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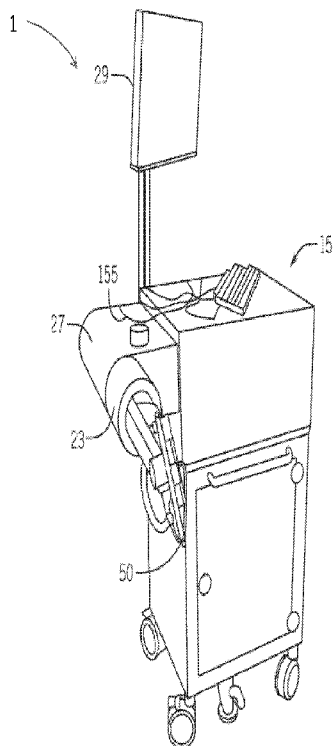


FIG. 1A

(57) Abstract: Embodiments of the invention provide a guided surgical tool assembly with a guide tube including a sensor, a surgical instrument including a detectable feature moveable within the guide tube, and the sensor capable of detecting the detectable feature when the surgical instrument is inserted in the guide tube. Some embodiments include a sensor pad, a guide stop coupled to the surgical instrument, a plunger mechanism including a compressible spring mechanism coupled to the guide tube, and a wiper capable of being sensed by the sensor pad. Some embodiments include a guided surgical tool assembly system comprising a tool sensor system including a processor and at least one data input/output interface. Some embodiments include a medical robot system with a guided surgical tool assembly and including a robot coupled to an effector element configured for controlled movement and positioning along one or more of an x-axis, a y-axis and a z-axis.

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## SURGICAL TOOL SYSTEMS AND METHOD

## RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 120 to United States Patent Application No. 13/924,505 filed on June 21<sup>st</sup>, 2013, which claims the priority 35 U.S.C. § 119 to United States Provisional Patent Application No. 61/662,702 filed on June 21<sup>st</sup>, 2012 and United States Provisional Patent Application No. 61/800,527 filed on March 15<sup>th</sup>, 2013, each of which are incorporated herein by reference in their entirety.

## BACKGROUND

[0002] Various medical procedures require the accurate localization of a three-dimensional position of a surgical instrument within the body in order to effect optimized treatment. For example, some surgical procedures to fuse vertebrae require that a surgeon drill multiple holes into the bone structure at specific locations. To achieve high levels of mechanical integrity in the fusing system, and to balance the forces created in the bone structure, it is necessary that the holes are drilled at the correct location. Vertebrae, like most bone structures, have complex shapes including non-planar curved surfaces making accurate and perpendicular drilling difficult. Conventionally, a surgeon manually holds and positions a drill guide tube by using a guidance system to overlay the drill tube's position onto a three dimensional image of the bone structure. This manual process is both tedious and time consuming. The success of the surgery is largely dependent upon the dexterity of the surgeon who performs it.

[0003] Limited robotic assistance for surgical procedures is currently available. For example, the da Vinci® medical robot system (da Vinci® is a registered trademark of Intuitive Surgical) is a robot used in certain surgical applications. In the da Vinci® system, the user controls manipulators that control a robotic actuator. The system converts the surgeon's gross movements into micro-movements of the robotic actuator. Although the da Vinci® system eliminates hand tremor and provides the user with the ability to work through a small opening, like many of the robots commercially available today, it is expensive, obtrusive, and the setup is cumbersome. Further, for procedures such as thoracolumbar pedicle screw insertion, these conventional methods are known to be error-prone and tedious.

[0004] One of the characteristics of many of the current robots used in surgical applications which make them error prone is that autonomous movement and precise placement of a surgical instrument can be hindered by lack of mechanical feedback and/or loss of visual placement once the instrument is submerged within a portion of a patient.

#### SUMMARY

[0005] Some embodiments of the invention provide a guided surgical tool assembly comprising a guide tube including at least one sensor and a surgical instrument including at least one detectable feature moveable within the guide tube. In some embodiments, the at least one sensor is configured and arranged to detect the at least one detectable feature when the surgical instrument is at least partially inserted in the guide tube.

[0006] Some embodiments include a detectable feature comprising a magnetically detectable feature capable of generating a magnetic flux field, and in some embodiments, the sensor is a position sensor capable of detecting the magnetic flux field. Some embodiments also include a position sensor configured and arranged to detect insertion into and movement of the surgical instrument in the guide tube by sensing the magnetically detectable feature. In some embodiments, the position sensor is a magnetic flux field sensor selected from a group consisting of a ferrite-based magnetic material, a rare-earth based magnetic material, an aluminum-nickel-cobalt based magnetic material, and mixtures thereof.

[0007] In some embodiments, the detectable feature includes at least one longitudinal magnetic strip and at least one radial magnetic strip. Further, in some embodiments, the guide tube includes at least three position sensors, and in some embodiments, the at least three position sensors are configured and arranged to sense a magnetic field flux from the longitudinal magnetic strip or the radial magnetic field strip or both.

[0008] In some embodiments, the longitudinal position of the surgical instrument in the guide tube can be at least partially determined using a measurement of a magnetic field flux from the longitudinal magnetic strip. In other embodiments, a radial position of the surgical instrument in the guide tube can be at least partially determined using a measurement of a magnetic field flux from the radial magnetic strip.

[0009] Some embodiments include a detectable feature comprising an optically detectable feature, and at least one sensor comprising at least one optical sensor. In some embodiments, the optically detectable feature comprises a contrasting or high contrast marking distributed along at least a partial longitudinal length of the guided surgical tool assembly.

[0010] Some embodiments include at least one optical sensor comprising a light sensitive detector selected from a group consisting of a photodiode, a phototransistor, a fiber-optic sensor, a photo-multiplier, a CCD, a camera, or a combination thereof.

[0011] In some embodiments, the longitudinal position of the surgical instrument in the guide tube can be at least partially determined by optically sensing light from the high contrast marking using the at least one optical sensor.

[0012] Some embodiments include an optically detectable feature comprising a graduated coating distributed along at least a partial longitudinal length of the guided surgical tool assembly. In some embodiments, the graduated coating comprises a graduated reflective coating. In other embodiments, the graduated coating comprises a graduated color coating.

[0013] In some embodiments, the longitudinal position of the surgical instrument in the guide tube can be at least partially determined by optically sensing light from the graduated coating using the at least one optical sensor.

[0014] Some embodiments include a guided surgical tool assembly wherein the guide tube comprises a distal guide tube end and a proximal guide tube end, and the surgical instrument includes a distal end and a proximal end. In some embodiments, the sensor comprises at least one sensor pad. The guided surgical tool assembly can further comprise a guide stop coupled to the proximal end of the surgical instrument, and a plunger mechanism. The plunger mechanism can include a compressible spring mechanism coupled to the distal end of the guide tube and a wiper configured and arranged to be sensed by the at least one sensor pad.

[0015] In some embodiments of the guided surgical tool assembly, longitudinal movement of the surgical instrument within the guide tube (where the guide stop moves toward the proximal end of the guide tube) can at least partially compress the spring and move the wiper with respect

to the at least one sensor pad. In other embodiments, longitudinal movement of the surgical instrument within the guide tube where the guide stop moves away from the proximal end of the guide tube can at least partially decompress the spring and move the wiper with respect to the at least one sensor pad.

[0016] Some embodiments include a guided surgical tool assembly system comprising a tool sensor system including at least one processor and at least one data input/output interface. In some embodiments, the data input interface including at least one sensor, a guide tube including the at least one sensor, and a surgical instrument moveable within the guide tube. In some embodiments, the surgical instrument includes at least one detectable feature, and the at least one sensor is configured and arranged to detect the at least one detectable feature.

[0017] In some embodiments, the guided surgical tool assembly system includes a guide tube comprising a distal guide tube end and a proximal guide tube end, and the surgical instrument includes a distal end and a proximal end. In some embodiments, the sensor comprises at least one sensor pad, and the guided surgical tool assembly further comprises a guide stop coupled to the proximal end of the surgical instrument, the plunger mechanism can include a compressible spring mechanism coupled to the distal end of the guide tube and a wiper configured and arranged to be sensed by the at least one sensor pad. The at least one processor can be configured and arranged to detect the at least one surgical instrument when the instrument at least partially inserted or moved in the guide tube.

[0018] In some embodiments of the guided surgical tool assembly system, the detectable feature comprises a magnetically detectable feature capable of generating a magnetic flux field. The sensor can be a position sensor capable of detecting the magnetic flux field, and be configured and arranged to detect insertion into and movement of the surgical instrument in the guide tube by sensing the magnetically detectable feature.

[0019] Some embodiments include a guided surgical tool assembly system in which the detectable feature comprises an optically detectable feature, and the at least one sensor comprises at least one optical sensor. The optically detectable feature can comprise a contrasting or high contrast marking distributed along at least a partial longitudinal length of the guided surgical tool assembly. In some embodiments, the detectable feature comprises an optically detectable

feature, and the at least one sensor comprises at least one optical sensor. The optically detectable feature can comprise a graduated coating distributed along at least a partial longitudinal length of the guided surgical tool assembly.

[0020] Some embodiments include a medical robot system comprising a robot coupled to an effector element configured for controlled movement and positioning, and a motor assembly coupled to the robot. The motor assembly can be configured to move the effector element along one or more of an x-axis, a y-axis, and a z-axis such that movement of the effector element along one of the x-, y-, or z-axes occurs independently of movement of the effector element along the other axes of the x-, y-, and z-axes, wherein the x-axis is substantially perpendicular to the y- and z-axes, the y-axis is substantially perpendicular to the x- and z-axes, and the z-axis is substantially perpendicular to the x- and y axes.

[0021] In some embodiments, the medical robot system also comprises a tool sensor system including at least one processor and at least one data input/output interface, the data input interface including at least one sensor, and a guide tube including the at least one sensor. In some embodiments, the surgical instrument is moveable within the guide tube, and the surgical instrument includes at least one detectable feature. Further, in some embodiments, the at least one sensor is configured and arranged to detect the at least one detectable feature, and the at least one processor is configured and arranged to detect when the surgical instrument is at least partially inserted in the guide tube. In some embodiments, the detectable feature can include one or more of instrument length, type, torque ranges, depth of treatment parameters and other instrument parameters. Some embodiments include a tracking marker coupled to the surgical instrument.

## DESCRIPTION OF THE DRAWINGS

[0022] FIGS. 1A-1B illustrate a surgical robot in accordance with one embodiment of the invention.

[0023] FIG. 1C illustrates a portion of a surgical robot with control of the translation and orientation of the end-effector in accordance with another embodiment of the invention.

[0024] FIG. 1D illustrates a partial view of a surgical robot having a plurality of optical markers mounted for calibration and tracking movement in accordance with one embodiment of the invention.

[0025] FIG. 2 illustrates a surgical robot operating on a patient in accordance with one embodiment of the invention.

[0026] FIGS. 3A-3B each illustrates a tool assembly including a surgical instrument having a guide stop mechanism in accordance with one embodiment of the invention.

[0027] FIGS. 4A-4D each depict a tool assembly including a surgical instrument having a guide stop mechanism in accordance with one embodiment of the invention.

[0028] FIGS. 5A-5C each illustrates tools for manually adjusting a drill stop with reference to drill bit markings in accordance with one embodiment of the invention.

[0029] FIGS. 5D-5F each illustrates tools for locking and holding a drill bit in a set position in accordance with one embodiment of the invention.

[0030] FIGS. 5G-5H each illustrates methods of use of the tools as depicted in FIGS. 5A-5F with a robot end effector coupled to a robot system.

[0031] FIG. 6A illustrates a tool assembly including a surgical instrument having a sensor enabled guide stop mechanism in accordance with one embodiment of the invention.

[0032] FIG. 6B illustrates a tool assembly system architecture in accordance with one embodiment of the invention.

[0033] FIG. 7A illustrates a tool comprising a surgical instrument having a guide stop mechanism in accordance with another embodiment of the invention.

[0034] FIG. 7B is a modified guide tube for use with the tool assembly shown in FIG. 7C in accordance with one embodiment of the invention.

[0035] FIG. 7C shows the tool shown in FIG. 7A inserted within the modified guide tube shown in FIG. 7B to form a tool assembly in accordance with one embodiment of the invention.



[0036] FIG. 8A illustrates a tool assembly including a surgical instrument having a guide stop mechanism in accordance with another embodiment of the invention.

[0037] FIG 8B illustrates a tool assembly including a surgical instrument having a guide stop inserted within a modified guide tube in accordance with another embodiment of the invention.

[0038] FIG. 9 illustrates a tool assembly including a surgical instrument having a guide stop inserted within a modified guide tube in accordance with another embodiment of the invention.

[0039] FIG. 10 illustrates a tool assembly including a surgical instrument having at least one tracking marker in accordance with a further embodiment of the invention.

#### DETAILED DESCRIPTION

[0040] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings.

[0041] The following discussion is presented to enable a person skilled in the art to make and use embodiments of the invention. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the generic principles herein can be applied to other embodiments and applications without departing from embodiments of the invention. Thus, embodiments of the invention are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein.

The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of embodiments of the invention. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the invention.

[0042] FIGS. 1A-1B illustrate a surgical robot system 1 in accordance with one embodiment of the invention, and FIG. 1C illustrates a portion of a surgical robot system 1 with control of the translation and orientation of the end-effectuator in accordance with another embodiment of the invention. Referring now to FIGS. 1A-1B, some embodiments include a surgical robot system 1. As shown, in some embodiments, the surgical robot 15 can comprise a display 29 and a housing 27. In some embodiments, the display 29 can be attached to the surgical robot 15. In other embodiments, a display 29 can be detached from surgical robot 15, either within a surgical room with the surgical robot 15, or in a remote location. In some embodiments, the housing 27 can comprise a robot arm 23, and an end-effectuator 30 coupled to the robot arm 23 controlled by at least one conventional motor. In some embodiments, the end-effectuator 30 can comprise an instrument used to perform surgery on a patient 18 (such as for example the surgical instrument 35 depicted in FIGS. 3A-3B, 4A-4D, 6A, 7A, 7C, 8A-8B, 9 and 10). In other embodiments, the end-effectuator 30 can be coupled to the surgical instrument 35. As used herein, the term “end-effectuator” is used interchangeably with the term “effectuator element.” In some embodiments, the end-effectuator 30 can comprise any known structure for effecting the movement of the surgical instrument 35 in a desired manner.

[0043] FIG. 1C illustrates a portion of a surgical robot 15 with control of the translation and orientation of the end-effectuator in accordance with another embodiment of the invention. As shown, some embodiments include a surgical robot system 1 capable of the utilization of a robot 15 with the ability of moving the end-effectuator 30 along x-, y-, and z-axes (see 66, 68, 70 in FIG. 1C). In this embodiment, the x-axis 66 can be orthogonal to the y-axis 68 and z-axis 70, the y-axis 68 can be orthogonal to the x-axis 66 and z-axis 70, and the z-axis 70 can be orthogonal to the x-axis 66 and the y-axis 68. In some embodiments, the robot 15 can be configured to effect movement of the end-effectuator 30 along one axis independently of the other axes. For example, in some embodiments, the robot 15 can cause the end-effectuator 30 to move a given

distance along the x-axis 66 without causing any substantial movement of the end-effectuator 30 along the y-axis 68 or z-axis 70. As used in this context “substantial” means a deviation of less than two degrees from an intended path.

[0044] In some further embodiments, the end-effectuator 30 can be configured for selective rotation about one or more of the x-axis 66, y-axis 68, and z-axis 70 (such that one or more of the Cardanic Euler Angles (e.g., roll, pitch, and/or yaw) associated with the end-effectuator 30 can be selectively controlled). In some embodiments, during operation, the end-effectuator 30 and/or surgical instrument 35 can be aligned with a selected orientation axis (labeled “Z Tube” in FIG. 1C) that can be selectively varied and monitored by the robot system 1.

[0045] In some embodiments, selective control of the translation and orientation of the end-effectuator 30 can permit performance of medical procedures with significantly improved accuracy compared to conventional robots that utilize, for example, a six degree of freedom robot arm 23 comprising only rotational axes. For example, in some embodiments, as shown in FIG. 2, a surgical robot system 1 as depicted in FIGS. 1A-1C, can be used to operate on a patient, and the robot arm 23 that can be positioned above the body of the patient 18, with the end-effectuator 30 selectively angled relative to the z-axis toward the body of the patient 18.

[0046] In some embodiments, the position of surgical instrument 35 can be dynamically updated so that surgical robot 15 can be aware of the location of surgical instrument 35 at all times during the procedure. Consequently, in some embodiments, the surgical robot 15 can move the surgical instrument 35 to the desired position quickly, with minimal damage to patient 18, and without any further assistance from a physician (unless the physician so desires). In some further embodiments, the surgical robot 15 can be configured to correct the path of surgical instrument 35 if the surgical instrument 35 strays from the selected, preplanned trajectory. In some embodiments, the surgical robot 15 can be configured to permit stoppage, modification, and/or manual control of the movement of the end-effectuator 30 and/or surgical instrument 35. Thus, in use, in some embodiments, a physician or other user can operate the system 1, and has the option to stop, modify, or manually control the autonomous movement of end-effectuator 30 and/or surgical instrument 35. Further details of the surgical robot system 1 including the control and movement of a surgical instrument 35 by the surgical robot 15 can be found in co-pending

United States Patent Application No. 13/924,505 from which this application claims priority under 35 U.S.C. § 120, and which is incorporated herein by reference in its entirety.

[0047] In some embodiments, a guide tube 50 is used with a surgical instrument 35 to operate on a patient 18. For example, some embodiments include a guide tube 50 comprising a distal end 50a and a proximal end 50b. As used herein, “tube” is used to refer to somewhat hollow structures of any one or more desired cross-sectional shapes. In some embodiments, when the surgical instrument 35 is advanced into the tissue of the patient 18 with the assistance of a guide tube 50, the surgical instrument 35 can comprise a guide stop 52 that is configured to prevent the surgical instrument 35 from advancing when it reaches a predetermined amount of protrusion. For example, FIGS. 3A-3B each illustrate a tool assembly 100 including a surgical instrument 35 having a guide stop 52 in accordance with one embodiment of the invention. As shown in FIG. 3B, when the guide stop 52 contacts the proximal end 50b of the guide tube 50, the instrument 35 is prevented from extending further. In some embodiments, by knowing the lengths of the guide tube 50 and the surgical instrument 35, the distance between the respective ends of the surgical instrument 35, and the location where the guide stop 52 is attached, it is possible to determine the maximum distance past the end of the guide tube 50 that the surgical instrument 35 can protrude (and therefore the length of extension and the location of the tip 35c at the distal end 35a relative to the guide tube distal end 50a during a procedure). In some embodiments, the instrument 35 can be guided by (and at least partially surround) or contact a guide structure.

[0048] In some embodiments, it can be desirable to monitor not just the maximum protrusion distance of the surgical instrument 35, but also the actual protrusion distance periodically or at any instant during the insertion process. Therefore, in some embodiments, the robot 15 can periodically or substantially continuously monitor the protrusion distance, and in some embodiments, the distance can be displayed (e.g., such as on display 29). In some embodiments, protrusion distance can be substantially continuously monitored using a spring-loaded plunger 54 including a compressible spring-loaded mechanism 55a and sensor pad 55b that has a coupled wiper 56 (see for example FIGS. 4A-4D). In some embodiments, the guide stop 52 on the surgical instrument 35 can be configured to contact the spring-loaded mechanism 55 well before it encounters the proximal end of the guide tube 50. As shown in FIGS. 4A-4D, by comparing

the position of the surgical instrument 35 within the guide tube 50, in some embodiments, as the surgical instrument 35 extends toward the distal end 50a of the guide tube 50, the distal end 35a can approach the distal end 50a of the guide tube (FIG. 4B). Further, as the surgical instrument 35 is moved further downwards (i.e., the guide stop 52 moves toward the proximal end 50b of the guide tube 50), the distal end 35a can extend outwards away from the distal end 50a of the guide tube (see FIG. 4C showing the extension of the distal end 35a and change in tip 35c position after the stop 52 contacts the plunger 54, shown as region 36.) Further, as the surgical instrument 35 is moved further downwards and the guide stop 52 contacts the guide tube 50, the distal end 35a can come to a stop, extending away from the distal end 50a of the guide tube 50 (see FIG. 4D, showing the change in tip 35c position (region 36.) As shown in FIGS. 4C-4D, as the guide stop 52 moves toward the proximal end 50b of the guide tube 50, the compressible spring-loaded mechanism 55a within the spring-loaded plunger 54 can compress. One of ordinary skill in the art will recognize that conversely, when the instrument 35 is moved back out of the guide tube 50, as the guide stop 52 moves away from the proximal end 50b of the guide tube 50, the compressible spring-loaded mechanism 55a within the spring-loaded plunger 54 can decompress from the compressed state.

[0049] In some embodiments, the tool assembly system 1000 (shown in FIG. 6B) can include a data input/output system including a sensor pad 55b coupled to a wiper 56. As shown, some embodiments include system 1000 comprising at least one processor 1010 coupled to a network interface 1040 including an application interface 1050. In some embodiments, the application interface 1050 is coupled to at least one operating system 1020 and at least one enterprise application 1030. In some embodiments, the at least one processor 1010 can send and receive data from at least the network interface 1040 and the application interface 1050. Further, the network interface 1040 can be coupled to at least one computer readable medium 1060 that in some embodiments can include data sources 1060a and data storage 1060b.

[0050] In some embodiments, the surgical robot system 1 may be coupled to the tool assembly system 1000. In some other embodiments, the surgical robot system 1 may comprise the tool assembly system 1000. In some embodiments, the data input/output interface 1100 may be coupled directed to the display 29 (e.g., to directly display from one or more sensors), and in other embodiments, the data input/output interface 1100 may be coupled to the surgical robot

system 1 or the display 29, or both. In some embodiments, the data input/output interface 1100 may include a conventional low voltage circuit coupled to one or more sensors 55b, 56, 310, and 510. In other embodiments, the data input/output interface 1100 may be coupled to a conventional low voltage circuit coupled to one or more sensors 55b, 56, 310, and 510. In some embodiments, the one or more sensors 55b, 56, 310, and 510 may be powered by the data input/output interface through a conventional low voltage circuit. In some other embodiments, the one or more sensors 55b, 56, 310, and 510 may be powered through a conventional low voltage circuit and coupled to the data input/output interface.

[0051] In some embodiments, the at least one processor 1010 can receive data from at least one data input/output interface 1100. As depicted in FIG. 6B, in some embodiments, the data input/output interface 1100 can include at least the sensor pad 55a and coupled wiper 56. In some embodiments, when the wiper 56 moves across the position sensor pad 55b, its linear position is sampled by the tool assembly system 1000 and may be processed using the at least one processor 1010. For example, in some embodiments, a calculation of the distance by which the surgical instrument 35 protrudes past the distal end 50a of the guide tube 50 may be processed substantially in real-time. For example, as shown in FIGS. 4A-4D, as the position of the surgical instrument 35 within the guide tube 50 is changed, as the surgical instrument 35 extends toward the distal end 50a of the guide tube 50, the wiper 56 can move toward the distal end 50a of the guide tube and across the sensor pad 55b within the wiped region 58 (e.g., see the movement from FIG. 4B to FIG. 4C). Further, as the surgical instrument 35 is moved further downwards toward the distal end 50a of the guide tube 50, and the guide stop 52 contacts the guide tube 50 at the proximal end, the wiper 56 can move toward the distal end 50a of the guide tube 50 and across the sensor pad 55b toward the lower end of the wiped region 58 (see FIG. 4D).

[0052] In some embodiments, as the wiper 56 moves across the sensor pad 55b toward the lower end of the wiped region 58, the tool assembly system 1000 can communicate the position of the wiper 56 and/or movement of the wiper 56 with respect to the sensor pad 55b. As described earlier, in some other embodiments, the surgical robot system 1 may comprise the tool assembly system 1000, and the data input/output interface 1100 may be coupled to the surgical

robot system 1 to enable the surgical robot system 1 to read the wiper 56 position on the sensor pad 55b, or movement of the wiper 56 with respect to the sensor pad 55b.

[0053] In some embodiments, the surgical instrument can comprise a drill bit 42. Some embodiments include instruments 35 that enable the stop on a drill bit 42 to be manually adjusted with reference to markings 44 on the drill bit 42. For example, FIGS. 5A-5C each illustrate tools for manually adjusting a drill stop 46 with reference to drill bit 42 markings 44 in accordance with one embodiment of the invention. Further, FIGS. 5D-5F each illustrate tools for locking and holding a drill bit in a set position in accordance with one embodiment of the invention, and FIGS. 5G-5H each illustrate methods for use of the tools as depicted in FIGS. 5A-5F with a robot end effector 30 coupled to a surgical robot system 1. As shown, in some embodiments, the drill bit 42 can include commercially available oppositely oriented one-way spring-loaded release mechanisms 48a, 48b on each end of the drill stop 46. When not being pulled against their spring, one-way release mechanisms prevent movement in one direction but allow free movement in the opposite direction. For example, in FIG. 5A, the resting release 48a on the left side of the stop 46 allows the drill bit 42 to move freely through the release 48a from right to left but prevents movement of the drill bit 42 from left to right. The release 48b to the right of the stop 46 allows the drill bit 42 to move freely through the release 48b from left to right but prevents movement from right to left. In some embodiments, when neither release 48a, 48b is being pulled it is therefore not possible to move the bit 42 in either direction. In some embodiments, if the release 48a or 48b on one end of the drill stop 46 is pulled, it is possible to move the drill stop 46 up the shaft of the drill bit 42, away from the direction of pull. In some embodiments, if the release 48a or 48b on the other end of the drill stop 46 is pulled, it is possible to move the drill stop 46 down the shaft (away from the direction of pull, see the direction of movement in FIGS. 5B and 5C). The direction in which the release 48a, 48b is pulled is opposite to the direction in which movement of the drill stop 46 is allowed so that accidental pulling of one release 48a, 48b does not result in unintended movement of the drill stop 46. For example, pulling the release 48a toward the left in Fig. 5B allows the drill stop 46 to be moved toward the right. In some embodiments, if neither release mechanism 48a, 48b is pulled, the drill stop 46 will not move in either direction, even if bumped.

[0054] Some embodiments include the ability to lock and hold the drill bit 42 in a set position relative to the guide tube 50 in which it is housed. For example, in some embodiments, the drill bit 42 can be locked by locking the drill stop 46 relative to the guide tube 50 using a locking mechanism. FIGS. 5D-5H illustrates tools for locking and holding a drill bit 42 in a set position in accordance with one embodiment of the invention. In some embodiments, the locking mechanism 49 shown in FIG. 5F can comprise two clam shells 49 (shown in FIG. 5D). In some embodiments, a drill bit 42 can be locked into position by assembling the clam shells around the drill stop 46 (shown in FIG. 5E). For example, this feature allows the user to lock the drill bit 42 in a position such that the tip slightly protrudes past the end of the guide tube 50 (see FIGS. 5G and 5H). In this position, the user can force the guide tube 50 to penetrate through soft tissues to force the guide tube 50 to contact bone (for example during a percutaneous spine screw insertion). Further details of the tools illustrated in FIGS. 5A-5G and described above can be found in co-pending United States Patent Application No. 13/924,505 from which this application claims priority 35 U.S.C. § 120, and which is incorporated herein by reference in its entirety.

[0055] In some embodiments, the tool assembly system 1000 can include the data input/output interface 1100 with at least one position sensor 310. In some embodiments, the at least one processor 1010 can send and receive data from at least the network interface 1040 and the application interface 1050 and may receive data from the data input/output interface 1100 with at least one position sensor 310.

[0056] FIG. 6A illustrates a tool assembly 300 including a surgical instrument 35 having a sensor enabled guide stop 52 in accordance with one embodiment of the invention. As shown, in some embodiments, the surgical instrument 35 can include a magnetic strip 320 extending along some portion of the longitudinal length of the instrument 35, and the surgical instrument 35 can include at least one position sensor 310. The embodiment shown in FIG. 6A includes a magnetic strip 320 that extends from a region substantially immediately adjacent to the guide stop 52, and extending to approximately three quarters of the length of the surgical instrument 35.

[0057] In some other embodiments, the magnetic strip 320 may extend closer to or farther away from the distal end 35a of the surgical instrument 35. As shown, in some embodiments,



the magnetic strip 320 is positioned on the outer surface of the surgical instrument 35. However, in some other embodiments, the magnetic strip 320 can be positioned below the outer surface of the instrument 35 (i.e., the magnetic strip 320 may be embedded in the instrument 35). In some embodiments, the magnetic strip 320 comprises a thickness that is sufficient to retain adequate mechanical integrity. For example, in some embodiments, the magnetic strip 320 comprises a thickness that is sufficient to retain adequate durability during use, while having with enough magnetic field flux to be detected by the position sensor 310.

[0058] In some embodiments, the magnetic strip 320 can comprise a thin, flexible, rigid or semi-rigid magnetic material with a thickness of between about 0.001 and about 0.15 inches. In some embodiments, the magnetic strip 320 may be thinner than 0.001 inches, and in other embodiments, the magnetic strip 320 may be thicker than 0.15 inches. In some embodiments, the magnetic strip 320 comprises a self-supporting tape or similar material that can be cut to size and adhered to the surgical instrument 35. In other embodiments, the magnetic strip 320 is formed on the surgical instrument 35 from a liquid or semi-liquid (e.g., magnetic paint that is applied to the surface of the instrument 35 in defined locations which then dries to form the magnetic strip 320). In some embodiments, the magnetic strip 320 comprises a ferrite-based magnetic material. In other embodiments, the magnetic strip 320 comprises a rare-earth based magnetic material (e.g., a neodymium-based permanent magnet). In some further embodiments, the magnetic strip 320 comprises an alnico-based magnetic material (i.e., an aluminum-nickel-cobalt based magnetic material). For example, in some embodiments, the magnetic strip 320 can comprise a thin, flexible, rigid or semi-rigid magnetic strip 320 that comprises a material selected from a group consisting of ferrite-based magnetic material, a neodymium-based permanent magnet, an alnico-based magnetic material, and mixtures thereof. Alternatively, in some other embodiments, the magnetic strip 320 is formed on the surgical instrument 35 from a liquid or semi-liquid (e.g., magnetic paint) that comprises a material selected from a group consisting of ferrite-based magnetic material, a neodymium-based permanent magnet, an alnico-based magnetic material, and mixtures thereof. In some embodiments, the magnetic strip 320 can be embedded within the interior structure of the instrument 35. For example, it may be positioned in the core of the instrument 35. In other embodiments, if the instrument 35 is tubular, the magnetic strip 320 can be placed on the inside surface of the tubular orifice.

[0059] In some embodiments, the tool assembly 300 can include the position sensor 310 coupled to the guide tube 51a (see FIG. 6A). In some embodiments, the position sensor 310 can be a Hall-effect sensor capable of varying an output voltage in response to a magnetic field detected from the magnetic strip 320. In some embodiments, the position sensor 310 can comprise a magnetic sense-coil, or magneto-resistive read-head. In some embodiments, as the position sensor 310 moves with respect to the magnetic strip 320, and magnetic fluctuation is detected, an output signal is generated by the data input/output interface 1100. In some embodiments, an insertion of the surgical instrument 35 in the guide tube 51a can be detected using the position sensor 310. In some embodiments, the magnetic strip 320 can include a variable magnetic field flux capable of being detected by the position sensor 310 as it moves with respect to the magnetic strip 320. For example, in some embodiments, the magnetic field flux of the magnetic strip 320 can rise and fall periodically through at least a portion of the longitudinal length of the magnetic strip 320. In the case of the position sensor 310 being a Hall-effect sensor, this movement can produce a varying an output voltage in response to a magnetic field detected from the magnetic strip 320 as it moves from a region of low magnetic field flux to a region of higher magnetic field flux.

[0060] In some embodiments, magnetic strip 320 can comprise alternative arrangements of regions of higher and lower magnetic field flux strength capable of being detected by the position sensor 310 as it moves with respect to the magnetic strip 320. In some other embodiments, the alternative arrangements of regions of higher and lower magnetic field flux strength can comprise a magnetic bar code capable of being detected by the magnetic strip 320 and processes using the at least one processor 1010 through the data input/output interface 1100. In some embodiments, the arrangements of regions of higher and lower magnetic field flux strength can comprise a magnetic bar code (depicted as the magnetically coded region 321 of the magnetic strip 320 shown in FIG. 6A). In some embodiments, at least some fraction of the magnetically coded region 321 can be capable of being detected by the magnetic strip 320 for the purpose of identifying the surgical instrument 35. For example, in some embodiments, a surgical instrument 35 can include a magnetic strip 320 that includes a magnetically coded region 321 with at least a type code of the surgical instrument 35. Moreover, in some embodiments, the surgical robot system 1 can include a safety protocol to perform a check of the

surgical instrument 35 prior to its use in a surgical procedure. In some embodiments, an insertion of the surgical instrument 35 in the guide tube 51a for example, can be detected using the position sensor 310 which can be capable of reading the magnetically coded region 321 within the magnetic strip 320 as it passes the sensor 310. In some embodiments, information about the instrument 35 that will be inserted into the guide tube 51a can be stored magnetically and permanently or semi-permanently in the magnetic strip 320 before surgery. Then, during surgery, when the tool is introduced in the guide tube 51a, the sensor 310 can read the magnetically coded region 321 of the strip 320 and detect data regarding the tool's diameter, length, shape, or other important information. These data can be automatically conveyed to the processor 1010 and displayed to the user via data input/output interface 1100.

[0061] Some embodiments can include additional or alternative position sensors 310. For example, FIG. 7A illustrates a surgical instrument 35 having a guide stop 52 in accordance with another embodiment of the invention. As shown, the surgical instrument 35 can include three position sensors 310, substantially equally spaced on the surgical instrument 35. In some embodiments, an insertion of the surgical instrument 35 in the guide tube 51a can be detected using the position sensor 310, and the movement of the surgical instrument 35 within a guide tube 51a can be detected as it passes over the remaining position sensors (located approximately half-way down the length of the surgical instrument 35 and adjacent the distal end 35a of the surgical instrument 35). It should be apparent to those of ordinary skill in the art that different lengths of guide tube 51a and instrument 35 can be assembled that necessitate different numbers of position sensors 310 such that the magnetic strip 320 is always adjacent to at least one sensor 310 at any longitudinal position of the instrument 35 within the guide tube 51a.

[0062] In some other embodiments, the tool assembly 400 (shown in FIG. 7C) can include an alternative guide tube 51b including a longitudinal magnetic strip 420 and a radial magnetic strip 430. As used herein, "tube" is intended to cover circular and other shaped structures which may or may not form a complete circle or other enclosing structure. For example, FIG. 7B is a modified guide tube 51b for use with the instrument 35 shown in FIG. 7A in accordance with one embodiment of the invention. FIG. 7C shows the tool assembly 400 including the instrument 35 shown in FIG. 7A inserted within the modified guide tube 51b shown in FIG. 7B in accordance with one embodiment of the invention. In some embodiments, an insertion of the

surgical instrument 35 in the guide tube 51b can be detected using the position sensor 310 using the longitudinal magnetic strip 420, and the movement of the surgical instrument 35 within a guide tube 51b can be detected as it passes over the remaining position sensors (located approximately half-way down the length of the surgical instrument 35 and adjacent the distal end 35a of the surgical instrument 35) using the longitudinal magnetic strip 420. In some embodiments, a rotational movement of the instrument within the guide tube 51a can be detected using the radial magnetic strip 430 as it moves with respect to any one of the positions sensors 310. For example, in some embodiments, the tool assembly system 1000 can include the data input/output interface 1100 with at least one position sensor 310. The at least one processor 1010 can send and receive data from at least the network interface 1040 and the application interface 1050, and may receive data from the data input/output interface 1100 with at least one position sensor 310 through an interaction with either the longitudinal magnetic strip 420 or the radial magnetic strip 430. Therefore, in some embodiments, the surgical robot system 1 can detect at least the movement of the surgical instrument 35 longitudinally with respect the guide tube 51b, and when the instrument 35 is twisting within the guide tube 51b. In some other embodiments, the instrument 35 can be coupled to an exterior surface of a guide tube.

[0063] In addition to magnetic field based sensing, some embodiments include optical sensing of the movement of a surgical instrument 35 in a guide tube. For example, FIG. 8A illustrates a surgical instrument 35 having a guide stop 52 in accordance with another embodiment of the invention, and FIG 8B illustrates a tool assembly 500 including a surgical instrument 35 having a guide stop 52 inserted within a modified guide tube 51c in accordance with another embodiment of the invention. As shown, in some embodiments, the surgical instrument 35 can include a plurality of high contrast markings 520 distributed along at least a partial longitudinal length of the instrument 35. In some other embodiments, the plurality of high contrast markings 520 may extend over substantially the entirety of the longitudinal length of the instrument 35.

[0064] In some embodiments, the modified guide tube 51c can include at least one optical sensor 510 capable of sensing at least one of the plurality of high contrast marking 520. In some embodiments, as the surgical instrument 35 is inserted in the guide tube 51c, the at least one optical sensor 510 can be capable of sensing at least one of the plurality of high contrast marking

520. Further, in some embodiments, the tool assembly system 1000 can include the data input/output interface 1100 coupled with at least one of plurality of high contrast marking 520. The at least one processor 1010 can send and receive data from at least the network interface 1040 and the application interface 1050 and may receive data from the data input/output interface 1100 with at least one of the plurality of high contrast marking 520, through an interaction with the at least one optical sensor 510. Therefore, in some embodiments, the surgical robot system 1 can detect at least the movement of the surgical instrument 35 longitudinally with respect the guide tube 51c as the optical sensor 510 detects at least one of the plurality of high contrast markings 520.

[0065] In some embodiments, the optical sensor 510 can be a photodiode, a phototransistor, a fiber-optic sensor, a photo-multiplier, a CCD, a camera or a combination of those described. In some embodiments, the optical sensor 510 can detect ambient light reflected from the surgical instrument 35 including the plurality of high contrast marking 520. In other embodiments, a conventional light source (e.g., an incandescent bulb or an LED light) can be used in combination with the optical sensor 510 and high contrast marking 520, and the optical sensor 510 can detect light emitted by the light source, reflected from the surgical instrument 35 including the plurality of high contrast markings 520.

[0066] Some embodiments can include an alternative optical recognition of a surgical instrument 35. For example, FIG. 9 illustrates a tool assembly 600 including a surgical instrument 35 having a guide stop 52 inserted within a modified guide tube 51c in accordance with another embodiment of the invention. As shown, in some embodiments, the surgical instrument 35 can include an optically graduated coating 37. In some embodiments, the optically graduated coating 37 can include a graduation of color across at least a partial longitudinal length of the instrument 35. In some other embodiments, the optically graduated coating 37 can include a graduation in light reflectivity across at least a partial longitudinal length of the instrument 35. For example, in some embodiments, the optically graduated coating 37 can include a graduation in light reflectivity extending from the proximal end (shown as a substantially colorless region adjacent the guide stop 52 in FIG. 9) to a darker region adjacent the distal end 35a. In some embodiments, as the surgical instrument 35 is inserted in the guide tube 51c, the at least one optical sensor 510 can be capable of sensing the coating 37. Further, in some embodiments, the

tool assembly system 1000 can include the data input/output interface 1100 coupled with the coating 37. The at least one processor 1010 can send and receive data from at least the network interface 1040 and the application interface 1050, and may receive data from the data input/output interface 1100 with at least one of the plurality of high contrast marking 520, through an interaction with the at least one optical sensor 510. Therefore, in some embodiments, the surgical robot system 1 can detect at least the movement of the surgical instrument 35 longitudinally with respect the guide tube 51c as the optical sensor 510 detects the coating 37. For example, when the surgical instrument 35 is initially inserted into the guide tube 51c, the optical sensor 510 may detect a low level of light due to the coating 37 comprising a dark color and/or a low reflectivity. As the surgical instrument 35 is further inserted into the guide tube 51c, the optical sensor 510 may detect an increasing level of light due to the optical sensor 510 moving over a coating 37 comprising a gradually increasingly lighter color and/or a higher reflectivity

[0067] In some embodiments, the robotic surgical system 1 can comprise a plurality of tracking markers 720 configured to track the movement of the robot arm 23, the end-effectuator 30, and/or the surgical instrument 35 in three dimensions. It should be appreciated that three dimensional positional information from tracking markers 720 can be used in conjunction with the one dimensional linear positional information from absolute or relative conventional linear encoders on each axis of the robot 15 to maintain a high degree of accuracy. In some embodiments, the plurality of tracking markers 720 can be mounted (or otherwise secured) thereon an outer surface of the robot 15, such as, for example and without limitation, on the base 25 of the robot 15, or the robot arm 23 (see for example FIG. 1B). In some embodiments, the plurality of tracking markers 720 can be configured to track the movement of the robot 15 arm, the end-effectuator 30, and/or the surgical instrument 35. In some embodiments, the robotic surgical system 1 can utilize the tracking information to calculate the orientation and coordinates of the surgical instrument 35 based on encoder counts along the x-axis 66, y-axis 68, z-axis 70, the Z-tube axis 64, and the roll 62 and pitch 60 axes. Further, in some embodiments, the plurality of tracking markers 720 can be positioned on the base 25 of the robot 15 spaced from the surgical field 17 to reduce the likelihood of being obscured by the surgeon, surgical tools, or other parts of the robot 15. In some embodiments, at least one tracking marker 720 of the

plurality of tracking markers 720 can be mounted or otherwise secured to the end-effectuator 30 (see for example FIG. 1D). Further embodiments, at least one optical marker of the plurality of optical tracking markers 720 can be positioned on the robot 15 between the base 25 of the robot 15 and the end-effectuator 30 instead of, or in addition to, the markers 720 on the base 25 of the robot 15. In some embodiments, the positioning of one or more tracking markers 720 on the end-effectuator 30 can maximize the accuracy of the positional measurements by serving to check or verify the end-effectuator 30 position (calculated from the positional information from the markers on the base 25 of the robot 15 and the encoder counts of the z 70, x 66, y 68, roll 62, pitch 60, and Z-tube 64 axes). In some embodiments, the at least one tracking marker 720 can be mounted to a portion of the robot 15 that effects movement of the end-effectuator 30 and/or surgical instrument 35 along the x-axis to enable the tracking marker 720 to move along the x-axis 66 as the end-effectuator 30 and surgical instrument 35 move along the x-axis 66 (see FIG. 1D). In some embodiments, the placement of the tracking markers 720 as described can reduce the likelihood of a surgeon blocking the tracking marker 720 from the cameras or detection device, or the tracking marker 720 becoming an obstruction to surgery.

[0068] In certain embodiments, because of the high accuracy in calculating the orientation and position of the end-effectuator 30 based on the tracking marker 720 outputs and/or encoder counts from each axis, it can be possible to very accurately determine the position of the end-effectuator 30. For example, in some embodiments, without requiring knowledge of the counts of axis encoders for the z-axis 70 (which is between the x-axis 66 and the base 25), knowing only the position of the markers 720 on the x-axis 66 and the counts of encoders on the y axis 68, roll axis 62, pitch 60, and Z-tube axes 64 can enable computation of the position of the end-effectuator 30. In some embodiments, the placement of markers 720 on any intermediate axis of the robot 15 can permit the exact position of the end-effectuator 30 to be calculated based on location of such markers 720 and counts of encoders on axes (66, 62, 60, 64) between the markers 720 and the end-effectuator 30. Further details of the surgical robot system 1 including the control, movement and tracking of the surgical robot 15 and of a surgical instrument 35 can be found in co-pending United States Patent Application No. 13/924,505 from which this application claims priority under 35 U.S.C. § 120, and which is incorporated herein by reference in its entirety as earlier recited.

[0069] Some embodiments include one or more markers 725 coupled to the surgical instrument 35. In some embodiments, the markers 720, 725 can comprise conventional light-emitting diodes or an Optotrak® diode or reflective Polaris sphere capable of being tracked using a commercially available infrared optical tracking system such as Optotrak®. Optotrak® is a registered trademark of Northern Digital Inc., Waterloo, Ontario, Canada. In some embodiments, light emitted from and/or reflected by the markers 720, 725 can be read by cameras 8200 used to monitor the location and movement of the robot 15 (see for example the camera 8200 mounted on the camera arm 8210 and capable of movement through camera arm joint 8210a and camera arm joint 8210b shown in FIG. 2). In some other embodiments, the markers 720, 725 can comprise a radio-frequency and/or electromagnetic reflector or transceiver and the camera 8200 can include or be replaced by a radio-frequency and/or electromagnetic transceiver.

[0070] FIG. 10 illustrates a tool assembly 900 including a surgical instrument 35 having at least one tracking marker 725 in accordance with a further embodiment of the invention. In some embodiments, a single marker 725 can be adequate to determine the linear position of the instrument 35 within the guide tube 50 if the guide tube 50 is tracked with a tracking array 690. As depicted in FIG. 10, if this single tracking marker 725 is coupled to the tool is offset from the longitudinal midline of the tool 50, the marker's position in space relative to the guide tube 50 can provide information about both the radial orientation and longitudinal position of the instrument 35 within the guide tube 50. In some other embodiments, a plurality of markers 725 can be used to determine the linear position of the instrument 35 within the guide tube 50 if the guide tube 50 is tracked with a tracking array 690.

[0001] Although several embodiments of the invention have been disclosed in the foregoing specification, it is understood that many modifications and other embodiments of the invention will come to mind to which the invention pertains, having the benefit of the teaching presented in the foregoing description and associated drawings. It is thus understood that the invention is not limited to the specific embodiments disclosed hereinabove, and that many modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although specific terms are employed herein, as well as in the claims which follow,



they are used only in a generic and descriptive sense, and not for the purposes of limiting the described invention, nor the claims which follow.

[0001] It will be appreciated by those skilled in the art that while the invention has been described above in connection with particular embodiments and examples, the invention is not necessarily so limited, and that numerous other embodiments, examples, uses, modifications and departures from the embodiments, examples and uses are intended to be encompassed by the claims attached hereto. The entire disclosure of each patent and publication cited herein is incorporated by reference, as if each such patent or publication were individually incorporated by reference herein. Various features and advantages of the invention are set forth in the following claims.

## CLAIMS

1. A guided surgical tool assembly comprising:
  - a guide tube including at least one sensor;
  - a surgical instrument moveable with respect to the guide tube,
  - the surgical instrument including at least one detectable feature; andwherein the at least one sensor is configured and arranged to detect the at least one detectable feature when the surgical instrument is at least partially coupled with the guide tube.
2. The guided surgical tool assembly of claim 1, wherein the detectable feature comprises a magnetically detectable feature capable of generating a magnetic flux field; and  
wherein the sensor is a position sensor capable of detecting the magnetic flux field.
3. The guided surgical tool assembly of claim 1, wherein the position sensor is a magnetic flux field sensor selected from a group consisting of a ferrite-based magnetic material, a rare-earth based magnetic material, an aluminum-nickel-cobalt based magnetic material, and mixtures thereof.
4. The guided surgical tool assembly of claim 2, wherein the position sensor is configured and arranged to detect insertion into and movement of the surgical instrument in the guide tube by sensing the magnetically detectable feature.
5. The guided surgical tool assembly of claim 1, wherein the detectable feature includes at least one longitudinal magnetic strip and at least one radial magnetic strip.

6. The guided surgical tool assembly of claim 5, wherein the guide tube includes at least two position sensors.
7. The guided surgical tool assembly of claim 6, wherein the at least two position sensors are configured and arranged to sense a magnetic field flux from the longitudinal magnetic strip or the radial magnetic field strip or both.
8. The guided surgical tool assembly of claim 7, wherein a longitudinal position of the surgical instrument in the guide tube can be at least partially determined using a measurement of a magnetic field flux from the longitudinal magnetic strip.
9. The guided surgical tool assembly of claim 7, wherein a radial position of the surgical instrument in the guide tube can be at least partially determined using a measurement of a magnetic field flux from the radial magnetic strip.
10. The guided surgical tool assembly of claim 1, wherein the detectable feature comprises an optically detectable feature; and  
  
wherein the at least one sensor comprises at least one optical sensor.
11. The guided surgical tool assembly of claim 10, wherein the optically detectable feature comprises a high contrast marking distributed along at least a partial longitudinal length of the guided surgical tool assembly.
12. The guided surgical tool assembly of claim 11, wherein the at least one optical sensor comprises a light sensitive detector selected from a group consisting of a photodiode, a phototransistor, a fiber-optic sensor, a photo-multiplier, a CCD, a camera, or a combination thereof.
13. The guided surgical tool assembly of claim 11, wherein a longitudinal position of the surgical instrument in the guide tube can be at least partially determined by optically sensing light from the high contrast marking using the at least one optical sensor.

14. The guided surgical tool assembly of claim 10, wherein the optically detectable feature comprises a graduated coating distributed along at least a partial longitudinal length of the guided surgical tool assembly.
15. The guided surgical tool assembly of claim 14, wherein the graduated coating comprises a graduated reflective coating.
16. The guided surgical tool assembly of claim 14, wherein the graduated coating comprises a graduated color coating.
17. The guided surgical tool assembly of claim 14, wherein a longitudinal position of the surgical instrument in the guide tube can be at least partially determined by optically sensing light from the graduated coating using the at least one optical sensor.
18. The guided surgical tool assembly of claim 1, wherein
- the guide tube comprises a distal guide tube end and a proximal guide tube end; and
- the surgical instrument includes a distal end and a proximal end; and
- wherein the sensor comprises at least one sensor pad; and
- wherein the guided surgical tool assembly further comprises:
- a guide stop coupled to the proximal end of the surgical instrument; and
- a plunger mechanism including a compressible spring mechanism coupled to the distal end of the guide tube and a wiper configured and arranged to be sensed by the at least one sensor pad.
19. The guided surgical tool assembly of claim 18, wherein longitudinal movement of the surgical instrument within the guide tube where the guide stop moves toward the

proximal end of the guide tube can at least partially compress the spring and move the wiper with respect to the at least one sensor pad.

20. The guided surgical tool assembly of claim 18, wherein longitudinal movement of the surgical instrument within the guide tube where the guide stop moves away from the proximal end of the guide tube can at least partially decompress the spring and move the wiper with respect to the at least one sensor pad.

21. A guided surgical tool assembly system comprising:

a tool sensor system including at least one processor and at least one data input/output interface, the data input interface including at least one sensor;

a guide tube including the at least one sensor;

a surgical instrument moveable within the guide tube,

the surgical instrument including at least one detectable feature; and

wherein the at least one sensor is configured and arranged to detect the at least one detectable feature.

22. A guided surgical tool assembly system of claim 21, wherein

the guide tube comprises a distal guide tube end and a proximal guide tube end; and

the surgical instrument includes a distal end and a proximal end; and

wherein the sensor comprises at least one sensor pad; and

wherein the guided surgical tool assembly further comprises:

a guide stop coupled to the proximal end of the surgical instrument; and

a plunger mechanism including a compressible spring mechanism coupled to the distal end of the guide tube and a wiper configured and arranged to be sensed by the at least one sensor pad; and

wherein the at least one processor is configured and arranged to detect the at least one surgical instrument when at least partially inserted or moved in the guide tube.

23. The guided surgical tool assembly system of claim 21, wherein the detectable feature comprises a magnetically detectable feature capable of generating a magnetic flux field; and

wherein the sensor is a position sensor capable of detecting the magnetic flux field; and

wherein the position sensor is configured and arranged to detect insertion into and movement of the surgical instrument in the guide tube by sensing the magnetically detectable feature.

24. The guided surgical tool assembly system of claim 21, wherein the detectable feature comprises an optically detectable feature; and

wherein the at least one sensor comprises at least one optical sensor; and

wherein the optically detectable feature comprises a high contrast marking distributed along at least a partial longitudinal length of the guided surgical tool assembly.

25. The guided surgical tool assembly system of claim 21, wherein the detectable feature comprises an optically detectable feature; and

wherein the at least one sensor comprises at least one optical sensor; and

wherein the optically detectable feature comprises a graduated coating distributed along at least a partial longitudinal length of the guided surgical tool assembly.

26. A guided surgical tool assembly system of claim 21, wherein the surgical instrument includes at least one tracking sensor.

27. A medical robot system, comprising;

a robot coupled to an effectuator element, the robot configured for controlled movement and positioning;

a motor assembly coupled to the robot, the motor assembly being configured to move the effectuator element along one or more of an x-axis, a y-axis, and a z-axis such that movement of the effectuator element along one of the x-, y-, or z-axes occurs independently of movement of the effectuator element along the other axes of the x-, y-, and z-axes, wherein the x-axis is substantially perpendicular to the y- and z-axes, the y-axis is substantially perpendicular to the x- and z-axes, and the z-axis is substantially perpendicular to the x- and y axes;

a tool sensor system including at least one processor and at least one data input/output interface, the data input interface including at least one sensor;

a guide tube including the at least one sensor;

a surgical instrument moveable with respect to the guide tube, the surgical instrument including at least one detectable feature; and

wherein the at least one sensor is configured and arranged to detect the at least one detectable feature; and

wherein the at least one processor is configured and arranged to detect when the surgical instrument is at least partially coupled with the guide tube.

28. A medical robot system of claim 27, wherein the surgical instrument includes at least one tracking sensor.



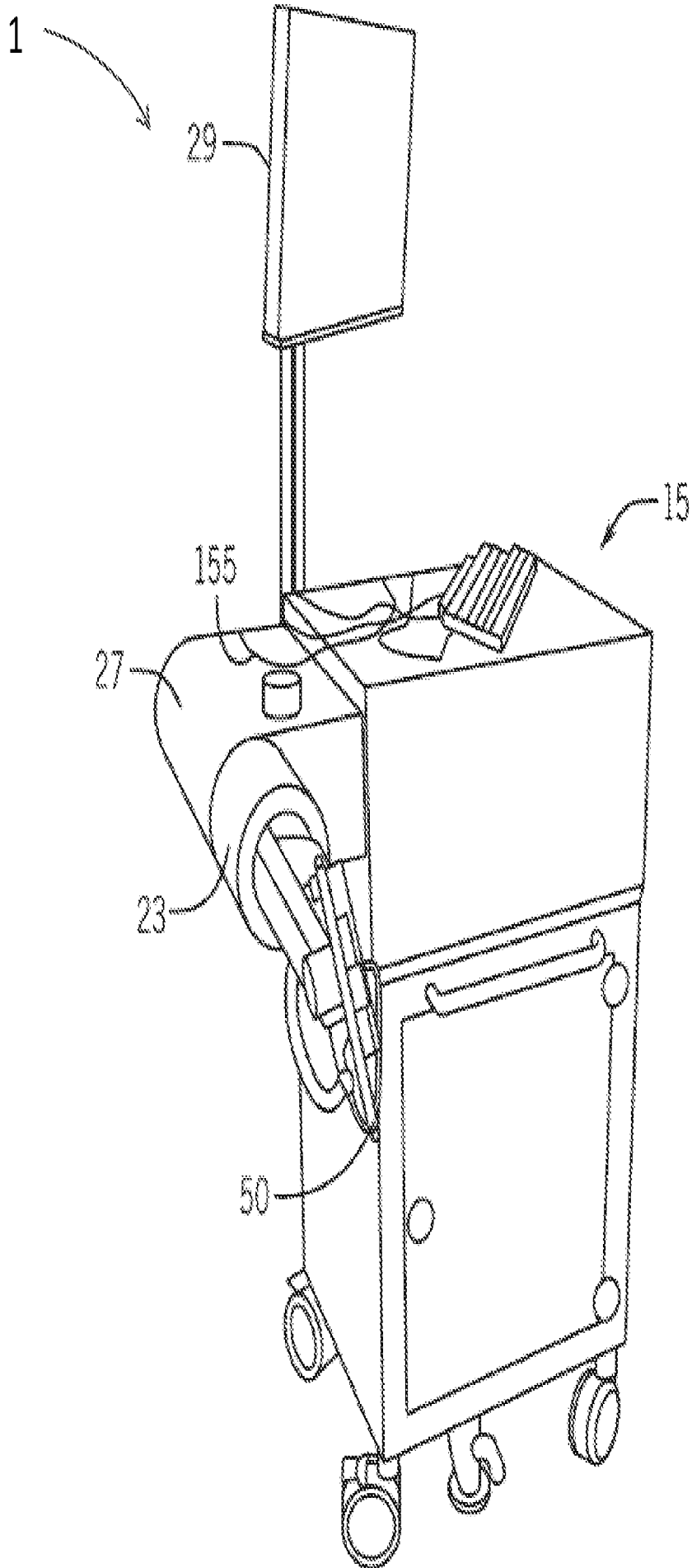
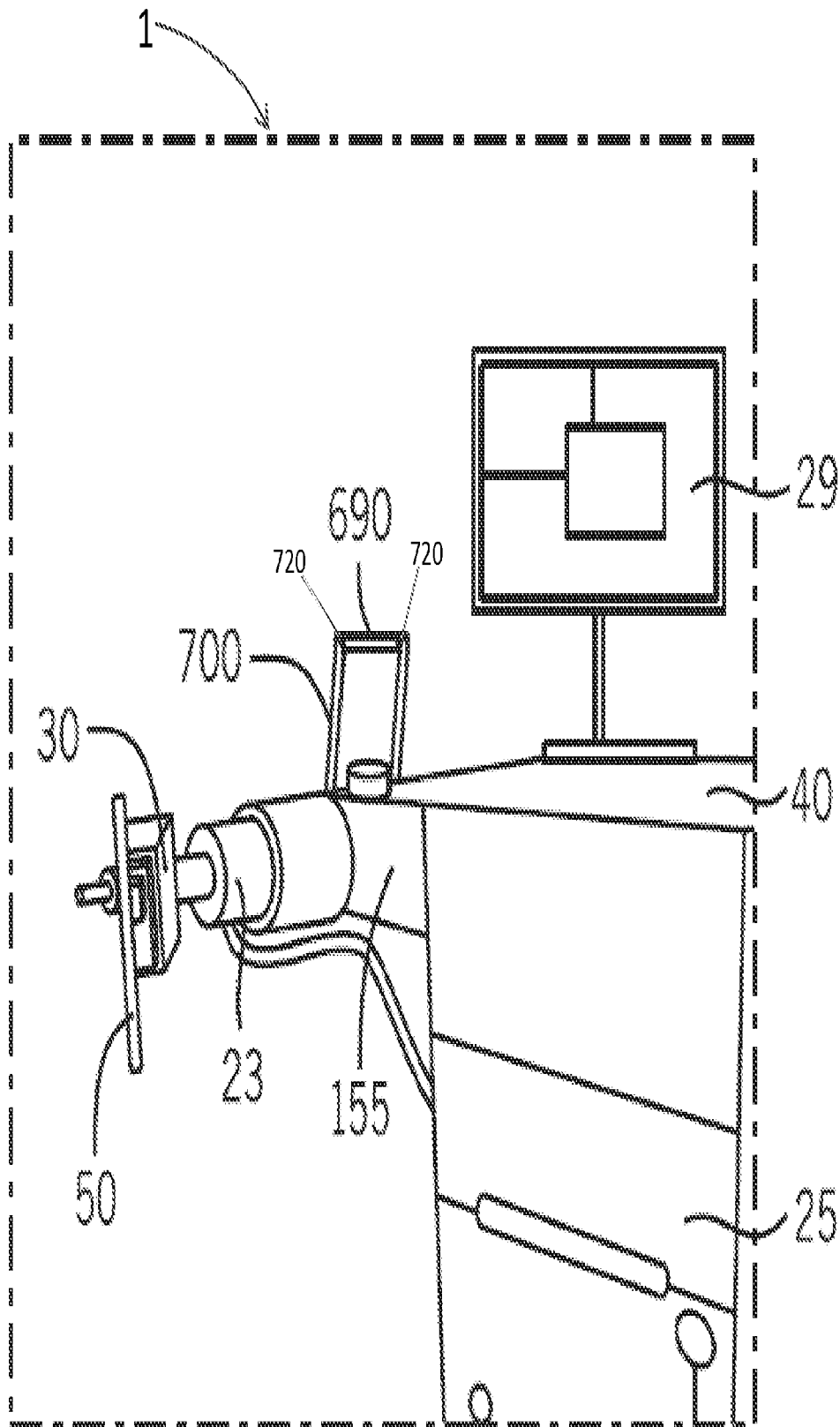


FIG. 1A



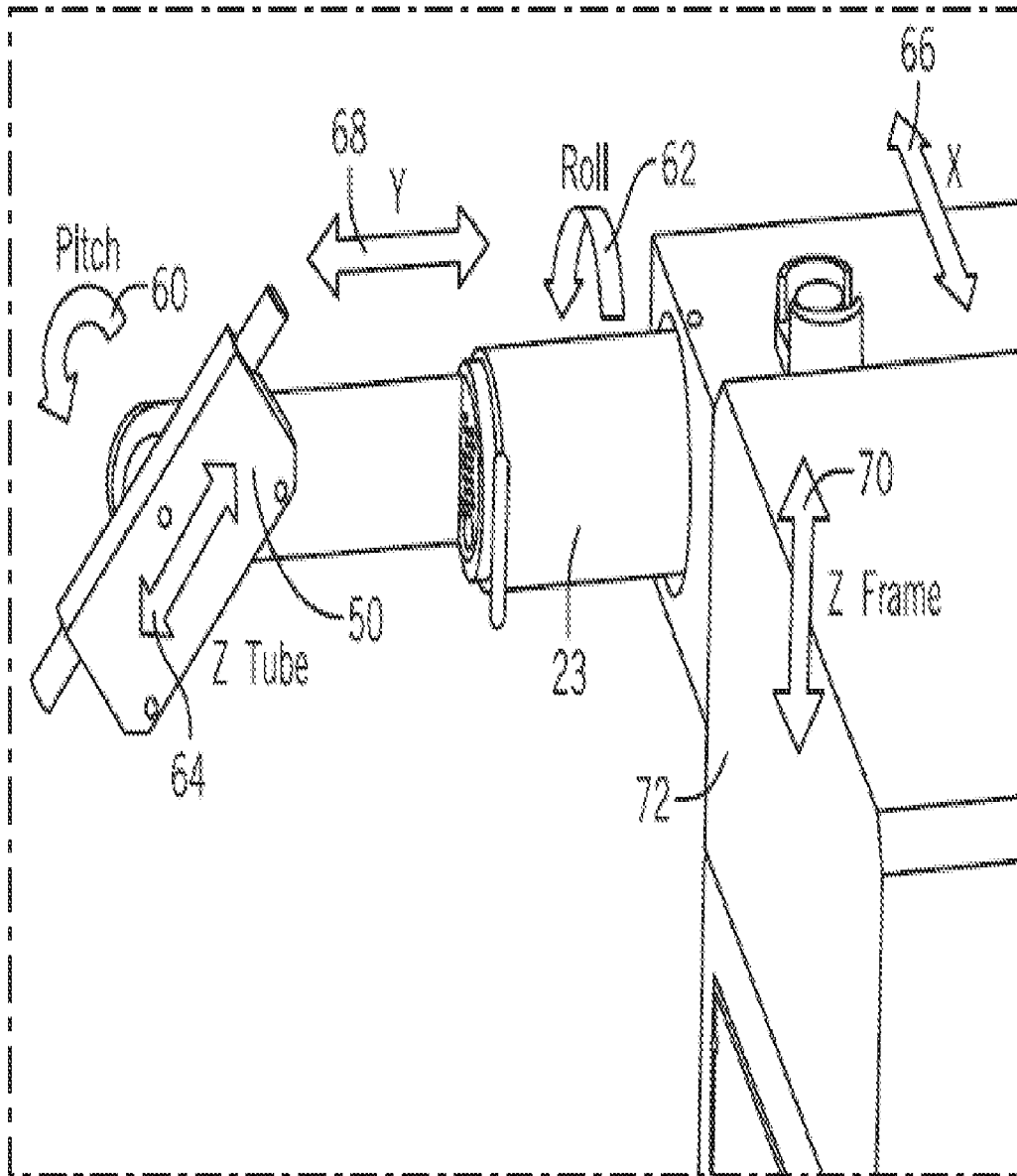


FIG. 1C

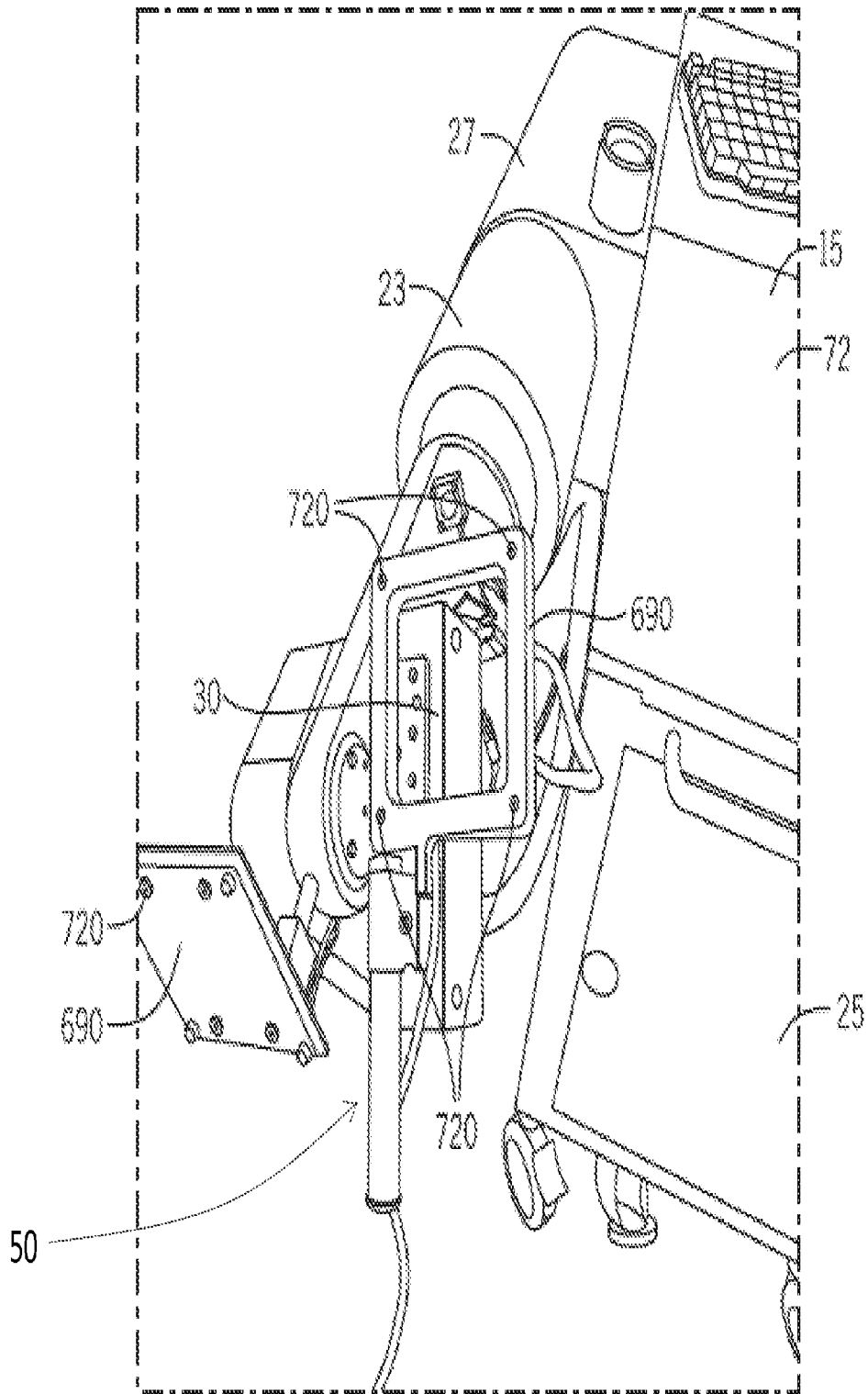
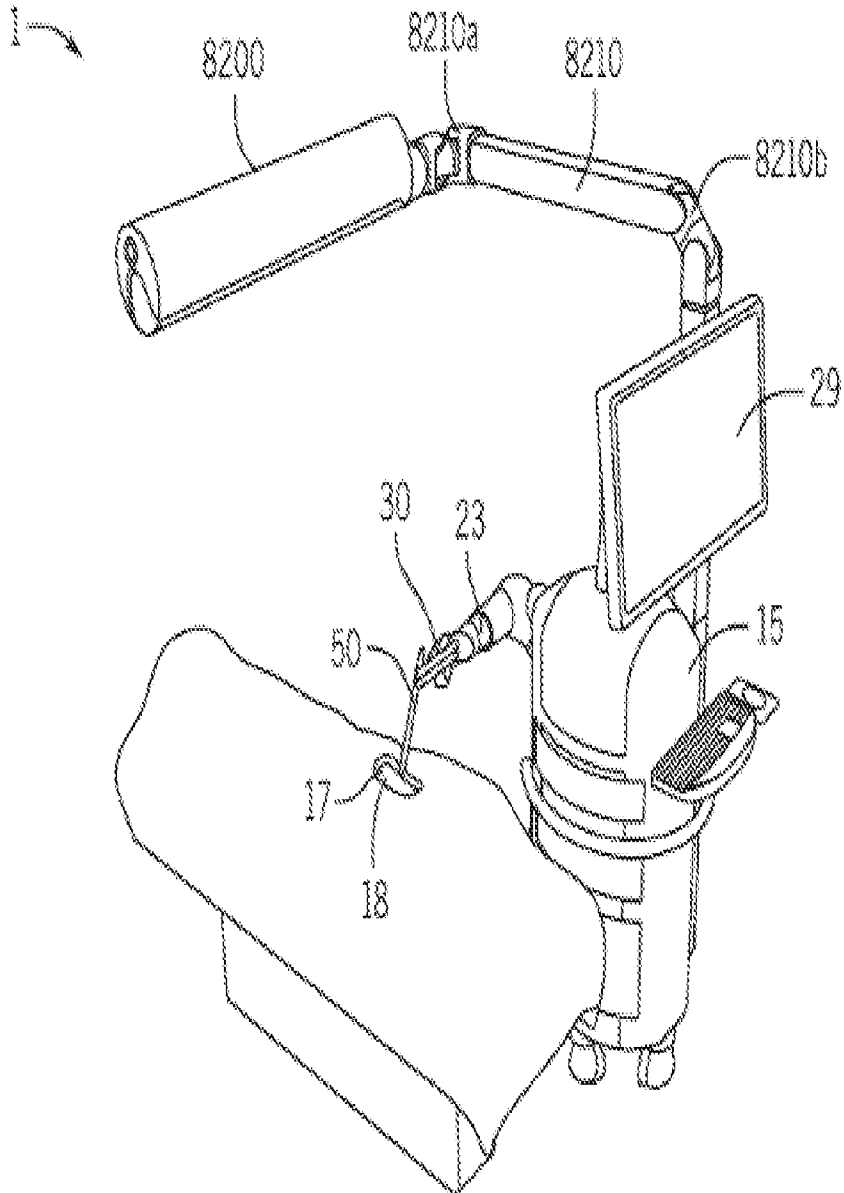


FIG. 1D



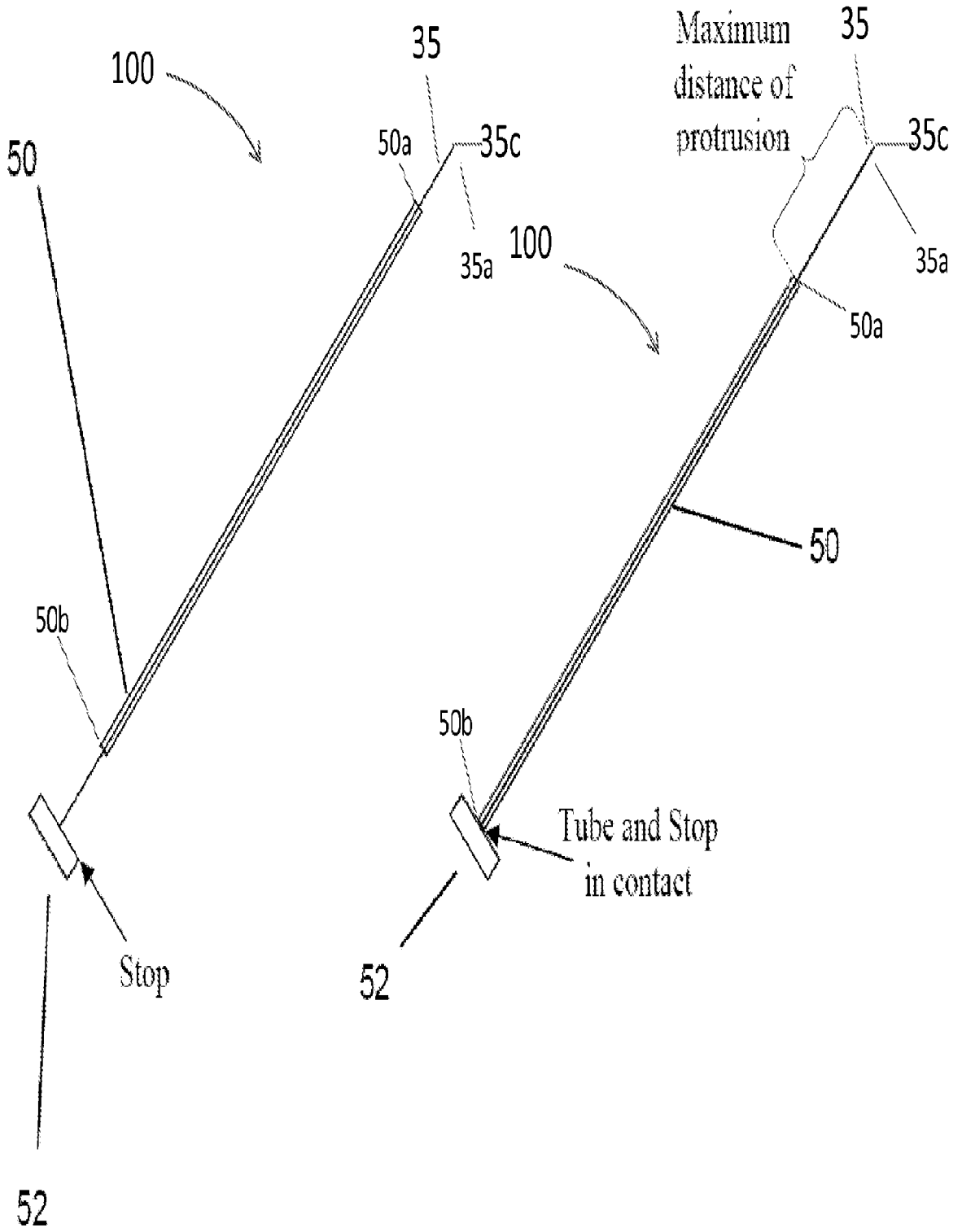


FIG. 3A

FIG. 3B

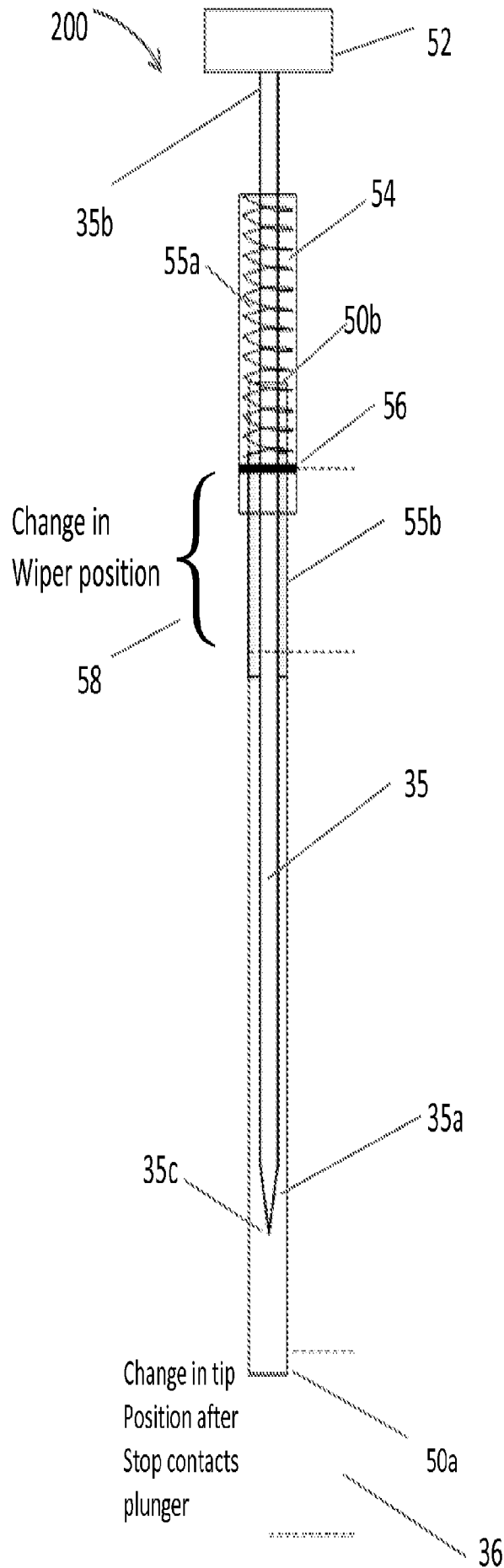


FIG. 4A

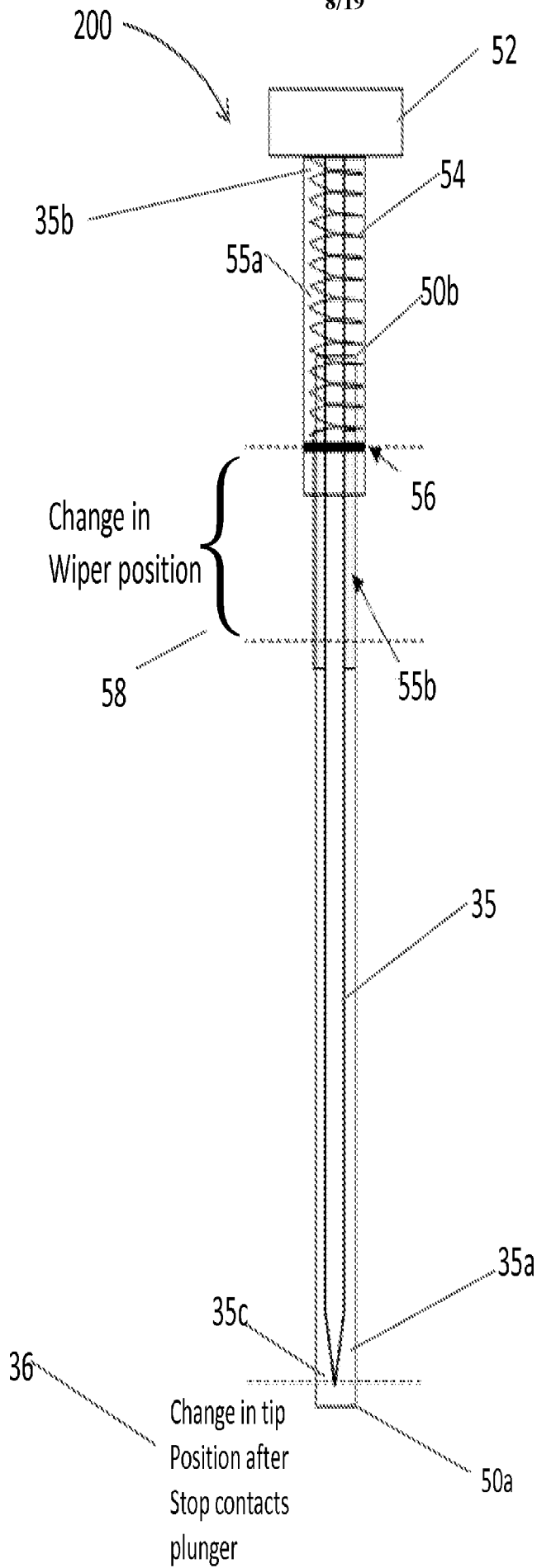


FIG. 4B



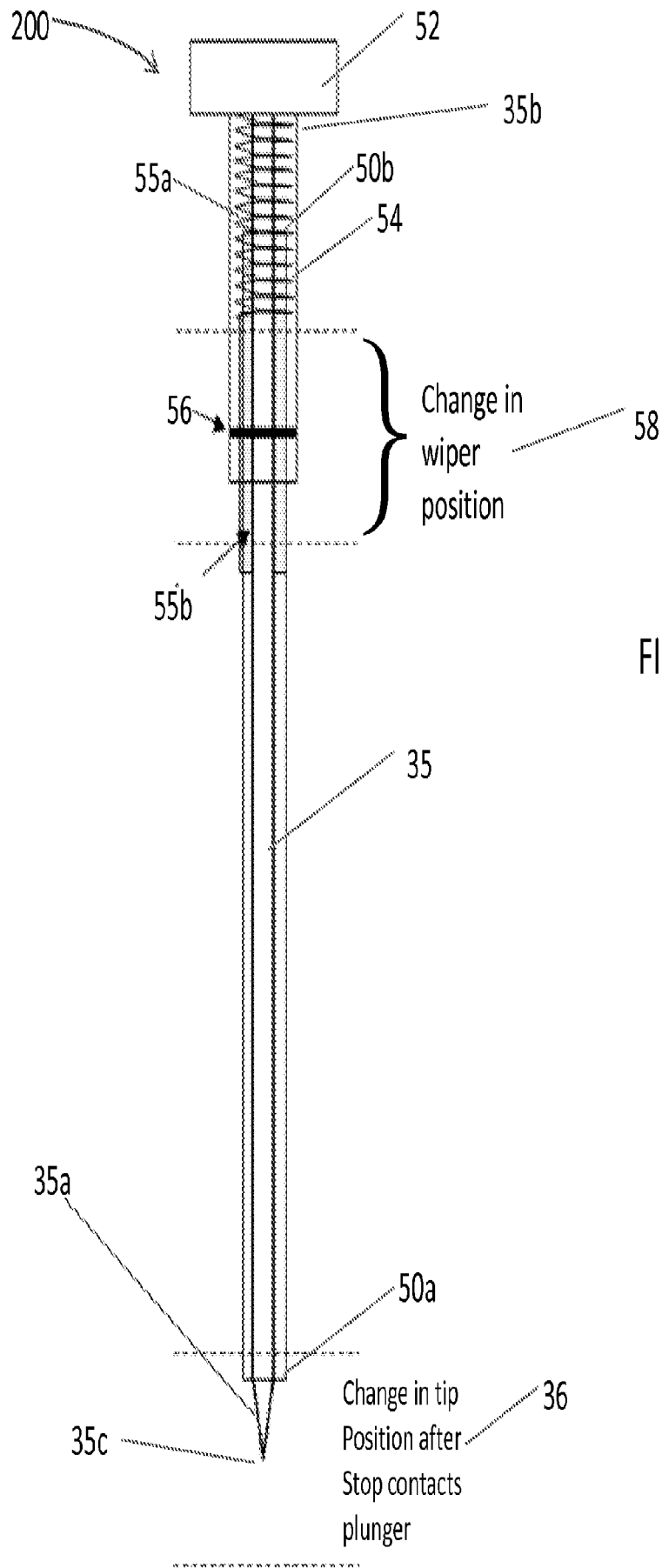


FIG. 4C

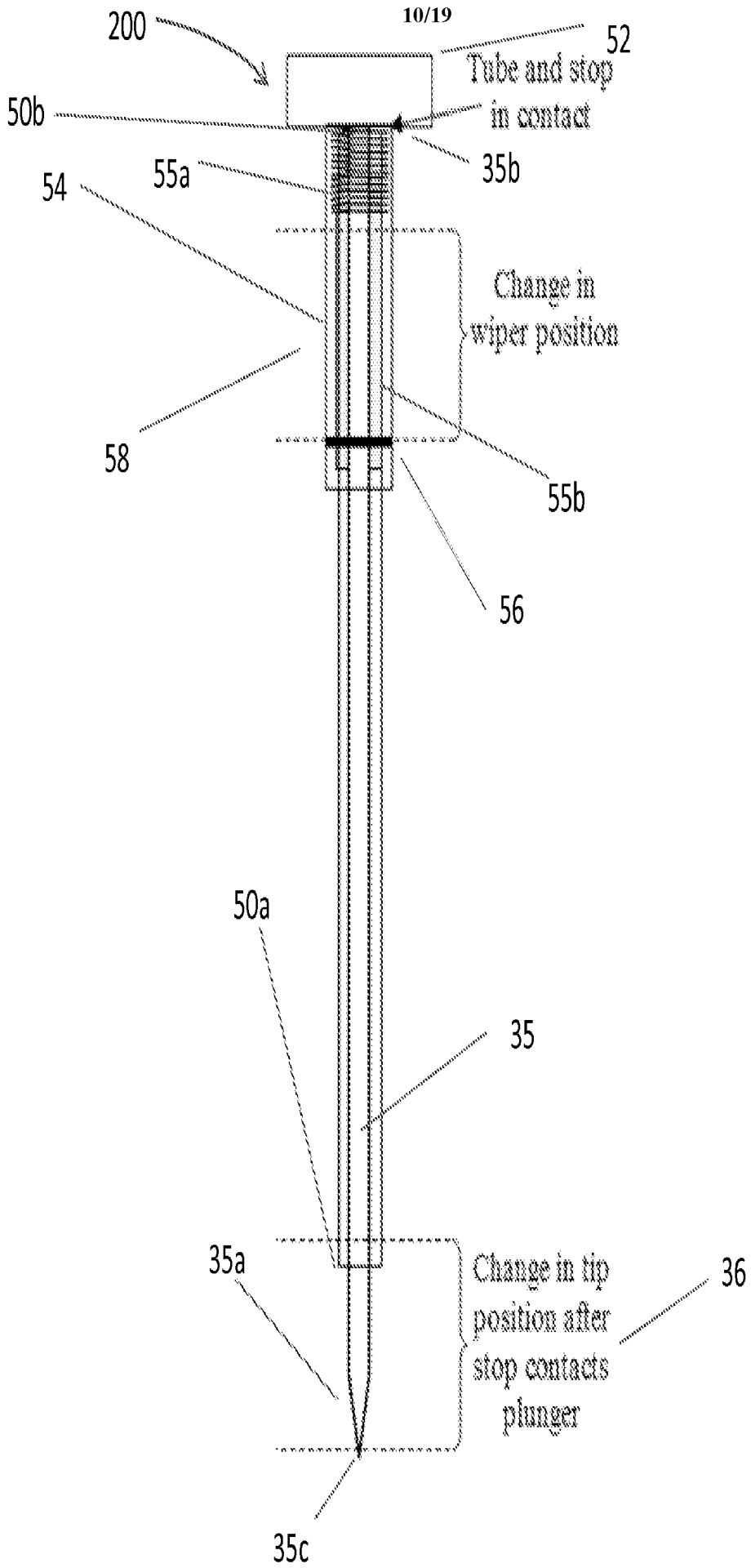


FIG. 4D

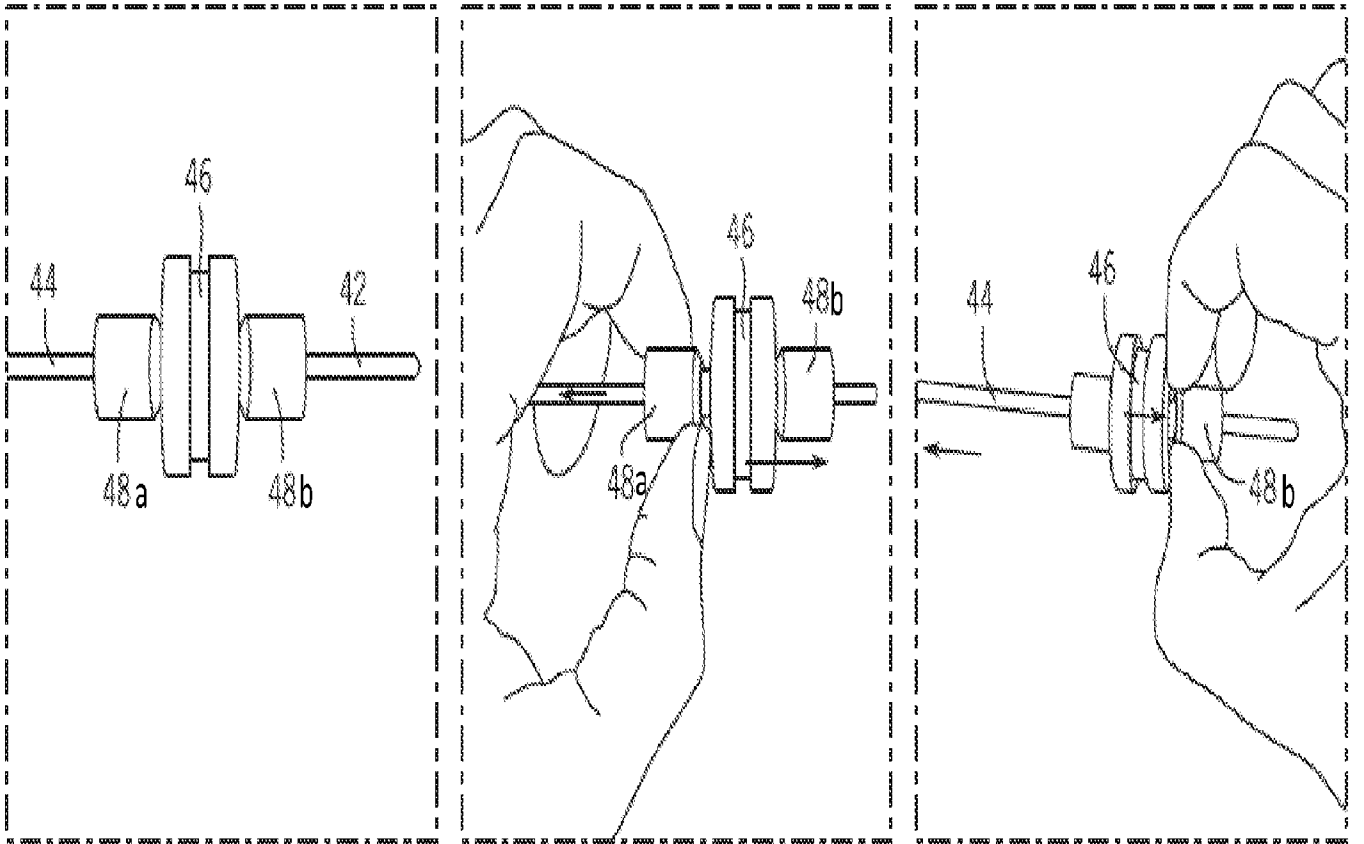


FIG. 5A

FIG. 5B

FIG. 5C

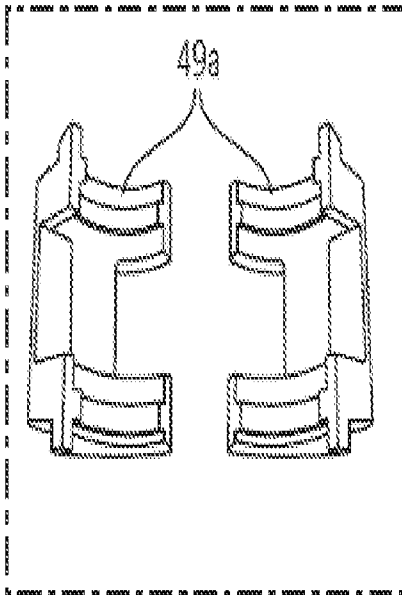


FIG. 5D

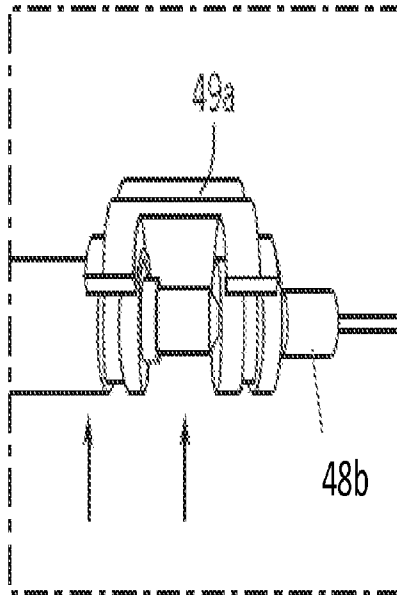


FIG. 5E

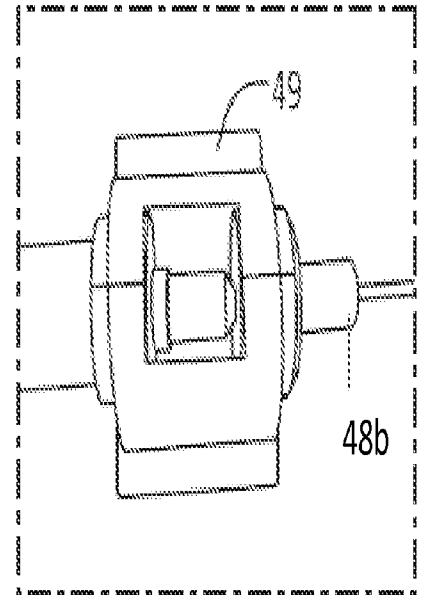


FIG. 5F

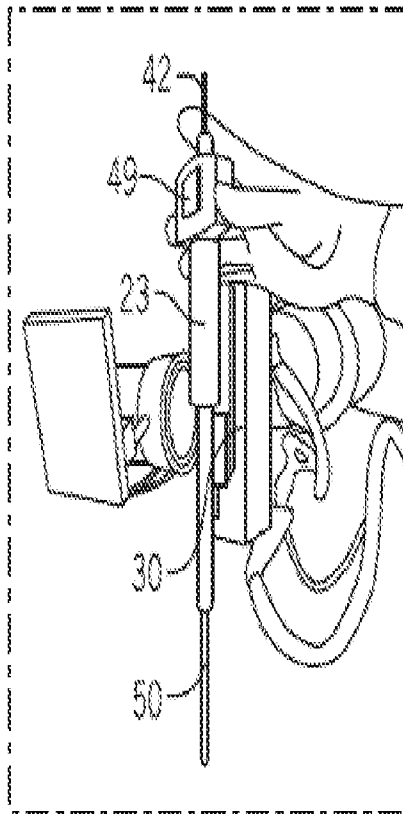


FIG. 5G

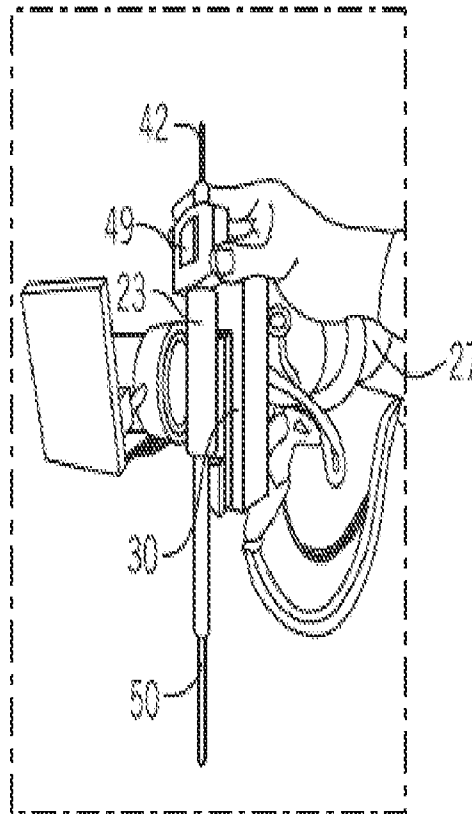


FIG. 5H

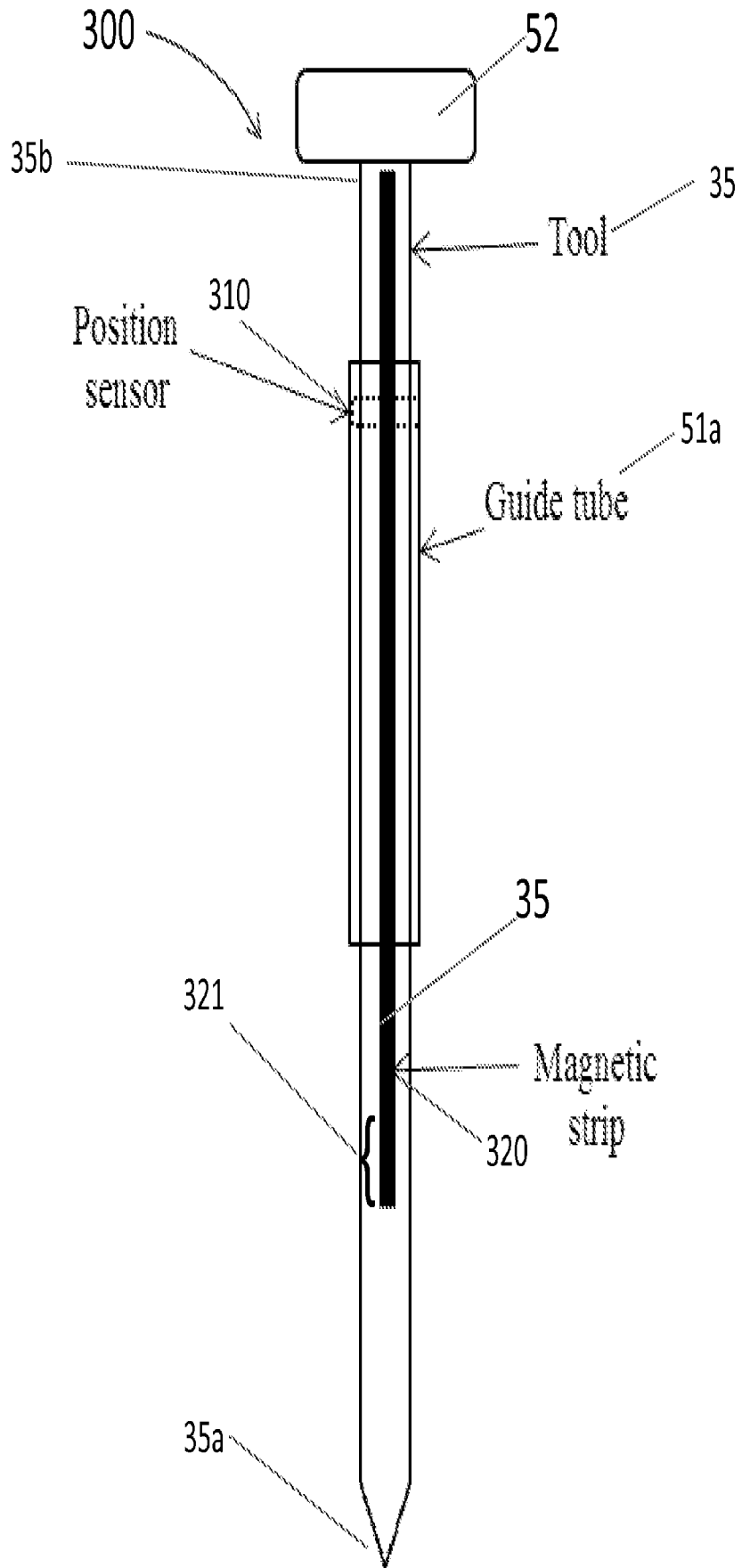


FIG. 6A

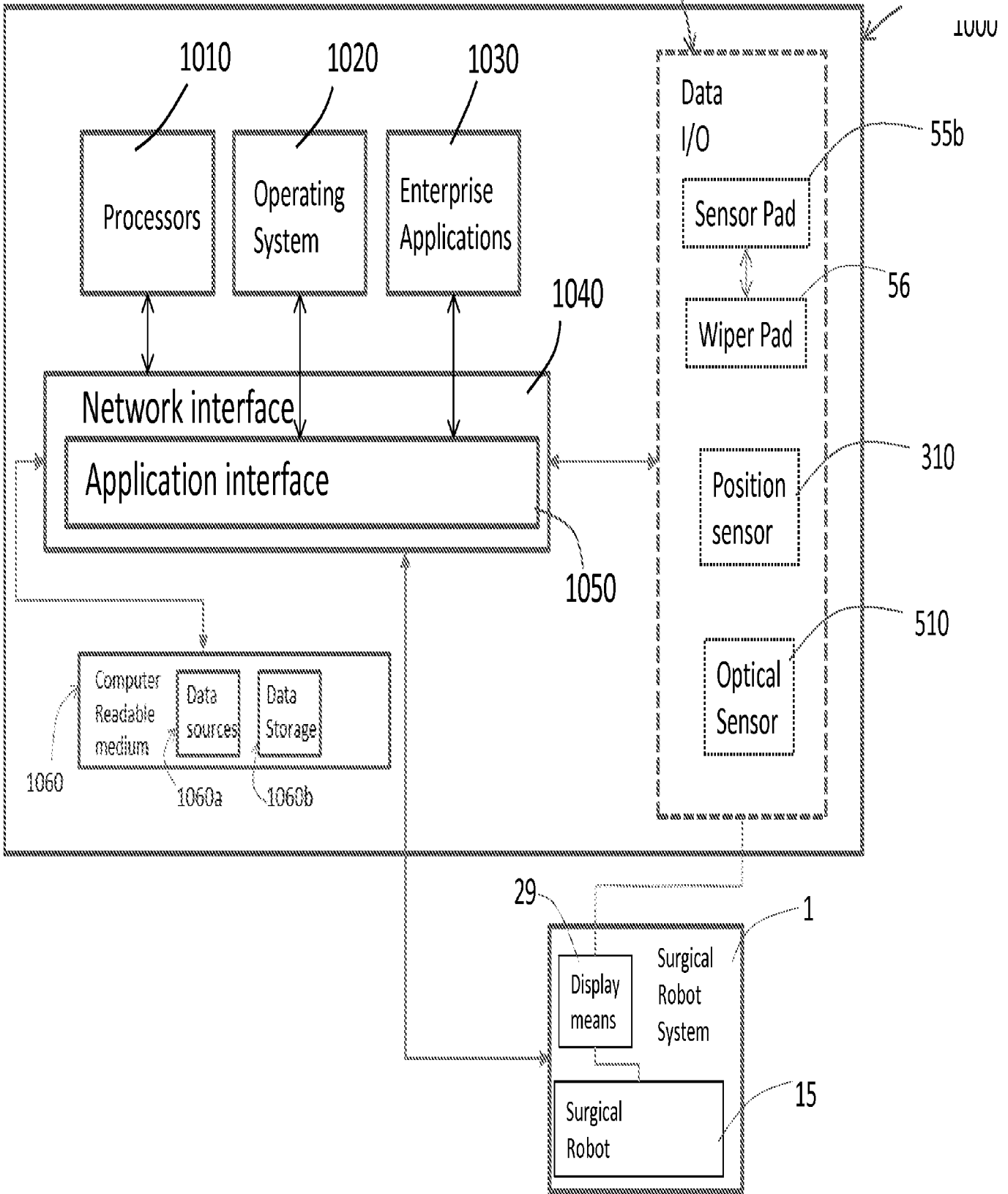
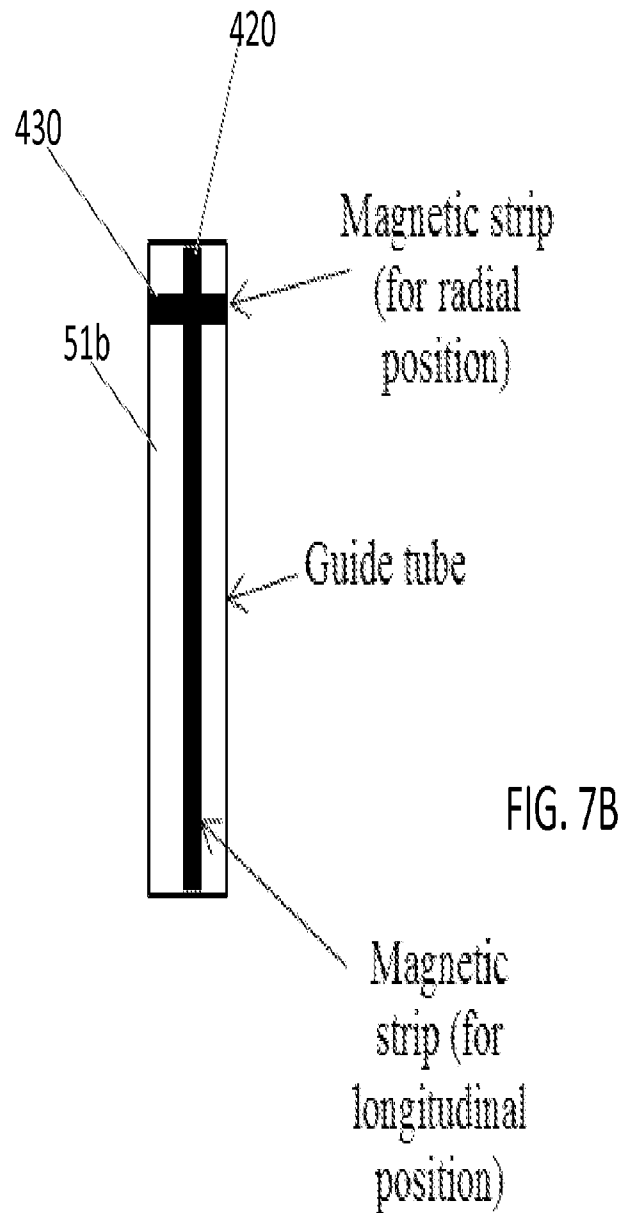
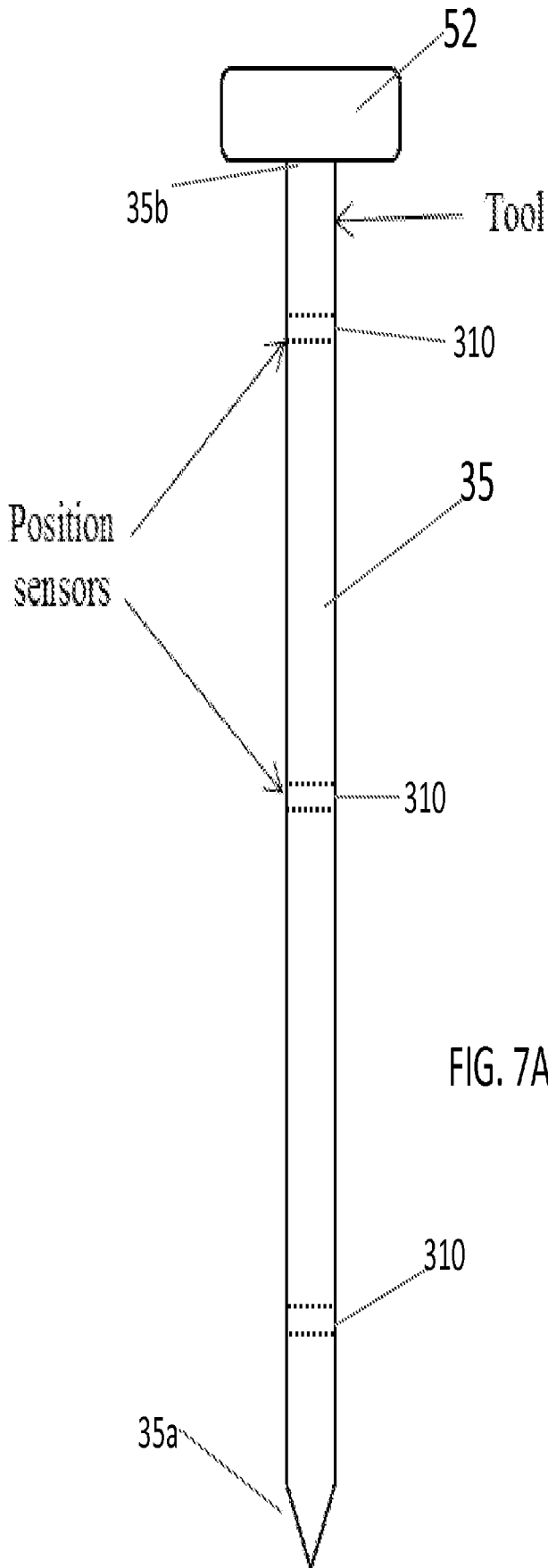


FIG. 6B



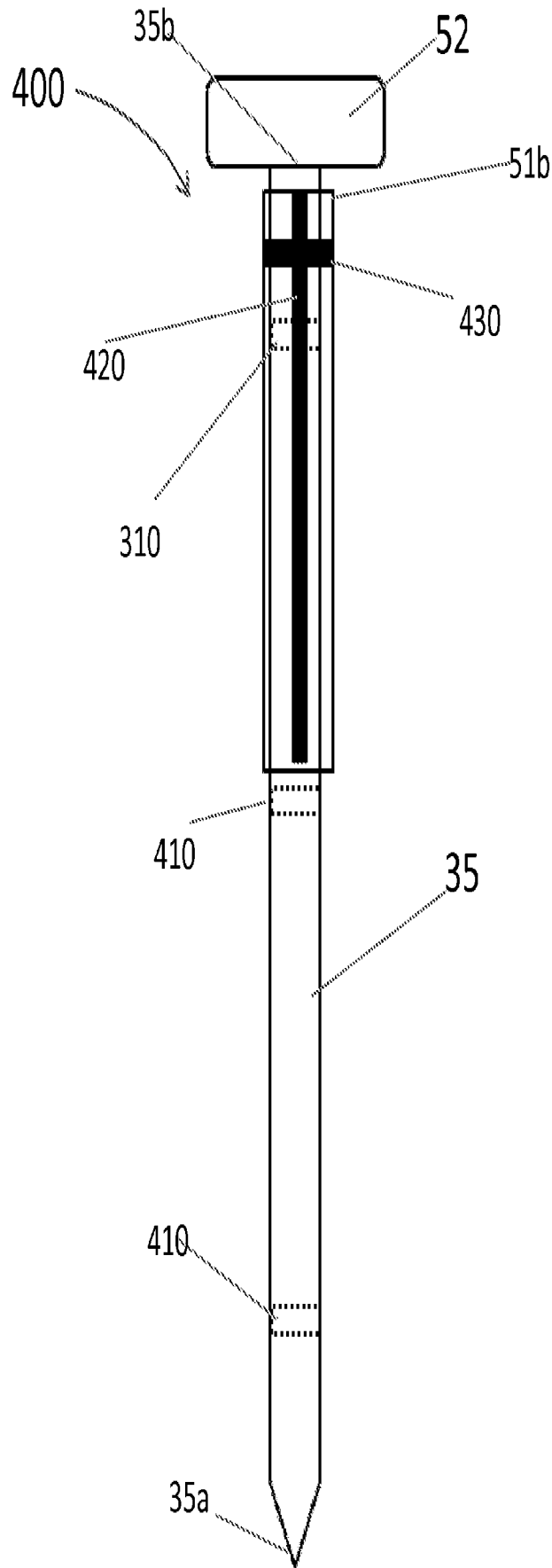
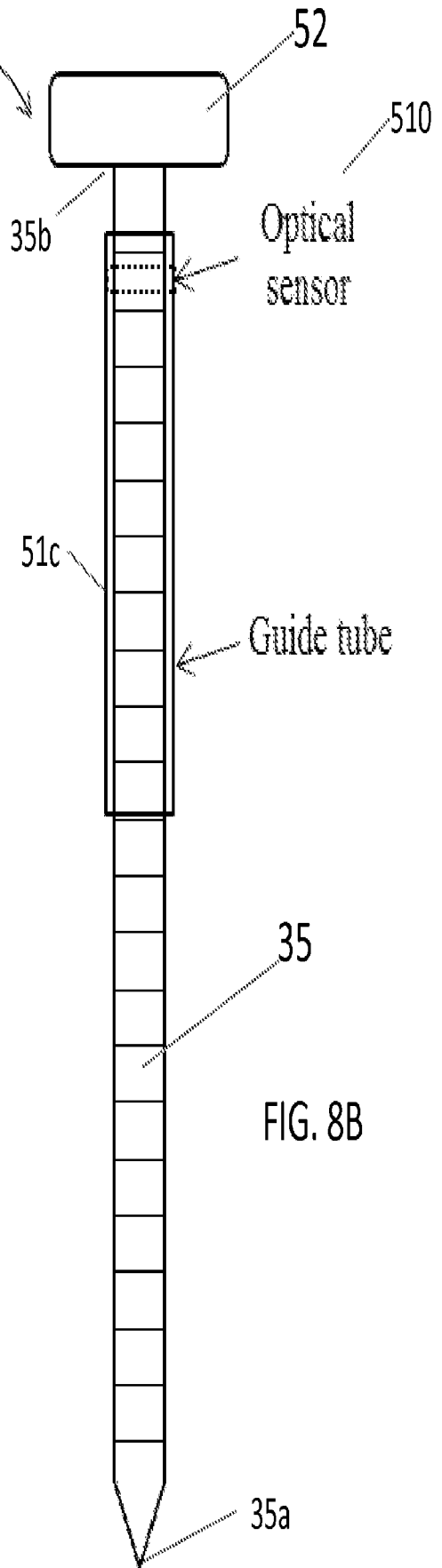
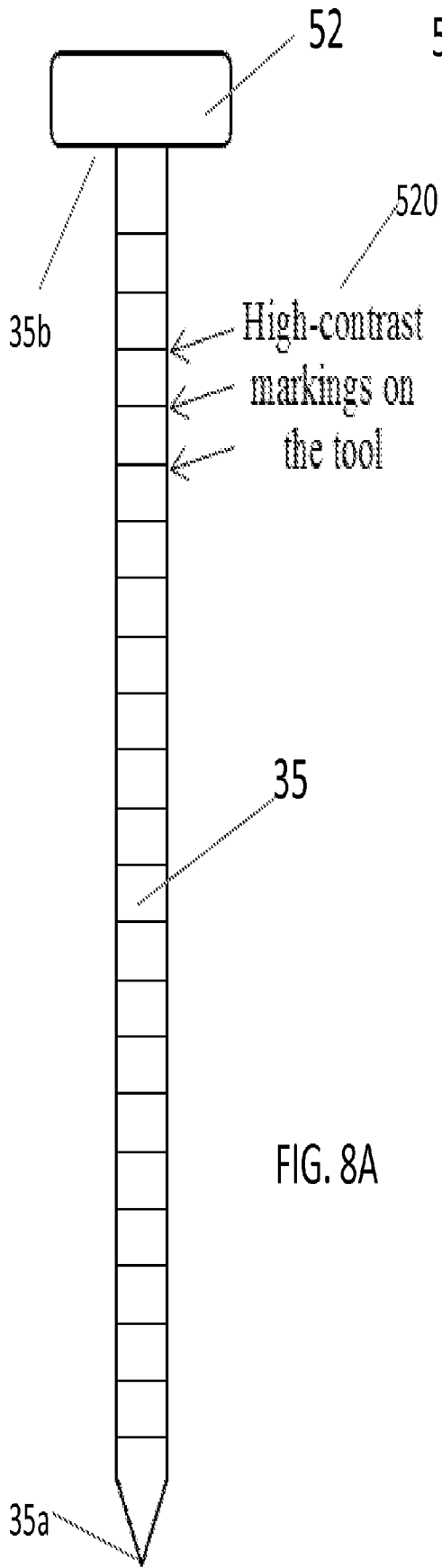


FIG. 7C





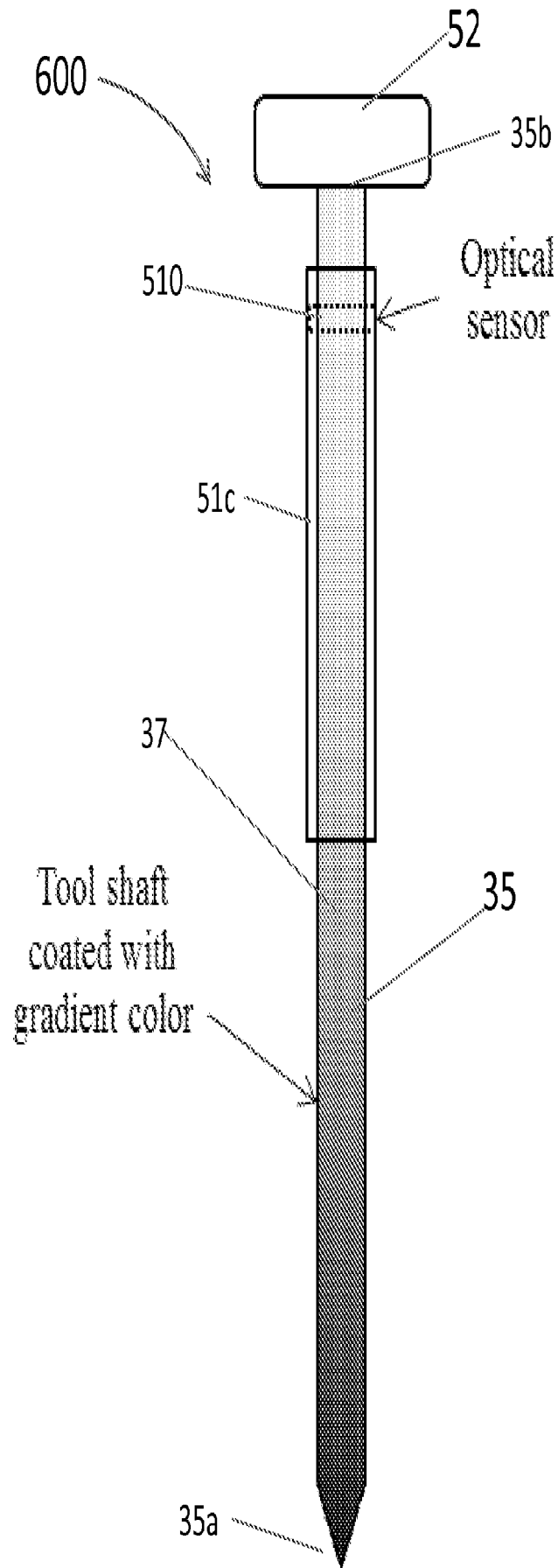


FIG. 9

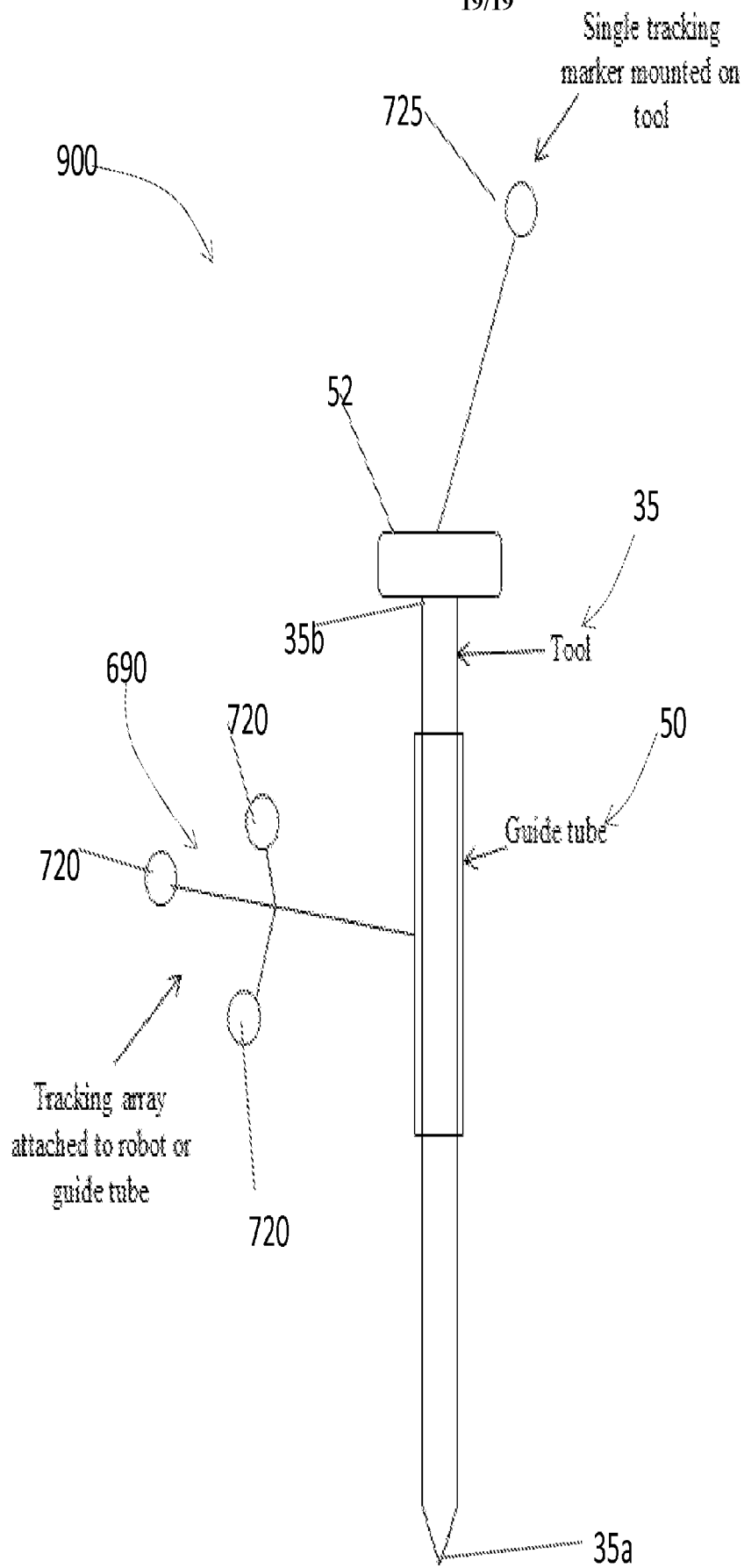


FIG. 10

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2014/062083****A. CLASSIFICATION OF SUBJECT MATTER****A61B 17/00(2006.01)i, A61B 17/34(2006.01)i, A61B 19/00(2006.01)i**

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)

A61B 17/00; A61M 5/46; A61M 25/01; A61B 5/05; F21V 21/00; A61B 17/20; B25J 13/00; A61M 5/00; F21L 4/00; G01B 11/14; A61B 19/00; A61B 17/34

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

Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; Keywords: guide tube, surgical instrument, sensor, detectable feature, processor, robot, effector element, motor assembly

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0172908 A1 (SANG et al.) 4 July 2013 See paragraphs [0041]-[0045], [0047], [0048], [0050]-[0054], [0060], [0063]-[0066], [0068], [0071], [0094]-[0100], [0104]; and figures 1-3, 5-7.	1, 21, 27
Y		2-20, 22-26, 28
Y	US 5492527 A (GLOWA et al.) 20 February 1996 See column 8, lines 4-48; and figure 19.	2-17, 23-25
Y	US 5066288 A (DENIEGA et al.) 19 November 1991 See column 3, lines 10-41; and figures 1-4.	18-20, 22
Y	US 2003-0040667 A1 (FEUSSNER et al.) 27 February 2003 See abstract; paragraphs [0022], [0023]; claim 1; and figure 1.	26, 28
A	US 2008-0154389 A1 (SMITH et al.) 26 June 2008 See abstract; and claim 1.	1-28
A	US 7981092 B2 (DUKE, DANIEL H.) 19 July 2011 See column 6, line 61-column 7, line 45; column 8, lines 4-27, 43-59; and figures 1, 2.	1-28

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

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"&amp;" document member of the same patent family

Date of the actual completion of the international search

27 January 2015 (27.01.2015)

Date of mailing of the international search report

**28 January 2015 (28.01.2015)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

International application No.

**PCT/US2014/062083**

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013-0107508 A1 (ROCKROHR et al.) 2 May 2013 See paragraphs [0022]-[0031]; and figures 1-4.	1-28

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Information on patent family members

International application No.

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