(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2018 (31.05.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/098319 A1

(51) International Patent Classification:
A61B 34/20 (2016.01) *B25J 9/04* (2006.01)
A61B 34/30 (2016.01) *A61B 34/00* (2016.01)

(21) International Application Number:
PCT/US2017/063067

(22) International Filing Date:
22 November 2017 (22.11.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/425,149 22 November 2016 (22.11.2016) US

(71) Applicant: **BOARD OF REGENTS OF THE UNIVERSITY OF NEBRASKA** [US/US]; Varner Hall, 3835 Holdrege Street, Lincoln, Nebraska 68583-0745 (US).

(72) Inventors: **REICHENBACH, Mark**; 6049 Chartwell Lane, Lincoln, Nebraska 68516 (US). **FARRITOR, Shane**; 6137 Blackstone Road, Lincoln, Nebraska 68526 (US).

(74) Agent: **SOLBERG, Sean**; 215 10th Street, Suite 1300, Des Moines, Iowa 50309 (US).

(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, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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, 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).

Published:
— *with international search report (Art. 21(3))*

(54) **Title:** IMPROVED GROSS POSITIONING DEVICE AND RELATED SYSTEMS AND METHODS

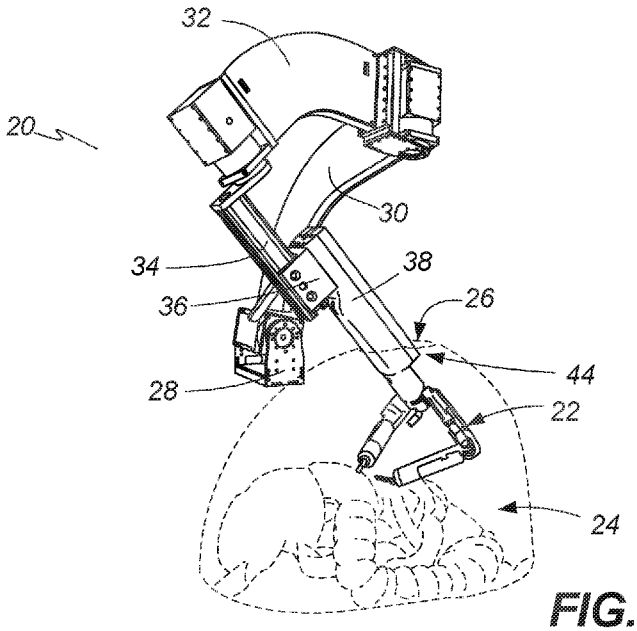


FIG. 2A

(57) **Abstract:** Disclosed herein are gross positioning systems for use with robotic surgical devices to provide gross positioning of the robotic surgical devices. The gross positioning systems have a base, a first arm link operably coupled to the base, a second arm link operably coupled to the first arm link, a third arm link operably coupled to the second arm link, and a slidable coupling component slidably coupled to the third arm link.

WO 2018/098319 A1

IMPROVED GROSS POSITIONING DEVICE AND RELATED SYSTEMS AND METHODS

Government Support

[001] This invention was made with government support under Grant No. W81XWH-14-1-0058, awarded by the U.S. Department of Defense. The government has certain rights in the invention.

Cross-Reference to Related Application(s)

[002] This application claims the benefit under 35 U.S.C. § 119(e) to U.S. Provisional Application 62/425,149, filed November 22, 2016 and entitled "Gross Positioning Device and Related Systems and Methods," which is hereby incorporated herein by reference in its entirety.

Field of the Invention

[003] The various embodiments herein relate to robotic surgical devices, and more specifically to gross positioning systems and devices that aid in the gross repositioning of surgical devices during surgical procedures. The combination of a gross positioning system with an *in vivo* surgical device results in an increase in the degrees of freedom of the *in vivo* device without increasing the size of the device.

Background of the Invention

[004] The known positioning systems currently used for robotic surgery are large and cumbersome. For example, the Da Vinci SP Surgical System™ takes up a significant portion of the operating room and creates a crowded space over the surgical site, and the system created by Waseda University has bulky motor housings that create a larger than necessary profile. In a further example, the Raven™ mimics current laparoscopic techniques by inserting a single tool (in contrast to the *in vivo* robot systems used in the other two systems discussed above).

[005] FIGS. 1A and 1B depict a known, generic spherical mechanism 10 and the necessary workspace 16 of the mechanism to reach the extents of the abdominal cavity of a patient. A "spherical mechanism" is a physical mechanism or software application that can cause all end effector motions to pass through a single point, thereby allowing a surgical system to use long rigid tools that perform procedures through incisions that serve as single pivot points. As an example, both COBRASurge and the Raven have mechanical spherical mechanisms, while Da Vinci has a software-based spherical mechanism.

[006] This known mechanism as shown in FIGS. 1A and 1B has a cable-driven tool coupled to it. The link angles 12, 14 in the device 10 have been optimized at the University of Washington's BioRobotics lab to create the workspace 16 depicted in FIG. 1B. The workspace 16 is an elliptical cone 90° in the lateral directions and 60° in the cranial/caudal direction with a remote center 18 that is disposed at the bottom of the cone 16. The link angles 12, 14 can be changed for different workspaces.

[007] There is a need in the art for an improved gross positioning system.

Brief Summary of the Invention

[008] Discussed herein are various gross positioning systems for use with in vivo robotic surgical devices.

[009] In Example 1, a gross positioning system for use with a robotic surgical device comprises a base, a first arm link operably coupled to the base at a first rotational joint, a second arm link operably coupled to the first arm link at a second rotational joint, a third arm link operably coupled to the second arm link, and a slidable coupling component slidably coupled to the third arm link such that the slidable coupling component can move along a length of the third arm link between an extended position and a retracted position. The third arm link is rotatable about a third rotational joint and is configured to be positionable through an incision in a patient. The slidable coupling component is configured to be coupleable to the robotic surgical device..

[010] Example 2 relates to the gross positioning system according to Example 1, wherein an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint intersect at a single point of intersection.

[011] Example 3 relates to the gross positioning system according to Example 2, wherein wherein the single point of intersection is a spherical joint.

[012] Example 4 relates to the gross positioning system according to Example 2, wherein the single point of intersection is disposed at some point along a portion of the robotic surgical device.

[013] Example 5 relates to the gross positioning system according to Example 2, wherein the gross positioning system is positioned such that the single point of intersection is disposed at an incision in a patient.

[014] Example 6 relates to the gross positioning system according to Example 5, wherein the third arm link is disposed through the single point of insertion.

[015] Example 7 relates to the gross positioning system according to Example 2, wherein the single point of intersection is disposed at an insertion point of a patient.

[016] Example 8 relates to the gross positioning system according to Example 7, wherein the insertion point comprises an incision or a natural orifice.

[017] Example 9 relates to the gross positioning system according to Example 7, wherein the third arm link is disposed through the single point of intersection.

[018] Example 10 relates to the gross positioning system according to Example 1, wherein the robotic surgical device comprises at least one arm, wherein the gross positioning system and robotic surgical device are configured to operate together to position the robotic surgical device within a body cavity of a patient.

[019] Example 11 relates to the gross positioning system according to Example 10, further comprising a controller operably coupled to the gross positioning system and the robotic surgical device.

[020] In Example 12, a gross positioning system for use with a robotic surgical device comprises a base, a first arm link operably coupled to the base at a first rotational joint, a second arm link operably coupled to the first arm link at a second rotational joint, a third arm link operably coupled

to the second arm link at a third rotational joint, a slidable coupling component slidably coupled to the third arm link such that the slidable coupling component can move along a length of the third arm link between an extended position and a retracted position, and the robotic surgical device operably coupled to the slidable coupling component. The robotic surgical device comprises a device body, a first arm operably coupled to the device body, and a second arm operably coupled to the device body. The first arm comprises at least one first actuator and the second arm comprises at least one second actuator.

[021] Example 13 relates to the gross positioning system according to Example 12, wherein an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint intersect at a single point of intersection.

[022] Example 14 relates to the gross positioning system according to Example 12, wherein the third arm link is disposed through the single point of intersection and further is configured to be positionable through an insertion point in a patient.

[023] In Example 15, a external gross positioning system for use with an internal robotic surgical device comprises a base, a first arm link operably coupled to the base at a first rotational joint, a second arm link operably coupled to the first arm link at a second rotational joint, a third arm link operably coupled to the second arm link at a third rotational joint, a slidable coupling component slidably coupled to the third arm link such that the slidable coupling component is moveable along a length of the third arm link between an extended position and a retracted position, and a single point of intersection at an intersection of an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint. The slidable coupling component is configured to be coupleable to the robotic surgical device. The single point of intersection is disposed at an insertion point of a patient.

[024] Example 16 relates to the gross positioning system according to Example 15, wherein a portion of the third arm link is disposed through the single point of intersection.

[025] Example 17 relates to the gross positioning system according to Example 15, wherein a portion of the robotic surgical device is disposed through the single point of intersection.

[026] Example 18 relates to the gross positioning system according to Example 15, wherein the insertion point is an incision.

[027] Example 19 relates to the gross positioning system according to Example 15, wherein the robotic surgical device comprises at least one arm, wherein the gross positioning system and robotic surgical device are configured to operate together to position the robotic surgical device within a body cavity of the patient.

[028] Example 20 relates to the gross positioning system according to Example 19, further comprising a central processing unit operably coupled to the gross positioning system and the robotic surgical device and a controller operably coupled to the central processing unit. The central processing unit comprises software configured to transmit control instructions to the gross positioning system and the robotic surgical device.

[029] In Example 21, a gross positioning system for use with a robotic surgical device comprises a base, a first arm link operably coupled to the base at a first rotational joint, a second arm

link operably coupled to the first arm link at a second rotational joint, a third arm link operably coupled to the second arm link at a third rotational joint, a slidable coupling component slidably coupled to the third arm link, and the robotic surgical device operably coupled to the slidable coupling component. Further, the robotic surgical device comprises a device body, a first arm operably coupled to the device body, the first arm comprising at least one first actuator, and a second arm operably coupled to the device body, the second arm comprising at least one second actuator. In addition, the third arm link is positionable through an insertion point in a patient such that the robotic surgical device is positionable within a body cavity of the patient.

[030] Example 22 relates to the gross positioning system according to Example 21, wherein the slidable coupling component is slidable along a length of the third arm link between an extended position and a retracted position.

[031] Example 23 relates to the gross positioning system according to Example 21, wherein an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint intersect at a single point of intersection and the third arm link is disposed through the single point of intersection.

[032] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

Brief Description of the Drawings

[033] FIG. 1A is a perspective view of a known spherical mechanism.

[034] FIG. 1B is a perspective view of the workspace of the known spherical mechanism of FIG. 1A.

[035] FIG. 2A is a perspective view of a gross positioning device coupled to an *in vivo* robotic device that is disposed within a cavity of a patient, according to one embodiment.

[036] FIG. 2B is another perspective view of the gross positioning device and *in vivo* robotic device of FIG. 2A disposed within the cavity of the patient.

[037] FIG. 2C is another perspective view of the gross positioning device and *in vivo* robotic device of FIG. 2A disposed within the cavity of the patient.

[038] FIG. 3 is an exploded perspective view of a gross positioning device, according to one embodiment.

[039] FIG. 4 is an expanded, exploded perspective view of the first joint of the device of FIG. 3.

[040] FIG. 5 is an expanded, exploded perspective view of the second joint of the device of FIG. 3.

[041] FIG. 6 is an expanded, exploded perspective view of the third joint of the device of FIG. 3.

[042] FIG. 7 is an expanded, exploded perspective view of the coupling component of the device of FIG. 3 coupled to a robotic device.

[043] FIG. 8 is a side view of a gross positioning device and the actual axes of rotation resulting at each joint, according to one embodiment.

[044] FIG. 9 is a perspective view of the gross positioning device and the global axes of rotation created by the actual axes of rotation of FIG. 8.

[045] FIG. 10 is a schematic depiction of a control process for controlling a gross positioning device, according to one embodiment.

[046] FIG. 11 is a perspective view of a controller, according to one embodiment.

[047] FIG. 12 is a perspective view of another controller, according to a further embodiment.

[048] FIG. 13A depicts a perspective view of the arms of robotic device, according to one embodiment.

[049] FIG. 13B depicts a perspective view of the arms of the robotic device of FIG. 13A.

[050] FIG. 14A is a side view of a gross positioning device coupled to an *in vivo* robotic device that is disposed within a cavity of a patient, according to one embodiment.

[051] FIG. 14B is another side view of the gross positioning device and *in vivo* robotic device of FIG. 14A disposed within the cavity of the patient.

Detailed Description

[052] The various embodiments disclosed or contemplated herein relate to an improved gross positioning device that is coupled to a dexterous *in vivo* robotic device such that the gross positioning device can be used for global orientation of the robotic device within the cavity of a patient as described in further detail herein.

[053] The various gross positioning device implementations disclosed or contemplated herein

can be used to automatically grossly position a surgical device inside a cavity of a patient. "Gross positioning," as used herein, is intended to mean general positioning of an entire moveable surgical device (in contrast to precise movement and placement of the specific components of such a device, such as an arm or end effector). In known robotic surgical systems, the gross positioning of those devices during a surgical procedure can be a challenging task. Further, minimally invasive surgical procedures (using either robotic or non-robotic systems) frequently require a surgical technician to reposition the surgical equipment, such as a laparoscope. Such gross repositioning takes time and additional effort. In addition, in some cases, the surgical technician is a junior medical student who is not fully trained in laparoscopy. As a result, the repositioning instructions from the surgeon often result in an obstructed and/or fogged view of the surgical site, requiring additional cognitive resources from the surgeon. Hence, the Da Vinci® system as well as known single incision surgical devices often require timely manual repositioning of the patient, the robotic system, or both while performing complicated procedures.

[054] The various gross positioning devices contemplated herein aid in the gross repositioning of surgical devices (including, for example, any surgical devices that have a device body or rod configured to be positioned through an incision and at least one robotic arm coupled to the device body that is positioned entirely within the cavity of the patient) throughout the procedure without additional intervention or manual repositioning from the surgical staff. The gross positioning system embodiments are capable of controlling the degrees of freedom, azimuth and elevation angle, and roll and translation about the axis of insertion of laparoscopic surgical tools, including robotic laparoscopic surgical tools. As a result, the gross positioning device embodiments disclosed and contemplated herein can grossly position a surgical device through an incision into a patient cavity, such as the abdominal cavity, with high manipulability, reducing the operative time and stress induced upon the surgical staff. The combination of the external gross positioning system with the internal surgical device system will allow the degrees of freedom of the internal system to effectively increase without increasing the size of the surgical robot/device.

[055] In one implementation, the various devices described and contemplated herein can be used with any single site surgical device with an available external positioning fixture, such as a protruding body, rod, or magnetic handle.

[056] FIGS. 2A-2C depict a gross positioning device 20 with an *in vivo* robotic device 22 coupled thereto. The three figures depict the device 20 orienting the robotic device 22 in three different positions within the cavity 24 of the patient through an incision 26. The device 20 has a base (also referred to as a "body") 28, a first arm link (or "upper arm") 30, a second arm link (or "forearm") 32, and a third link (or "extender") 34. The extender 34 has a coupling component 36 that couples directly to the body 38 of the robotic device 22 such that the body 38 is disposed through the incision 26 that provides access to the cavity 24 (or, more typically, through a port (not shown) disposed in the incision 26 that provides access to the cavity 24).

[057] As shown, the links 30, 32, 34 of the positioning device 20 (and any other positioning device embodiment disclosed or contemplated herein) allow the robotic device 22 to access the full extent of the workspace within the cavity 24. That is, the positioning device 20 makes it possible to position the robotic device 22 within the patient's cavity 24 with the body 38 of the device 22 positioned through the incision 26 (or port disposed in the incision 26) such that the end effectors 42 attached to the arms 40 of the robotic device 22 can reach any desired location in the workspace in the cavity 24 while the links 30, 32, 34 of the positioning device 20 function to create a "spherical joint" 44 where the device body 38 passes through the incision 26 such that all movements of the robotic device 22 pass through a single point. In other words, regardless of the positioning of the three links 30, 32, 34 and the resulting positioning of the robotic device 22 within the patient's cavity 24, the portion of the device body 38 at the incision 26 (the spherical joint 44) remains in the same position (through the incision 26) as a result of the positioning device 20. This allows operation of a robotic device (such as robotic device 22) within a cavity (such as cavity 24) such that the end effectors (such as end effectors 42) can reach any desired location within the cavity while the entire device 22 is connected to the positioning device 20 via a device body 38 that passes through and never moves from a single point (the spherical joint 44) at the incision 26, thereby making it possible to operate and

position the device 22 through that single incision (such as incision 26). The creation of the spherical joint 44 by the positioning device 20 will be described in further detail below. Another advantage is that the positioning device 20 makes it possible to use the single *in vivo* robotic device within the patient's cavity instead of the multiple arms of the known Da Vinci™ system extending from the patient's cavity and thereby taking up a great deal of workspace outside the body of the patient.

[058] FIG. 3 depicts an exploded view of the components of the gross positioning device 20. As will be described in further detail below, the device 20 has three degrees of freedom ("DOF") and can utilize those DOFs to provide global orientation for the robotic device 22 (as best shown in FIGS. 2A-2C) coupled to positioning device 20. As discussed above, the device 20 has the base 28, the first arm link 30, the second arm link 32, the third link 34, and the coupling component 36. In this implementation, the first arm link 30 has a cover 30A and the second arm link 32 has a cover 32A. Alternatively, each of the links 30, 32 is a single, unitary component without a cover.

[059] As best shown in FIGS. 3 and 4, the first arm link 30 is rotatably coupled to the base 28 at a first joint 50. More specifically, the base 28 is made up of a bracket 52 that is configured to receive a first motor 54 that is rotatably coupled to the bracket 52 and a bearing 56, thereby creating the first joint 50. That is, the motor 54 is positioned in the openings 58A, 58B such that the motor 54 rotates within those openings 58A, 58B. The first link 30 is fixedly coupled to the first motor 54 such that actuation of the first motor 54 causes rotation of the motor 54 in relation to the bracket 52, thereby causing rotation of the first link 30 around the first joint 50.

[060] In one implementation, the base 28 is configured to keep the entire device 20 stable and secure during use. As shown, the base 28 is a bracket 52 as discussed above. In alternative embodiments, the base 28 can be any structure that provides such stability, including, for example, a very heavy or weighted structure that uses the weight to enhance stability. In certain implementations, the base 28 can be stably coupled to a surgical table on which the patient is placed. For example, the base 28 can be coupled to a rail (not shown) on the table (not shown). In a further alternative, the base 28 can be coupled to any fixed object in the operating room. Alternatively, the base 28 can be coupled to or be an integral part of a cart or other mobile standalone unit.

[061] As best shown in FIGS. 3 and 5, the first arm link 30 and the second arm link 32 are rotatably coupled to each other at a second joint 60. More specifically, the joint 60 is made up of a bracket 62 that is configured to receive a second motor 64 that is rotatably coupled to the bracket 62 and a bearing 66, thereby creating the second joint 60. That is, the motor 64 is positioned in the openings 68A, 68B such that the motor 64 rotates within those openings 68A, 68B. The first link 30 is fixedly coupled to the second motor 64 and the second link 32 is fixed coupled to the bracket 62 such that actuation of the second motor 64 causes rotation of the motor 64 in relation to the bracket 62, thereby causing rotation of the second link 32 in relation to the first link 30 around the joint 60.

[062] As best shown in FIGS. 3 and 6, the third link 34 is rotatably coupled to the second arm link 32 at a third joint 70. More specifically, the joint 70 is made up of a third motor 72 that is fixedly coupled to the second arm link 32 and rotatably coupled to the third link 34 such that actuation of the motor 72 causes rotation of the third link 34, thereby creating the third joint 70. As best shown in FIGS. 3 and 7, the third link 34 has the coupling component 36 at the distal end of the link 34 such

that a robotic device 74 can be coupled thereto. It is understood that the object 74 depicted in FIGS. 3 and 7 is intended to represent an in vivo robotic device 74. In this specific example, only the rod or body 76 of the device 74 is shown, but not the robotic arms or other components. It is understood that this particular body component 76 as shown is merely intended as a schematic depiction of the device 74, and not a fully depiction of an actual robotic device having robotic arms (such as the device 22 discussed and depicted above). Thus, actuation of the third motor 72 causes rotation of the robotic device via the rotation of the third link 34.

[063] Alternatively, any joint configurations can be used in the various gross positioning device implementations, so long as the links 30, 32, 34 can move in relation to each other as described herein.

[064] According to one implementation, the coupling component 36 is slidably coupled to the third link 34 such that the coupling component 36 (and thus the robotic device 74) can be positioned anywhere along the longitudinal length of the third link 34. As such, the robotic device 74 can be moved toward and away from the third joint 70 as desired to position the device 74 along the longitudinal axis of the third link 34. In accordance with certain embodiments, the coupling component 36 has a quick-release handle 78 that can be actuated to fix or unfix the position of the coupling component 36 along the length of the third link 34. That is, the handle 78 can be actuated to move the coupling component 36 into the unfixed configuration such that the component 36 can slide along the length of the link 34. Once the coupling component 36 (and thus the robotic device 74) is positioned at the desired point along the length of the link 34, the handle 78 can be moved into the fixed position, thereby fixing the coupling component 36 at that point such that the component 36 is not slidable. Thus, the coupling component 36 can move along the length of the third link 34 between an extended position and a retracted position and any position therebetween. Alternatively, the third link 34 can have any known component or device that provides for movement between an extended and retracted position.

[065] FIG. 8 depicts the axes of rotation 90, 92, 94 created by the joints 50, 60, 70 and further depict the linear stage D created by the coupling component 36 and third link 34. That is, rotation around axis 90 as shown at arrow A is caused by rotation of the first joint 50. Further, rotation around axis 92 as shown at arrow B is caused by rotation of the second joint 60. Finally, rotation around axis 94 as shown at arrow C is caused by rotation of the third joint 70. In addition, the linear movement represented by the arrow D results from the movement of the coupling component 36 along the third link 34. In one embodiment, the linear movement of the coupling component 36 is utilized at the surgeon's discretion to position the robotic device 74 further into the cavity of the patient (not shown) or to move the robotic device closer to the joint 70. In one implementation, the movement of the coupling component 36 in relation to the third link 34 is manual (and requires actuation of the quick-release lever 78 discussed above). Alternatively, the movement of the coupling component 36 can be motorized.

[066] In one embodiment, the rotational axis 90 at rotational joint 50 is perpendicular to both the rotational axis 92 at rotational joint 60 and the rotational axis 94 at joint 70. In other words, each axis 90, 92, 94 can be perpendicular in relation to the other two. The three axes 90, 92, 94

being perpendicular can, in some implementations, simplify the control of the system 20 by causing each axis 90, 92, 94 to contribute solely to a single degree of freedom. For example, if the third link 34 is rotated around axis 94, the tilt of the in vivo robotic device 74 does not change when all three axes 90, 92, 94 are perpendicular. Similarly, if the first link 30 is rotated around axis 90, only the tilt of the surgical device 74 from side to side is affected. Alternatively, two of the three axes 90, 92, 94 are perpendicular to each other. In a further alternative, none of the axes 90, 92, 94 are perpendicular to each other.

[067] FIG. 9 shows how the three local axes of rotation 90, 92, 94 of FIG. 8 result in the global orientation of the in vivo robot 74. That is, FIG. 8 depicts the actual axes of rotation 90, 92, 94 relating to each of the joints 50, 60, 70, respectively. In contrast, FIG. 9 depicts the global axes of rotation 100, 102, 104 that are created by the actual axes of rotation 90, 92, 94. That is, the global axes 100, 102, 104 are the axes used to describe the actual or desired orientation of the robotic device (such as device 74, for example). Thus, the axes 90, 92, 94 create global axis 100 such that rotation around axis 100 as shown at arrow D is the "pitch" rotation of the device 74. Further, the axes 90, 92, 94 create global axis 102 such that rotation around axis 102 as shown at arrow E is the "roll" rotation of the device 74. In addition, the axes 90, 92, 94 create global axis 104 such that rotation around axis 104 as shown at arrow F is the "yaw" rotation of the device 74. As such, according to certain embodiments, a desired global orientation of the device 74 can be controlled by the axes 90, 92, 94. For example, if the pitch of the device 74 is desired to be 90 degrees, then the local axes 90, 92, 94 can be rotated as necessary to some solved value such that the robotic device 74 has a pitch of 90 degrees.

[068] In one embodiment, as best shown in FIG. 8, the three axes 90, 92, 94 intersect at the intersection 100, also known as the "spherical joint" 100 as described above. The intersection 100 remains fixed at the same location, regardless of the positioning of the arm links 30, 32, 34, and can be used as the insertion point during surgeries. That is, the gross positioning system 20 can be positioned such that the intersection 100 is positioned at the incision in the patient through which the robotic device 74 is positioned.

[069] In one implementation, the intersection 100 causes the system 20 to act similarly to a spherical mechanism, as described above. In the device 20 as shown in FIG. 8, the configuration of the device 20 creates the spherical joint 100 such that the extender 34 must pass through the single point of the spherical joint 100, which is typically positioned at the incision in the patient. The spherical joint 100 created by the device 20 increases the size of the effective workspace for the surgical device 74 within the cavity of the patient while maintaining the spherical joint 100 at the incision.

[070] Alternatively, the gross positioning device 20 can have a fourth link, a fifth link, or any number of additional links, and a related additional number of rotational joints. Further, the device 20 can also have fewer than three links, and a related number of rotational joints. In sum, the gross positioning device 20 can have a single rotational joint, two rotational joints, or any number of rotational joints.

[071] According to one embodiment, the gross positioning device 20 can be controlled using the following control process 120 as shown in FIG. 10, according to one embodiment. A controller 122 is provided that is used as an input to communicate with the software architecture 124 (informally called the "RobotApp" in this exemplary embodiment). In accordance with one implementation, the software 124 is custom software 124 that allows for the integration of the different hardware and development of "plugins," thereby resulting in a modular platform on which it is easy to build additional features. Alternatively, the software architecture 124 limits the use of hardware to a limited set of hardware and has no modularity. In a further alternative, the software architecture 124 can be any known type of architecture.

[072] The communication from the controller 122 is interpreted (or "conditioned) by the software 124 (block 126) and used to calculate the kinematics (block 128). These kinematic calculations are then communicated to the gross positioning device 20 via a connection 130 such that the device 20 is actuated to move as communicated from the controller 122. In this specific embodiment, the connection is a USB port 130 in the hardware (not shown) that contains the software 124. The port 130 allows for connection of the gross positioning device 20 to the software 124 and thus to the controller 122. In one implementation, the controller 122 is the hardware that contains the software 124. Alternatively, the hardware can be any processing unit, such as a computer.

[073] According to certain embodiments, a hand controller is used to control the gross positioning device and/or the robotic device. In one implementation, the hand controller 150 is a joystick controller 150 as depicted in FIG. 11. The joystick controller 150 controls the orientation of the gross positioning device (such as device 20) A further controller embodiment 152 is depicted in FIG. 12, in which the controller 152 is the commercially available GeoMagic Touch™ controller 152. In this implementation, the controller 152 can be used to control the gross positioning device (such as device 20). In a further embodiment, the controller 152 can be used to control both the gross positioning device (such as device 20) and the robotic device (such as device 22), but the control scheme must be changed each time the user wants to switch from controlling one of the devices to the other.

[074] In another embodiment, two GeoMagic Touch™ controllers 152 are used in combination with a control process or application that allows for control of both the gross positioning device (such as device 20) and the robotic device (such as device 22) without having to change control schemes during a procedure. Instead, as best shown in FIGS. 13A and 13B, for purposes of the control process, the midpoint 160 between the two endpoints (end effectors) 162 of the *in vivo* robot 166 was identified. Using polar coordinates (θ, Φ), a midpoint envelope 164 was developed such that if the midpoint 160 leaves the area of the envelope 164, then the orientation of the *in vivo* robotic device 166 will be moved accordingly via the gross positioning device (such as device 20). More specifically, if the midpoint 160 of the end effectors 162 reaches the extent of the envelope 164, then the gross positioning device (such as device 20) will begin moving to adjust the view of the camera lens 168 on the device 166. As such, the robotic device 166 can control the view of the camera lens 168 by reaching or "gesturing" up, down, left, or right to move the camera lens 168 to the desired view. In order to stop the movement of the gross positioning device, the end effectors 162

must be returned to the midpoint profile (that is, they must be moved such that the midpoint 160 is within the envelope 164. In this way, the gross positioning device (such as device 20) and the robotic device (such as device 22) can both be operated such that the robotic device can reach the extent of the patient's cavity without changing control schemes.

[075] In one embodiment, the midpoint envelope 164 corresponds to the extent of the camera lens 168. Alternatively, other approaches could be used for different cameras or if the robotic device has an optimal workspace within which it must stay.

[076] Alternatively, the control process can operate in a different fashion, as best shown in FIGS. 14A and 14B. In this particular embodiment, if the midpoint 160 exits the envelope 164, both the gross positioning device (such as device 20) and the in vivo robotic device 166 could move together to keep the end effectors 162 fixed in space but return them inside the midpoint envelope 164 as shown. More specifically, the end effectors 162 are first offset to the right of the robotic device 166, but by repositioning the gross positioning device (such as device 20) and *in vivo* robot 166 together, the endpoints 162 remain fixed in space, but are returned inside the midpoint envelope 164.

[077] In use, the gross positioning device 20 and other embodiments disclosed or contemplated herein can operate in the following fashion to position the surgical device (such as device 22, device 74, or device 166) within the surgical space in the cavity of the patient through the incision. The three links 30, 32, 34 rotate about the respective axes 90, 92, 94 to position the device 22, 74, 166 as desired. More specifically, the third link 34 can be rotated around axis 94 to rotate the surgical device 22, 74, 166 about the axis 94. Further, the arm links 30, 32 in combination with the extender 34 can be used to articulate the device 20 through two separate angular planes. That is, the two axes 90, 92 can affect the angular position of the extender 34. In addition, the coupling component 36 can be extended or retracted to allow for the surgical device 22, 74, 166 to be advanced into and out of the cavity of the patient.

[078] In one implementation, the positioning system 20 and the surgical device 22, 74, 166 can be used in combination, such that the surgical device 22, 74, 166 is treated as an extension of the positioning system 20 wherein both are used together to move and operate the surgical device 22, 74, 166. For example, the surgeon may want to move the surgical device 22, 74, 166 a total of one inch to the right and thus actuates an external controller to cause this move. The controller (such as any controller embodiment discussed above) transmits the appropriate signals to the positioning system 20 and the surgical device 22, 74, 166 such that the system 20 and device 22, 74, 166 work in combination to move the surgical device 22, 74, 166 one inch to the right. In one example, the system 20 could move .5 inches and the device 22, 74, 166 could move .5 inches, thereby resulting in the device 22, 74, 166 moving the full one inch as desired. According to one embodiment, the positioning system 20 can thus be used to maximize the strength, workspace, and maneuverability of the combination of the system 20 and the device 22, 74, 166 by determining the optimal contribution of each component during use.

[079] Alternatively, the positioning system 20 and the device 22, 74, 166 operate separately. That is, the system 20 is not operable or does not operate while the device 22, 74, 166 is being used, and the device 22, 74, 166 is not operable or does not operate while the system 20 is

being used. For example, if the device 22, 74, 166 is being used and it is determined that a target object in the surgical space is outside the reach of the device 22, 74, 166, the device 22, 74, 166 is "shut down," otherwise rendered inoperable, or simply placed in a "pause mode," and the system 20 is used to reposition the device 22, 74, 166 accordingly.

[080] It is understood that the device 20 can be operably coupled to a processor or computer (not shown) such that the processor can be used to control the positioning system 20, including movement of the arm links 30, 32, 34 to grossly position the surgical device 22, 74, 166.

[081] In a further alternative implementation, the positioning system 20 can also be configured to incorporate or integrate equipment or devices that couple to the surgical device 22, 74, 166 to provide various functionalities to the device 22, 74, 166. For example, in one embodiment, the system 20 can contain suction and irrigation equipment that couples to corresponding equipment in the surgical device 22, 74, 166 such that the surgical device 22, 74, 166 includes suction and irrigation components. In another example according to a further implementation, the positioning device 20 can contain any known equipment that is configured to couple to corresponding equipment in the surgical device 22, 74, 166.

[082] Alternative embodiments contemplated herein also include systems that can be used with surgical devices that are magnetically controlled (in contrast to the surgical devices described above, which are controlled via a body or positioning rod inserted through the surgical incision). In those implementations, the positioning system positions the surgical device anywhere along an internal surface inside the patient's cavity by positioning an external magnetic component (such as a magnetic handle or other type of external magnetic component) along the outer skin of the patient. This positioning of the device can include any combination of movement in two dimensions along the surface of the patient's skin as well as rotation of the external magnetic component about an axis perpendicular to the surface of the skin. Of course, it is understood that while the movement of the magnetic component along the skin of the patient is considered to be two dimensional, the patient's skin is curved such that movement of the external component along the skin demonstrates absolute manipulation in all six degrees of freedom.

[083] Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

Claims

What is claimed is:

1. A gross positioning system for use with a robotic surgical device, the system comprising:
   (a) a base;
   (b) a first arm link operably coupled to the base at a first rotational joint;
   (c) a second arm link operably coupled to the first arm link at a second rotational joint;
   (d) a third arm link operably coupled to the second arm link, wherein the third arm link is rotatable about a third rotational joint, wherein the third arm link is configured to be positionable through an incision in a patient; and
   (e) a slidable coupling component slidably coupled to the third arm link such that the slidable coupling component can move along a length of the third arm link between an extended position and a retracted position, wherein the slidable coupling component is configured to be coupleable to the robotic surgical device.

2. The gross positioning system of claim 1, wherein an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint intersect at a single point of intersection.

3. The gross positioning system of claim 2, wherein the single point is a spherical joint.

4. The gross positioning system of claim 2, wherein the single point of intersection is disposed at some point along a portion of the robotic surgical device.

5. The gross positioning system of claim 2, wherein the gross positioning system is positioned such that the single point of intersection is disposed at an incision in a patient.

6. The gross positioning system of claim 5, wherein the third arm link is disposed through the single point of insertion.

7. The gross positioning system of claim 2, wherein the single point of intersection is disposed at an insertion point of a patient.

8. The gross positioning system of claim 7, wherein the insertion point comprises an incision or a natural orifice.

9. The gross positioning system of claim 7, wherein the third arm link is disposed through the single point of intersection.

10. The gross positioning system of claim 1, wherein the robotic surgical device comprises at least one arm, wherein the gross positioning system and robotic surgical device are configured to operate together to position the robotic surgical device within a body cavity of a patient.

11. The gross positioning system of claim 10, further comprising a controller operably coupled to the gross positioning system and the robotic surgical device.

12. A gross positioning system for use with a robotic surgical device, the system comprising:

(a) a base;

(b) a first arm link operably coupled to the base at a first rotational joint;

(c) a second arm link operably coupled to the first arm link at a second rotational joint;

(d) a third arm link operably coupled to the second arm link at a third rotational joint;

(e) a slidable coupling component slidably coupled to the third arm link; and

(f) the robotic surgical device operably coupled to the slidable coupling component, the robotic surgical device comprising:

(i) a device body;

(ii) a first arm operably coupled to the device body, the first arm comprising at least one first actuator; and

iii) a second arm operably coupled to the device body, the second arm comprising at least one second actuator,

wherein the third arm link is positionable through an insertion point in a patient such that the robotic surgical device is positionable within a body cavity of the patient.

13. The gross positioning system of claim 12, wherein the slidable coupling component is slidable along a length of the third arm link between an extended position and a retracted position.

14. The gross positioning system of claim 12, wherein an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint intersect at a single point of intersection and the third arm link is disposed through the single point of intersection.

15. An external gross positioning system for use with an internal robotic surgical device, the system comprising:

(a) a base;

(b) a first arm link operably coupled to the base at a first rotational joint;

(c) a second arm link operably coupled to the first arm link at a second rotational joint;

(d) a third arm link operably coupled to the second arm link at a third rotational joint;

(e) a slidable coupling component slidably coupled to the third arm link such that the slidable coupling component is moveable along a length of the third arm link between an extended position and a retracted position, wherein the slidable coupling component is configured to be coupleable to the robotic surgical device; and

(f) a single point of intersection of an axis of rotation of the first rotational joint, an axis of rotation of the second rotational joint, and an axis of rotation of the third rotational joint, wherein the single point of intersection is disposed at an insertion point of a patient.

16. The gross positioning system of claim 15, wherein a portion of the third arm link is disposed through the single point of intersection.

17. The gross positioning system of claim 15, wherein a portion of the robotic surgical device is disposed through the single point of intersection.

18. The gross positioning system of claim 15, wherein the insertion point is an incision.

19. The gross positioning system of claim 15, wherein the robotic surgical device comprises at least one arm, wherein the gross positioning system and robotic surgical device are configured to operate together to position the robotic surgical device within a body cavity of the patient.

20. The gross positioning system of claim 19, further comprising

(a) a central processing unit operably coupled to the gross positioning system and the robotic surgical device, wherein the central processing unit comprises software configured to transmit control instructions to the gross positioning system and the robotic surgical device; and

(b) a controller operably coupled to the central processing unit.

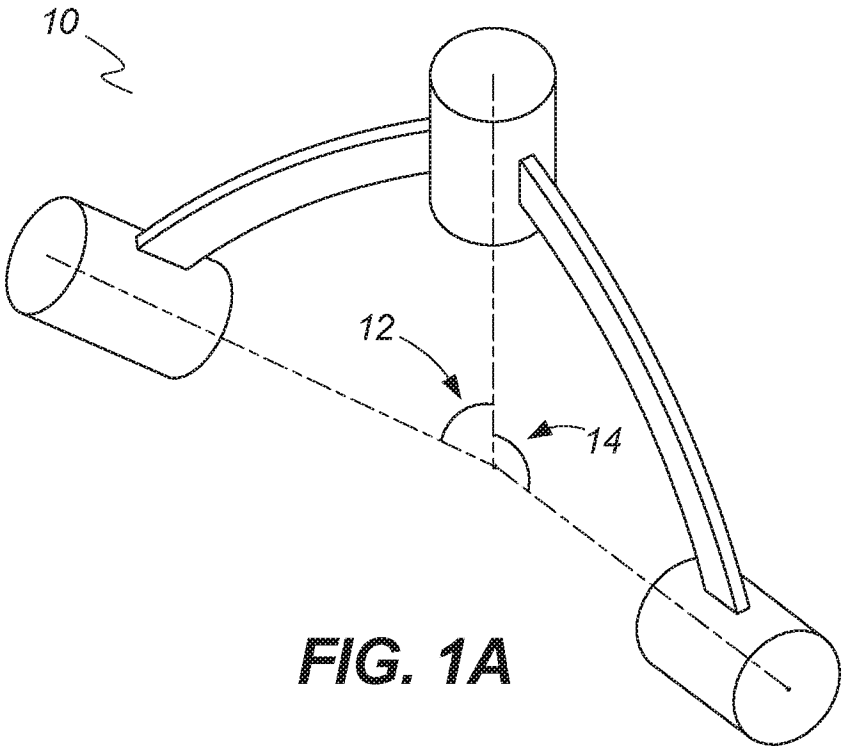


FIG. 1A

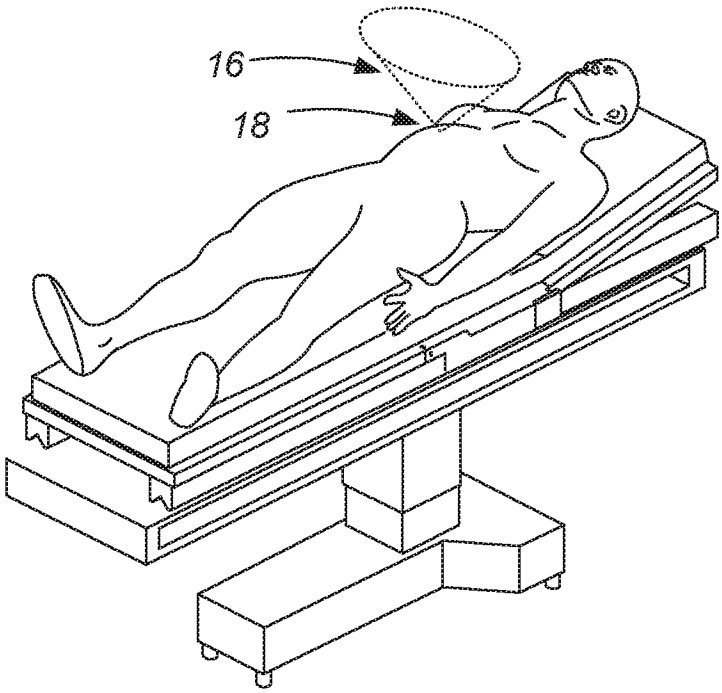


FIG. 1B

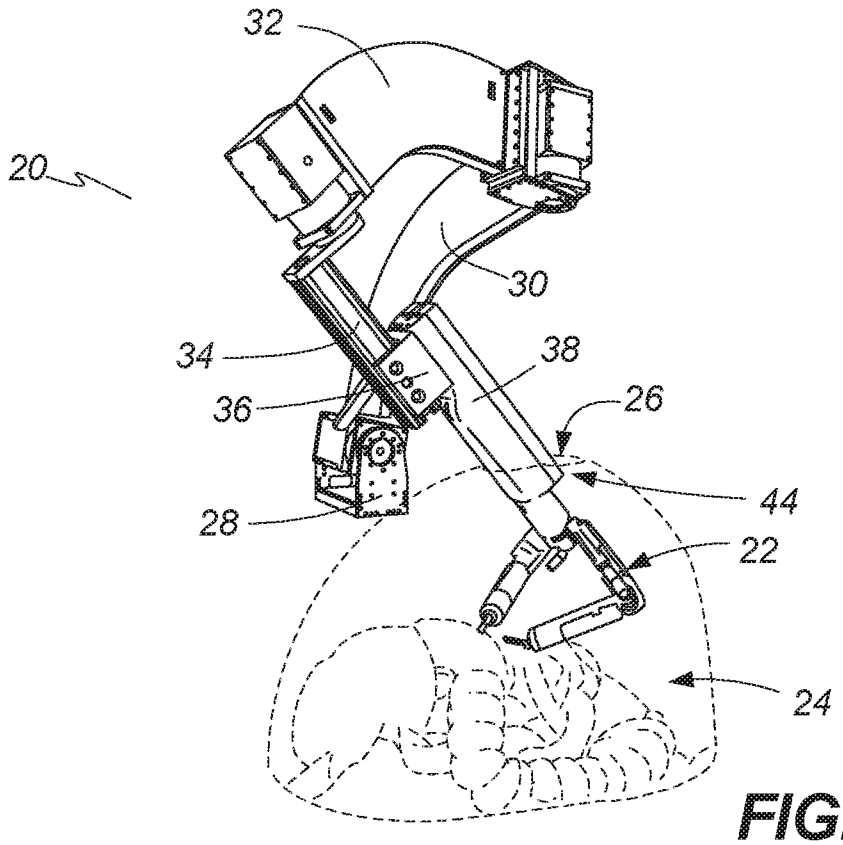

32
20
30
34
38
36
26
44
28
22
24

FIG. 2A

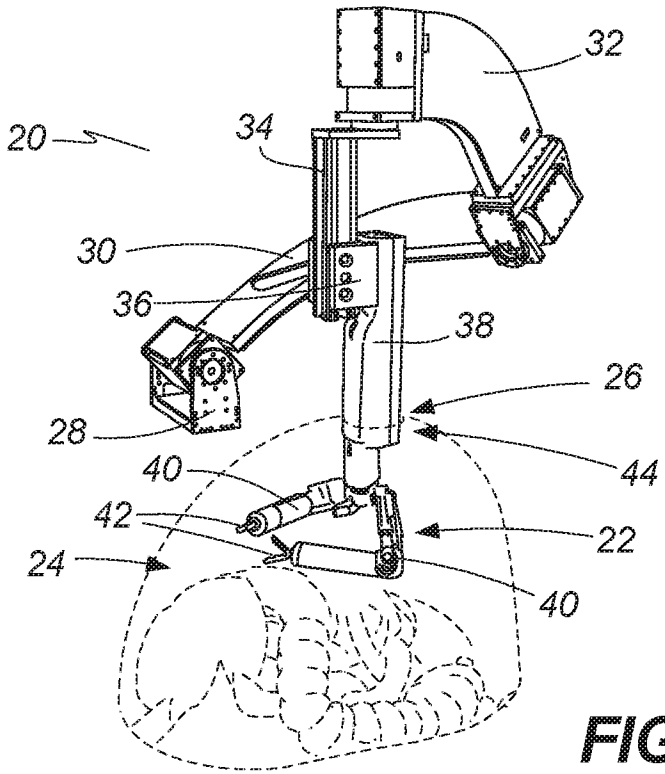

32
20
34
30
36
38
26
28
44
40
42
22
24
40

FIG. 2B

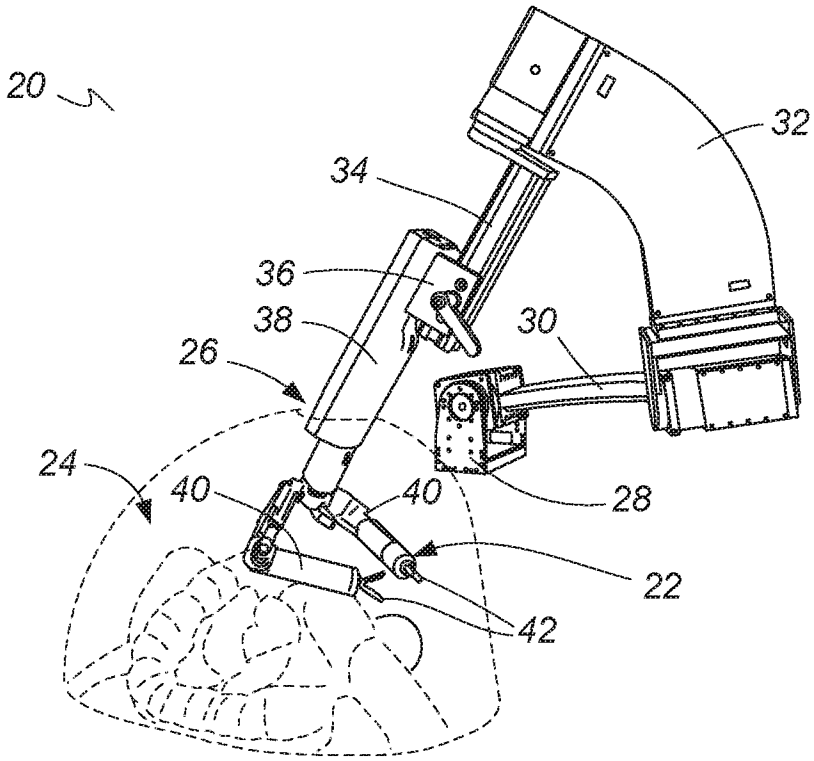


FIG. 2C

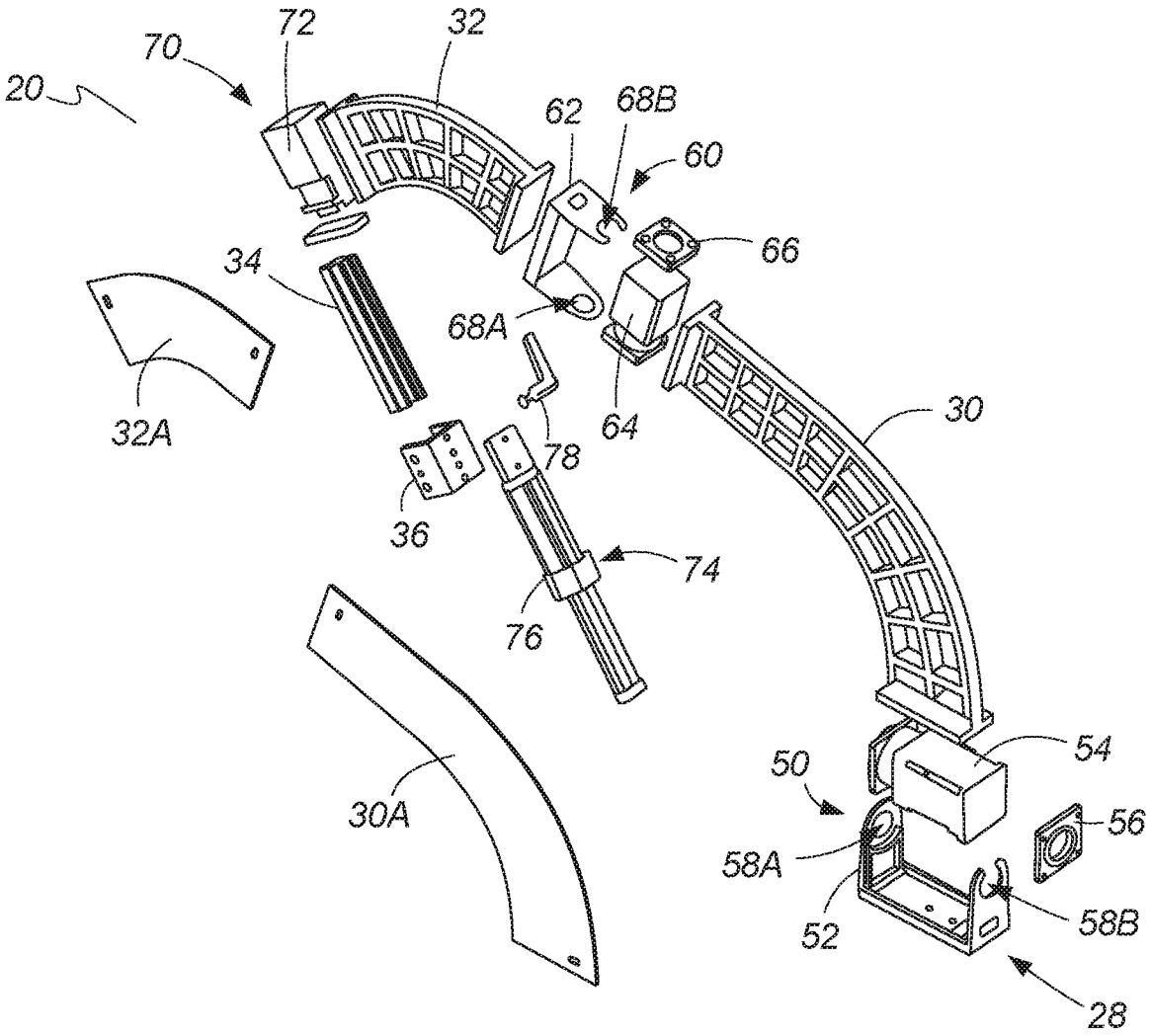

20
70
72
32
62
68B
60
66
34
68A
64
30
32A
78
36
74
76
30A
50
54
56
58A
52
58B
28

FIG. 3

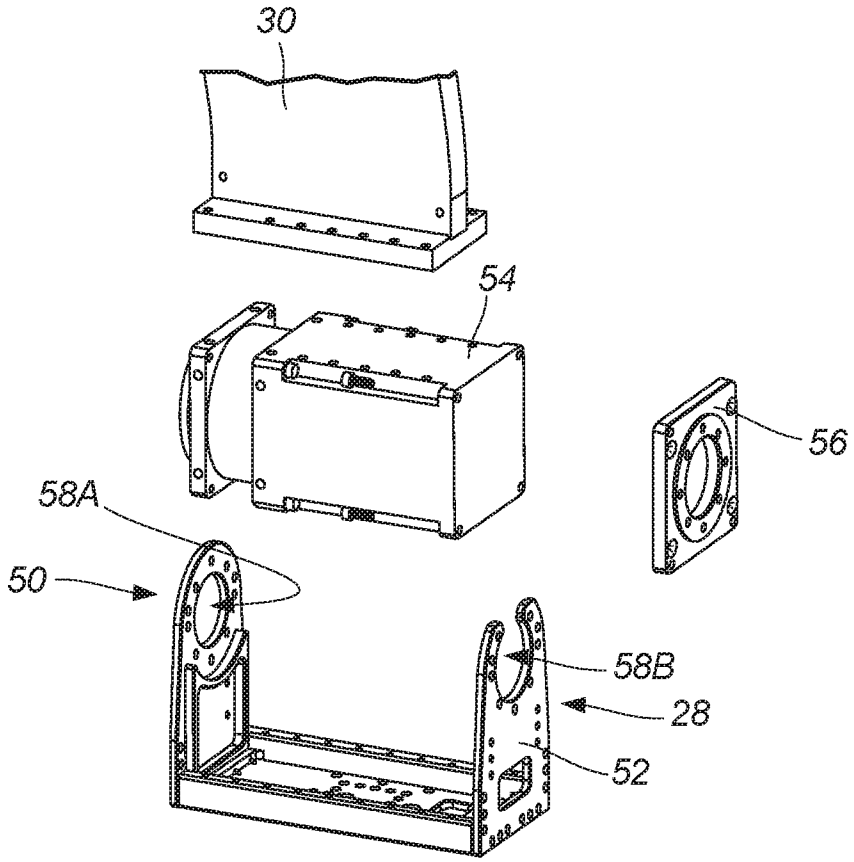


FIG. 4

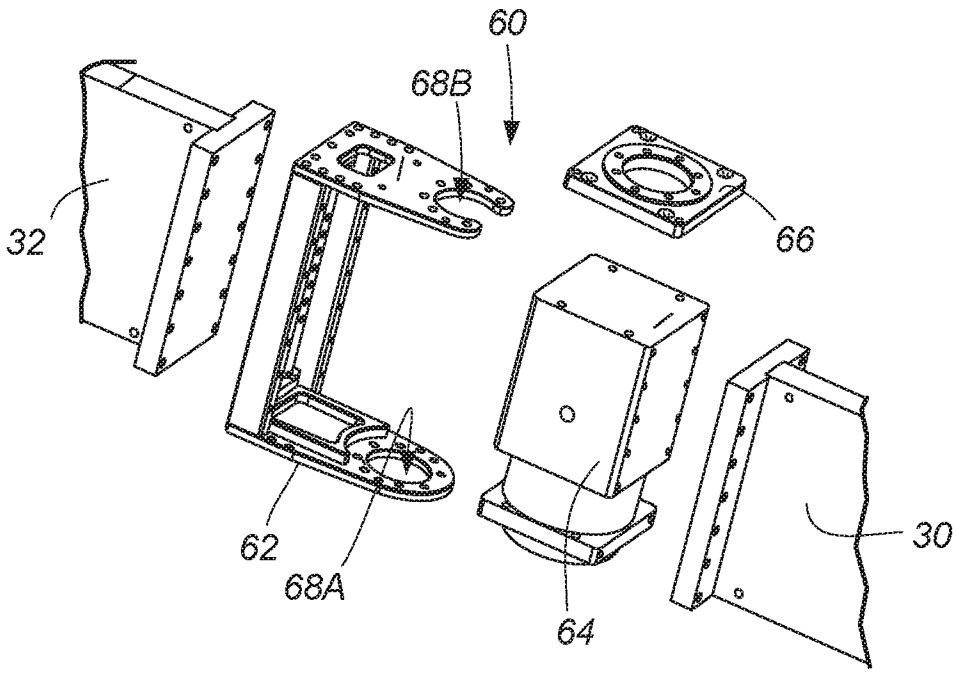


FIG. 5

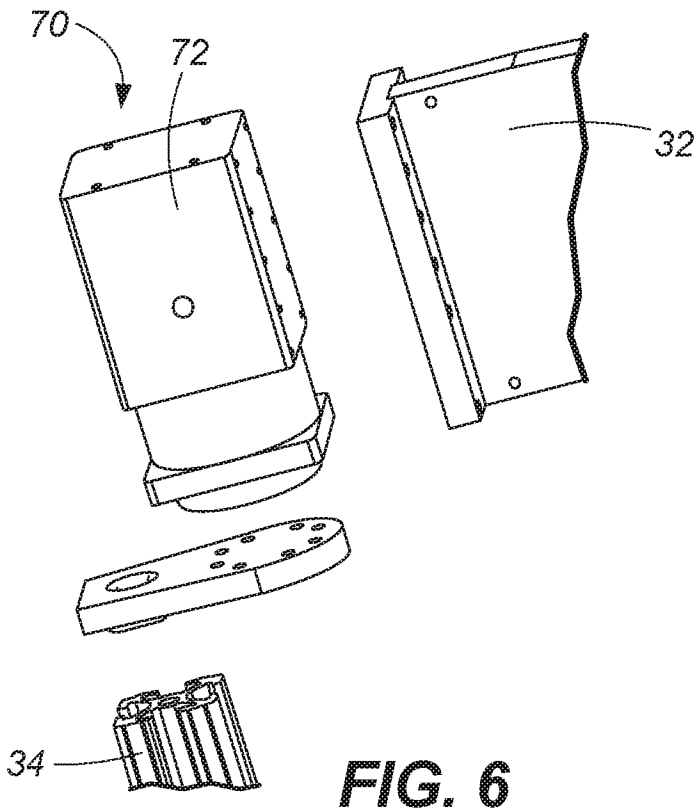


FIG. 6

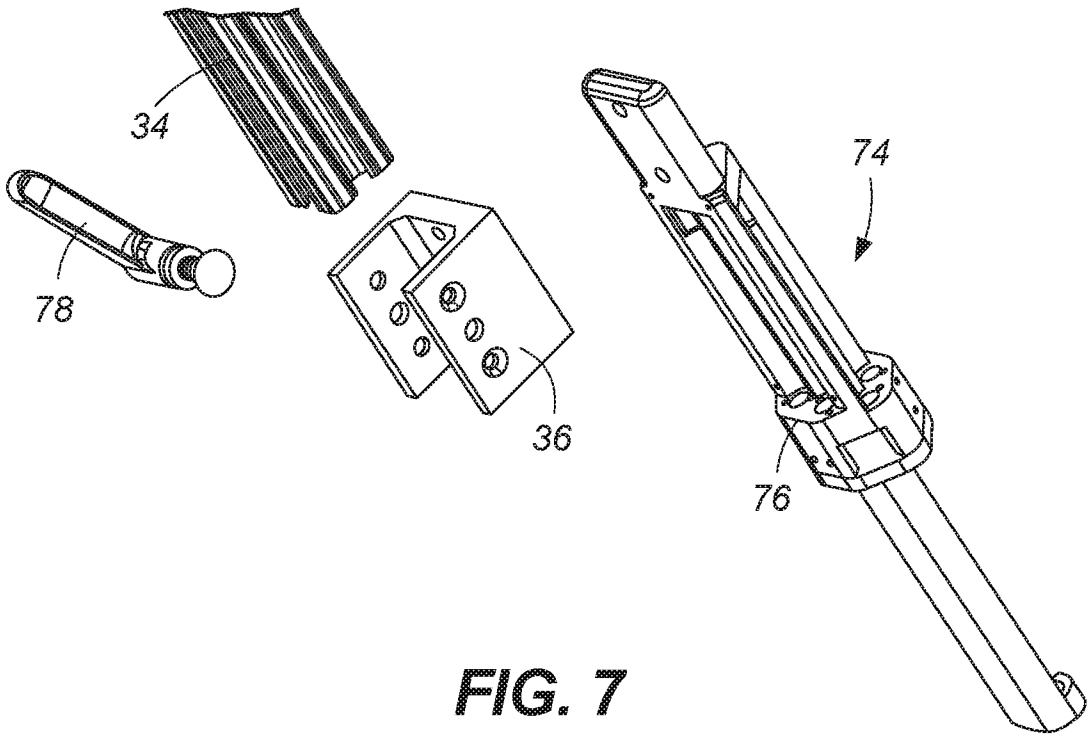


FIG. 7

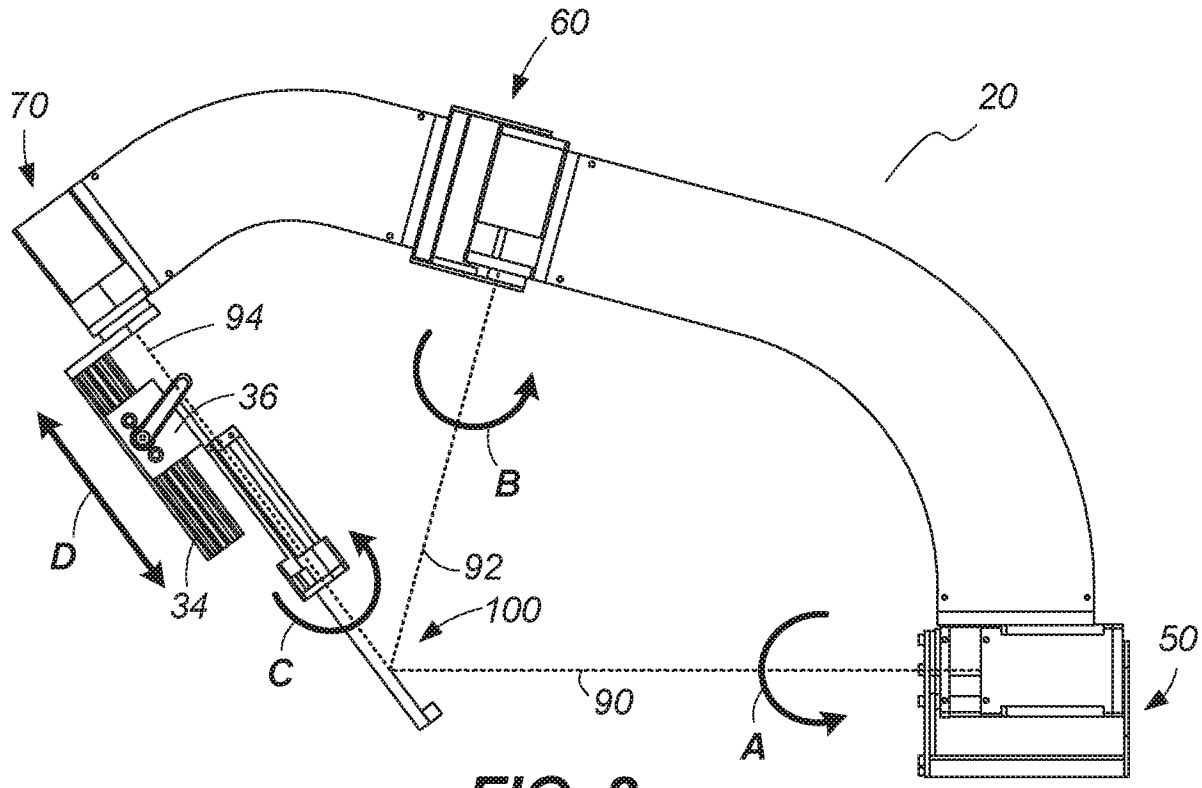


FIG. 8

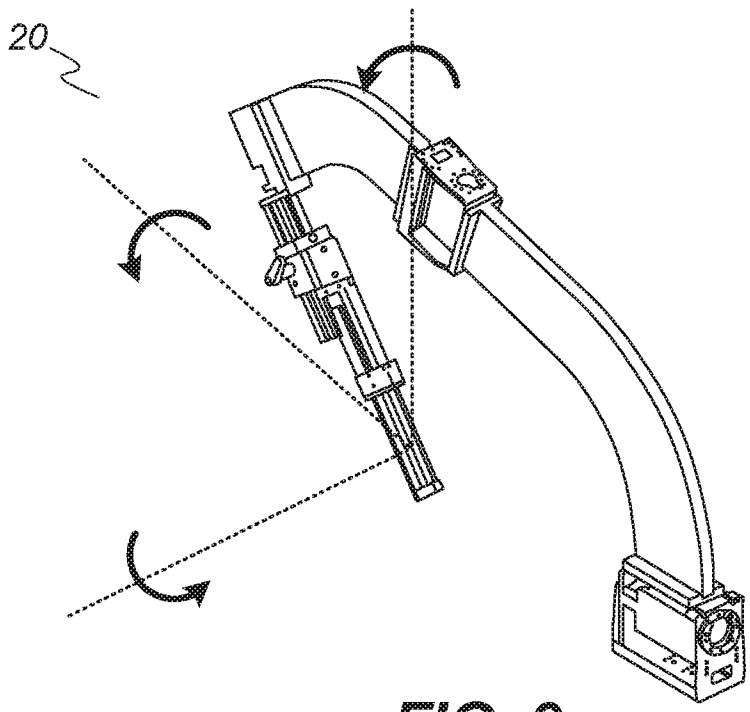


FIG. 9

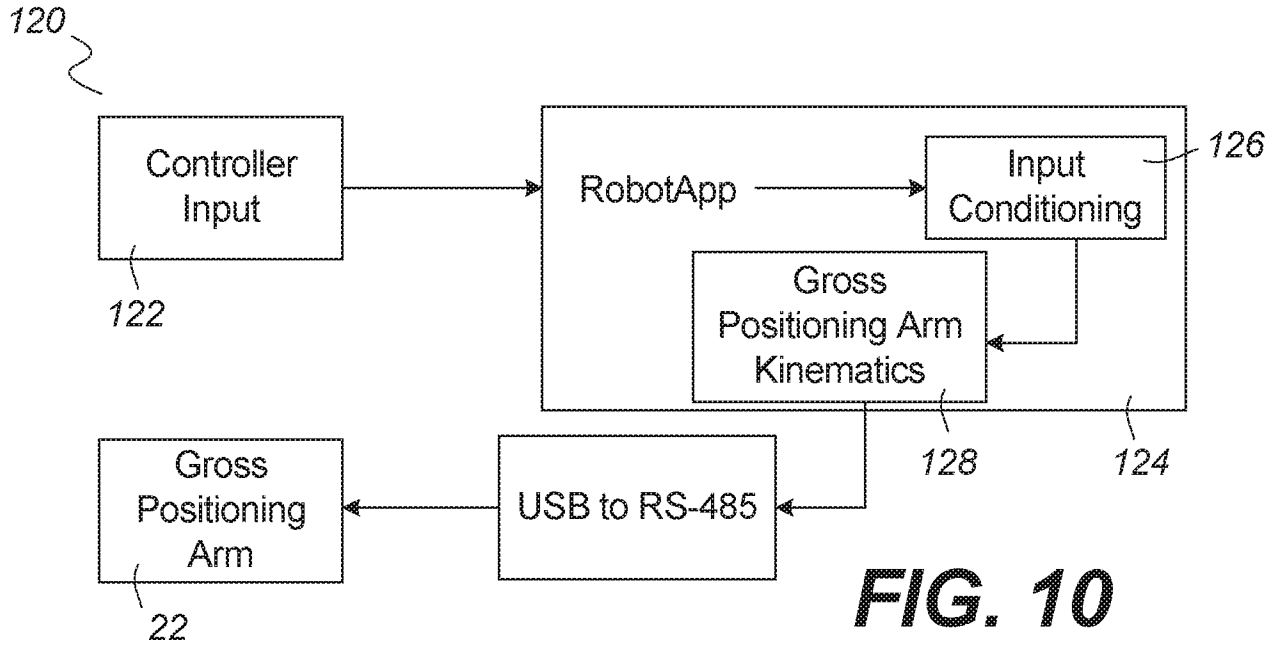


FIG. 10

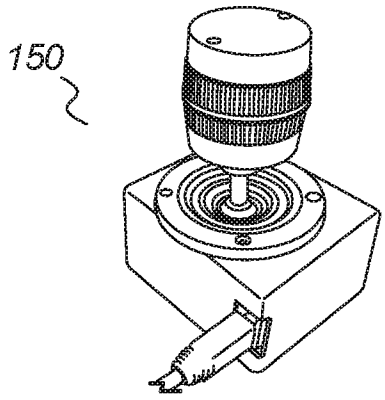


FIG. 11

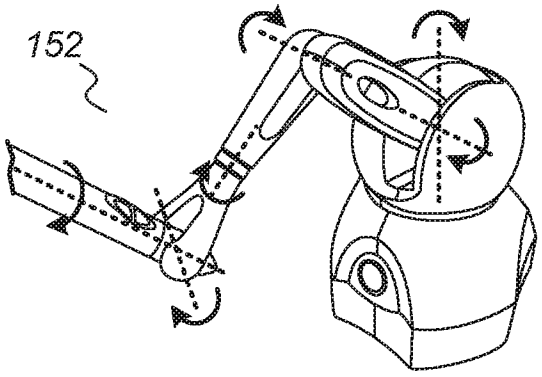


FIG. 12

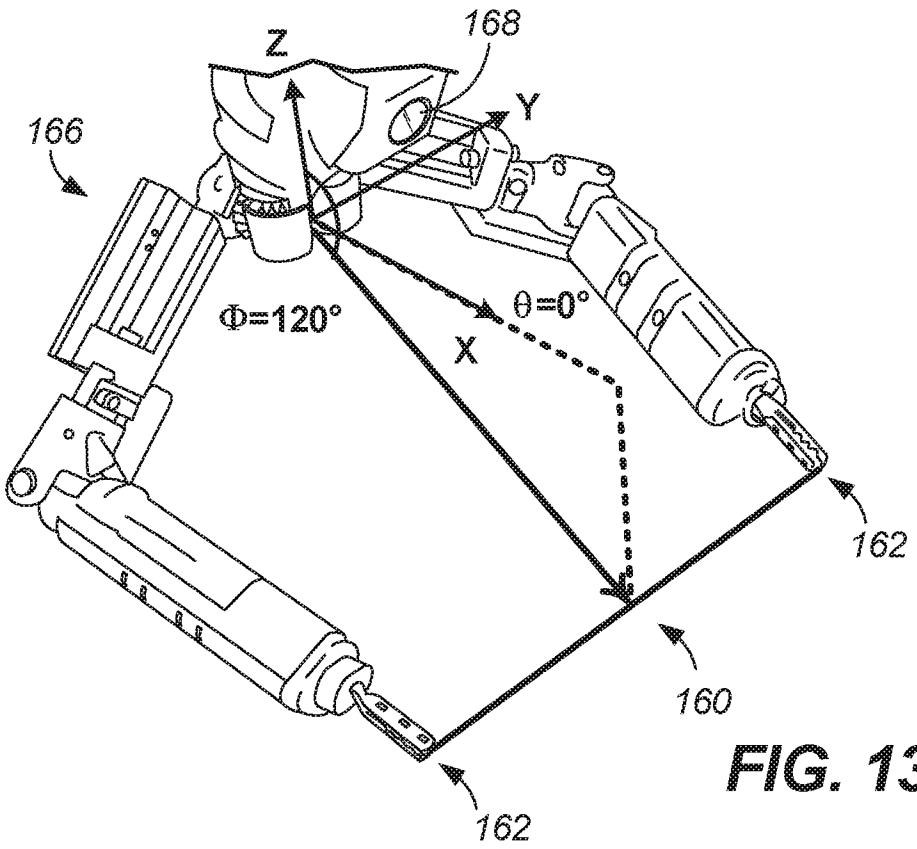


FIG. 13A

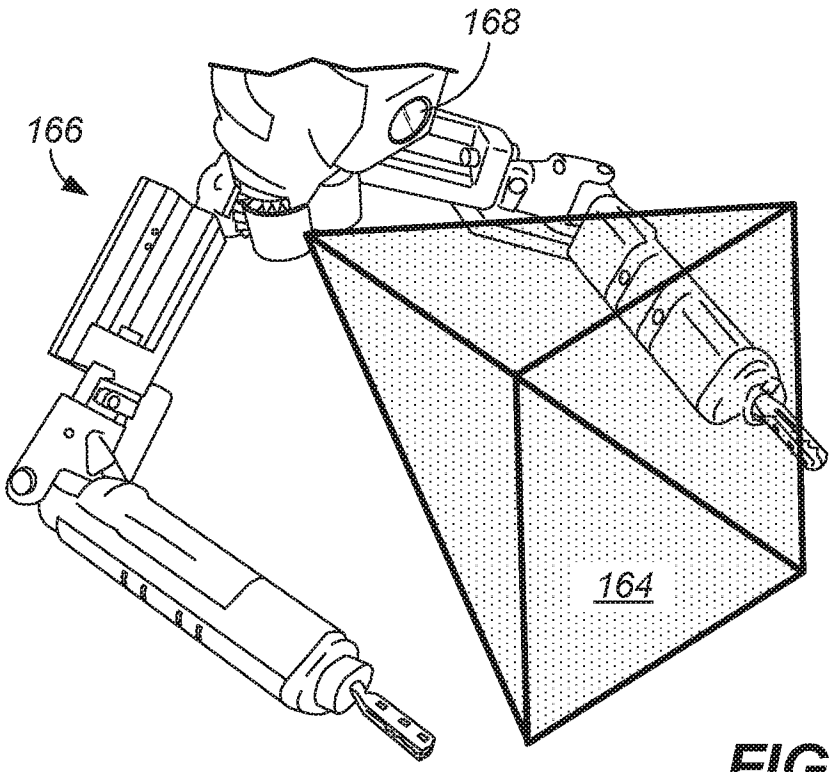


FIG. 13B

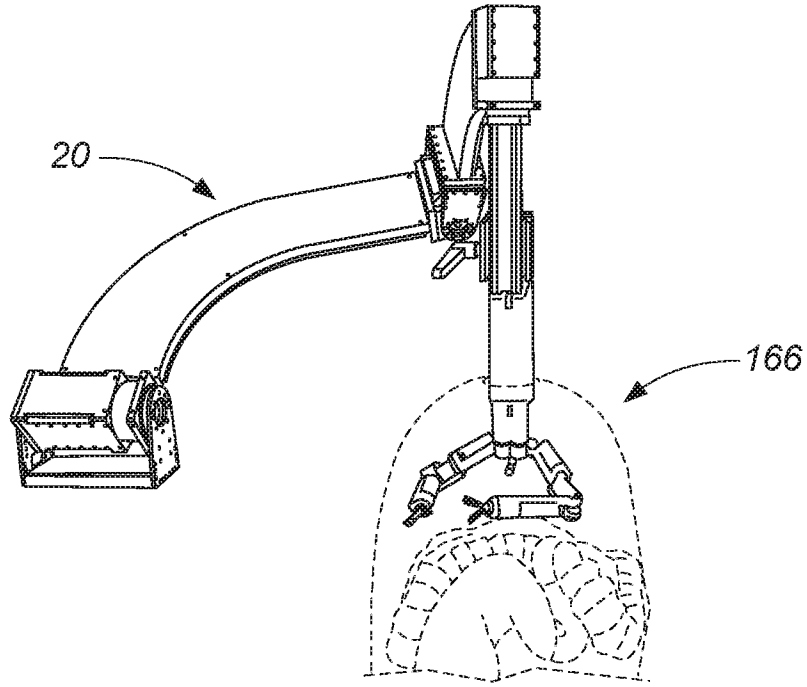


FIG. 14A

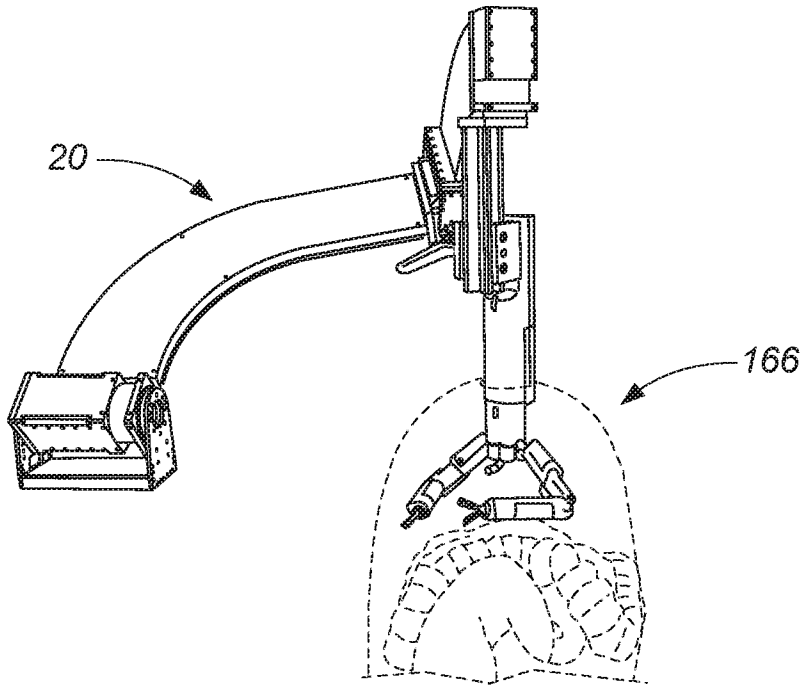


FIG. 14B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 17/63067

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61B 34/20, A61B 34/30, B25J 9/04, A61B 34/00 (2018.01)
CPC - A61B 2034/302, A61B 34/20, B25J 9/06, A61B 34/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/160086 A2 (BOARD OF REGENTS OF THE UNIVERSITY OF NEBRASKA) 02 October 2014 (02.10.2014) Entire document, especially para [062]-[063], [0104], [0107], [0110], [0113], [0115], [0118] and figs. 14A-14B and 1A-1C.	1-20
A	US 2007/070685 A1 (KANG et al.) 22 November 2007 (22.11.2007) Entire document.	1-20
A	US 2013/0345717 A1 (BOARD OF REGENTS OF THE UNIVERSITY OF NEBRASKA) 26 December 2013 (26.12.2013) Entire document.	1-20
A	US 2016/0015461 A1 (BOARD OF REGENTS OF THE UNIVERSITY OF NEBRASKA) 21 January 2016 (21.01.2016) Entire document.	1-20
A	WO 2015/132549 A1 (CAMBRIDGE MEDICAL ROBOTICS LIMITED) 11 September 2015 (11.09.2015) Entire document.	1-20
A	US 2009/0234369 A1 (BAX et al.) 17 September 2009 (17.09.2009) Entire document.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 January 2018	01 FEB 2018
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)