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(54) **ROBOTIC SURGERY SYSTEM**

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(57) **ABSTRACT**

A surgical system having a surgical device with an integrated user interface controllable by a hand of a surgeon, an adaptor for connecting the integrated user interface of the surgical device to a robotic arm and a control unit for remotely operating the surgical device when connected to the robotic arm.
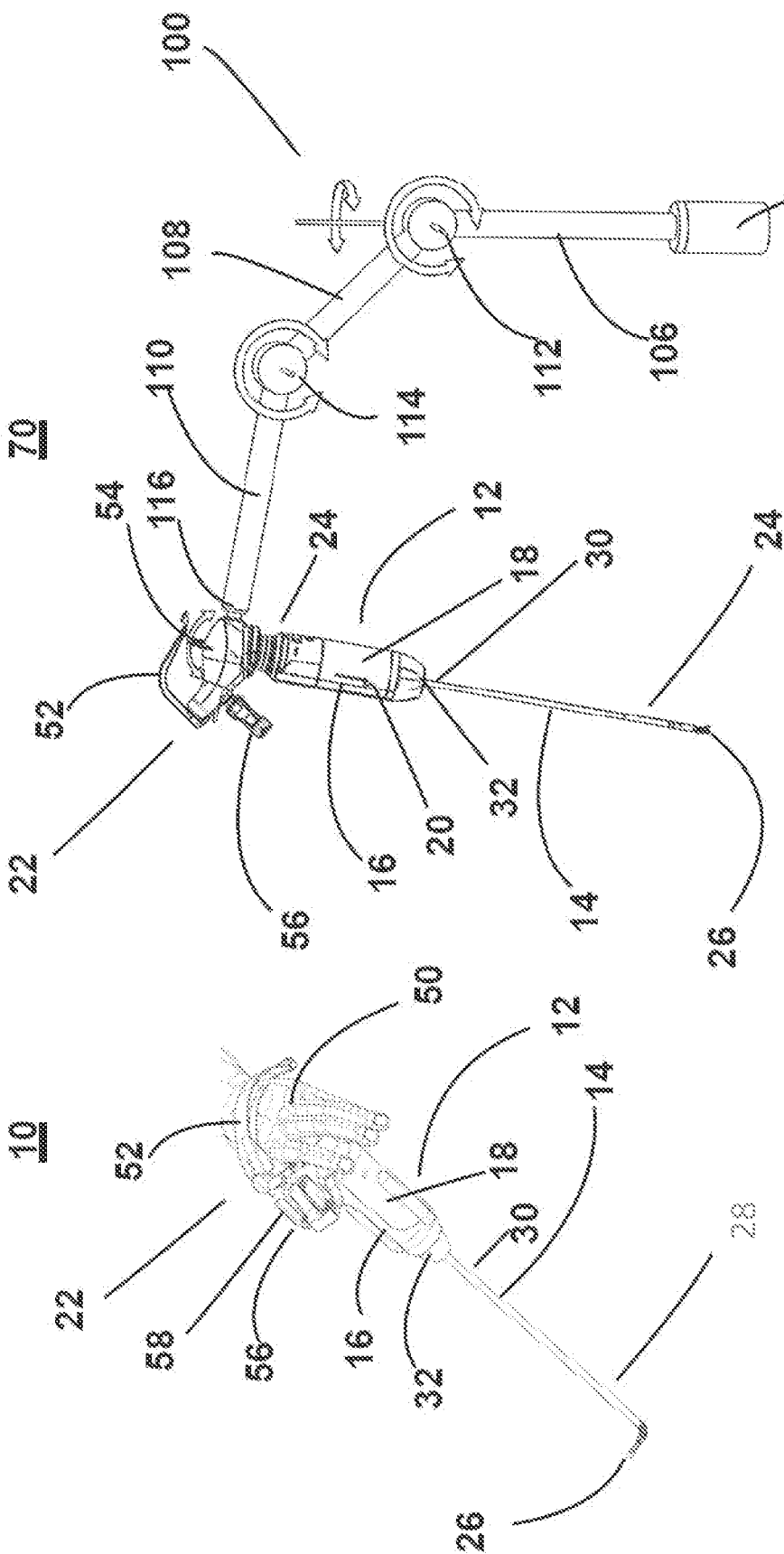
FIG. 2

FIG. 1

FIG. 3B

FIG. 3A

FIG. 4
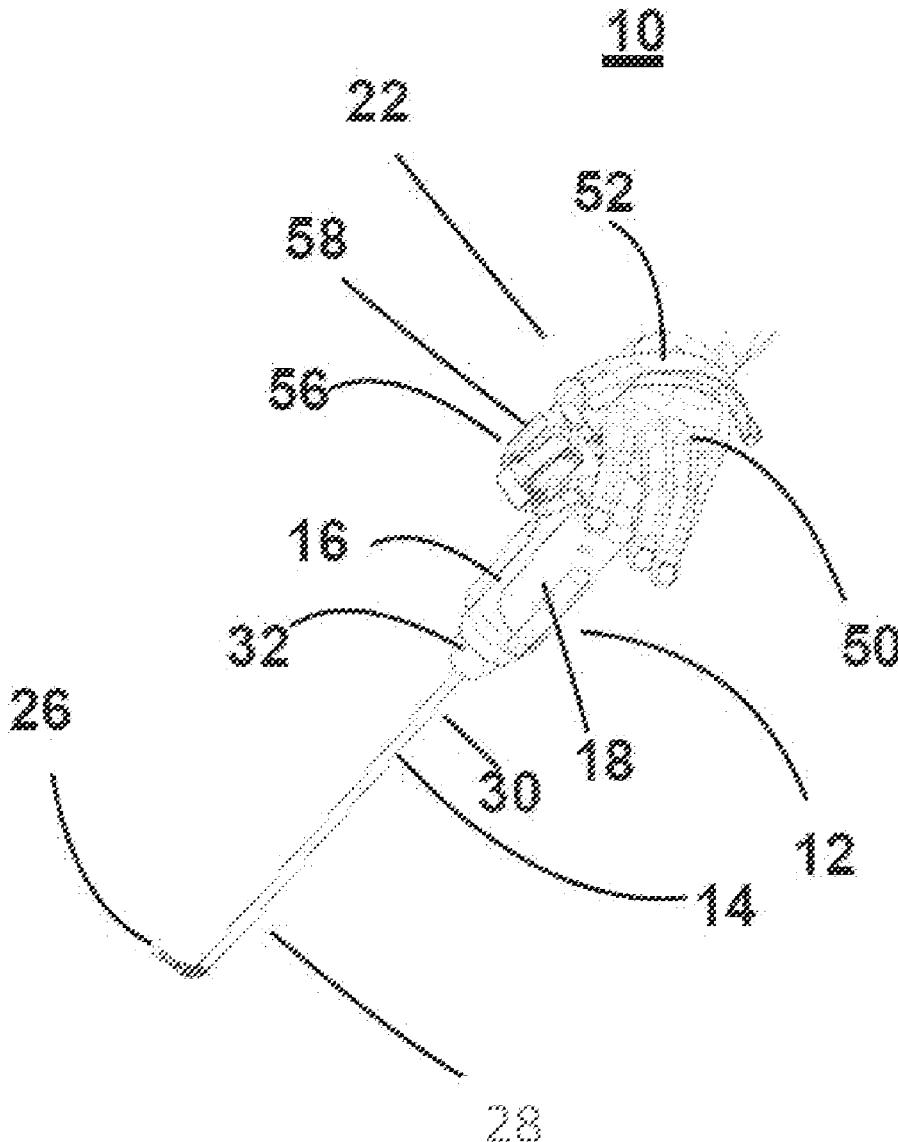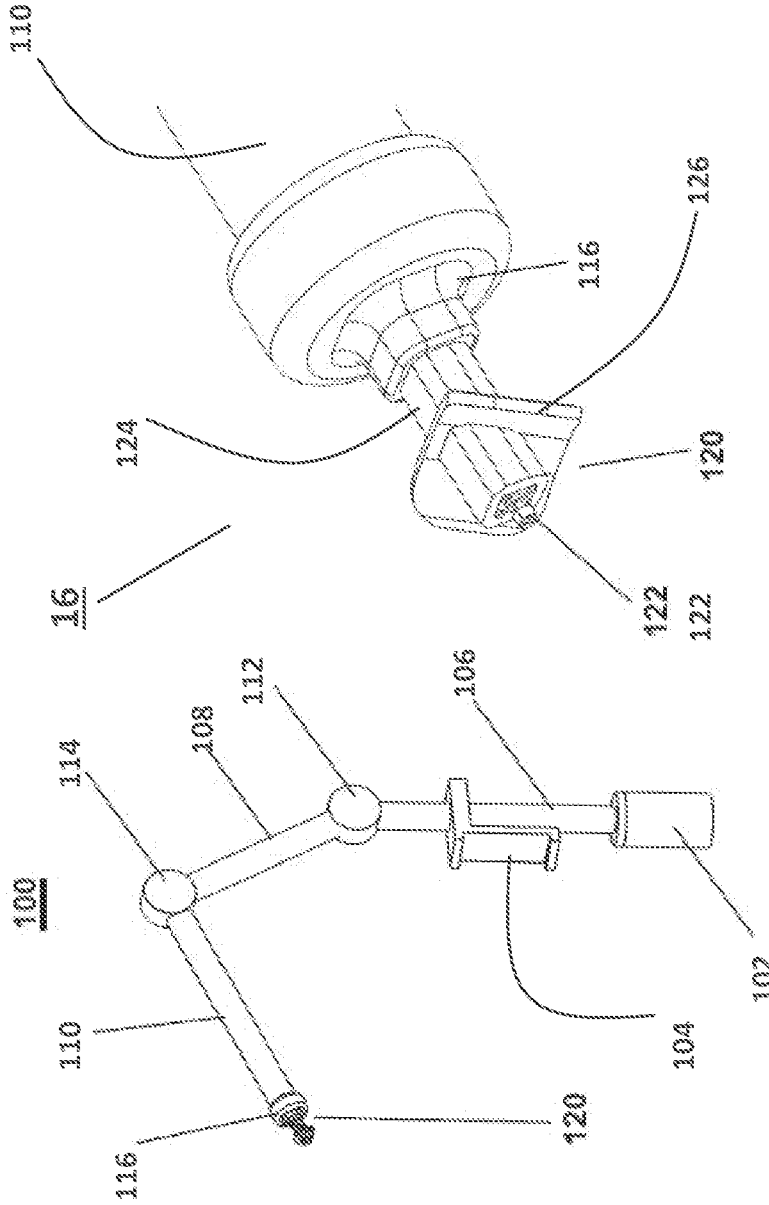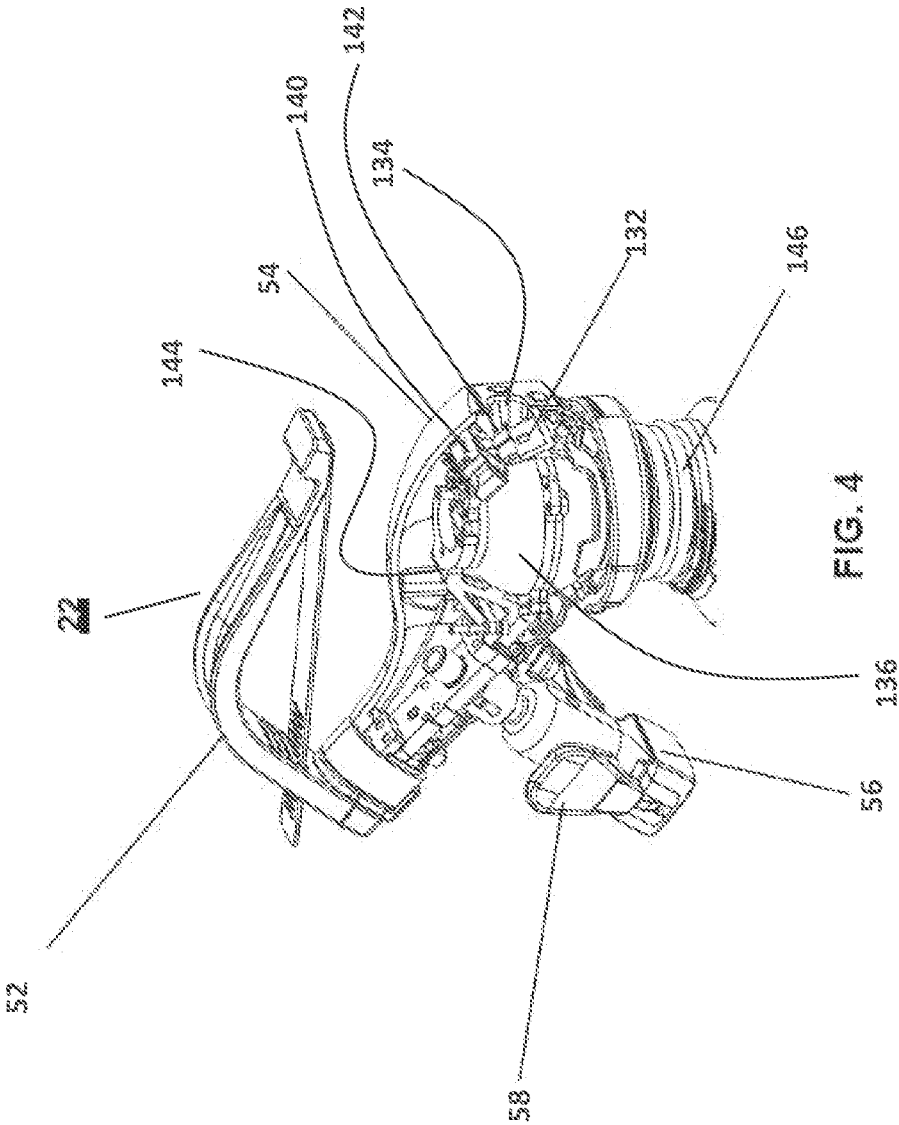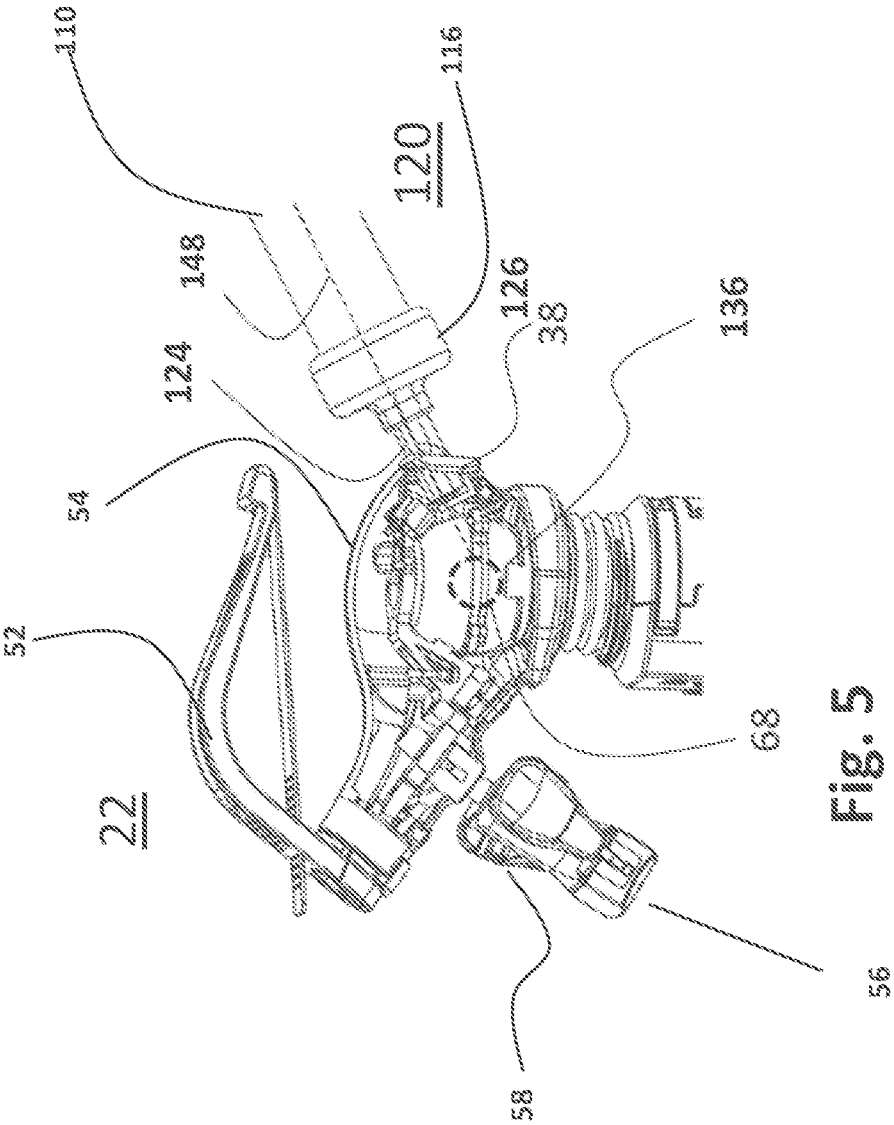
Fig. 5
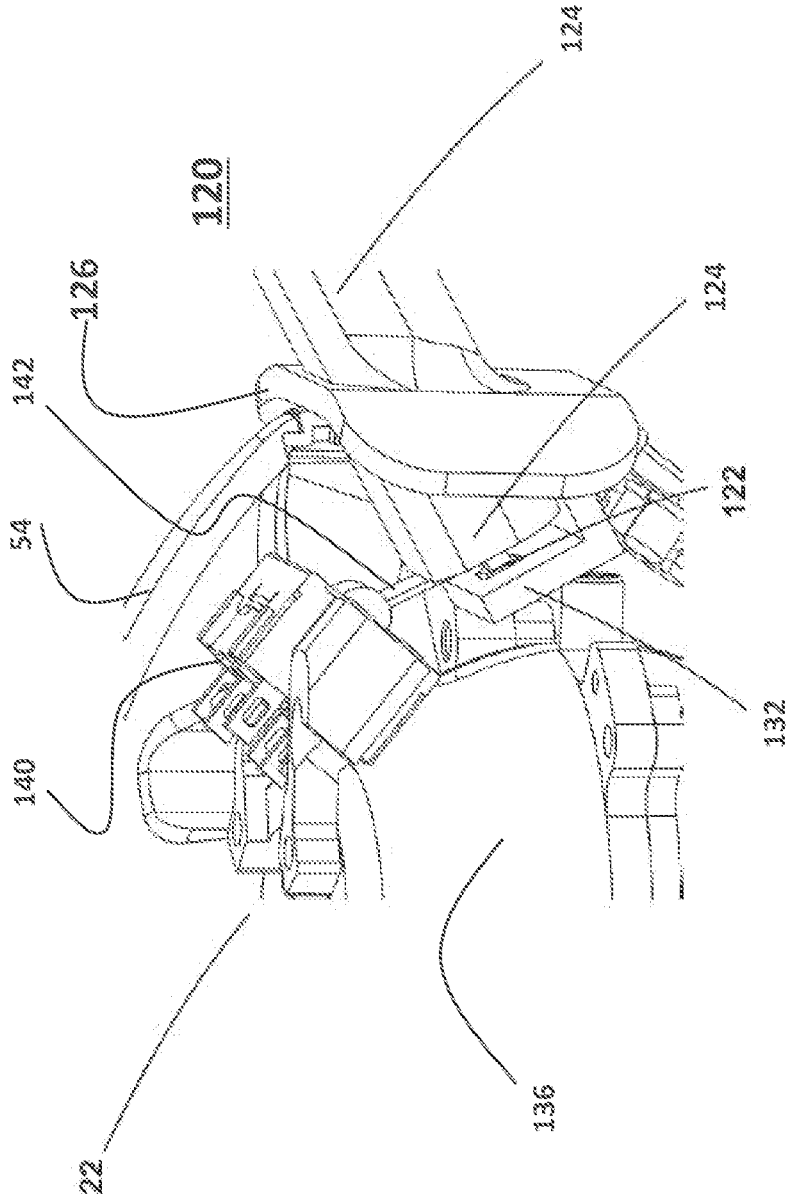
Fig. 6
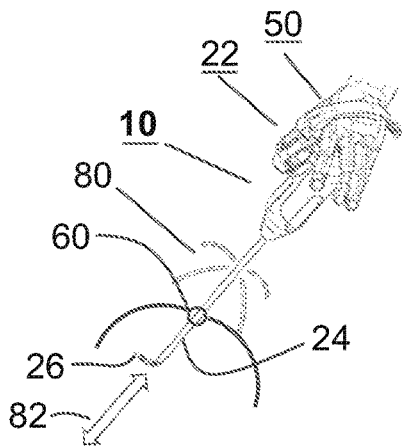
Fig. 7a
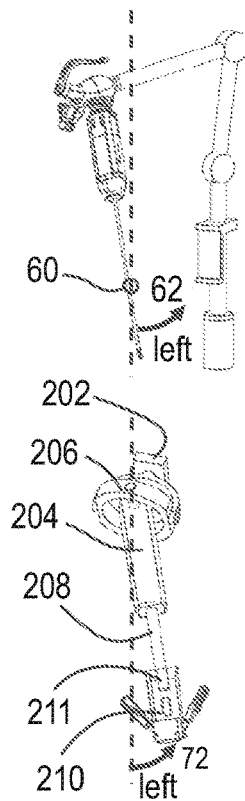
Fig. 7b
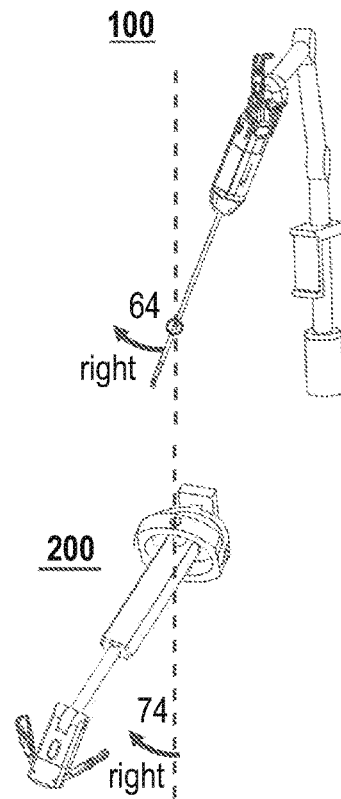
Fig. 7c
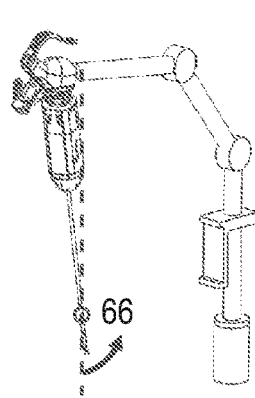
Fig. 7d
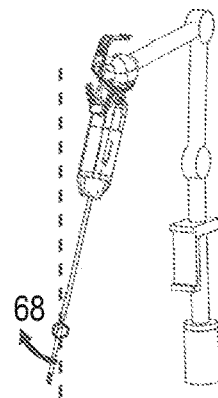
Fig. 7e

Fig. 7f

Fig. 8a

Fig. 8b

FIG. 9B

FIG. 9A

200

211

204

206

202

Direction
Speed
End effector

208

210

218

100

106

108

angle

angle

angle

110

angle

190

Force sensor (optional)

10

140 122

Limit switches

216

220

Central processing unit

222

Commands to:
robot motors
Articulation motors
Jaws motors

224

Instrument tip movement
Articulation movement
Jaws movement

214

212

14

26

Vx,Vy,Vz

219

CI sensors as passive joint (gimbal) :
Pitch, yaw

Fig. 10

Fig. 11

100

302

300

302

22

300

10

Fig. 12c

122

Fig. 12b

100

300

Fig. 12a

Fig. 12f

Fig. 12e

Fig. 12d

ROBOTIC SURGERY SYSTEM

RELATED APPLICATION/S

[0001] This application claims the benefit of priority of U.S. Provisional Patent Application No. 63/160,965 filed on 15 Mar. 2021, the contents of which are incorporated herein by reference in their entirety.

FIELD AND BACKGROUND OF THE INVENTION

[0002] The present invention relates to a system for robotic surgery and, more particularly, to a handheld surgical device couplable to a robotic arm and operable via a remote-control unit.

[0003] Robotic devices are increasingly being used to assist surgeons in surgical procedures. Such robotic devices are not designed to replace the surgeons but rather as collaborative robots.

[0004] Collaborative robots (cobots) typically include a moveable arm (robotic arm) having a maneuverable distal end to which a surgical instrument can be attached. An operator can precisely position the arm and the attached surgical instrument at an anatomical site to perform a medical or surgical procedure. One of the more familiar cobots is the da Vinci System, built with robot arms and high-tech cameras to assist surgeons during operations. The da Vinci's arms translate surgeon hand movements into smaller, more precise movements, allowing for less invasive procedures.

[0005] Precise control of the robotic arm is crucial to both safety and success of a medical procedure. Typical robotic systems have one of three control modes: passive control in which the robot is operated manually, active control in which the robot can move autonomously according to a pre-programmed trajectory and tele-control in which the robot is controlled by a remote operator.

[0006] One advantage of using a robotic system is that the system arm, unlike the arms and hands of a surgeon, are not subjected to muscle strain or neurological actions like twitching. Thus, using a medical robotic system it is possible to hold an instrument steady, or move the instrument along a defined path with a higher degree of accuracy.

[0007] While robotic surgical systems provide numerous benefits, surgical steps, like extensive or complex suturing, oftentimes require switching between manual and robotic surgery.

[0008] There thus remains a need for a robotic surgical system that enables the surgeon to seamlessly and rapidly switch between robotic and manual surgery thus leveraging the benefits of each approach when and where suitable.

SUMMARY OF THE INVENTION

[0009] According to one aspect of the present invention there is provided a surgical system comprising a surgical device having an integrated user interface controllable by a hand of a surgeon; an adaptor for connecting the surgical device to the integrated user interface; and a control unit for remotely operating the surgical device and the robotic arm, wherein remote control of the surgical device dictates movements of the robotic arm.
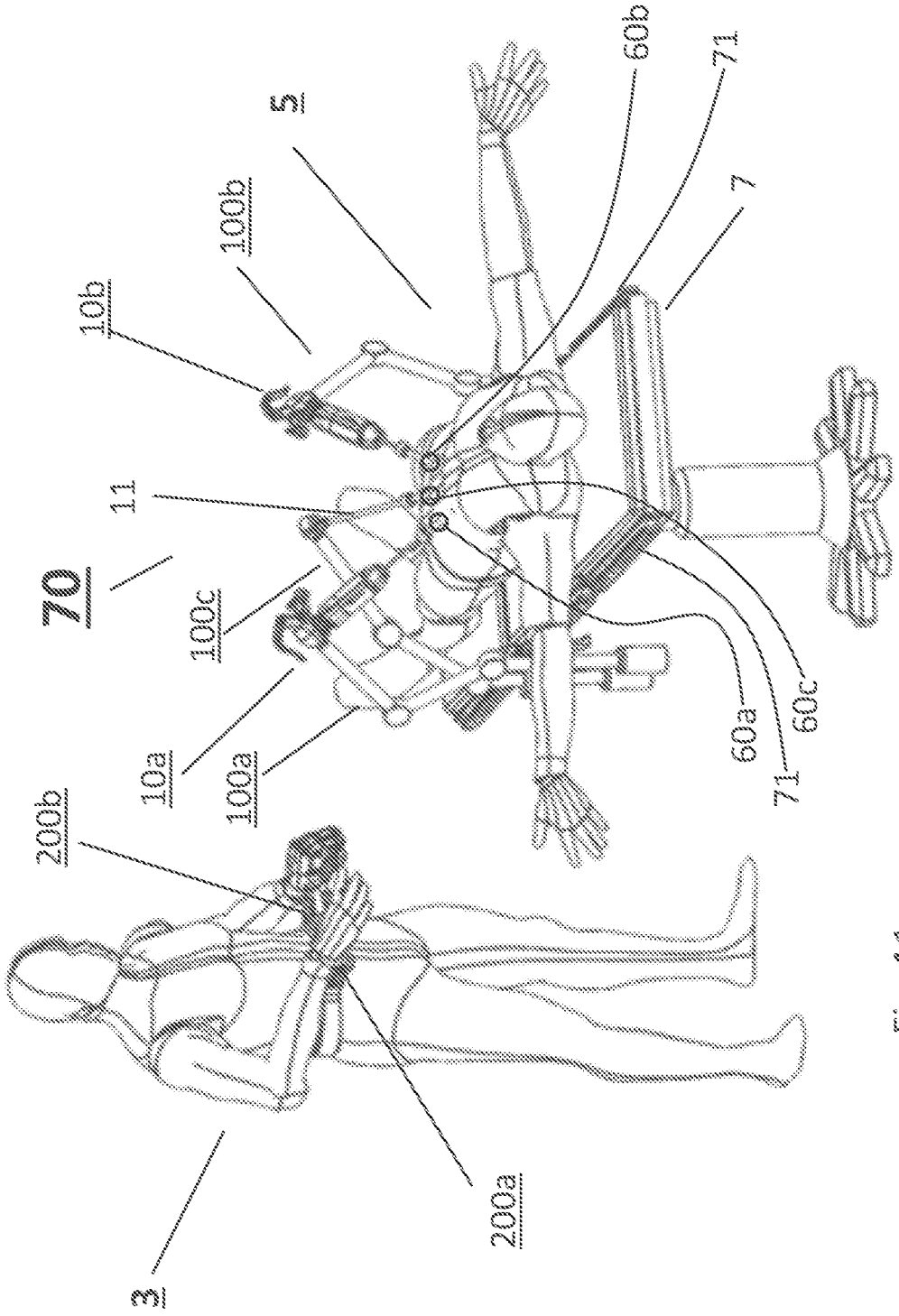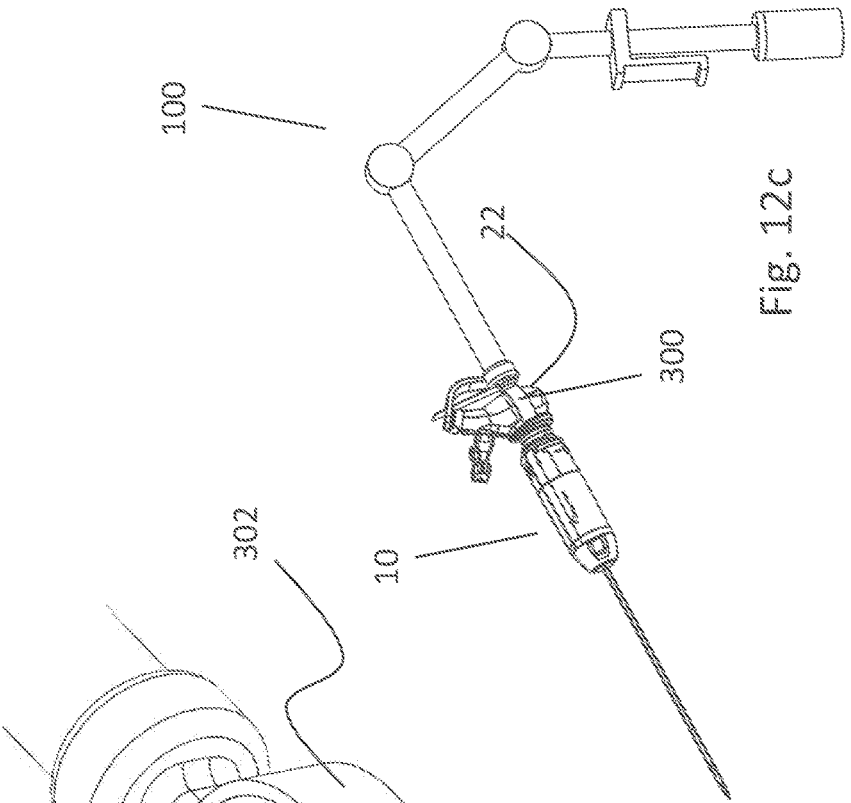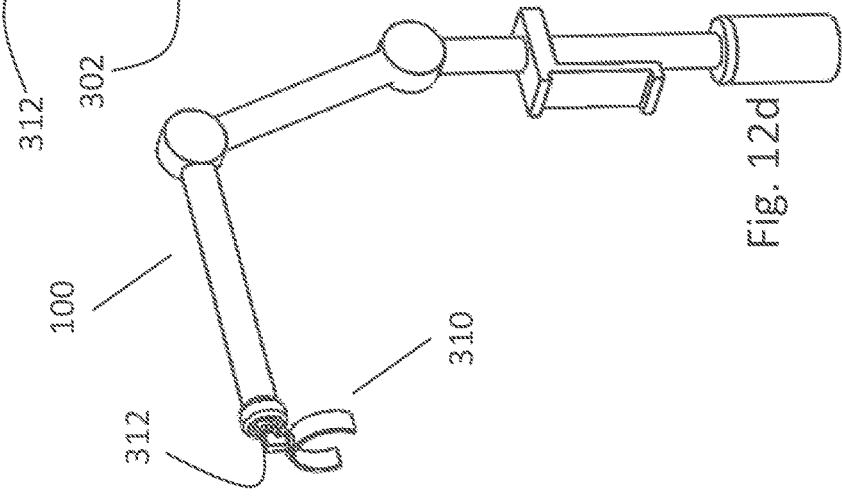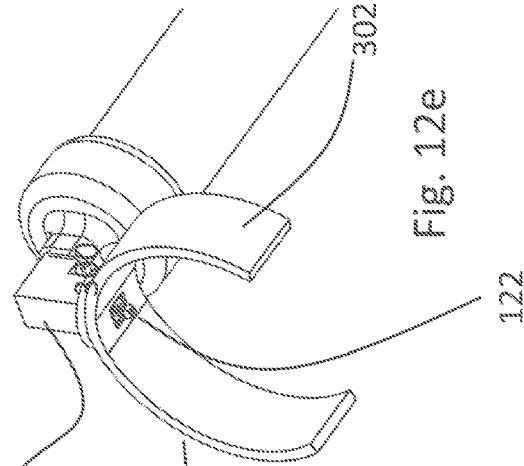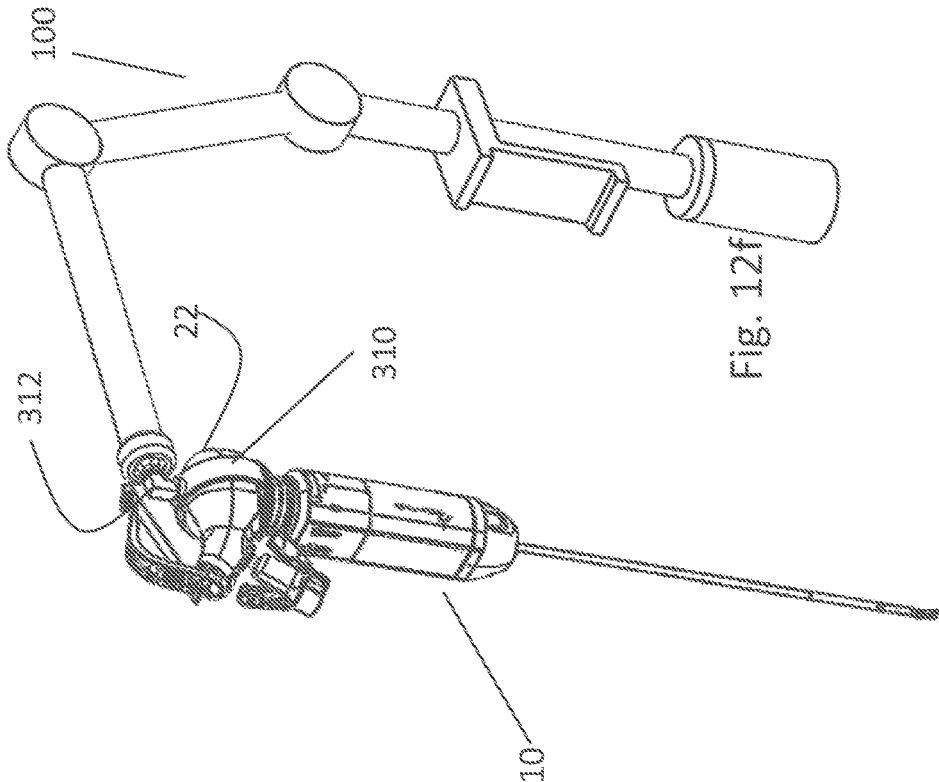
[0010] According to embodiments of the present invention when the adaptor is connected to the surgical device the integrated user interface is converted into a passive coupler to the robotic arm.

[0011] According to embodiments of the present invention the passive coupler provides orientation information for the robotic arm when the adaptor is coupled to the integrated user interface.

[0012] According to embodiments of the present invention a control of the surgical device end effector is transferred to the remote control unit when the adaptor is connected to the integrated user interface.

[0013] According to embodiments of the present invention the adaptor is connectable to or integrated with the robotic arm.

[0014] According to embodiments of the present invention the rod fits into a slot in the integrated user interface, the slot being in a center of rotation of the integrated user interface.

[0015] According to embodiments of the present invention fitting the rod into the slot activates a switch for transferring control of the integrated user interface to the control unit.

[0016] According to embodiments of the present invention the adaptor externally connects to the integrated user interface.

[0017] According to embodiments of the present invention the adaptor is configured for attachment to the integrated user interface over a sterile drape.

[0018] According to embodiments of the present invention when the adaptor is connected to the surgical device the integrated user interface is mechanically locked.

[0019] According to one aspect of the present invention there is provided a medical device comprising a control unit including an integrated user interface having a palm interface mounted on a pivotal support attached to a housing of the control unit, the palm interface being tiltable to operate the medical device, the palm interface being configured for attachment to a robotic arm such that when attached, the palm interface is locked in a center position and is incapable of operating the medical device.

[0020] According to embodiments of the present invention the pivotal support is gimbaled.

[0021] According to embodiments of the present invention the medical device includes a shaft having a steerable portion and further wherein manual tilting of the palm interface deflects the steerable portion of the medical device.

[0022] According to embodiments of the present invention the palm interface includes a slot for accepting a rod attached to the robotic arm.

[0023] According to embodiments of the present invention the slot is keyed for orientation.

[0024] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

[0025] Implementation of the method and system of the present invention involves performing or completing selected tasks or steps manually, automatically, or a combination thereof. Moreover, according to actual instrumenta-

tion and equipment of preferred embodiments of the method and system of the present invention, several selected steps could be implemented by hardware or by software on any operating system of any firmware or a combination thereof. For example, as hardware, selected steps of the invention could be implemented as a chip or a circuit. As software, selected steps of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In any case, selected steps of the method and system of the invention could be described as being performed by a data processor, such as a computing platform for executing a plurality of instructions.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0026] The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0027] In the drawings:

[0028] FIG. 1 illustrates a handheld surgical instrument having an integrated user interface controllable by a hand of a user.

[0029] FIG. 2 illustrates the handheld surgical instrument of FIG. 1 attached to a robotic arm configured in accordance with the teachings of the present invention.

[0030] FIGS. 3A-B illustrate the robotic arm (FIG. 3A) and the adaptor portion (FIG. 3B) for connecting to the handheld surgical instrument.

[0031] FIG. 4 illustrates in greater detail the integrated user interface of the handheld surgical instrument showing the internal components and the adaptor connection site of the integrated user interface.

[0032] FIG. 5 illustrates the connection between the adaptor of the robotic arm and the integrated user interface.

[0033] FIG. 6 illustrates the adaptor connection to the integrated user interface and the rod for maintaining the integrated user interface centered when connected to the robotic arm.

[0034] FIGS. 7A-E illustrate the movement of the handheld surgical instrument and its deflectable tip when operated manually via the integrated user interface (FIG. 7A) and remotely via the remote user interface operating the handheld surgical instrument when connected to the robotic arm (FIGS. 7B-E).

[0035] FIG. 7F illustrates the direction of motion as observed by the surgeon on a screen.

[0036] FIGS. 8A-B illustrate the surgical tool advance and retract motion as operated by the remote user interface and robotic arm.

[0037] FIGS. 9A-B illustrate the processing steps for controlling the surgical instrument when movement is actu-

ated via the integrated user interface (FIG. 9A) and the remote user interface and robotic arm (FIG. 9B).

[0038] FIG. 10 illustrates the measurement from sensors serving as feedback for control over the robotic arm via the remote user interface.

[0039] FIG. 11 illustrates a surgeon controlling several robotic arms and attached surgical devices via a single remote interface.

[0040] FIGS. 12A-F illustrate adapters configurations suitable for connecting the robotic arm to a draped handheld device.

DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

[0041] The present invention is of a system which can be used for manual and robotic surgery. Specifically, the present invention can be used to provide a surgeon with both manual and robotic surgical capabilities using a single surgical system.

[0042] The principles and operation of the present invention may be better understood with reference to the drawings and accompanying descriptions.

[0043] Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details set forth in the following description. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

[0044] Typical robotic systems have one of three control modes: passive control in which the robot is operated manually, active control in which the robot can move autonomously according to a pre-programmed trajectory and tele-control in which the robot is controlled by a remote operator.

[0045] Although robotic surgical systems allow precise control over surgery and enhance the safety and success of a medical procedure, they are typically dedicated systems in which the surgical instrument is designed specifically for attachment to, or integration with, the robotic arm and thus cannot be used manually in case of system failure, or when the surgeon wishes to operate the surgical instrument while the surgical instrument is not connected to the robotic arm.

[0046] While reducing the present invention to practice, the present inventor have devised a surgical system that is capable of providing both robotic and manual operating modes.

[0047] Thus, according to one aspect of the present invention there is provided a surgical system that can be used in open or minimally invasive procedures. The surgical system includes a surgical device having an integrated user interface controllable by a hand of a surgeon and an adaptor for connecting the surgical device to a robotic arm through the integrated user interface. The surgical device having an integrated user interface can be operated manually through hand control over its integrated user interface but when connected to the robotic arm through the adaptor, the surgical device is controlled via a remote user interface (e.g., that is attached to the surgeon). Thus, adaptor coupling effectively converts the integrated user interface into a passive coupler. The remote user interface controls the surgical device (in a manner similar to that of the integrated user interface) and thus dictates movement of the robotic

arm. Remote control over the operation of the end effector of the surgical device (e.g., operating device articulation, operation of a grasper attached thereto etc.) is not relayed through the integrated user interface of the surgical device, but transferred directly to the device controller and utilizes position/force sensors integrated into the surgical device or the adaptor. Remote control over the spatial position of the surgical device is relayed through the robotic arm and utilizes position/force sensors integrated into the robotic arm, adaptor and optionally those integrated into the surgical device.

[0048] This configuration and functionality of the present system enables a surgeon to manually operate the surgical device when detached from the robotic arm and to robotically control the same instrument when attached to the robotic arm in a manner similar to open surgery where the need to use a fulcrum is eliminated.

[0049] This enables a surgeon having experience with manually controlling a surgical device to quickly adapt to operating the same device through a robotic arm setup.

[0050] The adaptor can form a part of the robotic arm (or the integrated user interface). In any case, the adaptor can include a rod (or pin) that connects to a housing that preferably is co-aligned with the center of rotation of the integrated user interface thus locking the integrated user interface in a set position. Connecting the rod into the housing activates limit switches that transfer control from the integrated user interface of the surgical device to the control unit.

[0051] The robotic arm can be any type of arm having one, two, three or more joints that are capable of movement in one or more planes.

[0052] Unlike the present robotic surgery applications in which robots are isolated from human contact, collaborative robots (or Cobots) are designed to work collaboratively with humans in confined spaces and as such are designed for safety with lightweight construction, rounded edges, and inherent limitation on speed and force, while utilizing sensors and software that ensure safe operation.

[0053] The Cobot and human may work in the same area at the same time, while the human and cobot are both in motion, and the cobot responds in real-time to human movement.

[0054] A typical Cobot arm includes several individual arm sections interconnected by joint. Each arm can include motors, a brake system and sensors. The joints and arms are connected to central control system for controlling the motors and the braking system of each joint and receiving and processing sensors signals. Each joint includes a housing with input and output members.

[0055] The input member of the joint housing is connected to the distal end of a link proximal to the joint. The output member of the housing is rotatable relative to the housing by the motor mounted in the housing. The joint housing can also contains a safety brake. The safety brake typically includes an annular member mounted on the motor axle, whereby the annular member rotates relative to the motor axle, but with friction between the annular member and the motor axle. The braking mechanism can also include a solenoid, which upon activation of the brake, displaces a ratchet into engagement with the annular member to slow the rotation of motor axle relative to the housing.

[0056] The joint housing can also include two encoders as part of the sensors. The first encoder senses an angular

orientation of the output member relative to the housing, and the second encoder senses the angular orientation or rotation of the motor axle relative to the joint housing.

[0057] Each Cobot arm system also includes a proximal base that may be connected to a cart, working surface, or a clamp and a distal connector. The distal connector allows attachment of end effectors, camera, or additional sensors which are configured to be specifically used with a Cobot.

[0058] A central control circuit can be integral with the cobot arm system or may be placed in an external box.

[0059] There are numerous types of commercial cobots available on the market. The cobots system may vary in their dimensions, weight, reach, general envelope of motion, power consumption, pay load, accuracy, noise, and adaption to different environment conditions such as dust, humidity, and temperature.

[0060] For example: a small collaborative table-top Cobot, such as UR3e for light assembly tasks and automated workbench scenarios, may weighs 11 kg, with a payload of 3 kg, with reach of 0.5M and ±360-degree rotation on all wrist joints, and infinite rotation on the end joint.

[0061] A heavy duty Cobot such as UR16e, for use in heavy machine tending, material handling, packaging, and screw and nut driving applications, may weighs 33 kg, with a payload of 16 kg (35.3 lbs.) with reach of 0.9M and ±360-degree rotation on all wrist joints, and infinite rotation on the end joint.

[0062] In the field of laparoscopic surgery, the Cobot may have the ability to carry a payload of at least 1 Kg with a reach of at least 0.4M. The robotic arm can have at least 3 motorized degrees of freedom and a weight that does not exceed 15 Kg. A cobot can be fixed or clamped to the surgical table or attached to carts.

[0063] Cobots that can be modified for use with the present invention include the KINOVA-MICO2: 6 axis cobot that can carry a payload of 2.1 kg, with reach of 0.7M, and weights 4.6 kg, the UNIVERSAL ROBOTS-UR3, a 6 axis cobot that can carry a payload of 3 kg, with reach of 0.5M, and weights 11 kg or the UR3 cobot manufactured by UNIVERSAL ROBOTS.

[0064] The surgical device can be any type of motorized device that is operated manually via arm and hand movements. Such a device can be configured for minimally invasive surgery through an access port (trocar). The surgical device can include a control unit attached to a shaft having an end effector (grasper, cutter, camera etc.). The user interface can control shaft deflection/articulation (through wires or motors and wires/gears) as well as the operation of the effector end (e.g., grasper). Spatial positioning of the surgical device (up/down, side-to-side) can be controlled by arm movements. An example of a surgical device configured for use with the present system is described hereinbelow.

[0065] The remote user interface can be similar in function to the integrated user interface in that it provides similar controls over shaft deflection and effector end operation while also providing user controls for spatial positioning (carried out by the robotic arm). An example of a remote user interface configured for use with the present system is described hereinbelow.

[0066] Referring now to the drawings, FIGS. **1** and **2** illustrate a manually operable surgical device and a robotic arm fitted with the surgical device (respectively).

[0067] The surgical device (referred to hereinunder as device 10) includes a control unit 22 attached to a shaft 14.

[0068] Control unit 22 includes a housing 16 which contains a drive unit 18 circuitry 20 and an integrated user interface 22 (hereinafter interface 22) which is mounted on a proximal end 24 of housing 16. Housing 16 and interface 22 can be fabricated from a polymer and/or alloy using machining, 3D printing and/or casting/molding fabrication approaches. Housing 16 can be 40-60 mm in diameter and about 60-150 mm in height. Interface 22 is also shown in FIGS. 4-5. Shaft 14 can include a steerable portion 24 and a distally mounted end effector end/instrument (grasper 26 shown). Shaft 14 can be fabricated using materials and approaches well known in the art.

[0069] Shaft 14 includes a plurality of wires disposed along its length for transferring force from drive unit 18 to an end of steerable portion 28 and jaws 26.

[0070] Shaft 14 can be 20-40 cm in length and 3-16 mm in diameter and can be hollow or solid. A hollow shaft 14 enables internal routing of wires, in a solid configuration of shaft 14, wires can be routed on the external surface of shaft 14 through dedicated guides.

[0071] The steerable portion of shaft 14 can be fabricated from a tube having cutouts (e.g. such as those shown in U.S. Pat. No. 4,911,148) or from links (e.g. U.S. Pat. Nos. 7,682,307, 6,817,974) with control wires running through guides formed in the tube or links. Alternatively, the steerable portion can be fabricated as described in U.S. Provisional Patent Application No. 61/765,745 to the present inventor, the teachings of which are fully incorporated herein.

[0072] Proximal end 30 of shaft 14 is attached to a distal end 32 of housing 16, and control and actuation wires/rods of shaft 14 run through housing 32 and attach to drive unit 18. Drive unit 18 can include levers and gears for translating movements of user interface 22 to pulling of control and/or actuation wires. Such transfer can be mechanical (manual) or motorized.

[0073] The surgeon's hand 50 is placed in such a manner where the back of the user's hand is positioned under restraint 52 while three of the user's fingers are free to grasp a palm interface 54, the thumb and index fingers engage a finger interface 56.

[0074] Restraint 52 is elastically deformable to conform to back of the surgeon's hand while applying a downward force thereto.

[0075] Palm interface 54 is pivotally attached to a base which includes sensors for measuring the spatial orientation of the user's hand, by measuring the orientation of palm surface 54 with respect to the base.

[0076] Finger interface 56 is connected to palm interface 54. Additionally, paddles 58 of finger interface 56 (two are shown) are movable (pinched inward, released outward) and rotatable (clock wise, counter clock wise) to control an effector end (e.g. surgical tool such as grasper) of device 10.

[0077] As is shown in FIG. 2, device 10 is connectable to a robotic arm 100 through interface 22 (collectively, referred to herein as system 70). Robotic arm 100 includes a base 102 for connecting robotic arm 100 to a bed, table or the like, and 3 segments (106, 108, 110) interconnected via joints (112, 114). A joint 116 connects robotic arm 100 to device 10 via an adaptor (described hereinbelow).

[0078] FIGS. 3A-B illustrate robotic arm 100 and adaptor 120 with rod 124 for connecting robotic arm 100 to surgical device 10 through interface 22.

[0079] FIG. 3A is a general view of robotic arm 100 with adaptor 120 located at the distal end of the distal link 110. In this configuration, robotic arm 100 includes 3 links: vertical link 106 that rotates around its longitudinal axis relative to base 102, segment 108 that is connected to segment 106 via joint 112 (part of motor housing) and distal segment 110 that is connected to segment 108 via joint 114 (part of motor housing). Segments 108 and 110 rotate around the longitudinal axis of joints 112 and 114. It should be noted that in FIG. 3A, robotic arm 100 has the minimal number of arms and joints to enable robotic arm 100 to spatially locate adaptor 120 at any desired position. Various robotic arms and Cobots are available in the market offering various number of segments and joints. Robotic arm 100 can be fabricated by modifying a commercially available cobot to include distal adapter 120. Clamp 104 may be used for connecting robotic arm 100 to cart or surgical table. The length of segments 108 and 110 may be 20-40 cm allowing a reach of 40-80 cm.

[0080] FIG. 3B illustrates adaptor 120 in greater detail. Adaptor 120 connects the distal end of link 110 of robotic arm 100 preferably to the center of rotation of user interface 22 of device 10. Adaptor 120 is connected to distal end of arm 110 via ring adapter 116. Rod 124 projects out of ring 116 and has a keyhole (asymmetrical shape) allowing a single orientation of connection to interface 22 of device 10. Limit switch 122 on the distal end of rod 124 is depressed when rod 124 is fully connected to user interface 22. Bulge 126 interfaces with the external surface 54 of user interface 22 and functions as a support when robotic arm 100 carries device 10.

[0081] FIG. 4 is a cut-away view showing in greater detail the inner structure of user interface 22 and connector housing 132 for connecting with robotic arm 100 through adapter 120. Limit switch 140, located at user interface 22 of device 10. Lever 142 of limit switch 140 indicates if rod 124 of adapter 120 is clicked into connector housing 132. User interface 22 includes palm interface 54 covering a spherical base 136 that allows the user to tilt user interface 22 with respect to the body 16 of device 10, around the center of spherical base 136. Spherical base 136 is connected to palm interface 54 via frame 144. Palm interface 54 includes an opening 134 that allows rod 124 of adapter 120 to mechanically connect to spherical base 136, at a center thereof. When rod 124 is secured to housing 132 lever 142 of limit switch 140 is depressed indicating that the robotic arm 100 is connected to handheld device 10.

[0082] FIG. 5 is a cut-away view showing the connection between adaptor 120 of the robotic arm 100 and user interface 22 of device 10. Rod 124 is connected to housing 132, while center line 148 of rod 124 co-aligned with the longitudinal axis of link 110 is directed to the center of rotation 148 of spherical base 136 (as is indicated by dashed circle 68). When rod 124 is clicked into housing 132, switch 122 (shown in FIG. 3B) is depressed against housing 132 and lever 142 of limit switch 140 is depressed by rod 124.

[0083] FIG. 6 illustrates in greater detail the connection between adaptor 120 of the robotic arm 100 and user interface 22 of device 10. Rod 124 of adaptor 120 (passing through keyhole shaped opening 134) is clicked into housing 132 located in interface 22 thereby depressing switch 122

against housing **132** while lever **142** of limit switch **140** is depressed by rod **124**; bulge **126** supports cover **130** of interface **22**.

[0084] As is further described hereinbelow with respect to FIGS. **9A-10**, when both limit switches **122** and **140** are depressed the separate control systems of handheld motorized device **10** and robotic arm **100** unite under a single control circuit, enabling the surgeon to control simultaneously the end effector **26** of handheld motorized device **10** and robotic arm **100**.

[0085] FIGS. **12A-F** illustrate an adaptor suitable for connecting a robotic arm to a draped device.

[0086] In cases where device **10** is draped (for sterility reasons) an external adaptor configuration is needed in order to connect robotic arm **100** to device **10**. Adaptor **300** includes arms **302** that grip the external surface of interface **22**. When interface **22** is draped, arms **302** firmly grip interface **22** without interrupting the sterile barrier provided by the drape. Adapter **300** can include a limit switch **122** that indicates if adapter **310** is connected to interface **22**.

[0087] As is shown in FIGS. **12A-C**, adapter **300** can be co-aligned with the center of rotation of interface **22** (as is described hereinabove with respect to FIGS. **3A-6**). Adaptor can alternatively be connected to distal arm **110** via an angled connector **312** (FIGS. **12D-F**).

[0088] Another option that can be used to lock interface **22** when robotic arm **100** is connected to device **10** utilizes an interface lockout mechanism of device **10**. Device **10** can include a motorized braking mechanism that locks/unlocks interface **22** when used manually by a surgeon. Such a mechanism can be switched on when robotic arm **100** is connected to device **10** (over a drape). This locks the gimbal mechanism (at any desired position, e.g., center) of the palm interface and allows device **10** to be used with the robotic arm.

[0089] FIG. **7A** illustrates manual positioning of device **10** by the surgeon hand **50** while holding the integrated interface **22**. The surgeon may tilt device **10** to any desired orientation with respect to fulcrum point **60** as illustrated by orientation arrows **80**, and slide the shaft of device **10** in and out through fulcrum point **60** in the direction of linear arrows **82**.

[0090] FIGS. **7B-E** illustrate remote control over device **10** by remote user interface **200** (hereinafter interface **200**). In this configuration, integrated interface **22** serves as a passive coupler between robotic arm **100** and the body and the shaft **24** of device **10**, allowing the positioning and orientation of device **10** by robotic arm **100**.

[0091] Robotic control through interface **200** is affected as follows. Device **10** is connected to robotic arm **100** through adaptor **120** and rod **122**, while interface **22** is deactivated and engaged (via rod **124**) in a center position, changing the function of interface **22** to a passive gimbaled coupler, located at a known point at the end of the longitudinal axis of distal link **110** of robotic arm **100**, as represented with center line **148** at FIG. **5**.

[0092] Once device **10** is attached to robotic arm **100**, sensors located at spherical base **136** serve as pitch and yaw measuring sensors for the combined control circuits (**220**, **222**, **224**) as is described below with reference to FIGS. **9A-10**.

[0093] FIGS. **7B-C** illustrate remote control over end effector positioning when device **10** is attached to robotic arm **100**. It should be noted that the surgeon views the

procedure through a 2D screen (FIG. **7F**), and as such, the end effector positions are viewed as movements by directions left, right, up and down as is shown in FIG. **7F**.

[0094] When the surgeon wishes to move end effector **26** of device **10** to the left (as indicated by arrow **62**), while shaft **24** is positioned through fulcrum point **60**, the surgeon moves the tip of the remote control **200** to the left (arrow **72**) commanding robotic system **100** to tilt device **10** clock wise (CW) to the right with respect to fulcrum **60** thus rotating shaft **24** counter clockwise (CCW) around fulcrum **60** in direction **62** resulting in movement of tip **26** to the left.

[0095] As is shown in FIG. **7C**, when the surgeon wishes to move end effector **26** of device **10** to the right (direction **64**), the surgeon moves the tip of the remote control **200** to the right (arrow **74**), commanding robotic system **100** to tilt device **10** CW to the left with respect to fulcrum **60** thus rotating shaft **24** around fulcrum **60** resulting in movement of tip **26** to the right.

[0096] FIGS. **7D-E** show up and down remote control of end effector positioning while operating with robotic system.

[0097] When the surgeon wishes to move end effector **26** of device **10** down (arrow **66**), the surgeon moves the tip of the remote control **200** down (arrow **76**) as is shown in FIG. **7D** commanding robotic system **100** to tilt device **10** up with respect to fulcrum **60**, forcing tip **26** to move down.

[0098] When the surgeon wishes to move end effector **26** of device **10** up (arrow **68**), the surgeon moves the tip of the remote control **200** up (arrow **78**) as is shown in FIG. **7E**, commanding robotic system **100** to tilt device **10** down with respect to fulcrum **68**, forcing tip **26** to move up.

[0099] FIGS. **8A-B** show in and out remote control of end effector **26** positioning while operating with robotic system.

[0100] When the surgeon wishes to move end effector **26** of device **10** in (arrow **84**, FIG. **8A**), the surgeon slides tip **210** of the remote control **200** away from remote control base **202** (arrow **94**) commanding robotic system **100** to slide shaft **24** of device **10** through fulcrum **60** into the patient body, moving tip **26** deeper within the body cavity.

[0101] When the surgeon wishes to move end effector **26** of device **10** out (arrow **86** FIG. **8B**), the surgeon slides the tip of the remote control **200** toward remote control base **202** (arrow **96**) commanding robotic system **100** to slide shaft **24** and tip **26** out of the body cavity.

[0102] FIGS. **9A-B** illustrate the processing steps for controlling the surgical instrument when movement is actuated via user interface **22** (FIG. **9A**) and remote control **200** and robotic arm **100** (FIG. **9B**).

[0103] FIG. **9A** is a flowchart explaining the control of end effector **26** of device **10** using interface **22**. In order to operate with device **10**, the surgeon holds device **10** by user interface **22** while he positions end effector **26** in the patient body sliding the shaft trough the incision and use the incision as a fulcrum point. While the surgeon moves the device to the desired position, the surgeon may control the end effector orientation by tilting interface **22** with respect to the body **16** of device **10**. The orientation of the articulation is controlled by orientation sensors located at user interface **22** (CI). The central processing unit uses readings from the orientation sensors to calculate the desired articulation angles and translate them to commands to the motors that operate articulation of end effector **26**. The control of the end effector mechanism is performed by a similar control flow. For example, if the end effector is a grasper then pressing

and releasing the pedals of the fingers interface controls the jaws open and close movement and rotating the pedals controls the rotation of the grasper jaws.

[0104] FIG. 9B is a flowchart explaining the control of distal connector **120** of robotic arm **100** using remote controller **150** (which will be replaced by remote control **200** customized for control the robotic surgery system **70**). In order to move the tip of adapter **120** located at the distal end of the robotic arm **100**, to a desired position, the user moves the handle of remote controller **150** in a desired direction or to a desired position (depending on the algorithm used for control). The central processing unit of the robotic arm **100** calculates the commands needed to bring the tip of distal adapter **120** to the desired position and translates them to commands for the motors resulting in tip movement to a desired position.

[0105] FIG. **10** is a flowchart outlining signals and controls processed by central processing unit **220** of a surgical robotic system **70**. When interface **22** of device **10** is connected to robotic arm **100**, both limit switches **122** and **140** are depressed indicating to processing unit **220** that interface **22** is converted into a passive gimbal that measures the orientation of body **16** of device **10** relative to the distal link **110** of robotic arm **100**. Central processing unit **220** can then calculate the orientation of shaft **14** and the position of end effector **26** since the geometrical dimension of device **10** are known.

[0106] When lever **142** is depressed the control circuit of device **10** does not use readings from the pitch and yaw sensors of interface **22** of device **10** as inputs for controlling articulation and also disables the reading from sensors of the fingers interface **56**. Until both limit switches **122** and **142** are released, commands controlling articulation and end effector movement are generated by remote control **200** only.

[0107] When device **10** is moved by robotic arm **100**, it is essential to ensure that the movement of device **10** will be safe and will not harm the patient by, for example, applying forces to the incision site.

[0108] Thus, the present system enables the surgeon to calibrate the incision point location with respect to end effector **26** and shaft **24** by inserting end effector **26** into through the trocar. When end effector **26** is located in the rotation point of the trocar, the surgeon presses a calibration button/Since the dimensions of the segments and joints of robotic arm **100** and the angles between segments are known, and since the dimensions of device **10** and its orientation measured by pitch and yaw sensors of interface **22** are known, the exact location of the incision point can be calculated, and the fulcrum point may be determined, enabling the control circuit of system **70** to orient and slide device **10** safely with respect to the incision site. If the calibration process was performed incorrectly and was not accurate interface **22** (serving as a passive coupler), will also serve as a safety mechanism and may compensate for an inaccurate calibration process.

[0109] Following initial calibration, recalibration can be continuously executed as device **10** is moved by robotic arm **100**. When the control circuit of system **70** moves device **10** in a calculated path, the control circuit calculates also the angles of user interface **22**. Also a continuous online calibration may be executed: when a path is executed, the control circuit may read the signals from the pitch and yaw sensors of user interface **22** and compare them to pre-

calculated values. If the error is bigger than a desired value, the control system calculates new values for the incision point that will reduce the error to an acceptable value.

[0110] The same correction process may be executed when the shaft slides in and out through the incision site.

[0111] Adding an inertial measurement unit (IMU) component to device **10** may serve also for reducing positioning errors and ensuring smooth movement of device **10**.

[0112] User interface **22** may also serve as a safety mechanism by comparing the signals acquired from user interface **22** to the pre-calculated values of the sensors. For example, if the end effector collides unexpectedly with tissue in the body cavity then the robotic arm will continue its predetermined calculated path while the measured signals from user interface **22** will not match the these pre-calculated values. The control system will calculate and watch the increasing difference between the measured values and the expected pre-calculated values until reaching an unacceptable threshold leading to a stop or slow down in movement.

[0113] A combination of readings from IMU connected to device **10** and signals from the sensors of interface **22** can be also used to increase the level of safety of system **70** in the same manner as described above.

[0114] When using more than one robotic arm **100** (each attached to a dedicated device **10**), a second calibration process may be executed following calibration of each arm **100**. The second calibration process will be used by the central control system to avoid collisions between robotic arms **100** or collision between shafts of devices **10**.

[0115] In order to execute the second calibration process the user can attach the end effectors **26** of two devices **10** to each other, and then press a second calibration button on control unit **200**. Since the dimensions of both robotic arms **100** are known, the origin of each robotic arm **100** with respect to the other robotic arm **100** may be calculated. The second calibration process allows the control system to calculate the spatial location of each link, device, and shaft of each robotic system and to eliminate collision therebetween. It should be noted that the user may execute the two calibrations processes in a reversed order, i.e., first the calibration between the robotic arms and then the incision point calibration. Also, the calibration between the robotic arms may be done outside or inside the patient body and repeated whenever necessary.

[0116] Interface **200** may communicate with device **10** and robotic arm **100** through a physical wire or by wireless connection (e.g., Bluetooth, Wi-Fi or a dedicated RF protocol).

[0117] Interface **200** includes a base **202** connectable to an object or to the surgeon (e.g., at belt). Base **202** is connected to a first arm **204** through a gimbaled joint **206**. A second arm **208** is telescopically connected to first arm **204** and can move forward/back and rotate with respect thereto. The distal end of second arm **208** is connected to a finger interface **210** via hinge **211** that allows pivoting of finger interface **210** with respect to second arm **208**. Finger interface **210** can be used to rotate an effector end (e.g. grasper) via rotation of arm **208** with respect to arm **204**, to open/close grasper jaws via the open and close function of paddles **213** and deflect shaft **14** via movement at hinge **211**.

[0118] Interface **200** provides control over robotic arm **100** movement via movement of first arm **204** with respect to base **202** (through gimbaled joint **206**). As is shown in FIGS. 7B-D, tilt left of arm **204** with respect to base **202** translates

to tilt right of device **10** (as actuated by robotic arm **100**), while tilt right of arm **204** with respect to base **202** translates to tilt left of device **10** (as actuated by robotic arm **100**) Likewise tilt up of arm **204** with respect to base **202** translates to tilt back of device **10** (as actuated by robotic arm **100**) and tilt down of arm **204** with respect to base **202** translates to tilt forward of device **10** (as actuated by robotic arm **100**). Such control over the position of device **10** is similar to the control over a surgical device used in an open procedure where the end effector of the surgical device moves with the same direction of the hand of the surgeon.

[0119] FIG. **11** illustrates a typical setup using three system **70** in a laparoscopic surgery.

[0120] When surgeon **3** decides to use system **70**, robotic arms **10***a-c* may be positioned via carts next to surgical table **70** and clamped to rails **71** located at the side of surgical table **7**. Handheld devices **10***a-b* are then connected to robotic arms **100***a-b* and laparoscopic camera can be connected to robotic arm **100***c*.

[0121] Devices **10***a-b* are inserted through incisions **60***a-b* respectively and laparoscope **11** is inserted through incision **60***c*.

[0122] A two steps calibration process is executed for devices **10***a-b* and laparoscope **11**, as is described above. In order to perform the surgical procedure, surgeon **3** holds the fingers interfaces of remote user interfaces **200***a-b* to simultaneously control both handheld devices **10***a-b*. To position the laparoscopic camera, surgeon **3** switches control from one of interfaces **200***a* or **200***b* to the camera control. The laparoscopic camera may be also controlled by assistant (not shown) that uses an additional remote user interface **200**. At any point in the procedure, the surgeon and staff may disconnect one of devices **10***a-c* and another surgeon or assistant can manually operate one or more of devices **10***a-c*, while the surgeon remotely controls devices connected to robotic arms **100***a-c*. Since robotic arms **100***a-c* include safety protocols (As is described above), there is no potential risk for the assistant that works near robotic arms that are remotely controlled. In addition, any of robotic arms **100***a-c*, can be operated by a surgeon which is not present in the operating room (e.g., teleoperating). As the procedure continues the handheld devices may be re-connected to the robotic arms and if no setup changes were introduced, no additional calibration is needed.

[0123] As used herein the term "about" refers to ±10%.

[0124] It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

[0125] Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

[0126] It is the intent of the applicant(s) that all publications, patents and patent applications referred to in this specification are to be incorporated in their entirety by reference into the specification, as if each individual publication, patent or patent application was specifically and

individually noted when referenced that it is to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention. To the extent that section headings are used, they should not be construed as necessarily limiting. In addition, any priority document(s) of this application is/are hereby incorporated herein by reference in its/their entirety.

What is claimed is:

1. A surgical system comprising:
(a) a surgical device having an integrated user interface controllable by a hand of a surgeon;
(b) an adaptor for connecting said surgical device to said integrated user interface; and
(c) a control unit for remotely operating said surgical device and said robotic arm, wherein remote control of said surgical device dictates movements of said robotic arm.

2. The system of claim **1**, wherein when said adaptor is connected to said surgical device said integrated user interface is converted into a passive coupler to said robotic arm.

3. The system of claim **2**, wherein said passive coupler provides orientation information for said robotic arm when said adaptor is coupled to said integrated user interface.

4. The system of claim **1**, wherein a control of said surgical device end effector is transferred to said remote control unit when said adaptor is connected to said integrated user interface.

5. The system of claim **1**, wherein said adaptor is connectable to or integrated with said robotic arm.

6. The system of claim **5**, wherein said rod fits into a slot in said integrated user interface, said slot being in a center of rotation of said integrated user interface.

7. The system of claim **6**, wherein fitting said rod into said slot activates a switch for transferring control of said integrated user interface to said control unit.

8. The system of claim **1**, wherein said adaptor externally connects to said integrated user interface.

9. The system of claim **8**, wherein said adaptor is configured for attachment to said integrated user interface over a sterile drape.

10. The system of claim **2**, wherein when said adaptor is connected to said surgical device said integrated user interface is mechanically locked.

11. A medical device comprising a control unit including an integrated user interface having a palm interface mounted on a pivotal support attached to a housing of the control unit, said palm interface being tiltable to operate the medical device, said palm interface being configured for attachment to a robotic arm such that when attached, said palm interface is locked in a center position and is incapable of operating the medical device.

12. The medical device of claim **11**, wherein said pivotal support is gimbaled.

13. The medical device of claim **12**, wherein the medical device includes a shaft having a steerable portion and further wherein manual tilting of said palm interface deflects said steerable portion of the medical device.

14. The medical device of claim **12**, wherein said palm interface includes a slot for accepting a rod attached to said robotic arm.

15. The medical device of claim **14**, wherein said slot is keyed for orientation.

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