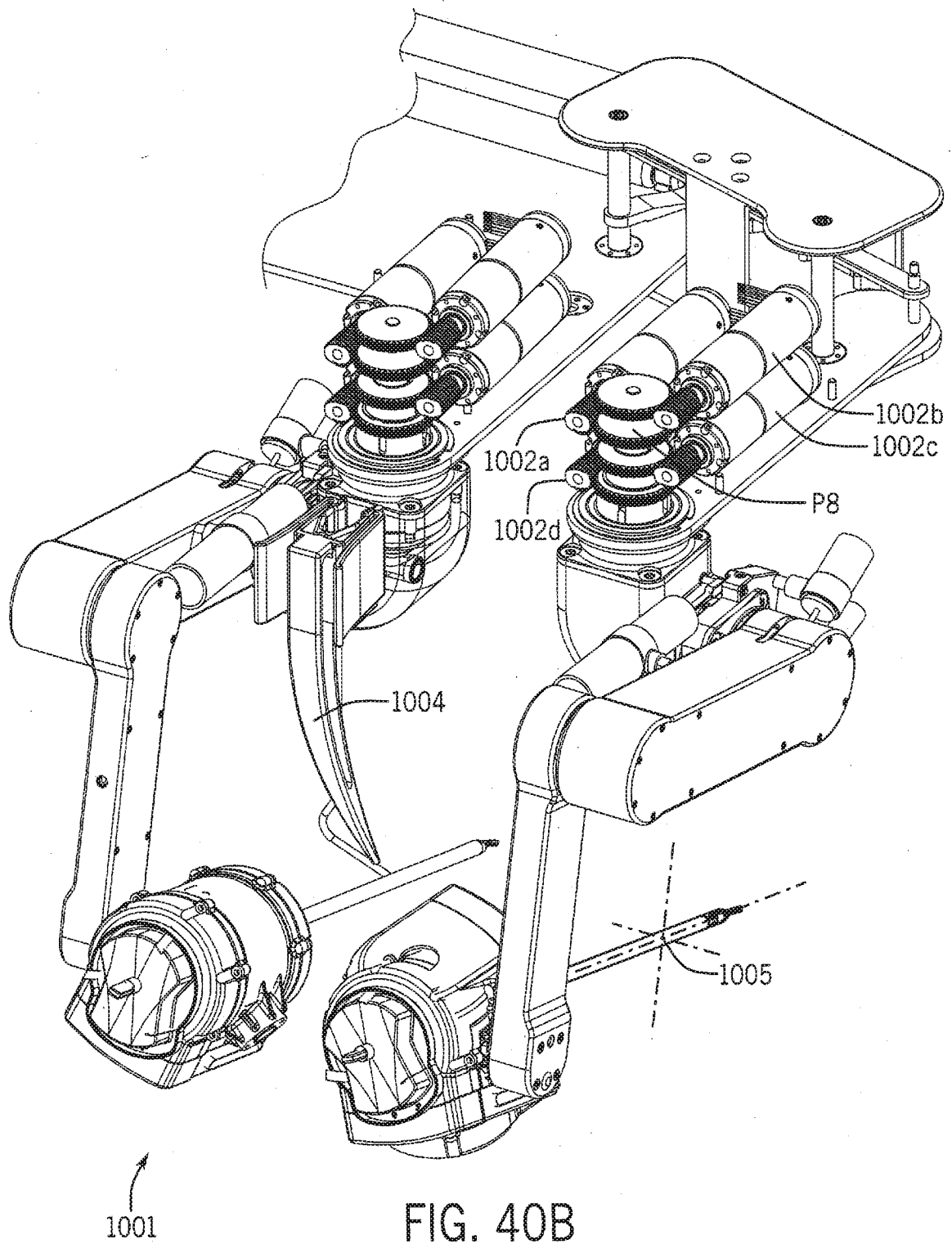


FIG. 40A



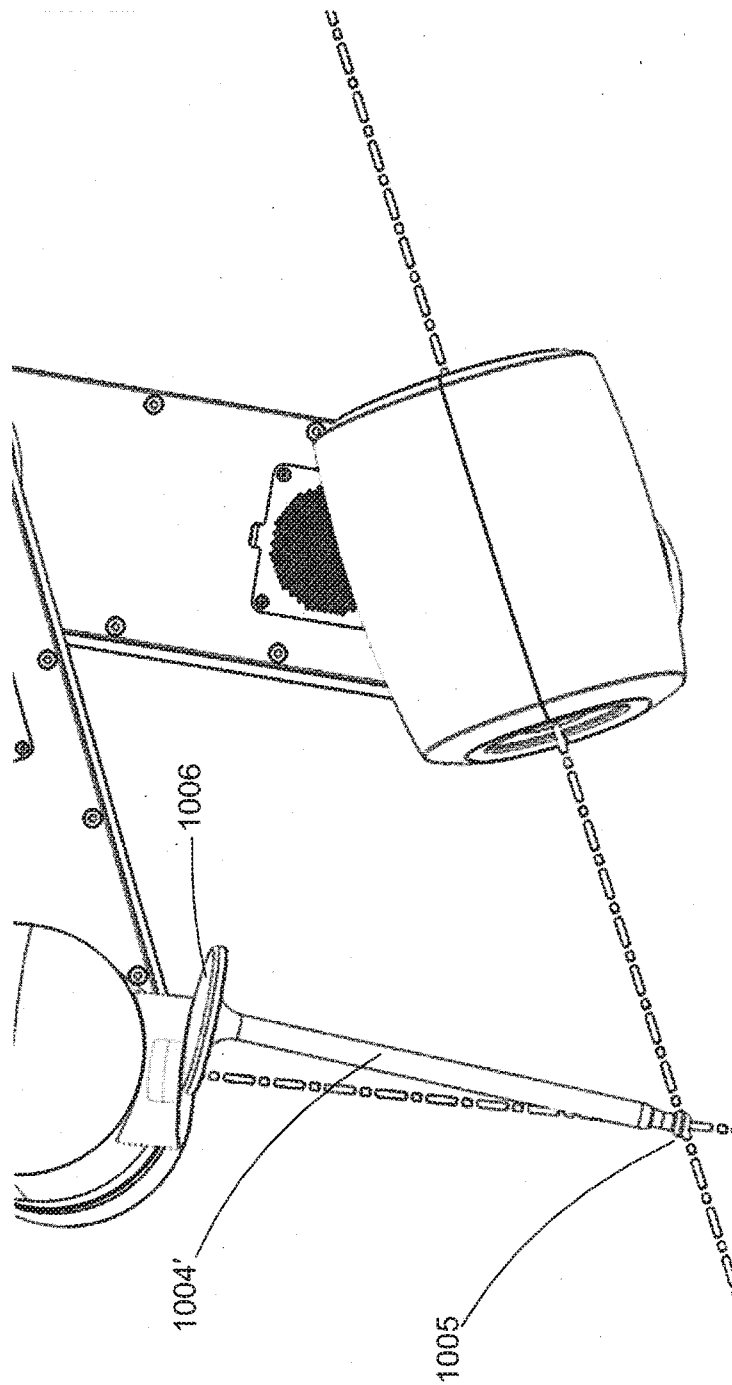


FIG. 40C

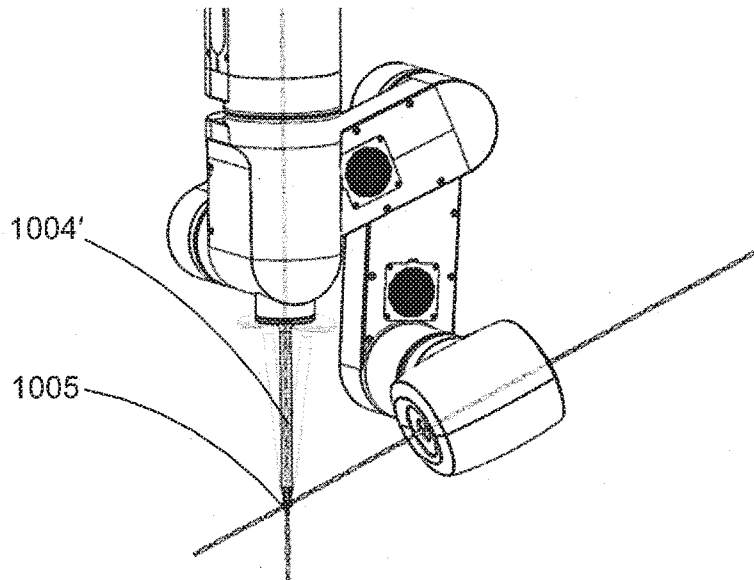


FIG. 40D

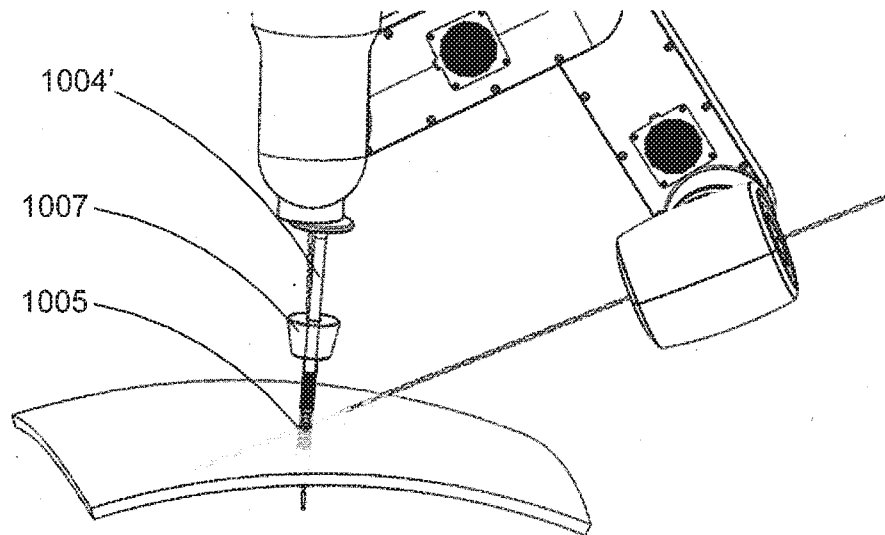


FIG. 40E

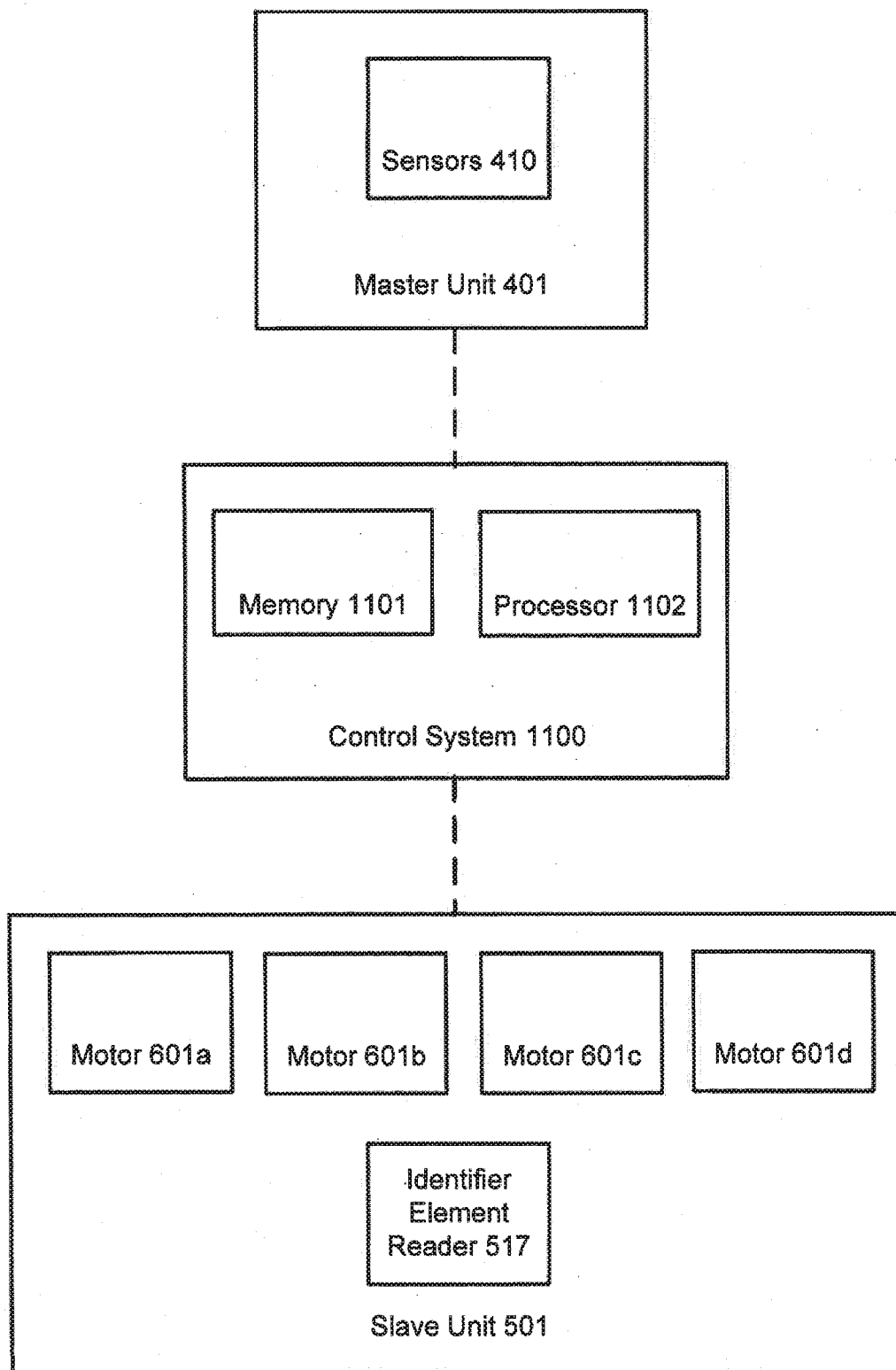


FIG. 41A

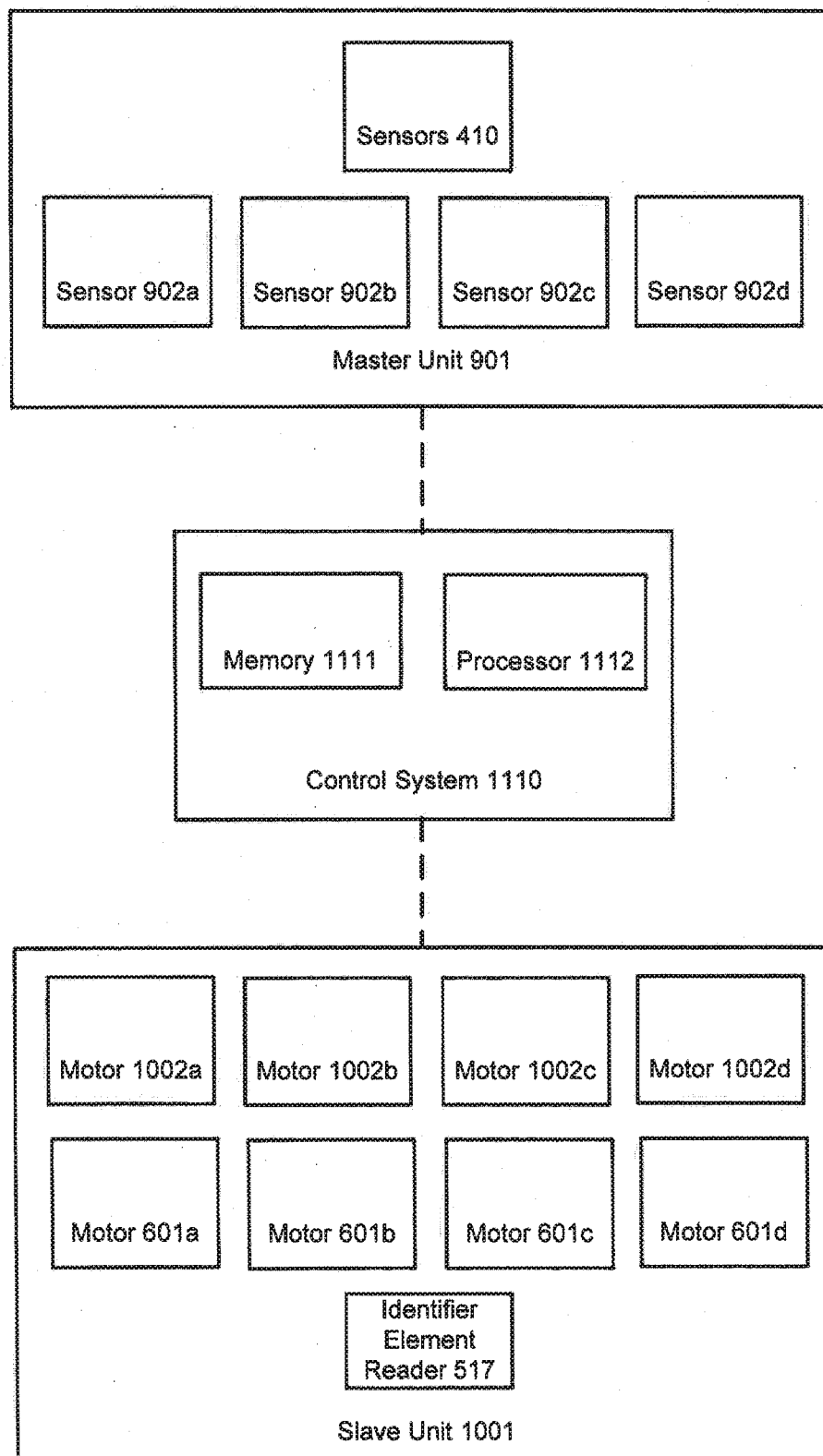


FIG. 41B

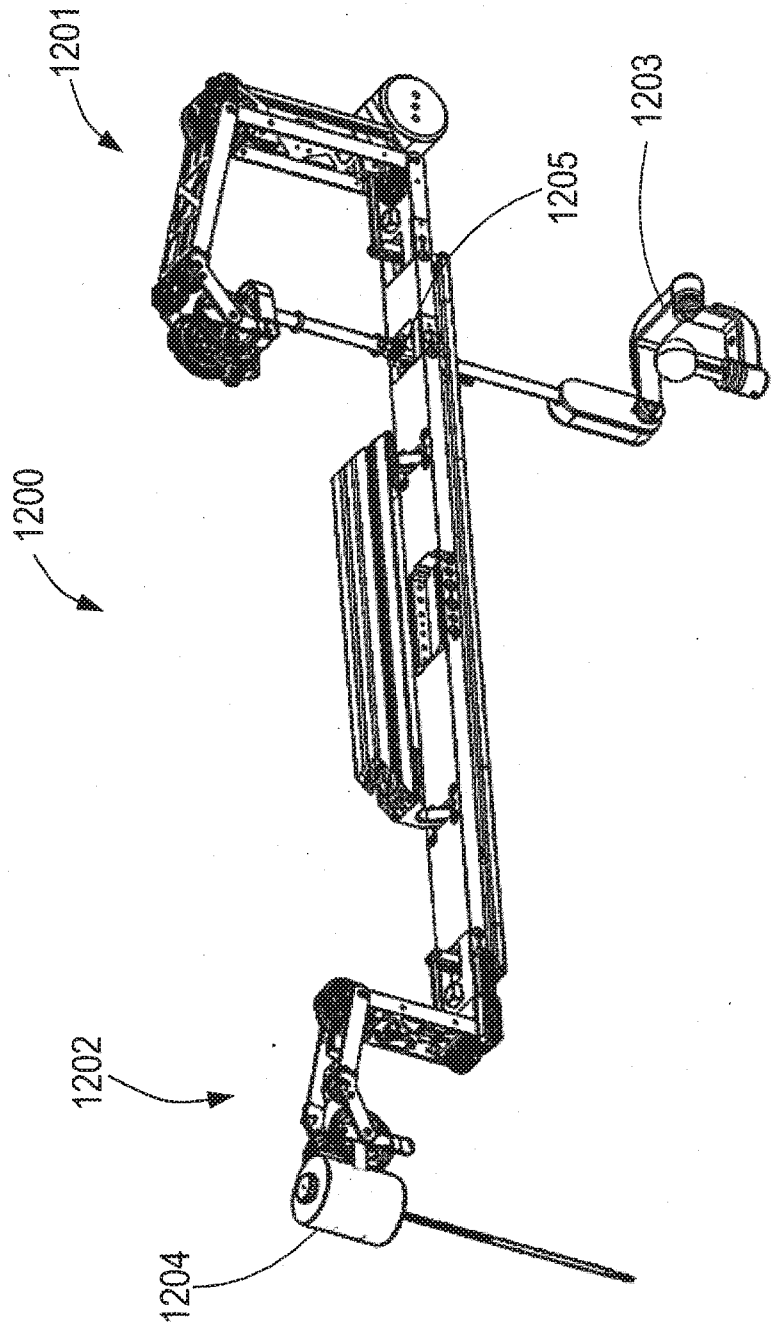


FIG. 42A

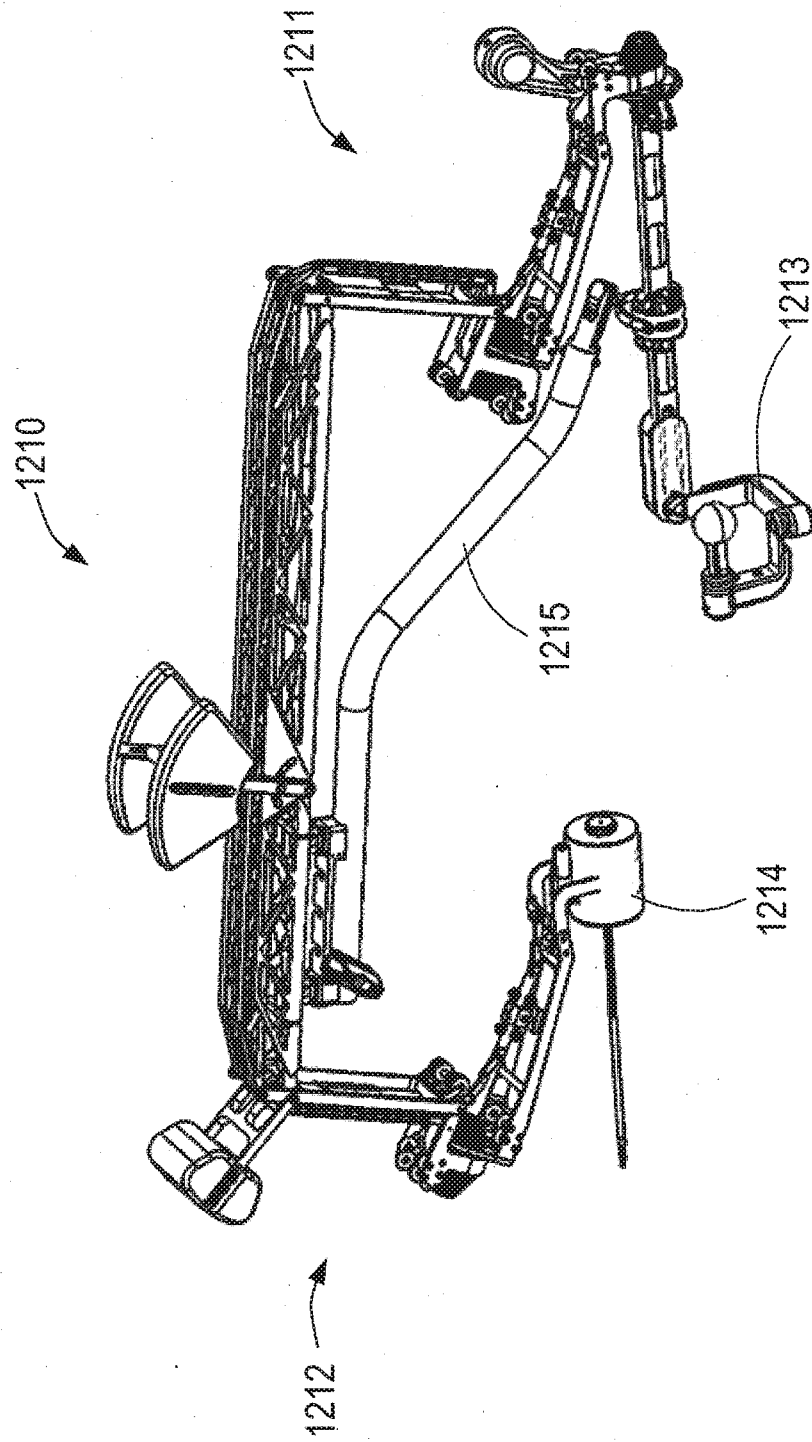


FIG. 42B

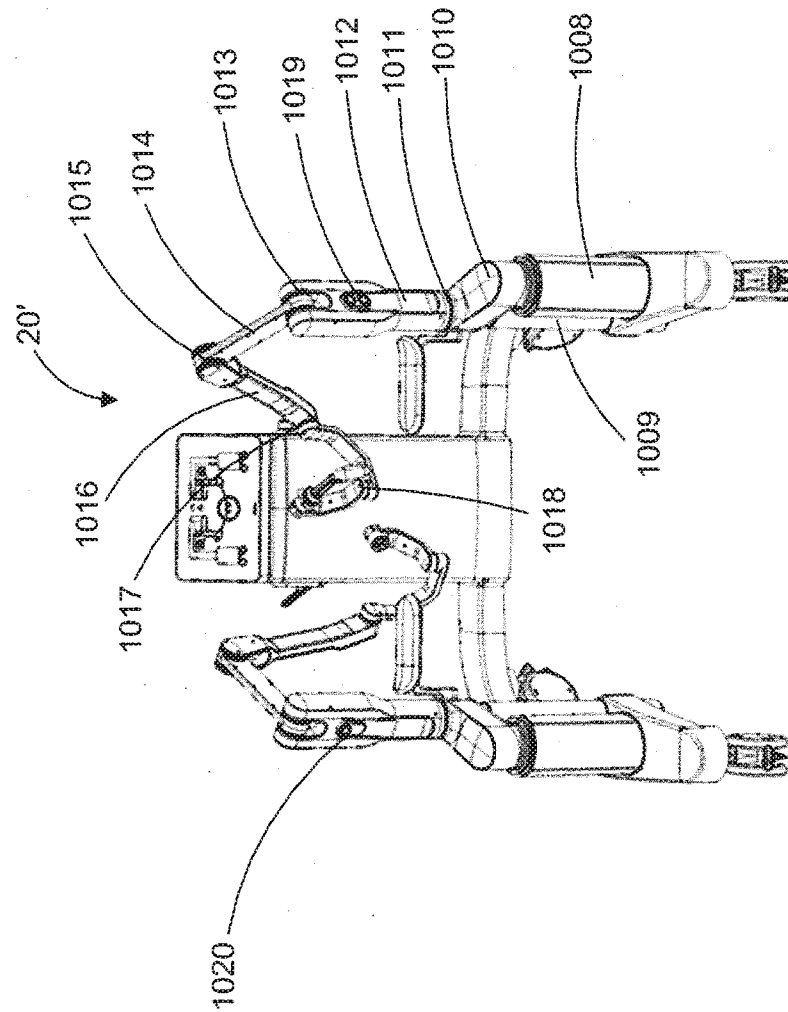


FIG. 43