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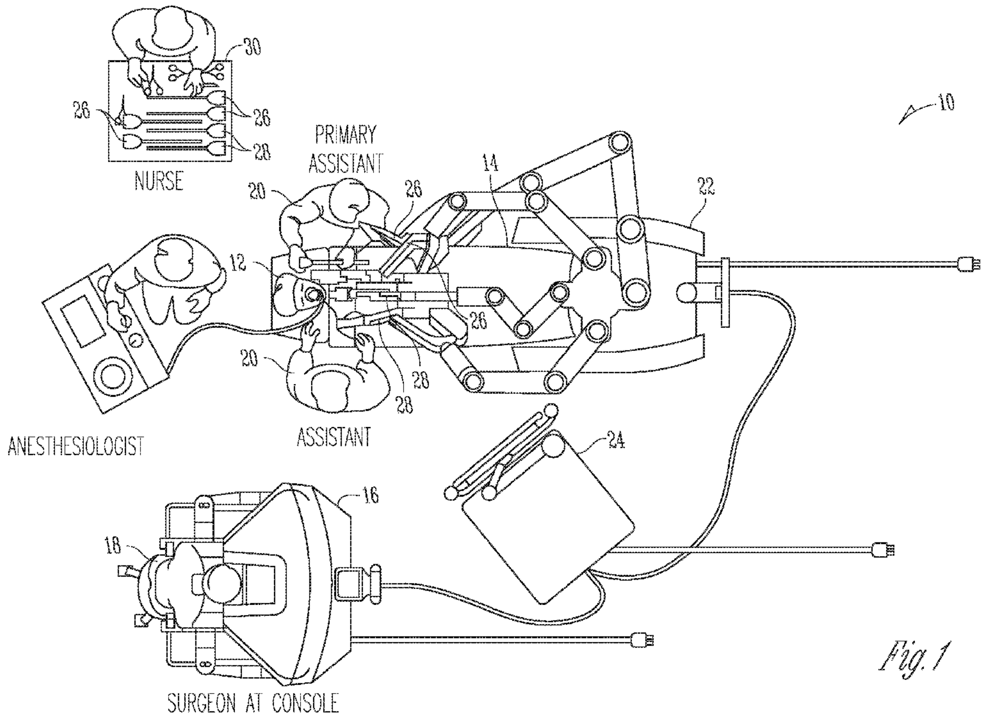

Fig. 1

(57) **Abstract:** A teleoperated surgical system is provided that includes a surgical instrument that includes an end effector mounted for rotation about a slave pivot axis; a master control input includes a mount member, first and second master grip rotatably secured at the mount member for rotation about a master pivot axis; sensor to produce a sensor signal indicative of a slave grip counter-force about the slave pivot axis; one or more motors to impart a shear force to the mount member, perpendicular to the master pivot axis; one or more processors to convert the sensor signal to motor control signals to cause the motors to impart the feedback shear force to the first and second master grip members.

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END EFFECTOR FORCE FEEDBACK TO MASTER CONTROLLER

RELATED APPLICATIONS

This application claims the benefit of priority to U.S. Provisional Patent Application Serial No. 62/567,005, filed on October 2, 2017, which is incorporated by reference herein in its entirety.

BACKGROUND

Minimally invasive medical techniques are intended to reduce the amount of tissue that is damaged during diagnostic or surgical procedures, thereby reducing patient recovery time, discomfort, and deleterious side effects. Teleoperated surgical systems that use robotic technology (so-called surgical robotic systems) may be used to overcome limitations of manual laparoscopic and open surgery. Advances in telepresence systems provide surgeons views inside a patient's body, an increased number of degrees of motion of surgical instruments, and the ability for surgical collaboration over long distances. In manual minimally invasive surgery, surgeons feel the interaction of the instrument with the patient via a long shaft, which eliminates tactile cues and masks force cues. In teleoperation surgery systems, natural force feedback is largely eliminated because the surgeon no longer manipulates the instrument directly. Kinesthetic or force feedback systems typically measure or estimate the forces applied to the patient by the surgical instrument.

SUMMARY

In one aspect, a teleoperated surgical system is provided that includes a surgical instrument that includes a shaft, an end effector that includes a first cantilever beam, mounted for rotation about a slave pivot axis disposed at the distal end portion of the shaft. A master control input includes a mount member and a first master grip member mounted upon the mount member for a direction of movement along a first path relative to the mount member. A sensor is configured to sense a magnitude of produce a slave cantilever beam force. One or more actuators are configurable to impart a force to the mount member. One or more processors are configured to cause the one or more acutators to impart a feedback force to the mount member, having a magnitude indicative of the magnitude of the slave cantilever beam force and having a direction of movement along a second path separate from the first path.

In another aspect, a method is provided to provide at a master control input an indication of a grip force at a slave end effector portion mounted to a distal end of a surgical instrument shaft in which the master control input includes a mount member and a first master grip member, mounted for a direction of movement along a first path. The method includes producing a sensor signal indicative of magnitude of a grip moment about a slave pivot axis of the end effector and producing a feedback force at the mount member, having a magnitude based upon the sensor signal and having a direction of movement along a second path separate from the first path.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

Figure 1 is an illustrative plan view of a minimally invasive teleoperated surgical system in accordance with some embodiments.

Figure 2 is a perspective view of the surgeon's console of the system of **Figure 1**.

Figure 3 is a perspective view of a patient-side cart of the system of **Figure 1**.

Figure 4 is a perspective view of a surgical instrument in accordance with some embodiments.

Figure 5 is an illustrative perspective showing details of a master control input mounted upon a gimbal assembly within the surgeon consloe 16 of **Figure 2** in accordacne with some embodiments.

Figure 6 is an illustrative side cross-section partially transparent view of an end effector of the surgical instrument of **Figure 4** in accordance with some embodiments.

Figure 7 is an illustrative side view of the chassis of the surgical instrument of **Figure 4** suspended from a support beam in accordance with some embodiments.

Figure 8 is an illustrative free body diagram to show forces upon grip members of the master control input of **Figure 5** and a surgeon's fingers in accordance with some embodiments.

Figure 9 is an illustrative control system flow diagram representing a transformation of a reactive beam force to a feedback force in accordance with some embodiments.

DESCRIPTION OF EMBODIMENTS

Teleoperated Surgical System

Figure 1 is an illustrative plan view of a minimally invasive teleoperated surgical system 10 for performing a minimally invasive diagnostic or surgical procedure on a patient 12 who is lying on an operating table 14. The system includes a surgeon's console 16 for use by a surgeon 18 during the procedure. One or more assistants 20 also may participate in the procedure. The minimally invasive teleoperated surgical system 10 further includes one or more patient-side cart (PSC) 22 and an electronics cart 24. The patient-side cart 22 can manipulate at least one surgical instrument 26 through a minimally invasive incision in the body of the patient 12 while the surgeon 18 views the surgical site through the surgeon's console 16. An image of the surgical site can be obtained by an endoscope 28, such as a stereoscopic endoscope, which may be manipulated by the patient-side cart 22 to orient the endoscope 28. Computer processors located on the electronics cart 24 may be used to process the images of the surgical site for subsequent display to the surgeon 18 through the surgeon's console 16. In some embodiments, stereoscopic images may be captured, which allow the perception of depth during a surgical procedure. The number of surgical instruments 26 used at one time will generally depend on the diagnostic or surgical procedure and the space constraints within the operative site among other factors. If it is necessary to change one or more of the surgical instruments 26 being used during a procedure, an assistant 20 may remove the surgical instrument 26 from the patient-side cart 22, and replace it with another surgical instrument 26 from a tray 30 in the operating room.

Figure 2 is a perspective view of the surgeon's console 16. The surgeon's console 16 includes a viewer display 31 that includes a left eye display 32 and a right eye display 34 for presenting the surgeon 18 with a coordinated stereoscopic view of the surgical site that enables depth perception. The console 16 further includes one or more hand-operated control inputs 36 to receive larger-scale hand control movements. One or more surgical instruments installed for use on the patient-side cart 22 move in smaller-scale distances that correspond to a surgeon 18's larger-scale manipulation of the one or more control inputs 36. The control inputs 36 may provide the same mechanical degrees of freedom as their associated surgical instruments 26 to provide the surgeon 18 with telepresence, or the perception that the control inputs 36 are integral with the instruments 26 so that the surgeon has a strong sense of directly controlling the instruments 26. To this end, position, force, and tactile feedback sensors (not shown) may be employed to transmit position, force, and tactile sensations from the surgical instruments 26 back to the surgeon's hands through the control inputs 36, subject to communication delay constraints.

Figure 3 is a perspective view of a patient-side cart 22 of a minimally invasive teleoperated surgical system 10, in accordance with some embodiments. The patient-side cart 22 includes four mechanical support arms 72. A surgical instrument manipulator 73, which includes actuators such as motors, to control instrument motion, is mounted at the end of each support arm assembly 72. Additionally, each support arm 72 can optionally include one or more setup joints (e.g., unpowered and/or lockable) that are used to position the attached surgical instrument manipulator 73 in relation to the patient for surgery. While the patient-side cart 22 is shown as including four surgical instrument manipulators 73, more or fewer surgical instrument manipulators 73 may be used. A teleoperated surgical system will generally include a vision system that typically includes an endoscopic camera instrument 28 for capturing video images and one or more video displays for displaying the captured video images.

In one aspect, for example, individual surgical instruments 26 and cannulas 27 are removably coupled to manipulator 73, with the surgical instrument 26 inserted through the cannula 27. One or more teleoperated actuator motors of the manipulator 73 move the surgical instrument 26 as a whole to position it in relation to a patient 12. Each support arm assembly includes an instrument carriage 75. A surgical instrument 26 is detachably connected to an instrument carriage 75. In one aspect, the instrument carriage 75 houses one or more teleoperated actuator motors (not shown) inside that provide a number of controller motions that the surgical instrument 26 translates into a variety of movements of an end effector at a distal end of the surgical instrument 26. Thus, the teleoperated actuator motors within the instrument carriage 75 move individual components of the surgical instrument 26 rather than the instrument as a whole. Inputs to control either the instrument as a whole or the instrument's components are such that the input provided by a surgeon or other medical person to a control input 36 (a "master" command) are translated into a corresponding action by a surgical instrument end effector (a "slave" response). A wire cable-based force transmission mechanism or the like is used to transfer the motions of each of the remotely located teleoperated actuator motors to a corresponding instrument-interfacing actuator output located on instrument carriage 75. In some embodiments, the surgical instrument 26 is mechanically coupled to a first actuator motor, which controls a first motion of the surgical instrument such as longitudinal (z-axis) rotation. The surgical instrument 26 is mechanically coupled to a second actuator, which controls second motion of the surgical instrument such as two-dimensional (x, y) motion. The surgical instrument 26 is mechanically coupled to a third actuator, which controls third motion of the surgical instrument such as opening and closing of jaws of an end effector, for example.

Figure 4 is a perspective view of a surgical instrument 26 in accordance with some embodiments. The surgical instrument 26 includes an elongated hollow tubular shaft 410 having a centerline longitudinal axis 411. The shaft 410 includes a distal end portion 450 for insertion into a patient's body cavity and proximal end portion 456 that that is mechanically secured to a chassis 440 that mounts motor-driven drive elements 458 that impart forces to cables (not shown) extending within the shaft that are coupled to actuate a surgical end effector 454. A cable drive mechanism 458 may include a motor-driven spindle (not shown), for example. Actuator motors 445, 447 may be mounted on the chassis 440 itself or on the instrument carriage 75, for example. The end effector 454 is coupled to the distal end portion 450 of shaft 410 by a wrist 452. Preferably, wrist 452 provides at least two degrees of freedom. In some embodiments, the wrist 452 is rotatable about the centerline longitudinal axis 411, thereby providing three orientational degrees of freedom for surgical end effector 454 at a surgical site internal to a patient's 12 body cavity. The motor driven drive elements 458 exert forces upon the cables to impart motion to the end effector 454 such as opening or closing of jaws and (x, y) rotational motion of a wrist, for example. A variety of alternative end effectors for alternative tools may be mounted at the distal end portion 450 of the shaft 410 such as forceps, scissors, and clip applier, which include first and second end effector cantilever beams 462, 464 which pivot relative to each other so as to define a pair of end effector jaws, for example. Other end effectors, such as a scalpel and electrocautery probe may have a single end effector element, for example.

Figure 5 is an illustrative perspective showing details of an control input 36 mounted upon a gimbal assembly 528 within the surgeon console 16 of **Figure 2** in accordacne with some embodiments. The control input 36, which also is referred to as a master tool manipulator (MTM), includes a mount member configured as a handle 530 and first and second articulable grip members 530a, 530b mounted upon the handle 530. The handle acts as a mount member to mount the first and second grip members 530a, 530b; The first and second grip members 530a, 530b upstand at an incline from opposite sides of the handle 530. The first and second grip members are inclined relative to the handle 530 with their distal ends spaced closer together and their proximal ends spaced farther apart. The first and second grip members have an angle α between their distal ends that may vary according to forces exerted by a surgeon. In some embodiments, the angle α is an acute angle. The first and second grip members 530a, 530b are secured to the handle to articulate relative to the mount member 530. More specifically, in accordance with some embodients, the first and second grip members 530a, 530b are secured to the handle to pivot about a master pivot axis 536 to follow a first path (not sown). A biasing member (not shown) urges the grip members 530a, 530b apart. A surgeon may grip the grip members 530a, 530b and apply forces to urge them along the first path so as to cause them to move closer together or to cause the biasing member to urge them in an oppositee direction along the first path to cause them to move apart. The mount member handle 530 may include a grip actuation sensor (not shown) such as a Hall effect device to sense movement of the grip members along the first path. Finger loops may be attached to the handle to avoid slipping from the grip members. The grip members 530a, 530b are operatively coupled through kinematices, for example, to control motion of a slave end effector 454 at the distal end portion 450 of a surgical instrument shaft 410 in response to motion of the grip members 530a, 530b along th first path. The slave end effector 454 may include first and second cantilever beams 462, 464 that open and close in response to the surgeon's causing corresponding movement of the first and second grip members 530a, 530b closer together and farther apart, for example.

More particulary, in some embodiments, a four-degree of freedom gimbal 528 allows rotation of the actuatable mount member handle 530 about three axes, axis 534a, axis 534b, and axis 534c. The handle 530 is coupled to a first elbow-shaped link 514 by a first pivotal joint 16. First link 532 is coupled to a second elbow-shaped link 537 by a pivotal joint 520. Second link 537 is pivotally coupled to a third elbow-shaped link 538 by a pivotal joint 524. In some embodiments, motors of arm 538 and gimbal 528 are capable of actively applying positional and orientational forces to mount member handle 530, thereby providing tactile feedback to the surgeon. In particular, the gimbal motors can be configured through control signals to impart a feedback force $F_{Z,MTM}$ along a second path separate from the first path. In the illustrative embodiment of **Figure 5**, the feedback force $F_{Z,MTM}$ is imparted parallel to an axis 531 of the handle 530 in a direction toward the vertex of the angle, which is directed perpendicular to a master pivot axis 536, such that the feedback force is felt equally by a surgeon's fingers on each of the grip members 530a, 530b. The gimbal 528 includes links 532, 537, 538. Gimbal 528 is mounted to platform 540 so as to rotate about axis 534d, and links 532, 537, 538 define additional axes

534a, 534b and 534c. Handle 530 is mounted to gimbal 528 by an actively driven joint for motion about axis 534d. Hence, gimbal 528 provides four driven orientational degrees of freedom, including a redundant orientational degree of freedom. Gimbal 528, arm 538, and the driving motors for these joints are described in more detail in U.S. Patent No. 6,714,839, entitled "Master Having Redundant Degrees of Freedom", the full disclosure of which is expressly incorporated by this by reference.

The grip members 530a and 530b of mount member handle 530 pivot passively about a master pivot axis 536 with no drive motor provided for feedback from the slave to control their pivot. In the exemplary embodiment, an actuator 545 is mounted to generate a master grip signal indicating the angular separation between grip members 530a and 530b. In some embodiments, the actuator 545 includes a Hall effect transducer in one of the grip members and a magnet mounted in the other, so that handle 530 generates a master grip signal indicating the angular separation between grip members 530a and 530b. A biasing system urges the grip members 530a and 530b apart, and the grip members may include loops of Velcro™ or the like to more firmly position the grip members relative to a thumb and finger of a system operator. A wide variety of grip member structures might be used within the scope of the disclosure, including any surgical instrument handles, optionally including rigid or flexible loops for the thumb and/or fingers, for example. Control relationships between the grip members and slave end effector jaws is explained in more detail in U.S. Patent No. 6,594,552, entitled, "Grip Strength with Tactile Feedback for Robotic Surgery", the full disclosure of which is expressly incorporated by this by reference.

Figure 6 is an illustrative side cross-section partially transparent view of an end effector 454 of the surgical instrument 26 of **Figure 4** in accordance with some embodiments. The end effector 454 includes a first and second cantilever beams 462, 464 disposed at a distal end 450 of the shaft 410 of the surgical instrument 26. The first cantilever beam 462 is mounted for rotation about a slave pivot axis 602. The end effector 454 is mounted at the distal end portion 450 of the elongated shaft 410. The first and second cantilever beams 462, 464 act as first and second jaws that may be opened to capture anatomical tissue 603 between them and may be closed to grip the anatomical tissue 603 between them. The first cantilever beam 462 may act as a first jaw. The second cantilever beam 464 may act as a second jaw. In some embodiments, the first cantilever beam 462 is rotatable about the slave pivot axis 602 and the second cantilever beam 464 has a fixed position at the distal end of the shaft such that the first cantilever beam 462, acting as a first jaw, moves relative to the fixed second cantilever beam 464, acting as the second jaw. In an alternative embodiment (not shown), both the first and second cantilever beams 462, 464 may be rotatable about the slave pivot axis 602, for example. The first cantilever beam 462 that is integrally secured to a first pulley 604, which is rotatably mounted to a clevis 606 (represented by dashed lines) to rotate in unison about the slave pivot axis 602. A first cable 608 extends longitudinally within the hollow shaft 410. A proximal end (not shown) of the first cable 608 is operatively coupled to an actuator motor to impart a first cable force F_{C1} upon the cable to rotate the first beam 462 toward the second beam 464 to 'close' the jaws. A distal end portion of the first cable wraps about a perimeter groove portion of the first pulley 604. An anchor 610, such as a crimp in the first cable 608, secures a distal end of the first cable 606 to the first cantilever beam so that a first cable force F_{C1} exerted in a proximal direction upon a proximal end of the first cable 608 imparts a force upon the distal end of the first cable that the rotatably mounted first cantilever beam 462 translates to a rotational force F_{C1} exerted at a working/tissue engagement surface 612 of the first cantilever beam 462 in a direction that is normal to the slave pivot axis 602, to urge rotation of the first cantilever beam 462 in a direction toward the second beam 464 to close the jaws.

A distal end portion of a second cable 614 that extends longitudinally within the hollow shaft 410 wraps about a perimeter groove portion of a second pulley (not shown) mounted to the clevis 606 in parallel with the first pulley 604. A proximal end (not shown) of the second cable 614 is operatively coupled to an actuator motor to impart a second cable force F_{C2} upon the second cable 614 to rotate the first beam 462 awayd the second beam 464 to 'open' the jaws. A distal end of the second cable 614 is secured to the first cantilever beam 462 such that a proximal direction second cable force F_{C2} exerted on the second cable 614 imparts causes the rotatably mounted first cantilever beam 462 to rotate in a direction away from the second beam 464 to open the jaws. In some embodiments the first and second cables 608, 614 include center segments that include elongated tubules and end segments that comprise wire.

During gripping of anatomical tissue 603, for example, a cable drive mechanism 458 described above, causes the first cable 608 to exert the first cable force F_C axially upon the first cable 608 to a impart rotation force to the first cantilever beam 462 that balances a slave grip counter-force F_{grip} imparted to the working surface 612 of the first cantilever beam 462 by the gripped tissue 603. The grip counter-force F_{grip} balances the first beam force first cable force F_C. The balanced first cable force F_C and the grip force F_{grip} each produce a grip moment about the slave pivot axis, M_{grip} represented in the following formulation.

$$M_{grip} = F_{grip} \cdot L = F_c \cdot l \quad (1)$$

where L represents a distance from the point where the slave grip force F_{grip} is applied to the slave pivot axis, and l represents a distance from the first cable anchor 610, where the first cable 608 is secured to the first cantilever beam 462, and the slave pivot axis 602. Thus, during gripping of anatomical tissue 603, the first cable force F_C has a magnitude to counter-balance the slave grip force F_{grip}.

Figure 7 is an illustrative side view of the chassis 440 of the surgical instrument 26 of **Figure 4** suspended from a support beam 702 in accordance with some embodiments. The chassis 440 is secured to the proximal end portion 456 of the shaft 410 of the surgical instrument 26. A first end portion 704 of the support beam 702 is secured to the chassis 440 and a second end portion 706 of the support beam 702 is secured to a mechanical ground 708. The support beam has a longitudinal axis 710 (the beam axis) that extends between its first and second ends 704, 706. In some embodiments, a mechanical support arm 72 acts as the mechanical ground 708. The center axis 411 of the hollow tube 410 is normal to the support beam axis 710.

A strain sensor 712 contacts the support beam 702 and is configured to measure strain imparted to the support beam 702. In some embodiments, the strain sensor includes resistive strain gauge, optical fiber Bragg grating, piezoelectric sensor. Strain is a measure of the amount of deformation of a body, such as the support beam and the strain sensor 702, due to an applied force. More specifically, strain can be defined as the fractional change of length. The mechanical ground 708 acts as a fixed reference structure that does not exhibit strain due to the cable force F_C or a slave grip force F_{grip}.

A third pulley 714 is rotatably secured to the chassis 440. A proximal end portion of the first cable 608 wraps about a perimeter groove portion of the third pulley 714. A first cable drive mechanism 458a, which is secured to the mechanical ground 708, is configured to impart the first force F_C upon the first cable 608. In some embodiments, the first cable drive mechanism 458a includes a motor driven rotatable spindle mechanically coupled to a proximal end portion of the first cable 608. The third pulley 714 and the first cable drive mechanism 458a are disposed at a vertical offset from each other relative to the support beam axis 702 such that a proximal segment 608a of the first cable 608 between them extends at an offset angle θ from the support beam axis 710. The first cable drive mechanism 458a may impart a first cable force F_C to the offset angled first cable segment 608a to close the jaws. The first cable force F_C applied to the offset first cable segment 608a results in a first cable offset force component $F_C\sin\theta$ upon the support beam 702 that is parallel to the shaft axis 411 and normal to the support beam axis 710 and a first cable offset force component $F_C\cos\theta$ upon the support beam 702 that is perpendicular to the shaft axis 411 and that is parallel to the beam axis 710. In reaction to the first cable force components, the support beam 702 produces reactive normal and parallel beam forces R_X and R_Z. The reactive beam force R_Z, which shall be referred to herein as $F_{Z,PSC}$, the z-force measured on the system side, acts as a strain force applied at the first end 704 of the support beam 702. The strain force F_Z is imparted in a direction normal to the support beam axis.

It will be appreciated that the first cable force F_C imparted by the first cable within the shaft in a direction normal to the support beam axis 710 is balanced by an equal and opposite proximal-direction end effector force F_C' resulting in a net force of zero upon the beam due to forces imparted to first cable segments within the shaft. Outside the shaft, however, the offset angled first cable segment 608a exerts a net force $F_C\sin\theta$ normal to the support beam and in response, the support beam produces an opposing reactive force F_Z.

A fourth pulley 716 is secured to the chassis 440. A proximal end portion of the second cable 614 wraps about a perimeter groove portion of the fourth pulley 716. A second cable drive mechanism 458b, which is secured to the mechanical ground 708, is configured to impart a second cable force F_{C2} upon the second cable 614 to open the jaws. In some embodiments, the second cable drive mechanism 458b includes a motor driven rotatable spindle mechanically coupled to a proximal end portion of the second cable 614. The fourth pulley 716 and the second cable drive mechanism 458b are disposed level with each other without a vertical offset between them relative to the support beam 702 such no net normal force is exerted by a level second cable segment 614a extending between the fourth pulley 716 and the second cable drive mechanism 458b.The strain force F_Z experienced by the support beam 702 due to the offset angled first cable segment 608a is a reactive force imparted that balances the net first cable force $F_C\sin\theta$ imparted to the support beam 702. The strain force F_Z imparts a strain to the support beam 702 and to the strain sensor 712. The relationship between the net normal force $F_C\sin\theta$ and the strain force F_Z imparted to the strain sensor 702 is represented by the following formulation (2).

$$F_{Z,PSC} = F_c sin\theta + F_{cd} - F_{cp} = F_c sin\theta = \frac{M_{grip}}{l} sin\theta \qquad (2)$$

The strain sensor produces a sensor signal Ss that has a magnitude indicative of the magnitude of the strain force $F_{Z,PSC}$, which in turn is proportional to a magnitude of the grip moment M_{grip} about the slave pivot axis, M_{grip}. In some embodiments, the signal may be a change in voltage on a Wheatstone bridge (not shown) produced by a resistance change on a strain gauge.

Figure 8 is an illustrative free body diagram to show forces upon the grip members of a master control input and a surgeon's fingers in accordance with some embodiments. During a surgical procedure, a surgeon's fingers are placed on outside grip surfaces of the first and second grip members 530a, 530b. The first and second grip members 530a, 530b have proximal ends 530ap, 530bp and distal ends 530ad, 530bd. The distal ends 530ad, 530bd of the first and second grip members are pivotally mounted to pivot about the master pivot axis 536 and are offset from each other by an angle α. A surgeon's fingers 802a, 802b may apply fingertip forces to the first and second grip members 530a, 530b to move them along the firs path 850 about the master pibot axis536, to move them closer together or farther apart so as to command corresponding movements of the first and second cantilever beams 462, 464 of the end effector 454. Specifically, for example, moving the proximal ends 530ap, 530bp of the first and second grip members 530a, 530b in a direction along the first path 850 to bring them closer together, which reduces the angle α between them, causes the first and seocond cantilever beams 462, 464 to move closer together, closing the end effector jaws. Conversely, for example, moving the proximal ends 530ap, 530bp of the first and second grip members 530a, 530b in an opposite direction along the first path850 to space them farther apart from each other, which increases the angle α between them, causes the first and second cantilever beams to move farther apart, opening the end effector jaws. U.S. Patent No. 6,594,552, which is incorporated in its entirety by this reference above explains grip member control of end effectors in accordance with some embodiments. Thus, the angle α between the distal ends 530ad, 530bd of the first and second grip members determines the postions of the corresponding first and second cantilever beams at the end effector.

More particularly, a bias member, such as a bias spring 804, provides a bias force F_{spring} to urge the first and second grip members 530a, 530b away from each other. A surgeon may apply forces $-F_N$, which are normal to longitudinal axes 806a, 806b of the first and second grip members 530a, 530b. The surgeon-applied force $-F_N$ rotates the first and second grip members along the first path 850 about the master pivot axis 533 to bring their proximal end portions 530ap, 530bp closer together, redcuing the angle α, between them, and commanding the imparting of the first cable force F_C to cause the first and second cantilever beams 462, 464 at the end effector 454 to move closer together. Addtionally, the surgeon's fingers 802a, 802b may impart surface forces $-\mu_S F_N$, which are parallel to surfaces of the first and second grip members 530a, 530b, in cobination with the surgeon-imparted normal forces $-F_N$.

The first and second grip members 530a, 530b impart opposite direction normal forces F_N to the surgeon's fingers 802a, 802b in reaction to the surgeon-imparted normal forces $-F_N$. The first and second grip members 530a, 530b also impart opposite direction surface forces $\mu_S F_N$ in reaction to the surgeon-imparted surface forces $-\mu_S F_N$.

Thus, in accordance with some embodiments, the first and second cantilever beams 462, 464 correspond to the first and second grip master members 530a, 530b. Larger scale motions imparted by a surgeon's fingers to the master members 530a, 530b are translated to corresponding smaller scale motions of the first and second cantilever beams 462, 464. In particular, in accordance with some embodiments, for example, a rotation of the master members 530a, 530b about the master pivot axis 536 is translated to corresponding rotation of the first and second cantilever beams 462, 464 about slave pivot axis 602. In some embodiments, for example, translation of movement of the master members 530a, 530b translates to corresponding movemrent of the first and second cantilever beams 462, 464 such that an angle α about the master pivot axis 536 between the master members 530a, 530b matches an angle α slave pivot axis 602 between the first and second cantilever beams 462, 464. It is noted that during routine operation, the surgeon imparted forces and the grip member reaction forces are balanced. During routine operation, a friction force at the grip members 530a, 530b is static friction, which is just enough to match the parallel surface forces applied by the surgeon's fingers 802a, 802b at the grip members. It will be apprecated that reaction surface forces $\mu_S F_N$ are less than a maximum permitted surface friction force F_{fr} at which the grip members 530a, 530b start sliding in the surgeon's fingers 802a, 802b, causing the surgeon's finger's to lose their grip, at which point the surgeon may need to apply an increased normal force to increase the surface friction to stop the sliding. The relationship between surface force $\mu_S F_N$ and maximum permitted F_{fr} is represented by the following formulation.

$$F_{fr,max} = \mu_s F_N \quad (3)$$

In operation, a moment imparted by a surgeon 18 at distance a D from the master pivot axis 536 equals and is balanced by a moment imparted by the bias spring 804 at a distance d from the pivot axis 536. If it is assumed that a torsional spring has a sping force in indicated in the formulation.

$$F_{spring} = k(\alpha_0 - \alpha) \quad (4)$$

where k is the spring constant.

If it is assumed that α_0 is the initial angular position, then the normal force F_N is directly related to the angle α by the moment balance the following formulation.

$$F_N D = F_{spring} d = k(\alpha_0 - \alpha) d \quad (5)$$

Thus,

$$F_N = \frac{k(\alpha_0 - \alpha) d}{D} \quad (6)$$

In view of equation (6), it will be appreciated that normal force F_N cannot be modulated directly to display the grip force to the surgeon without changing the α, which would be detrimental to performance since it would affect the gripping angle of the first and second cantilever beams 462, 464 at the end effector 454. However, the inventor herein realized that a feedback surface force $F_{z,MTM}$ imparted to mount member 530, and through it, to the first and second grip members 530a, 530b mounted thereon, along a second path 852 in a direction toward the pivot axis 533 and toward a palm 808 of the surgeon's hand may be modulated to increase a surface feedback force imparted to the fingers 802a, 802b to thereby display an indication of a magnitude of the grip force moment M_{grip} at the end effector 454.

An upper limit of the feedback force $F_{z,MTM}$ is dependent on the amount of force required to make the grip members slip against the surgeon's fingers by overcoming static friction:

$$F_{z,MTM} \leq 2 \cdot \left(F_N sin\alpha + F_{fr,max} cos\alpha\right) = 2 \cdot \left(F_N sin\alpha + \mu_s F_N cos\alpha\right)$$

(7)

$$F_{z,MTM} \leq 2 \cdot \left(\frac{k(\alpha_0 - \alpha)d}{D}\right) \cdot (sin\alpha + \mu_s \cos\alpha)$$

(8)

Since all of the values on the right are known (with the exception of the static friction coefficient, which may be estimated), this provides an upper limit for the $F_{z,MTM}$ that can be commanded. A master-side feedback force $F_{Z,MTM}$ may be imparted along the second path 852 toward the grip members 530a, 530b in a direction perpendicular to the master pivot axis 536 to indicate a magnitude of a sensor signal S_S, which is indicative of the grip moment M_{grip} at the slave end effector 454. Providing the master-side feedback force along the second path 852 separate from the first path 850 ensures that the user is provided an indication of magnitude of the slave force distinguishable from a bias force provided by the spring 804. Moreover, providing the master-side feedback force in a direction that is perpendicular to the master pivot axis 536 ensures that equal feedback forces are imparted to them, since in accordance with some embodiments, the grip paddles 530a are constrained to be symmetric. More particulalry, motors that control the gimbal assembly 528 may be controlled to impart a feedback force $F_{Z,MTM}$ to the handle 530 upon which the first and second grip members 530a, 530b are mounted that may be sensed by a surgeon through fingers 802a, 802b and that provide an indication of slave grip force F_{grip}. Moreover, a magnitude of the feedback force $F_{Z,MTM}$ may be modulated according to a magnitude of the sensor signal S_S, which is indicative of a magnitude of the grip moment M_{grip} and the slave grip force F_{grip}.

In some embodiments, a magnitude of a surface feedbackforce transferred to the fingers 802a, 802b is the friction component of the force:

$$F_{z,MTM} = 2 \cdot (F_N sin\alpha + F_{fr} cos\alpha) \quad (9)$$

$$F_{fr} = \frac{F_{z,MTM}}{2 \cdot cos\alpha} - \frac{k(\alpha - \alpha_0)d \cdot tan\alpha}{D} \quad (10)$$

For a given angle α this friction force F_{fr} felt at the fingers 802a, 802b is linear with the feedback surface force $F_{Z,MTM}$ and therefore, the feedback force $F_{Z,MTM}$ can be modulated linearly to control the surface feedback friction component F_{fr} of the feedack feedback force $F_{Z,MTM}$ that is felt by the surgeon and to limit the feedback friction component F_{fr} to a magnitude less than an magnitude required to make the grip members 530a, 530b slip against the surgeon's fingers. Maintaining a feedback force within the upper limit ensures that finger slippage does not occur that may cause pivotal movement pivotal of the grip members 530a, 530b about the master pivot axis 536 that could be translated to movement of the cantilever beams 462, 464 about the slave pivot axis 602. In other words, the shear force upper limit ensures that a feedback force intended to a feedback force to display to a surgeon a magnitude of a slave grip force at the end effector 454 does not cause a change in rotational positions of the cantilever beams 462, 464 at the end effector 454.

Figure 9 is an illustrative control system flow diagram 900 representing a transformation of a reactive beam force to a feedback force in accordance with some embodiments. A reactive beam force $F_{Z,PSC}$ imparts a strain go the sensor 712, which produces a sensor signal S_S having a magnitude that is proportional to a magnitude of the reactive beam force $F_{Z,PSC}$, which is proportional to a grip moment M_{grip} and a slave grip force F_{grip}. A converter block 902 converts the sensor signal S_S to a feedback force master control signal $S_{S,MTM}$. In some embodiments, the converter block 902 produces an $S_{S,MTM}$ signal having a magnitude that is a linear function of a magnitude of the sensor signal S_S. A motor control block 904 is configured to produce one or more motor control signals S_M in response to the $S_{S,MTM}$ signal, to control motors 906 that produce forces F_M to control motion of the gimbal assembly 528 to impart a feedback force $F_{Z,MTM}$ having a magnitude that is proportional to a magnitude of the $S_{S,MTM}$ signal and that is limited to avoid slippage of the first and second master grip members 530a, 530b in a surgeon's fingers. In some embodiments, the computer processors located on the electronics cart 24 are configured to determine the $S_{S,MTM}$ signal as a linear function of the S_S signal. Moreover, in some embodiments, the computer processors located on the electronics cart 24 are configured to produce the one or more motor control signals S_M based upon the $S_{S,MTM}$ signal. In various other embodiments, the motor control signals S_M can cause an oscillating (e.g., vibrating) feedback force F_{MTM} (not shown) at the master having a second path that is an oscillation path separate from the first path and having a parameter proportional to a magnitude of the $S_{S,MTM}$ signal (e.g., amplitude or frequency of oscillation of force F_{MTM}).

Although illustrative embodiments have been shown and described, a wide range of modification, change and substitution is contemplated in the foregoing disclosure and in some instances, some features of the embodiments may be employed without a corresponding use of other features. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, although mechanically supported masters are depicted and described for exemplary purposes, in various embodiments the masters can be wireless or connected to the system only by wires ("ungrounded"). In one alternative embodiment, for example, a master may include a joy stick grip member mounted to a mount member, wirelessly coupled to control a slave end effector in response to movement of the joy stick. In another alternative embodiment, for example, a master may include a pistol trigger grip member in which a trigger grip member is mounted to a pistol-shaped mount member, wirelessly coupled to control a slave end effector in response to movement of the trigger. Thus, the scope of the disclosure should be limited only by the following claims, and it is appropriate that the claims be construed broadly and in a manner consistent with the scope of the embodiments disclosed herein. The above description is presented to enable any person skilled in the art to create and use a surgical system having an end effector force coupled to provide a corresponding master controller feedback force. Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the scope of the invention. In the preceding description, numerous details are set forth for the purpose of explanation. However, one of ordinary skill in the art will realize that the invention might be practiced without the use of these specific details. In other instances, well-known processes are shown in block diagram form in order not to obscure the description of the invention with unnecessary detail. Identical reference numerals may be used to represent different views of the same or similar item in different drawings. Thus, the foregoing description and drawings of embodiments in accordance with the present invention are merely illustrative of the principles of the invention. Therefore, it will be understood that various modifications can be made to the embodiments by those skilled in the art without departing from the scope of the invention, which is defined in the appended claims.

CLAIMS

1. A teleoperated surgical system comprising:

a surgical instrument that includes,

an elongated shaft that includes a distal end portion and a proximal end portion, and

an end effector that includes a slave cantilever beam, mounted for rotation about a slave pivot axis, disposed at the distal end portion of the shaft;

one or more actuators configured to impart a rotation force about the slave pivot axis to the slave cantilever beam;

a sensor configured to sense a magnitude of a slave cantilever beam counter-force about the slave pivot axis;

a master control input that includes,

a mount member;

a first master grip member coupled to the mount member to allow motion of the first master grip member along a first path;

a feedback generator to provide a feedback force that is based upon the sensed magnitude of the slave cantilever beam counter-force about the slave pivot axis and that has a direction along a second path separate from the first path.

2. The teleoperated surgical system of claim 1,

wherein the feedback generator includes:

one or more actuators; and

one or more processors configured to cause the one or more actuators to impart the feedback force to the mount member.

3. A surgical system comprising:

a surgical instrument comprising an end effector, wherein the end effector comprises a first jaw and a second jaw pivotally coupled to the first jaw about a first axis;

a sensor configured to determine a grip force experienced between the first jaw and the second jaw;

a master controller comprising a first input member, a second input member pivotally coupled to the first input member about a second axis, and a feedback generator,

wherein pivoting the second input member about the second axis towards the first input member causes the second jaw to pivot about the first axis towards the first jaw, and

wherein the feedback generator generates a feedback force proportional to the grip force in a direction disjoint from the second axis.

4. A teleoperated surgical system comprising:

a surgical instrument that includes,

an elongated shaft that includes a distal end portion and a proximal end portion, and

an end effector that includes a first cantilever beam, mounted for rotation about a slave pivot axis, disposed at the distal end portion of the shaft;

a master control input that includes,

a mount member,

first and second master grip members having distal ends rotatably secured at the mount member for rotation about a master pivot axis, and

a bias member disposed to urge proximal ends of the first and second master grip members apart from each other;

a sensor configured to produce a sensor signal indicative of a slave grip counter-force about the slave pivot axis;

one or more motors configurable to impart a reactive feedback force to the mount member in a direction that is perpendicular to the master pivot axis;

one or more processors configured to convert the sensor signal to one or more motor control signals to cause the one or more motors to impart the feedback force to the first and second master grip members.

5. The teleoperated surgical system of claim 4,

wherein the one or more processors are configured to cause the one or more motors to limit the feedback force to less than an magnitude required to cause the master grip members to slip against a surgeon's fingers.

6. The teleoperated surgical system of claim 4,

wherein the one or more processors are configured to determine the feedback force based upon slave grip counter-force about the slave pivot axis and an angular separation between the first and second master grip members.

7. The teleoperated surgical system of claim 4,

wherein the bias member includes a spring that includes a spring constant; and

wherein the one or more processors are configured to determine the feedback force based upon slave grip counter-force about the slave pivot axis, an angular separation between the first and second master grip members and the spring constant.

8. The teleoperated surgical system of claim 4,

wherein the master control input includes an actuator to generate a master grip signal indicating an angular separation between the master grip members; and

wherein the one or more processors are configured to determine the feedback force based upon slave grip counter-force about the slave pivot axis and the angular separation between the first and second master grip members.

9. The teleoperated surgical system of claim 4 further including:

a gimble assembly;

wherein the master control input is mounted to the gimble assembly.

10. The teleoperated surgical system of claim 4,

wherein the end effector further includes,

a second cantilever beam, mounted for rotation about the slave pivot axis, disposed at the distal end portion of the shaft.

11. The teleoperated surgical system of claim 4 further including:

a mechanical ground;

a support beam extending perpendicular to the elongated shaft and having a first end portion secured to support the surgical instrument and including a second end portion secured to the mechanical ground;

wherein the sensor is configured to produce the sensor signal indicative of the slave grip counter-force about the slave pivot axis by sensing a strain within the support beam.

12. The teleoperated surgical system of claim 4, wherein the surgical instrument further includes,

a distal pulley mounted at the distal end portion of the shaft for rotation about the slave pivot axis,

a chassis secured to the proximal end portion of the shaft,

a proximal pulley rotatably mounted at the chassis, and

a first cable having a distal end portion that wraps about and is secured to impart a rotational force to the distal pulley and having a proximal end that wraps about the proximal pulley; further including:

a cable drive mechanism secured to the proximal end to impart a force component upon the first cable perpendicular to a longitudinal axis of the shaft.

wherein the sensor is configured to produce the sensor signal indicative of the slave grip counter-force about the slave pivot axis based upon the force component imparted upon the first cable perpendicular to the longitudinal axis of the shaft.

13. A teleoperated surgical system comprising:

a mechanical ground;

a surgical instrument that includes,

an elongated shaft that includes a distal end portion and a proximal end portion, and

an end effector that includes a first cantilever beam, mounted for rotation about a slave pivot axis, disposed at the distal end portion of the shaft;

a distal pulley mounted at the distal end portion of the shaft for rotation about the slave pivot axis,

a chassis secured to the proximal end portion of the shaft,

a proximal pulley rotatably mounted at the chassis, and a first cable having a distal end portion that wraps about and is secured to impart a rotational force to the distal pulley and having a proximal end that wraps about the proximal pulley;

a support beam extending perpendicular to the elongated shaft and having a first end portion secured to support the chassis and including a second end portion secured to the mechanical ground;

a master control input that includes,

a mount member,

first and second master grip members having distal ends rotatably secured at the mount member for rotation about a master pivot axis, and

a bias member disposed to urge proximal ends of the first and second master grip members apart from each other;

a sensor configured to produce a sensor signal indicative of a slave grip counter-force about the slave pivot axis based upon a force component imparted upon the first cable perpendicular to a longitudinal axis of the shaft;

one or more motors configurable to impart a reactive feedback force to the mount member in a direction that is perpendicular to the master pivot axis;

one or more processors configured to convert the sensor signal to one or more motor control signals to cause the one or more motors to impart the feedback force to the first and second master grip members in the direction that is perpendicular to the master pivot axis.

14. The teleoperated surgical system of claim 13 further including:

a cable drive mechanism secured to the proximal end of the first cable to impart a force component upon the first cable perpendicular to the longitudinal axis of the shaft.

15. The teleoperated surgical system of claim 13,

wherein the one or more processors are configured to cause the one or more motors to limit the feedback force to less than an magnitude required to cause the master grip members to slip against a surgeon's fingers.

16. The teleoperated surgical system of claim 13,

wherein the one or more processors are configured to determine the feedback force based upon slave grip counter-force about the slave pivot axis and an angular separation between the first and second master grip members.

17. A method to provide at a master control input an indication of a grip force at a slave end effector portion rotatably mounted to a slave pivot axis at an end of a surgical instrument shaft, wherein the master control input includes a mount member, first and second master grip members having distal ends rotatably secured at the mount member for rotation about a master pivot axis, and a bias member disposed to urge proximal ends of the first and second master grip members apart from each other, the method comprising:

producing a sensor signal indicative of magnitude of a grip counter-force about the slave pivot axis of the end effector;

producing a feedback force at the first and second master grip members, wherein the feedback force has a magnitude based upon the sensor signal and has a direction that is perpendicular to the master pivot axis.

18. The method of claim 17,

wherein producing the feedback force includes producing a feedback force that has a magnitude less than an magnitude required to cause the master grip members to slip against a surgeon's fingers.

19. The method of claim 17,

wherein producing the feedback force includes producing a feedback force based upon a slave grip counter-force about the slave pivot axis and an angular separation between the first and second master grip members.

20. The method of claim 17,

wherein producing the sensor signal includes,

supporting the surgical instrument upon a support beam,

imparting a cable force parallel upon a cable extending within the surgical instrument shaft in reaction to the grip force at a slave end effector, and

imparting to the support beam, a component of the cable force perpendicular to an axis of the shaft.

21. The method of claim 17,

wherein producing the sensor signal includes,

supporting the surgical instrument upon a support beam,

imparting a cable force parallel upon a cable extending within the surgical instrument shaft in reaction to the grip force at a slave end effector, and

imparting to the support beam, a component of the cable force perpendicular to an axis of the shaft;

wherein producing the feedback force includes producing a feedback force less than an magnitude required to cause the master grip members to slip against a surgeon's fingers.

22. The method of claim 17,

wherein producing the sensor signal includes,

supporting the surgical instrument upon a support beam,

imparting a cable force parallel upon a cable extending within the surgical instrument shaft in reaction to the grip force at a slave end effector, and

imparting to the support beam, a component of the cable force perpendicular to an axis of the shaft;

wherein producing the feedback force includes producing a feedback force based upon a slave grip counter-force about the slave pivot axis and an angular separation between the first and second master grip members.

23. The method of claim 17,

wherein producing the sensor signal includes,

supporting the surgical instrument upon a support beam,

imparting a cable force parallel upon a cable extending within the surgical instrument shaft in reaction to the grip force at a slave end effector, and

imparting to the support beam, a component of the cable force perpendicular to an axis of the shaft; further including:

generating a master grip signal indicating an angular separation between the master grip members;

wherein producing the feedback force includes producing the feedback force based upon slave grip counter-force about the slave pivot axis and the angular separation between the first and second master grip members.

24. A surgical control system comprising a master control input, the master control input comprising:

a first master grip member;

a second master grip member articulably coupled to the first master grip member to allow relative motion between the first master grip member and the second master grip member along a first path;

a feedback generator to provide a feedback force at the master control input on a second path separate from the first path.

25. The surgical control system of Claim 24, wherein the feedback generator comprises:

a support linkage coupled to the master control input; and

an actuator to generate the feedback force.

26. The surgical control system of Claim 25, wherein the actuator articulates the support linkage.

27. The surgical control system of Claim 25, wherein the actuator generates the feedback force without articulating the support linkage.

28. The surgical control system of Claim 24, wherein the master control input is ungrounded.

29. The surgical control system of Claim 24, further comprising an electronics cabinet, the electronics cabinet comprising a processor for receiving a sensed force signal and generating a feedback control signal for the feedback generator.

30. The surgical control system of Claim 29, wherein the feedback force is proportional to a sensed force magnitude associated with the sensed force signal.

31. The surgical control system of Claim 30, wherein the feedback force is continuously proportional to the sensed force magnitude.

32. The surgical control system of Claim 30, wherein the feedback force is an oscillating force.

33. The surgical control system of Claim 30, wherein the sensed force signal is received from a surgical instrument.

34. The surgical control system of Claim 30, wherein the sensed force signal is generated from a virtual surgical instrument within a simulation environment.

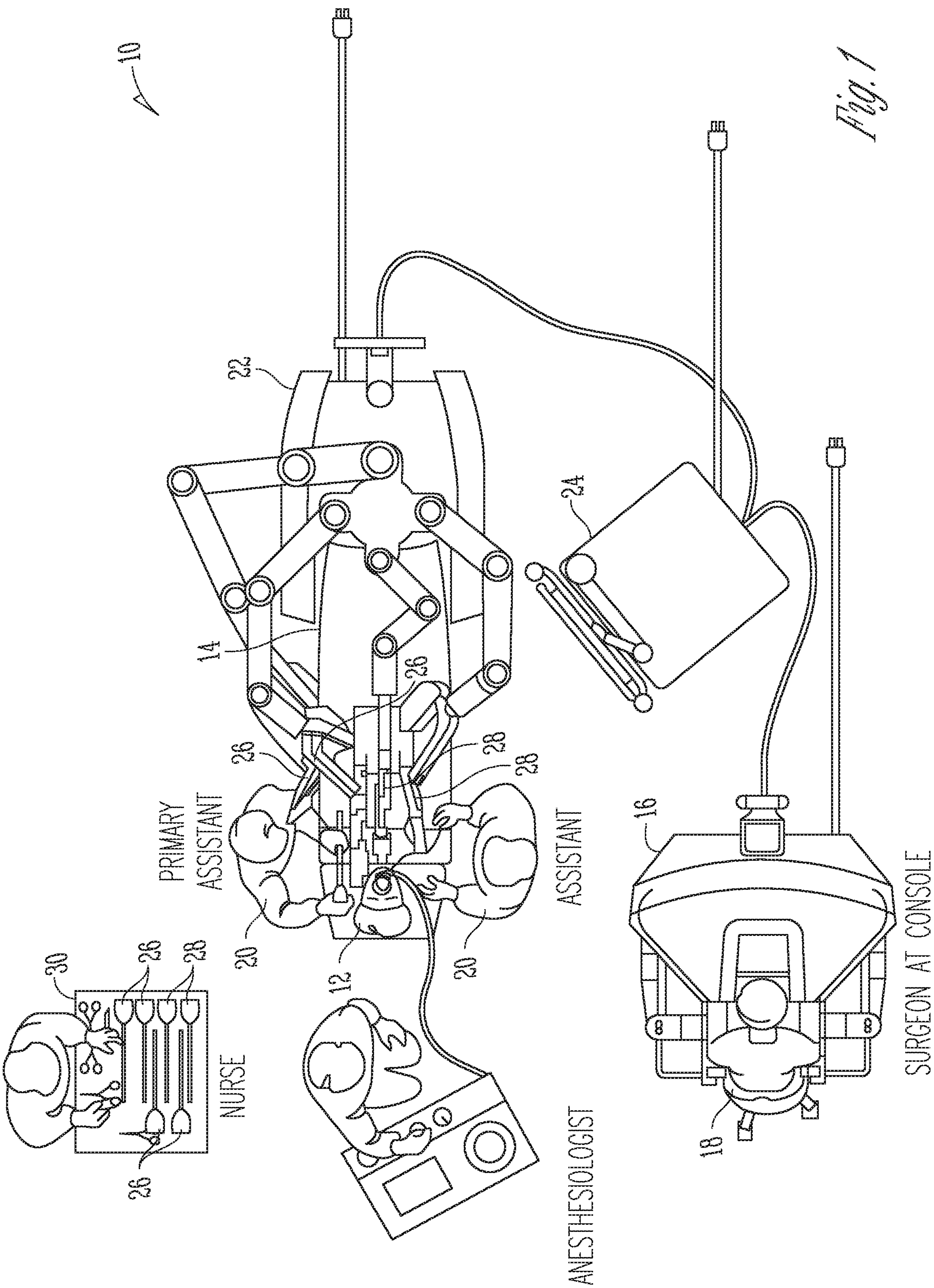

10
22
24
14
26
26
28
28
26
PRIMARY ASSISTANT
ASSISTANT
20
20
12
16
30
26
28
26
NURSE
ANESTHESIOLOGIST
SURGEON AT CONSOLE
18

Fig. 1

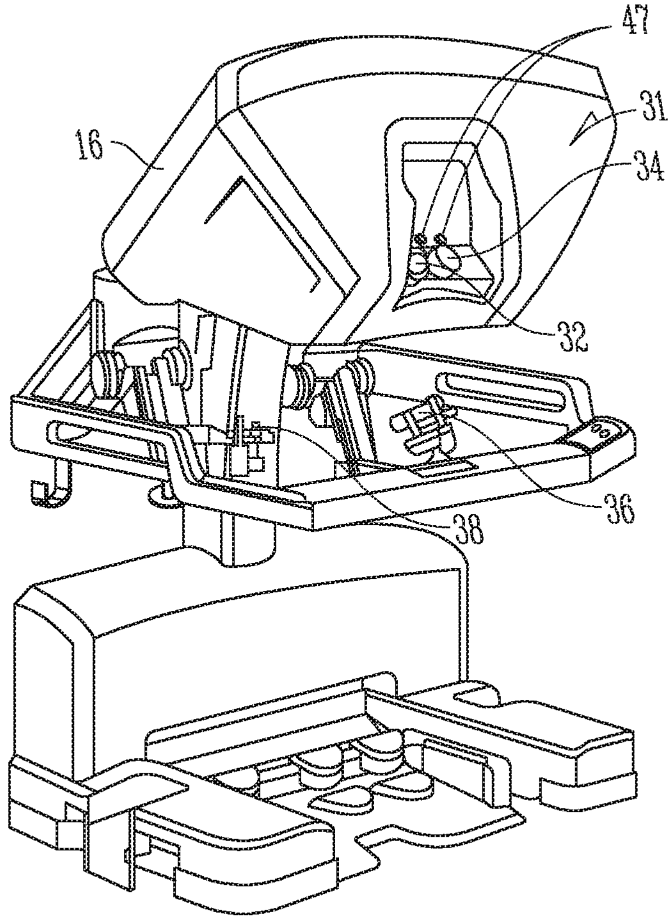


Fig.2

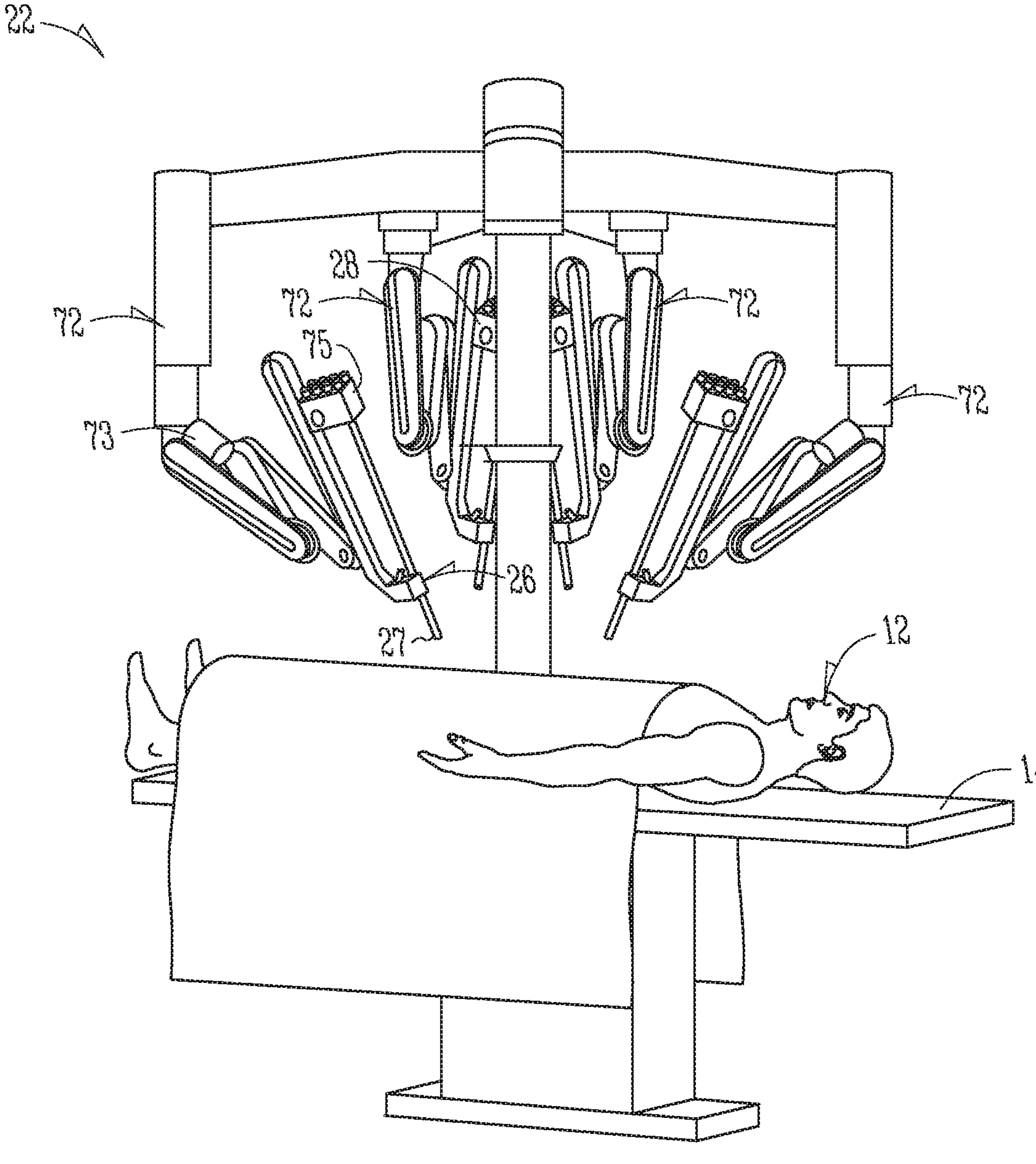


Fig.3

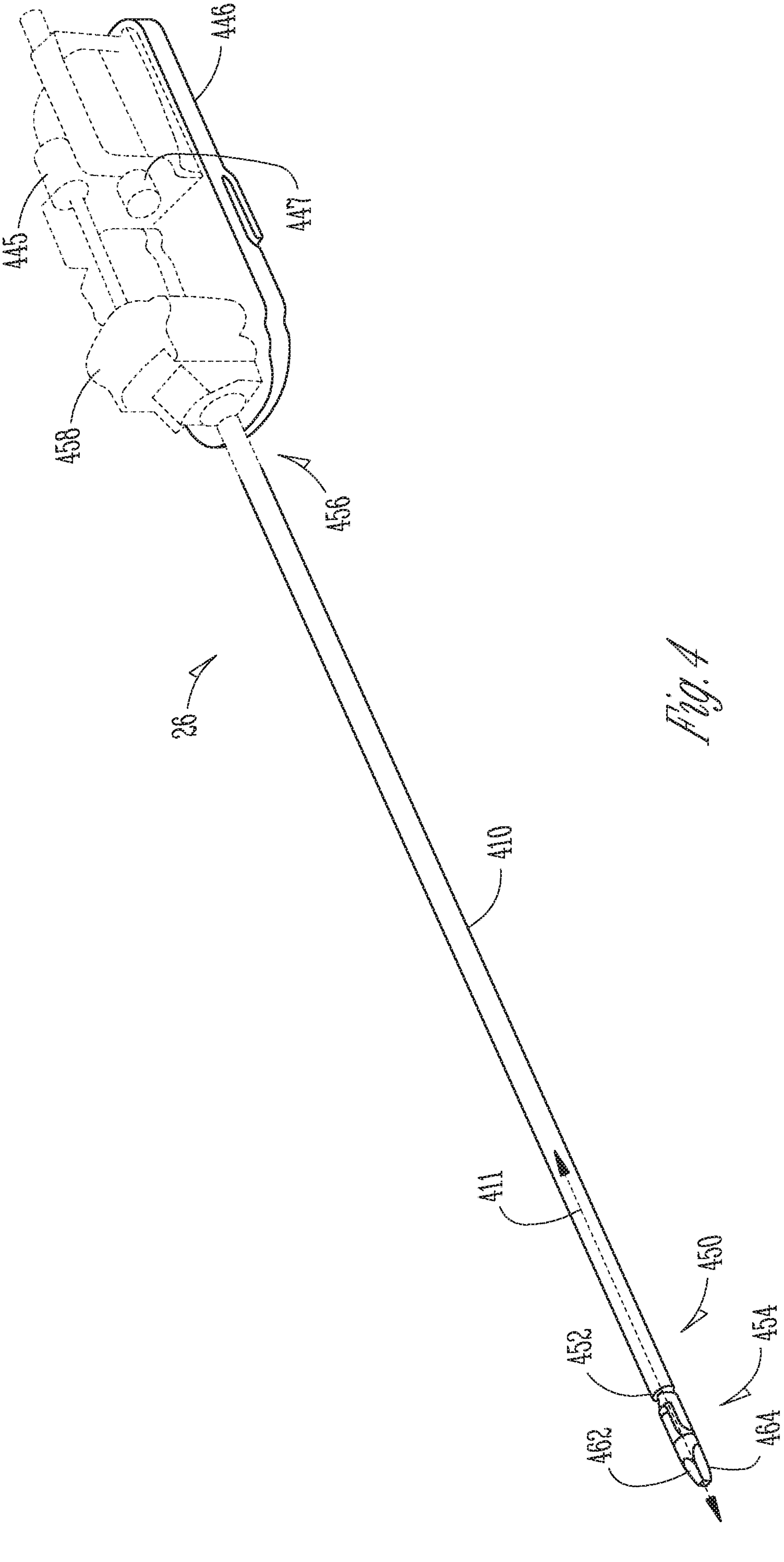


Fig. 4

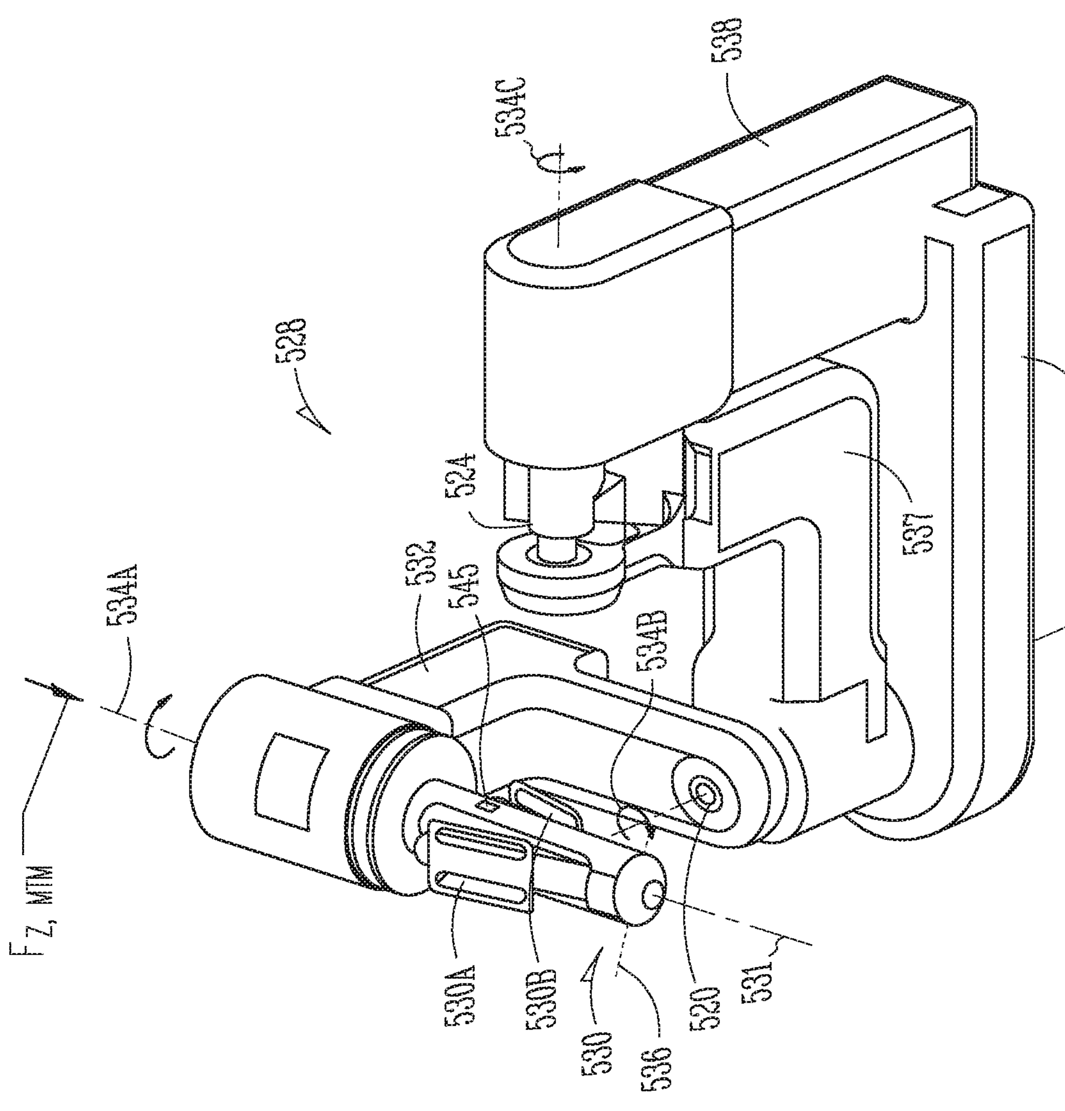
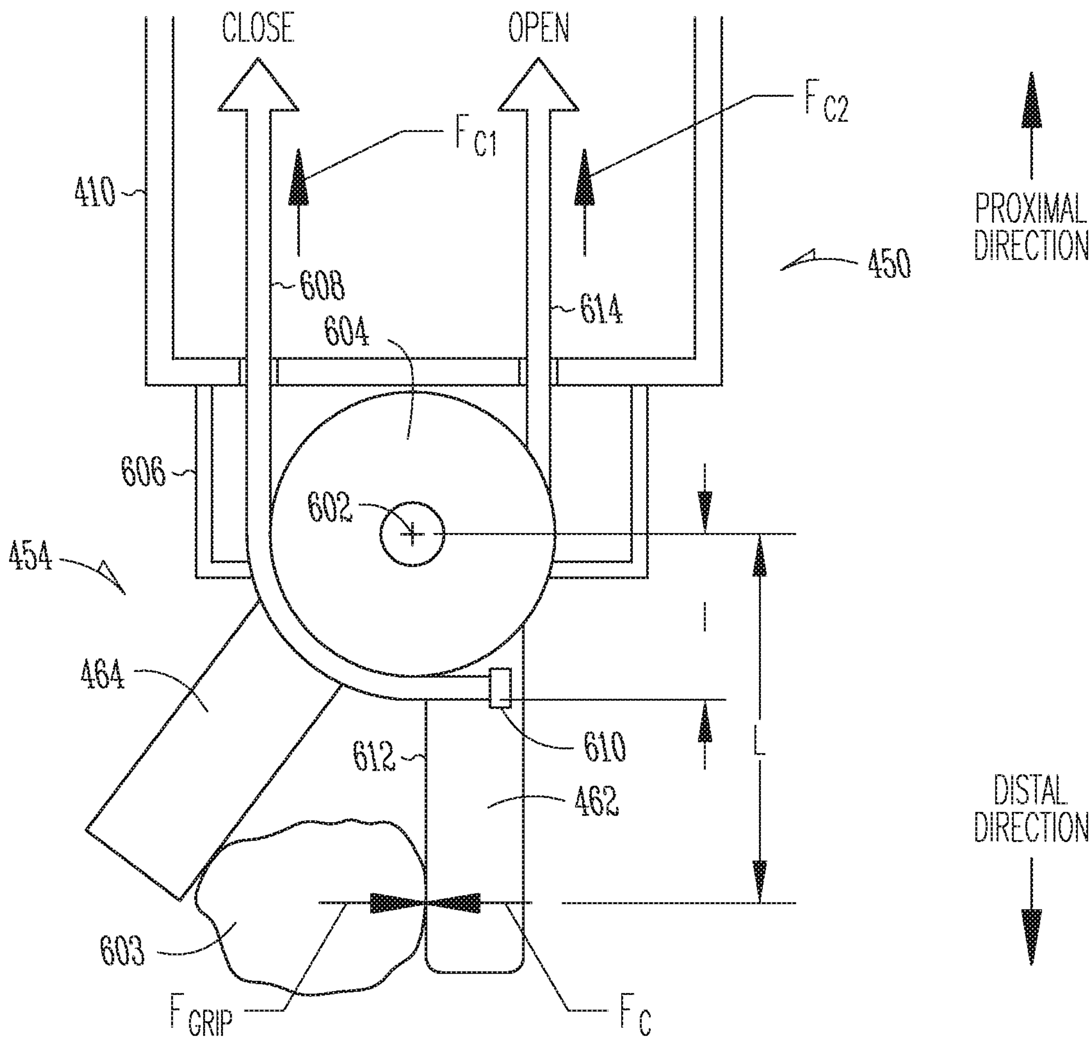

528
534C
538
540
537
534D
52A
532
545
534A
534B
520
531
536
530
530B
530A
F Z, MTM

Fig. 5


CLOSE
OPEN
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F_{C2}
410
608
614
604
450
PROXIMAL DIRECTION
606
602
454
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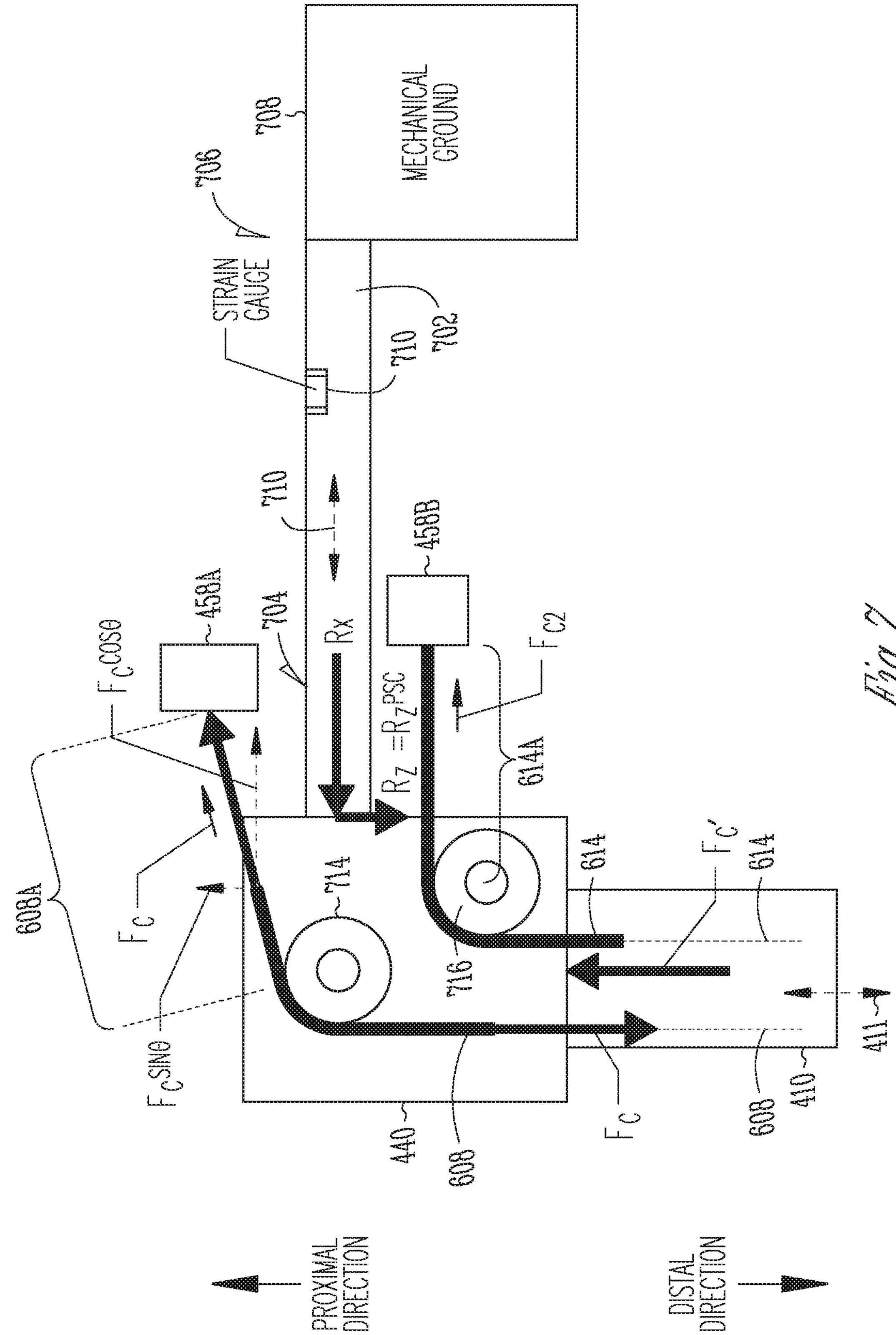
464
610
612
L
462
DISTAL DIRECTION
603
F_{GRIP}
F_C

Fig.6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706
STRAIN GAUGE
710
702
710
704
458A
458B
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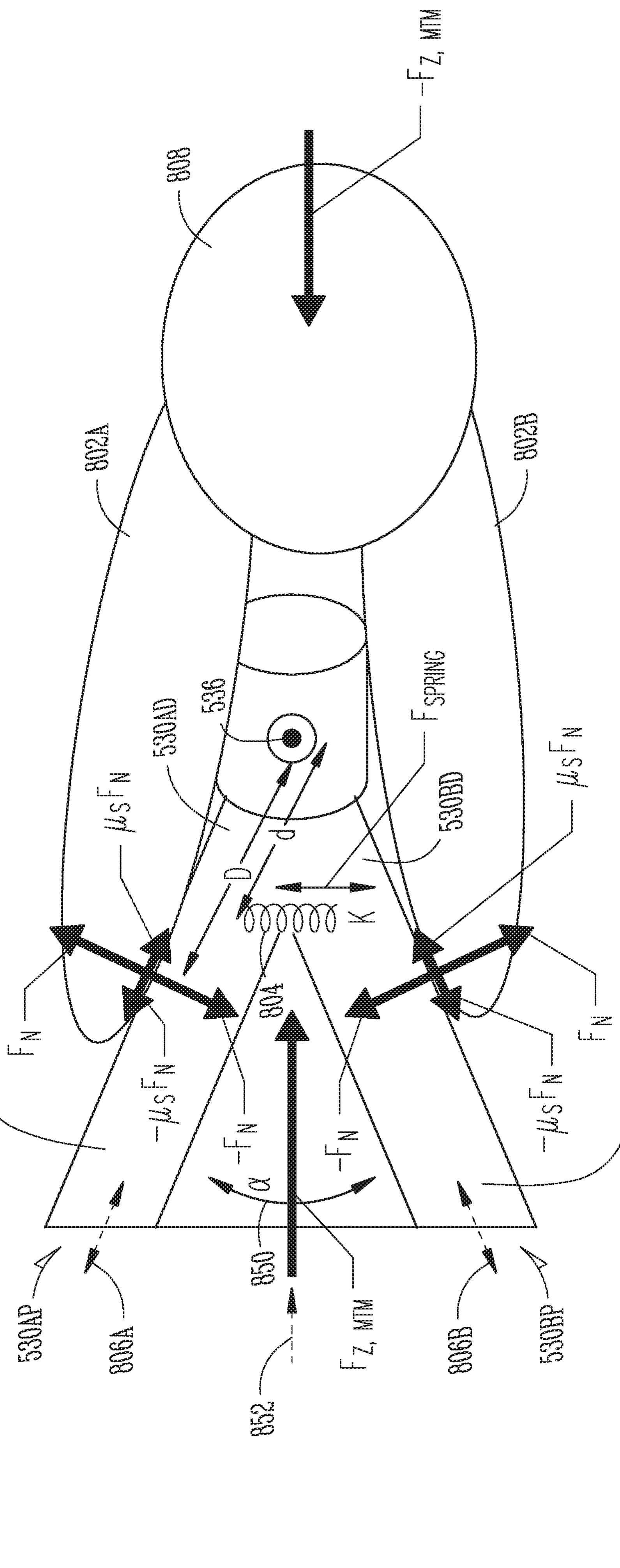
$F_C\cos\theta$
F_{C2}
614A
608A
F_C
$F_C\sin\theta$
714
716
614
614
F_C'
608
440
F_C
608
410
411
PROXIMAL DIRECTION
DISTAL DIRECTION

Fig. 7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530BD
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D
d
K
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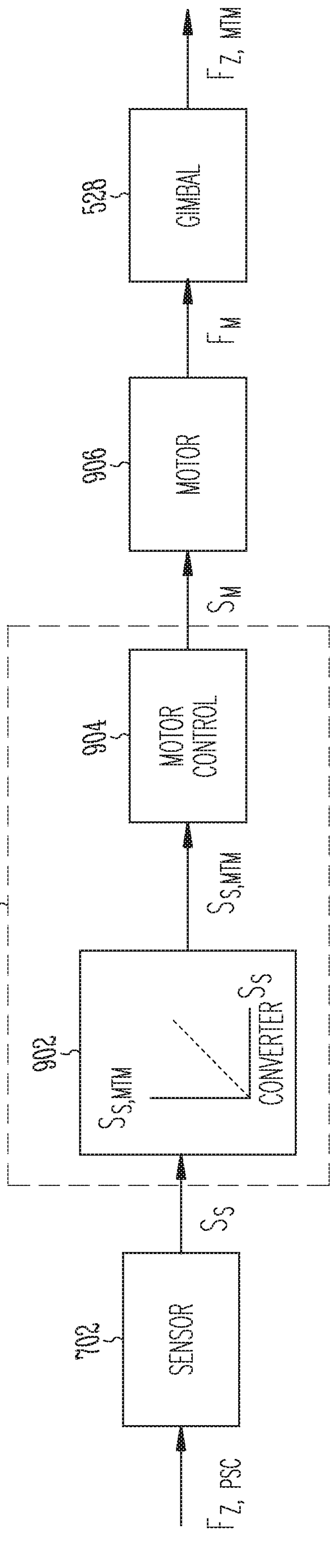
806B
530AP
530BP

Fig. 8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SENSOR
S S
24
902
S S,MTM
CONVERTER
S S
S S,MTM
904
MOTOR
CONTROL
S M
906
MOTOR
F M
528
GIMBAL
F Z, MTM

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/053998

A. CLASSIFICATION OF SUBJECT MATTER

A61B 34/35(2016.01)i, A61B 34/00(2016.01)i, A61B 17/29(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 34/35; A61B 17/068; A61B 17/28; A61B 17/32; A61B 34/37; G05B 15/00; G05B 19/00; A61B 34/00; A61B 17/29

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) & Keywords: teleoperated surgical system, surgical instrument, grip member, sensor, feedback, cable, pulley

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0213437 A1 (INTUITIVE SURGICAL OPERATIONS, INC.) 28 July 2016 See paragraphs [0004], [0010], [0023], [0024], [0031]-[0042], [0048]; and figures 6-8, 9A, 9B.	1-34
Y	US 2011-0290856 A1 (SHELTON, IV, FREDERICK E. et al.) 01 December 2011 See paragraphs [0027], [0225], [0289]-[0291], [0297], [0375], [0380]; and figures 55-58, 123.	1-34
A	US 6594552 B1 (NOWLIN, WILLIAM C. et al.) 15 July 2003 See the entire document.	1-34
A	US 2011-0106141 A1 (NAKAMURA, TOSHIO) 05 May 2011 See the entire document.	1-34
A	US 6385509 B2 (DAS, HARI et al.) 07 May 2002 See the entire document.	1-34

☐ 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
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Date of the actual completion of the international search	Date of mailing of the international search report
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