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Schuh et al.

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(54) **INSTRUMENT DEVICE MANIPULATOR WITH BACK-MOUNTED TOOL ATTACHMENT MECHANISM**

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(22) Filed: **Sep. 9, 2016**

(65) **Prior Publication Data**

US 2017/0065363 A1 Mar. 9, 2017

Related U.S. Application Data

(60) Provisional application No. 62/216,239, filed on Sep. 9, 2015.

(51) **Int. Cl.**
A61B 34/30 (2016.01)
A61B 90/50 (2016.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 90/50*** (2016.02); ***A61B 34/00*** (2016.02); ***A61B 34/30*** (2016.02); ***A61B 34/70*** (2016.02); ***A61B 46/00*** (2016.02); ***A61B 46/10*** (2016.02)

(58) **Field of Classification Search**
CPC A61B 34/30–2034/303; A61B 90/50
(Continued)

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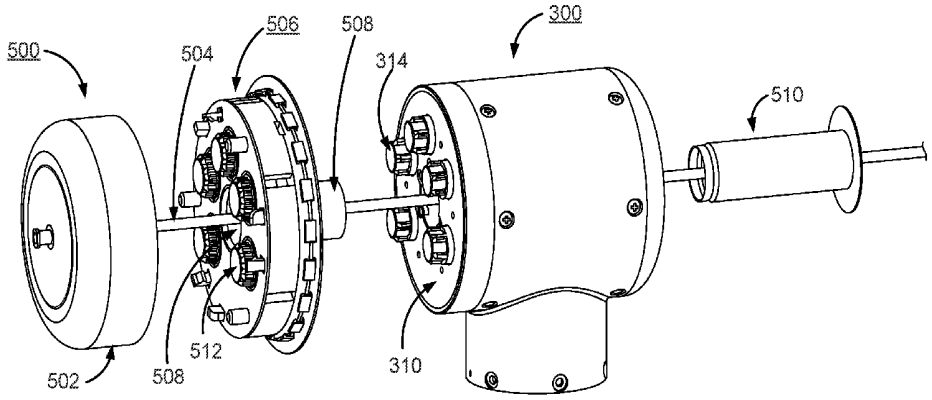
(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

An instrument device manipulator (IDM) is attached to a surgical arm of a robotic system and comprises a surgical tool holder and an outer housing. The surgical tool holder includes an attachment interface that can secure a surgical tool in a front-mount configuration (where the attachment interface is on a face opposite of an elongated body of the surgical tool) or a back-mount configuration (where the attachment interface is on the same face as the elongated body of the surgical tool). The surgical tool holder may rotate continuously within the outer housing. In a back-mount configuration, the surgical tool holder may have a passage that receives the elongated body of the tool and allows free rotation of the elongated body about the rota-
(Continued)



tional axis. A surgical drape separates the IDM and robotic arm from a tool, while allowing electrical and/or optical signals to pass therebetween.

19 Claims, 19 Drawing Sheets

(51) **Int. Cl.**
A61B 34/00 (2016.01)
A61B 46/00 (2016.01)
A61B 46/10 (2016.01)

(58) **Field of Classification Search**
USPC 606/185
See application file for complete search history.

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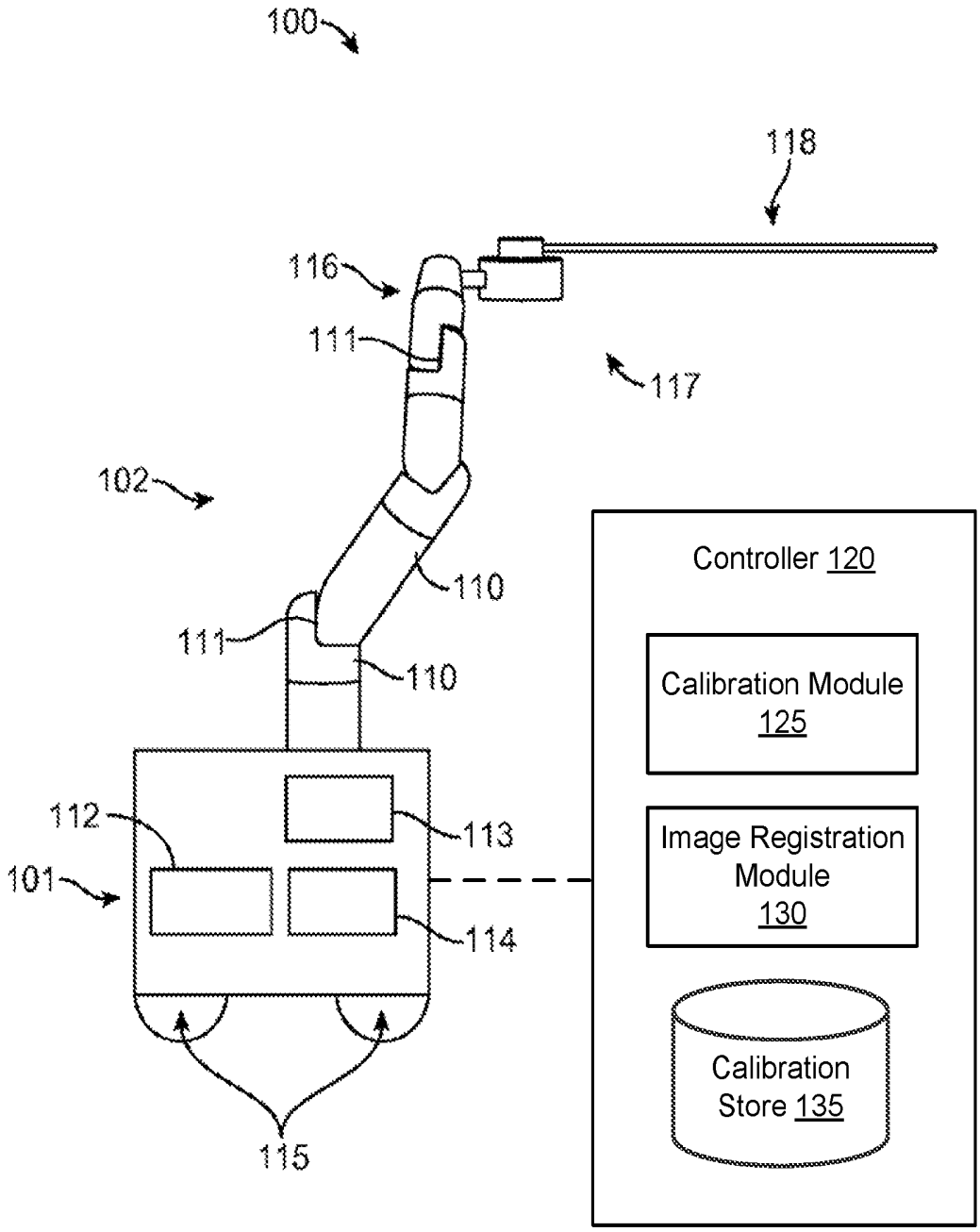
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118
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114
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Controller 120
Calibration Module 125
Image Registration Module 130
Calibration Store 135

FIG. 1

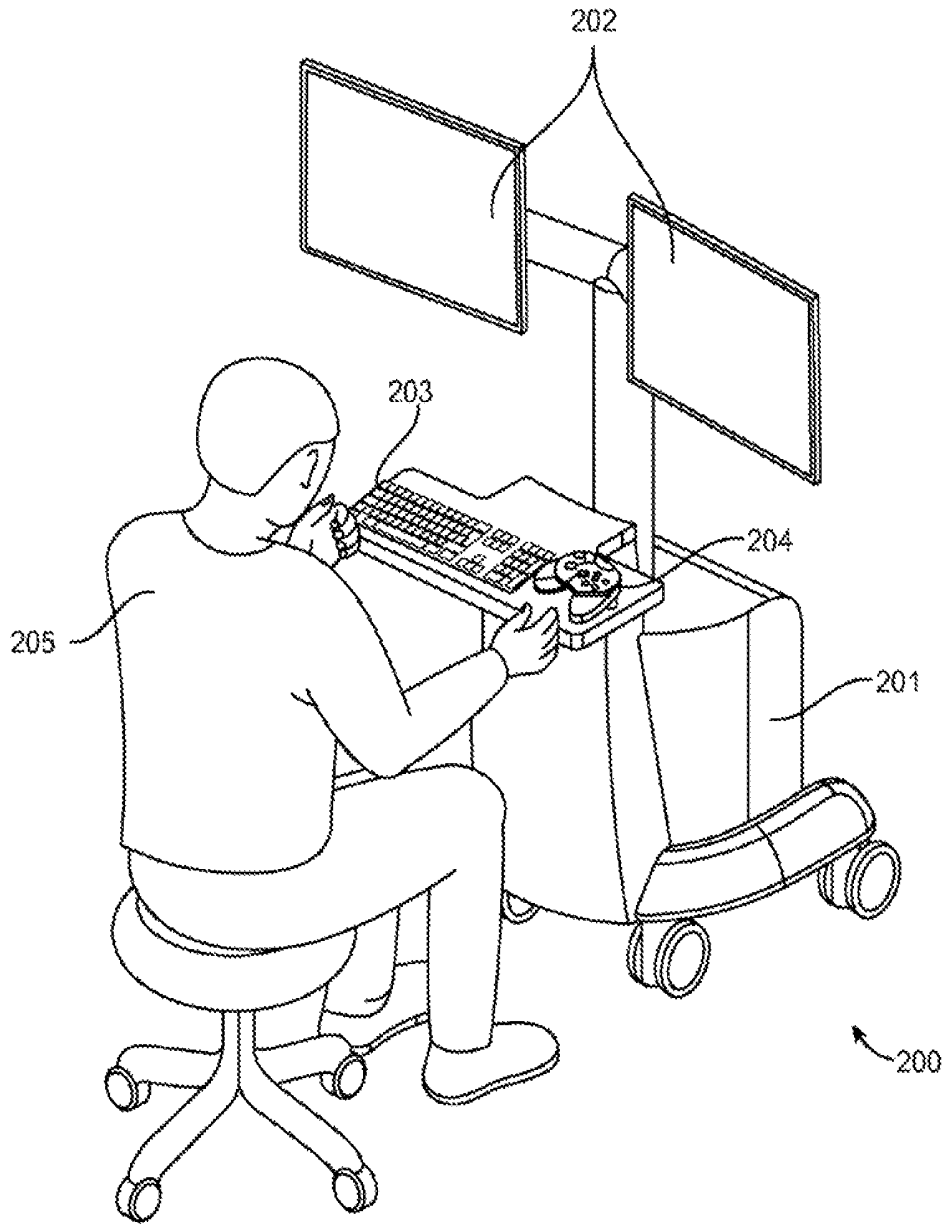


FIG. 2

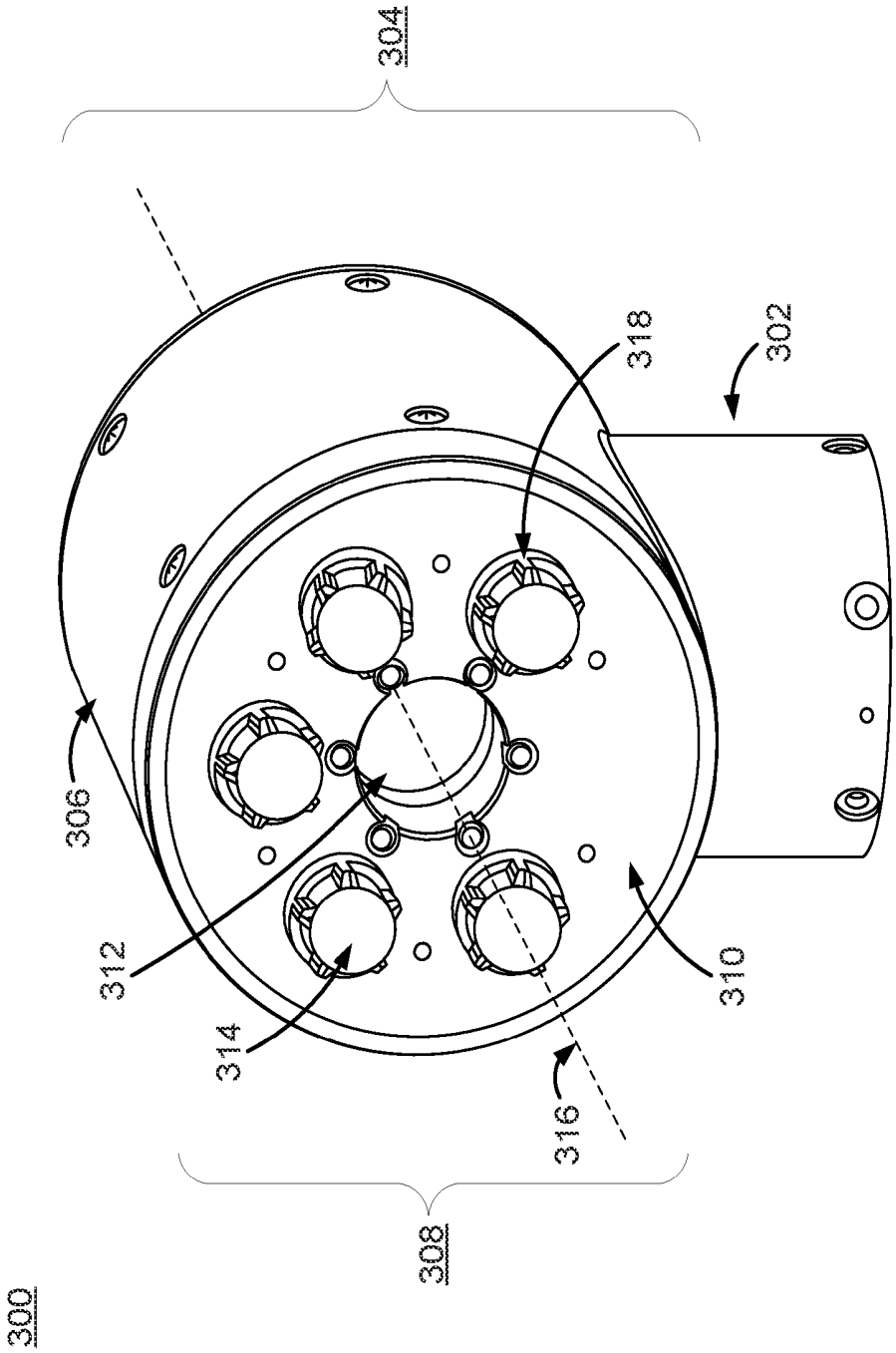


FIG. 3

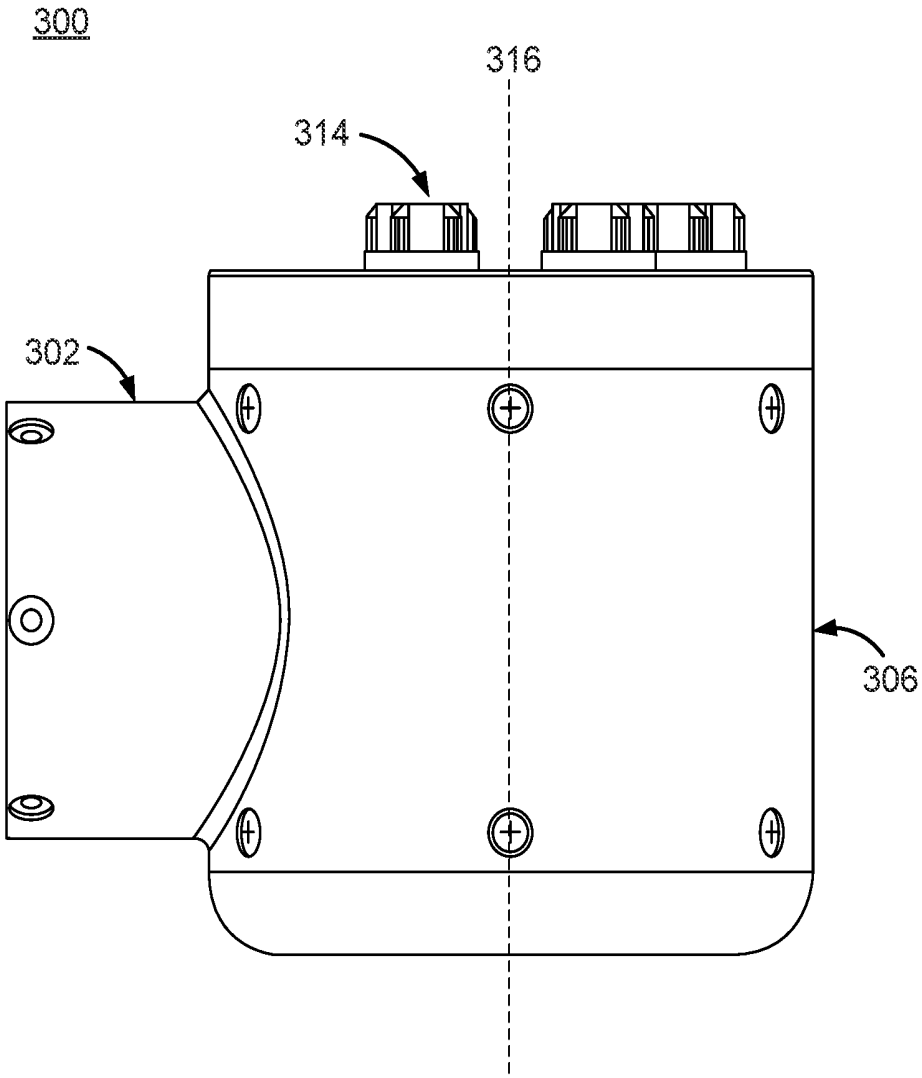


FIG. 4

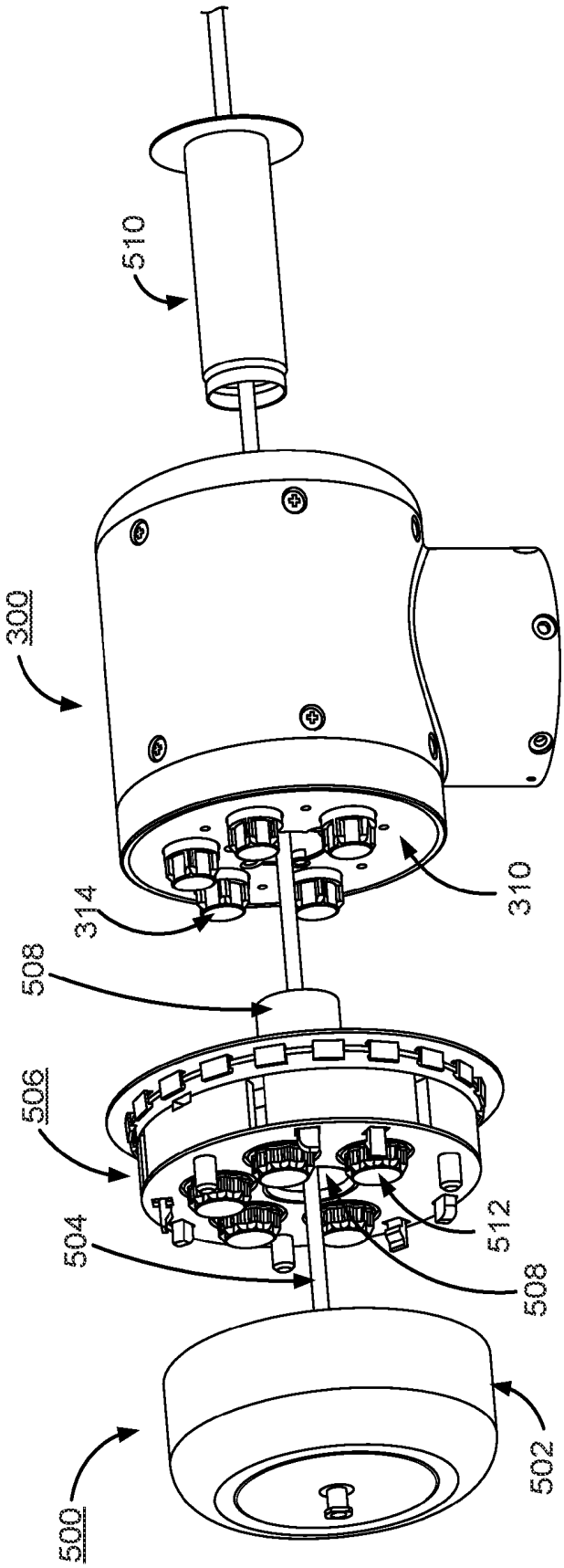


FIG. 5

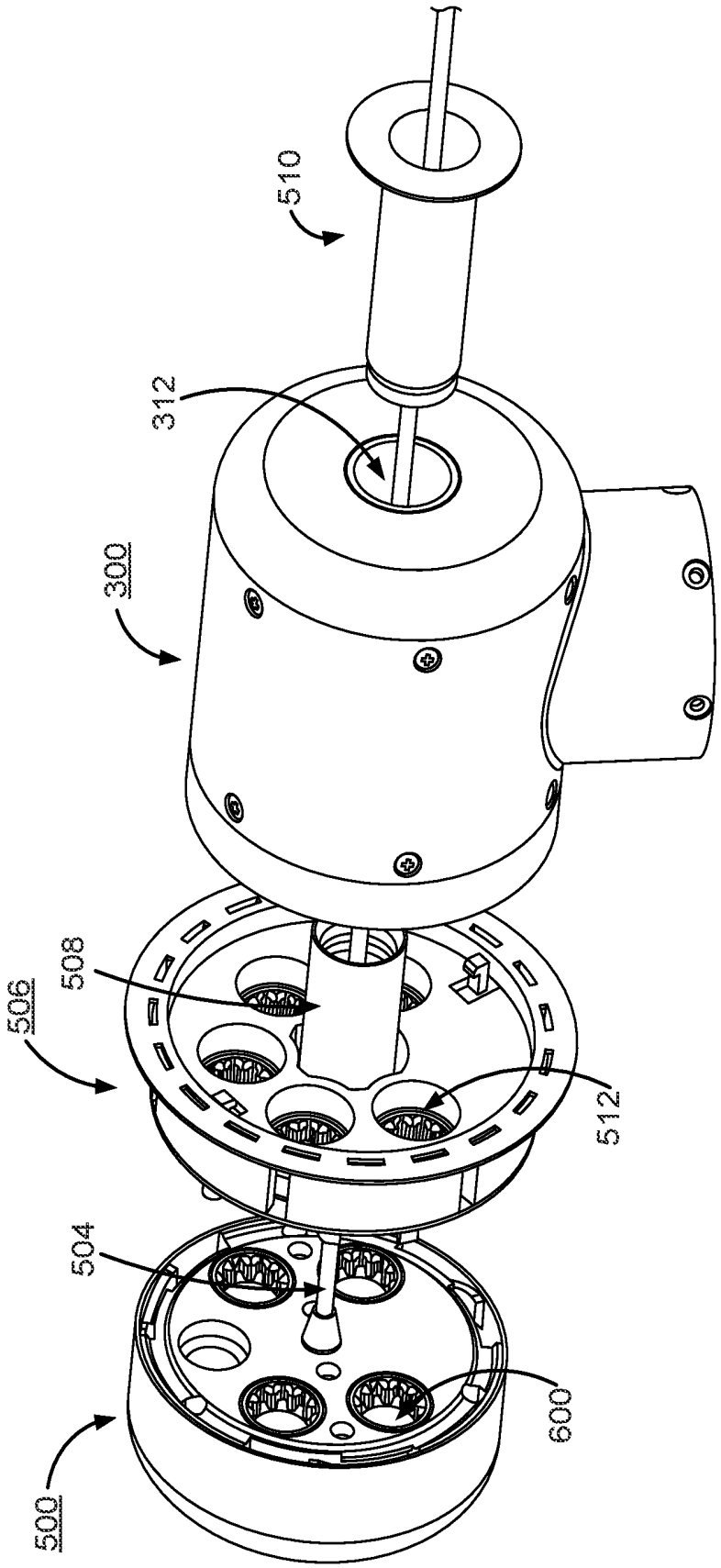


FIG. 6

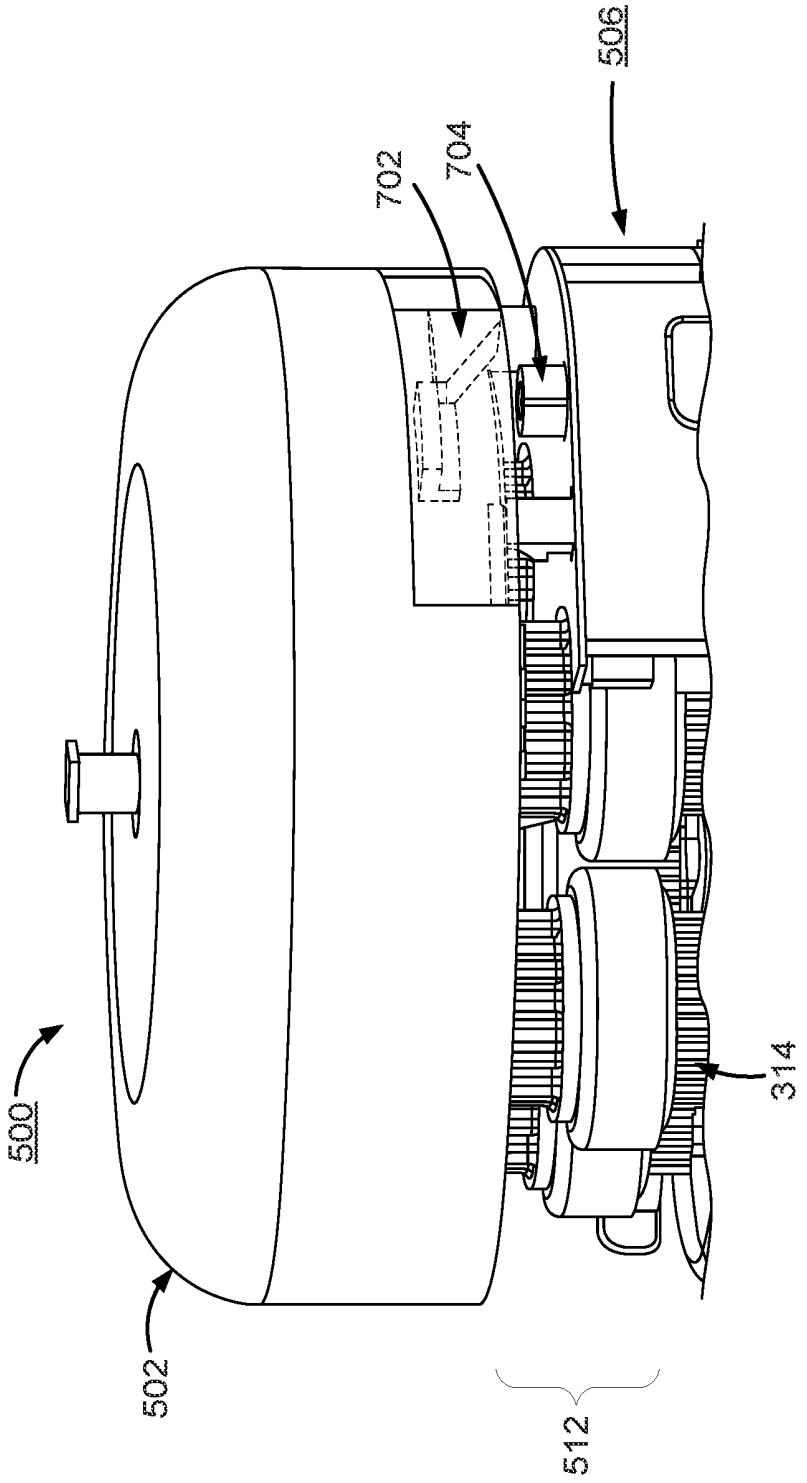


FIG. 7

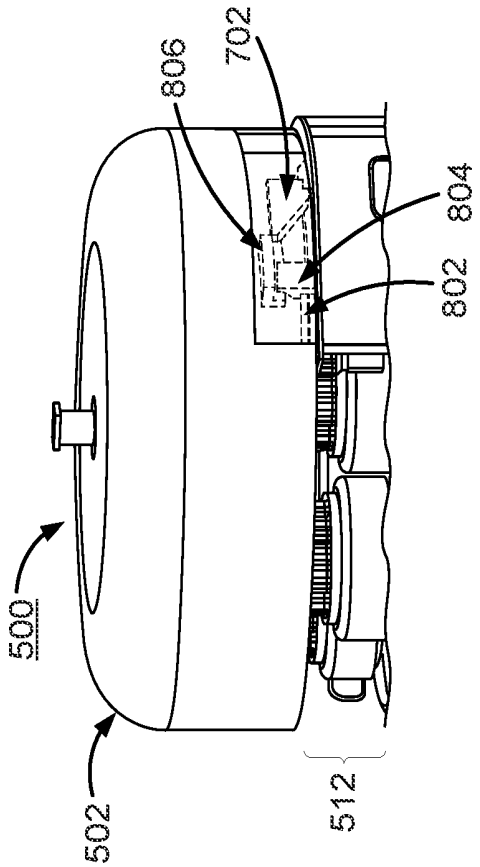


FIG. 8B

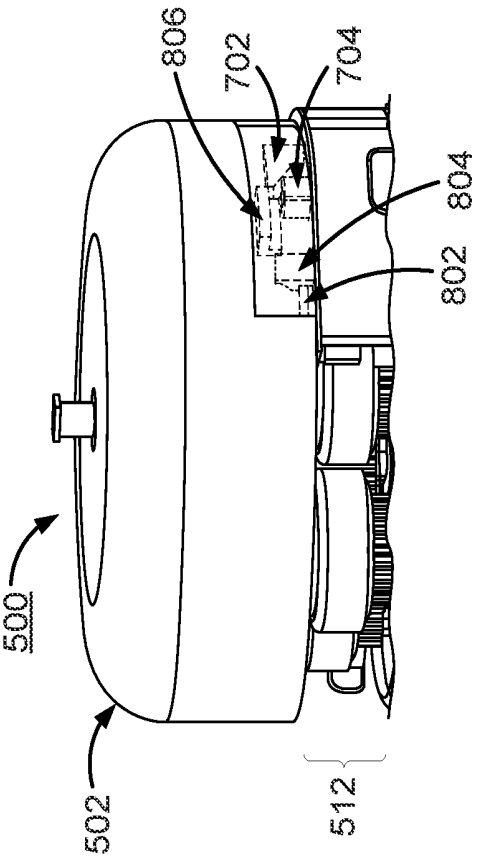


FIG. 8A

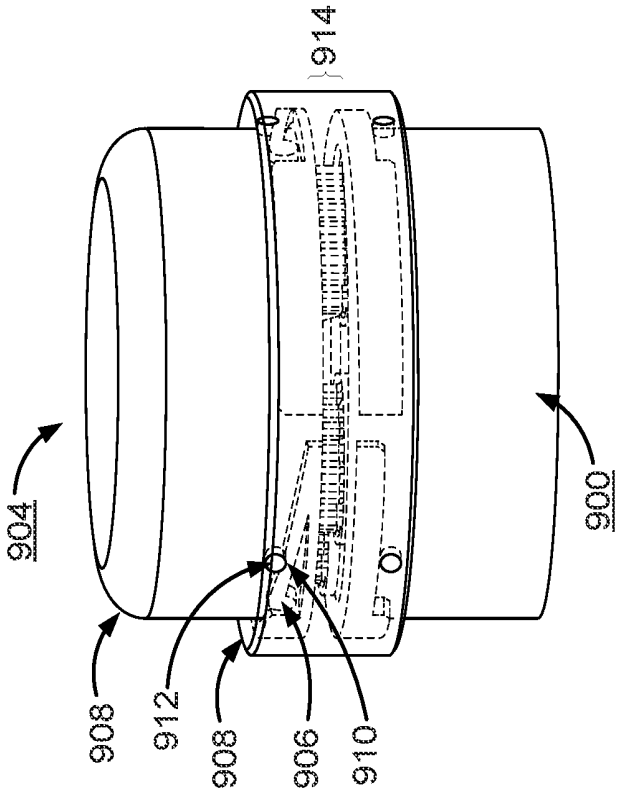


FIG. 9B

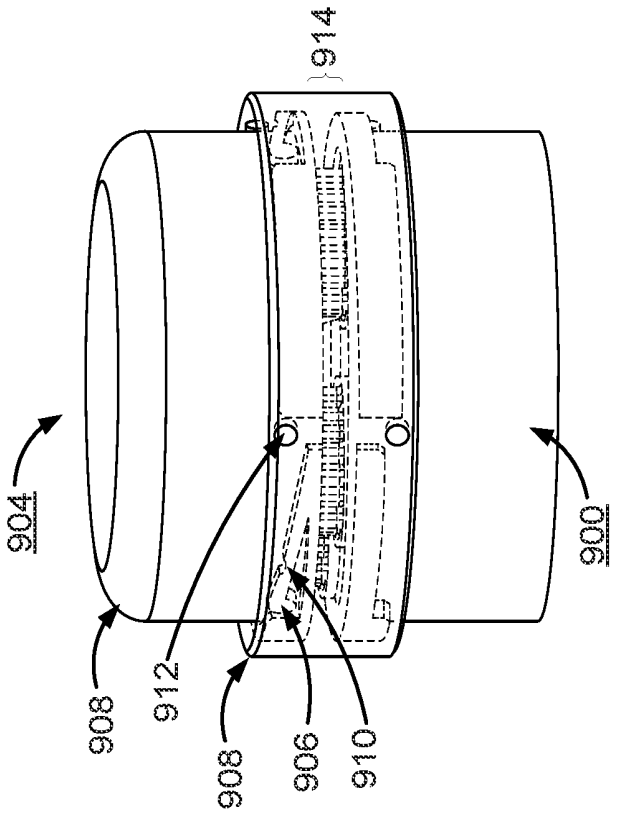


FIG. 9A

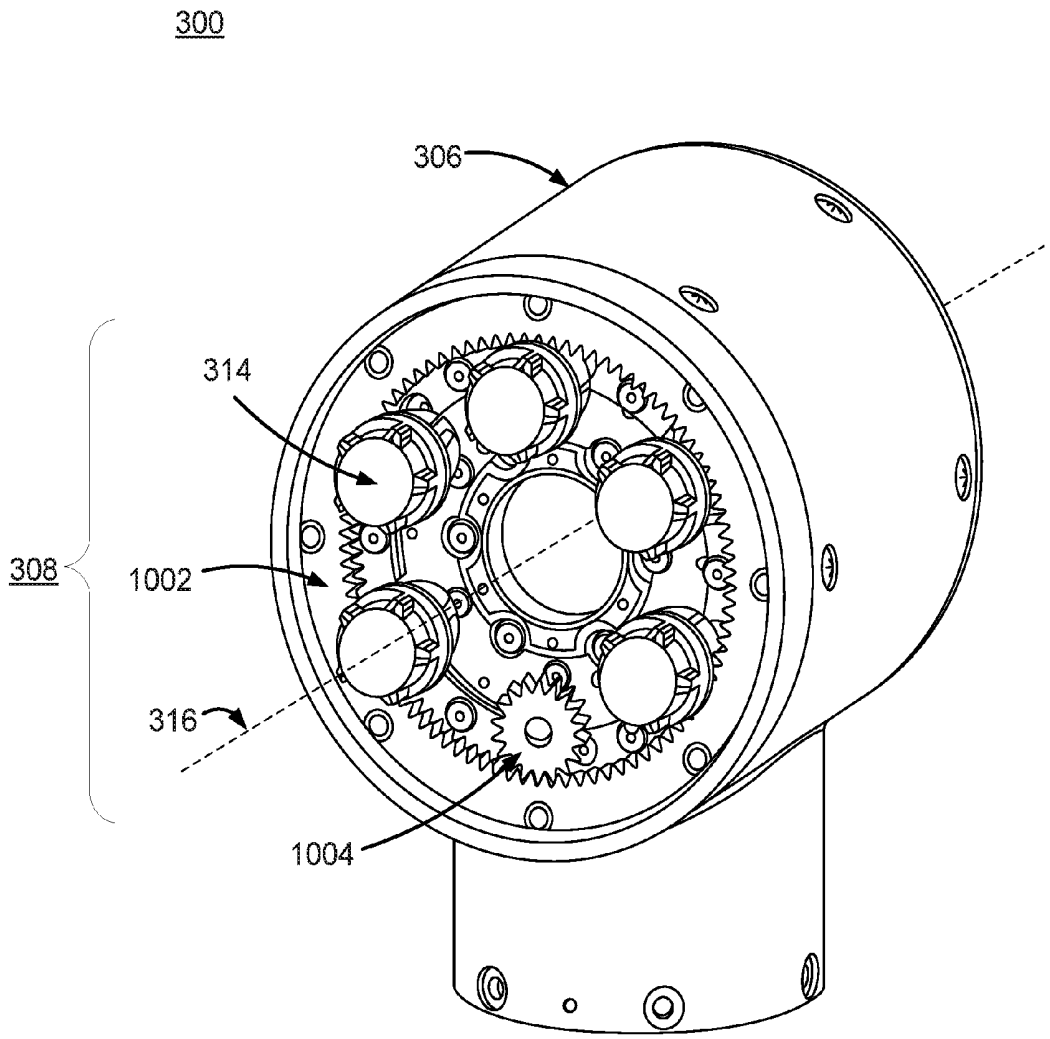
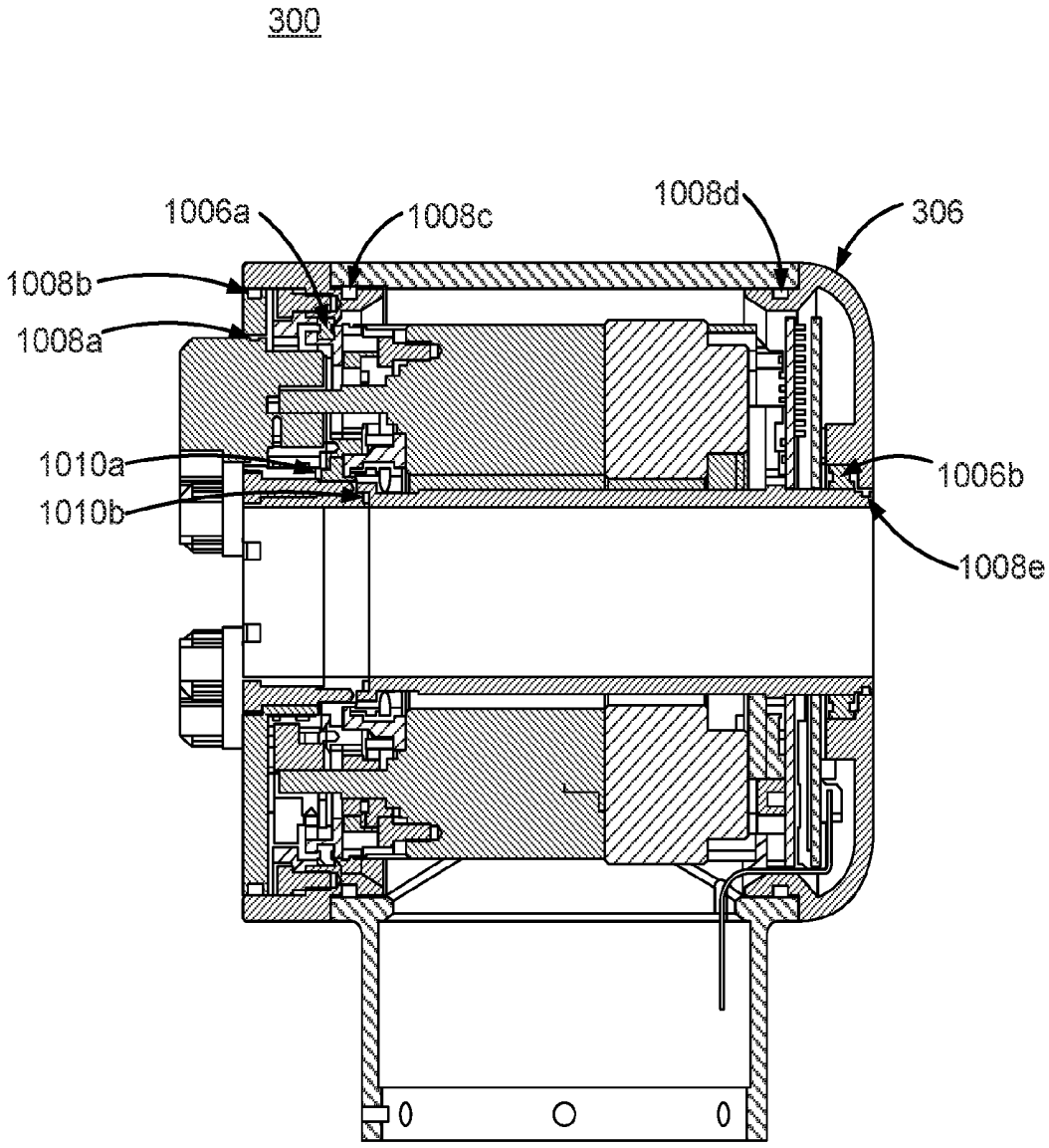


FIG. 10A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1008b
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1006b
1008e

FIG. 10B

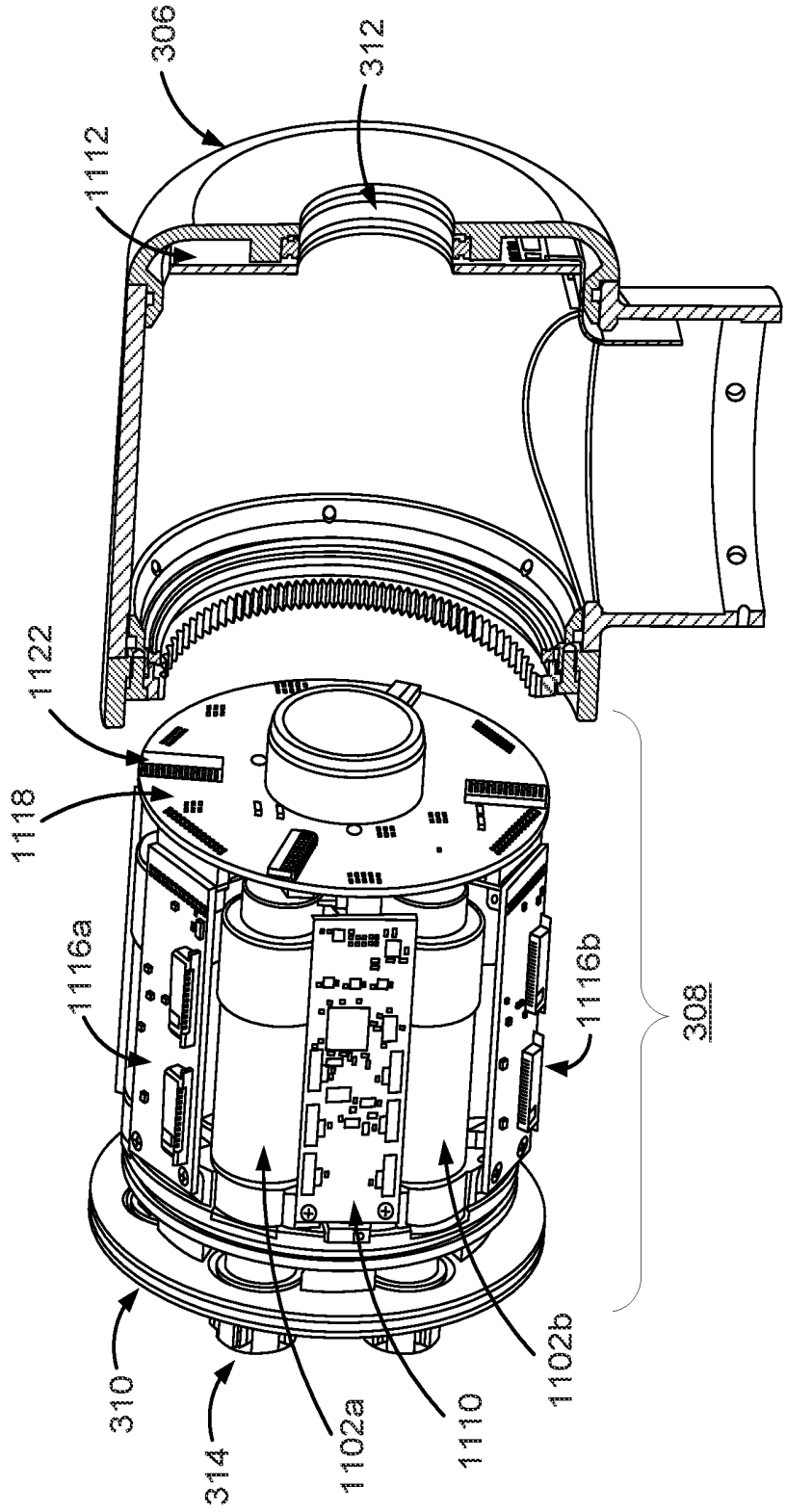
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FIG. 11A

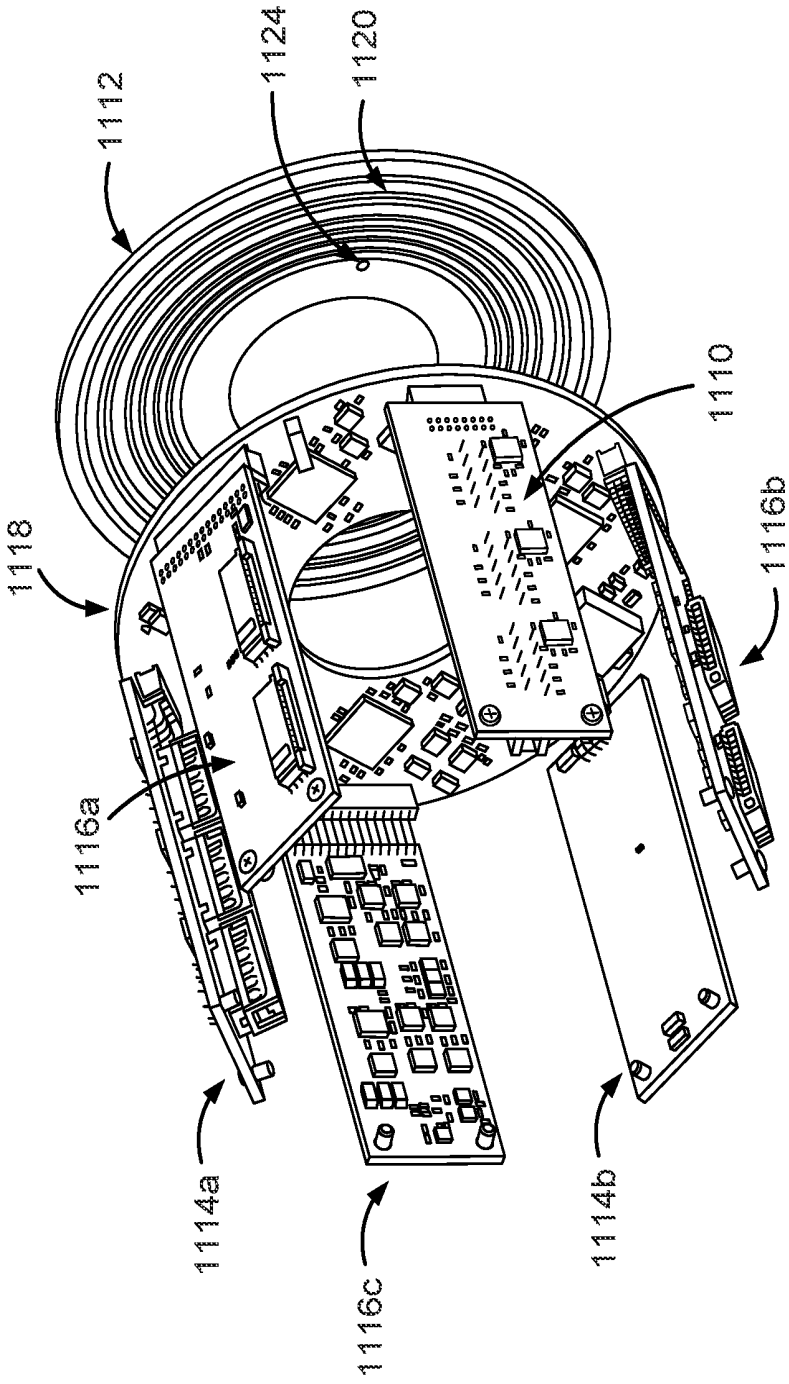

FIG. 11B

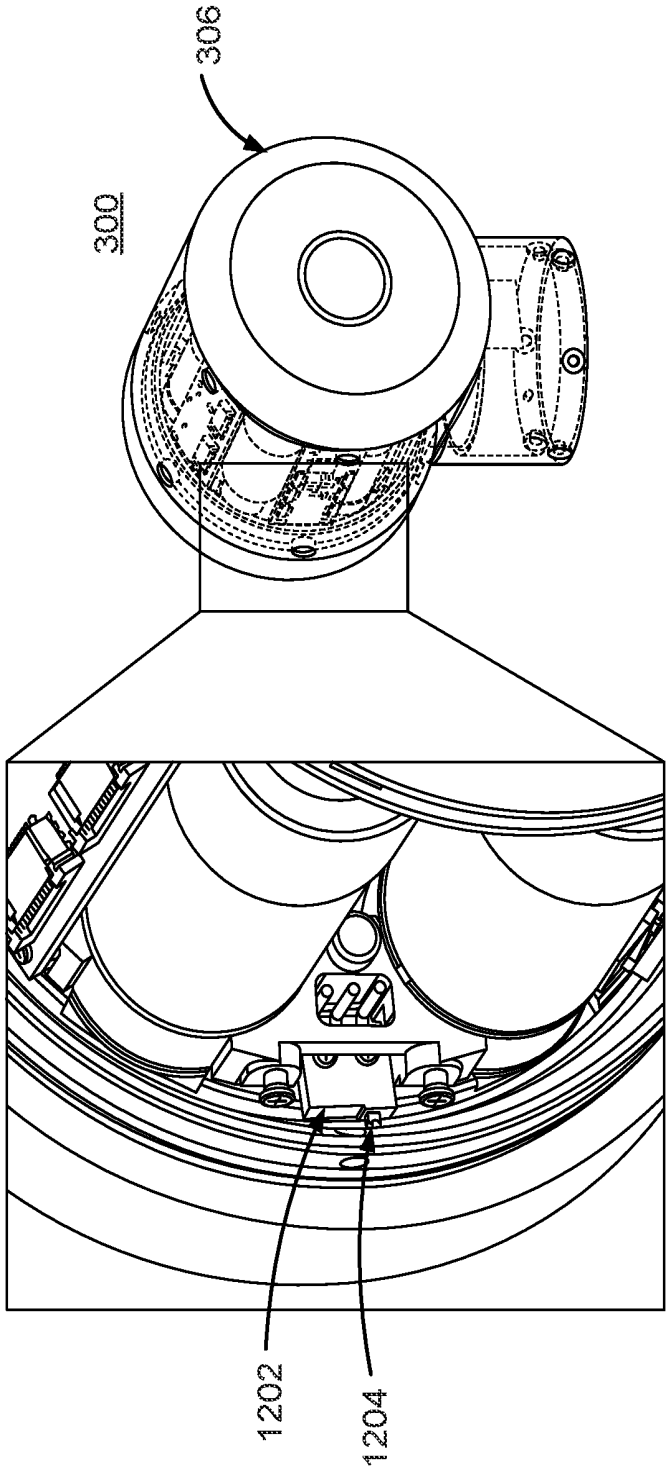

FIG. 12

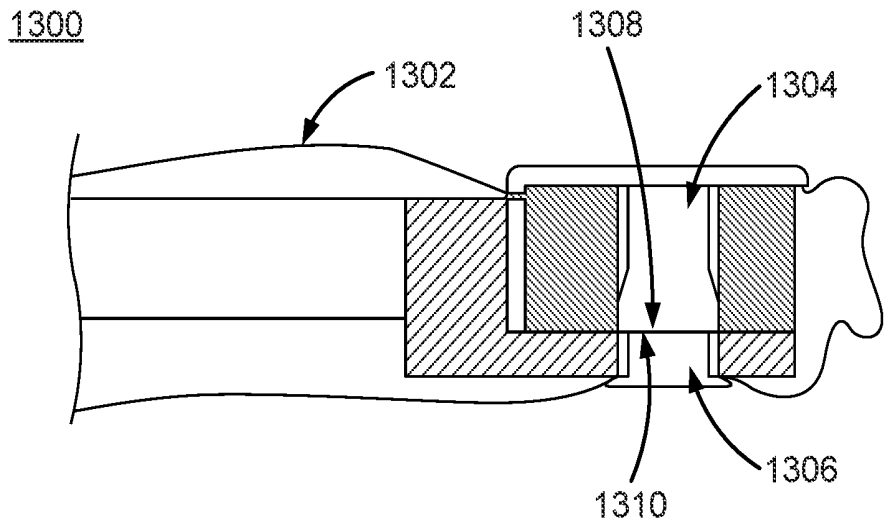

FIG. 13

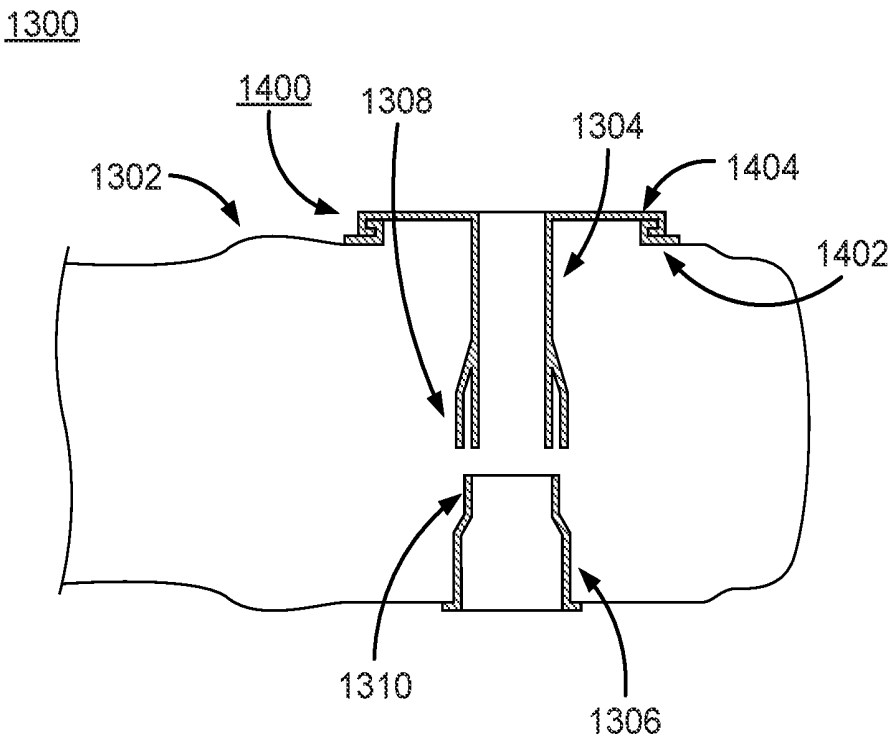

FIG. 14

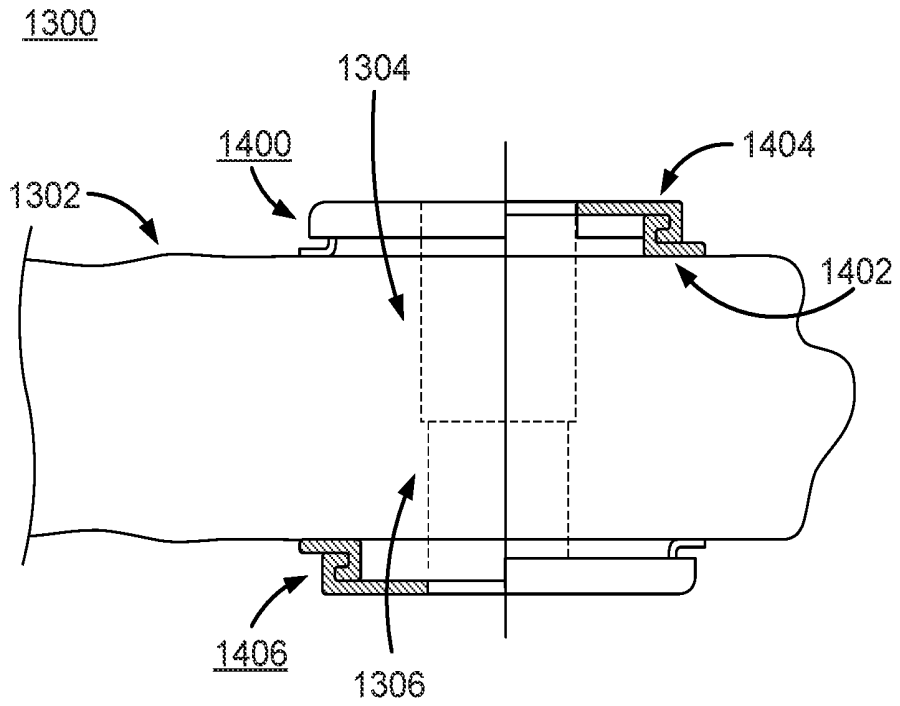

FIG. 15

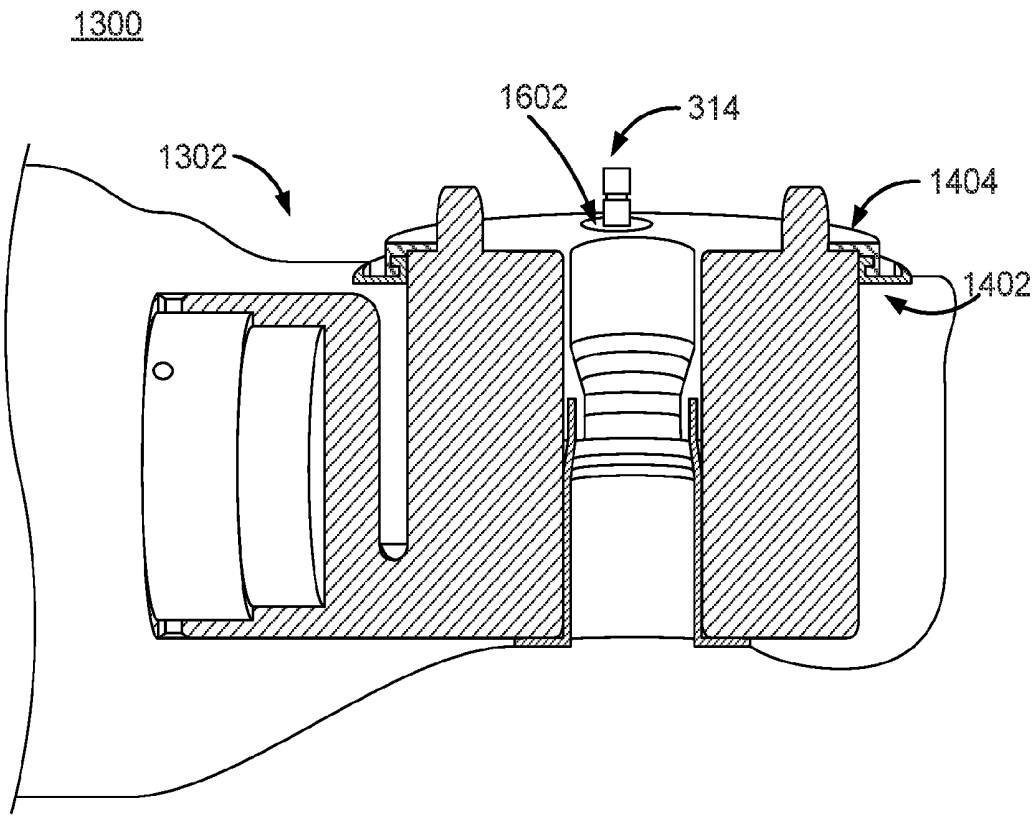

FIG. 16

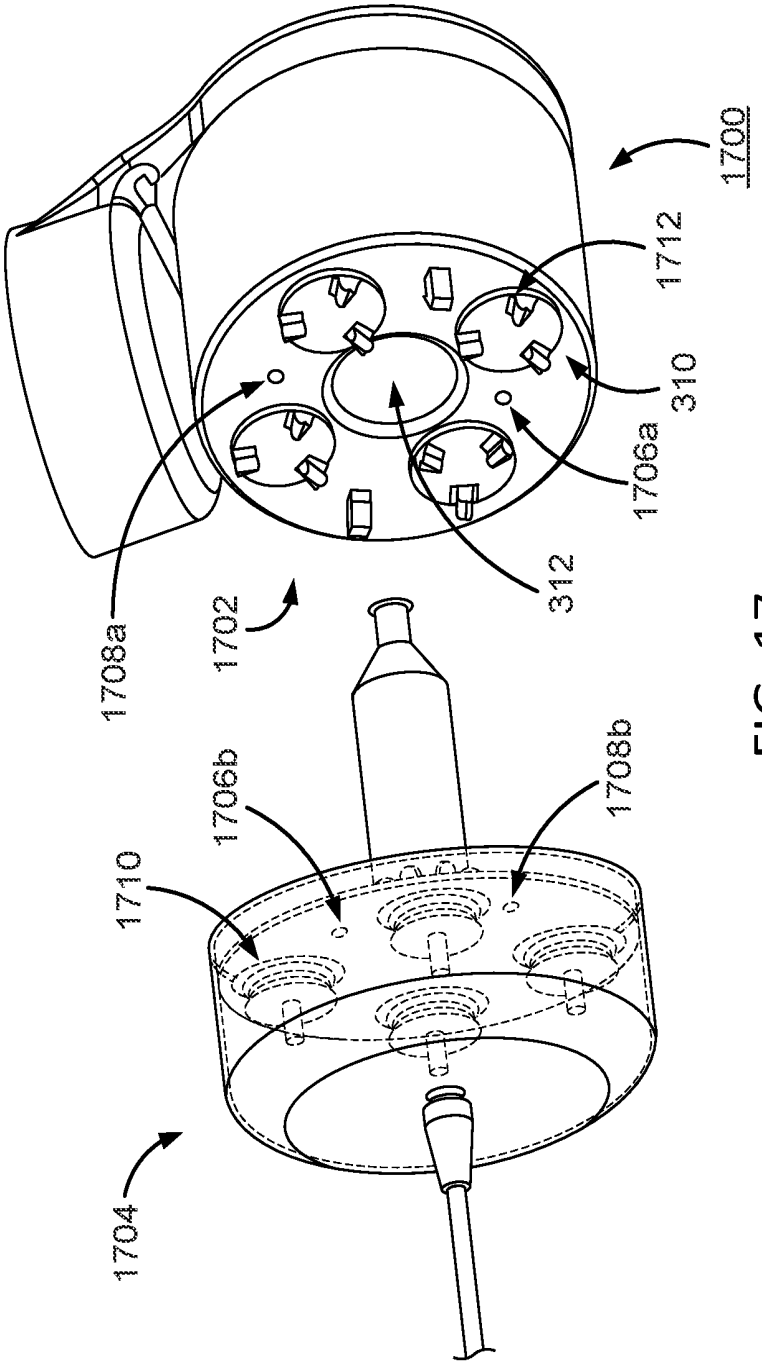

FIG. 17

INSTRUMENT DEVICE MANIPULATOR WITH BACK-MOUNTED TOOL ATTACHMENT MECHANISM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/216,239 filed Sep. 9, 2015, which is incorporated by reference herein in its entirety.

The subject matter of the present application is related to U.S. patent application Ser. No. 14/523,760, filed Oct. 24, 2014; U.S. patent application Ser. No. 14/542,403, filed Nov. 14, 2014 (which claims the benefit of U.S. Provisional Application No. 61/895,315, filed on Oct. 24, 2013); U.S. Provisional Application No. 62/019,816, filed Jul. 1, 2014; U.S. Provisional Patent Application No. 62/037,520, filed Aug. 14, 2014; U.S. Provisional Patent Application No. 62/057,936, filed Sep. 30, 2014; U.S. Provisional Patent Application No. 62/134,366, filed Mar. 17, 2015; and U.S. Provisional Patent Application No. 62/184,741, filed Jun. 25, 2015. Each of the foregoing is incorporated herein by reference in its entirety.

BACKGROUND

This description generally relates to surgical robotics, and particularly to an instrument device manipulator having a back-mounted attachment mechanism for a surgical tool.

Robotic technologies have a range of applications. In particular, robotic arms help complete tasks that a human would normally perform. For example, factories use robotic arms to manufacture automobiles and consumer electronics products. Additionally, scientific facilities use robotic arms to automate laboratory procedures such as transporting microplates. In the medical field, physicians have started using robotic arms to help perform surgical procedures.

In a surgical robotic system, a robotic arm is connected to an instrument device manipulator, e.g., at the end of the robotic arm, and is capable of moving the instrument device manipulator into any position within a defined work space. The instrument device manipulator can be detachably coupled to a surgical tool, such as a steerable catheter for endoscopic applications or any of a variety of laparoscopic tools. The instrument device manipulator imparts motion from the robotic arm to control the position of the surgical tool, and it may also activate controls on the tool, such as pull-wires to steer a catheter. Additionally, the instrument device manipulator may be electrically and/or optically coupled to the tool to provide power, light, or control signals, and may receive data from the tool such as a video stream from a camera on the tool.

During use, a surgical tool is connected to the instrument device manipulator so that the tool is away from a patient, and the robotic arm then advances the instrument device manipulator and the tool connected thereto towards a surgery site within the patient. In some situations during a surgery, it may be desirable to quickly disconnect the tool from the instrument device manipulator and remove it from the patient. But when the tool is connected to a distal face of the instrument device manipulator, removing the tool from the instrument device manipulator may require advancing the tool a small distance towards the surgical site so that the tool can be lifted off of the attachment mechanism of the instrument device manipulator. Even a slight motion towards the surgical site may cause damage to a patient. Alternatively, the surgical tool may be connected to a top face of the instrument device manipulator. Although this may allow the tool to be disconnected from the instrument device manipulator without advancing the tool towards the surgical site, connecting the tool in a way that is not symmetrical about an axis of the tool may limit the amount of roll that the surgical arm and/or instrument device manipulator can impart to the tool.

SUMMARY

Embodiments of the invention enable a surgical tool to be disconnected from an instrument device manipulator on a robotic arm of a surgical robotic system without advancing the tool towards a surgery site. For example, an attachment mechanism is included on a proximal face of the instrument device manipulator (away from the patient) so that the motion required to move the tool sufficiently to clear any attachment mechanism of the instrument device manipulator is in a direction away from the surgical site, thereby withdrawing a distal end of the tool from the surgery site. Moreover, the instrument device manipulator may also include a passageway therethrough to allow the tool to attach to the instrument device manipulator in a way that is generally symmetrical about an axis of the tool. As opposed to a side-mounted scheme, this allows for a greater amount of roll (possibly infinite) to be imparted to the tool by the instrument device manipulator.

In various embodiments, a surgical instrument manipulation system comprises a surgical arm, a surgical tool holder assembly, and a surgical tool. The surgical tool holder assembly can be attached to the surgical tool via an attachment interface on the surgical tool holder. The surgical tool holder assembly further comprises a passage that receives an elongated body of the surgical tool. The attachment interface includes one or more torque couplers, which can engage with a plurality of instrument inputs on the surgical tool. The torque couplers are driven by actuators that cause the torque couplers to rotate, thereby rotating the plurality of instrument inputs and thus driving a plurality of end-effectors of the surgical tool. The attachment interface further comprises an attachment mechanism that releasably secures the surgical tool and the surgical tool holder assembly. This configuration allows a surgical tool to be removed from the surgical tool holder assembly in a distal direction to a patient, improving patient safety during surgical tool removal.

In certain embodiments, the surgical tool holder assembly can continuously rotate or "roll" about a rotational axis that is co-axially aligned with the passage. This configuration allows free rotation of the surgical tool about a rotational axis and the elongated body of the surgical tool attached to the surgical tool holder assembly.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates a surgical robotic system, according to one embodiment.

FIG. **2** illustrates a command console for a surgical robotic system, according to one embodiment.

FIG. **3** illustrates a perspective view of an instrument device manipulator for a surgical robotic system, according to one embodiment.

FIG. **4** illustrates a side view of the instrument device manipulator of FIG. **3**, according to one embodiment.

FIG. **5** illustrates a front-perspective exploded view of an example surgical tool secured to the instrument device manipulator of FIG. **3**, according to one embodiment.

FIG. **6** illustrates a back-perspective exploded view of an example surgical tool secured to the instrument device manipulator of FIG. **3**, according to one embodiment.

FIG. **7** illustrates a zoomed-in, perspective view of an actuation mechanism for engagement and disengagement of a surgical tool from a surgical tool holder, according to one embodiment.

FIGS. **8**A and **8**B illustrate a process of engaging and disengaging a surgical tool from a sterile adapter, according to one embodiment.

FIGS. **9**A and **9**B illustrate a process of engaging and disengaging a surgical tool from a sterile adapter, according to an additional embodiment.

FIG. **10**A illustrates a perspective view of a mechanism for rolling a surgical tool holder within an instrument device manipulator, according to one embodiment.

FIG. **10**B illustrates a cross-sectional view of an instrument device manipulator, according to one embodiment.

FIGS. **11**A and **11**B illustrate partially exploded, perspective views of the internal components of an instrument device manipulator and certain electrical components thereof, according to one embodiment.

FIG. **12** illustrates a zoomed-in, perspective view of electrical components of an instrument device manipulator for roll indexing the surgical tool holder, according to one embodiment.

FIG. **13** illustrates a cross-sectional view of a surgical drape for an instrument device manipulator for a surgical robotics system, according to one embodiment.

FIG. **14** illustrates a cross-sectional view of reciprocal mating interfaces of a surgical drape for a surgical tool holder, according to one embodiment.

FIG. **15** illustrates a cross-sectional view of sterile adapters of a surgical drape for an instrument device manipulator, according to one embodiment.

FIG. **16** illustrates a cross-sectional view of a surgical drape for an instrument device manipulator, according to an additional embodiment.

FIG. **17** illustrates an optical interface for power and data transmission between a surgical tool and an instrument device manipulator, according to one embodiment.

The figures depict embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

I. Surgical Robotic System

FIG. **1** illustrates an embodiment of a surgical robotic system **100**. The surgical robotic system **100** includes a base **101** coupled to one or more robotic arms, e.g., robotic arm **102**. The base **101** is communicatively coupled to a command console, which is further described herein with reference to FIG. **2**. The base **101** can be positioned such that the robotic arm **102** has access to perform a surgical procedure on a patient, while a user such as a physician may control the surgical robotic system **100** from the comfort of the command console. In some embodiments, the base **101** may be coupled to a surgical operating table or bed for supporting the patient. Though not shown in FIG. **1** for purposes of clarity, the base **101** may include subsystems such as control electronics, pneumatics, power sources, optical sources, and the like. The robotic arm **102** includes multiple arm segments **110** coupled at joints **111**, which provides the robotic arm **102** multiple degrees of freedom, e.g., seven degrees of freedom corresponding to seven arm segments. The base **101** may contain a source of power **112**, pneumatic pressure **113**, and control and sensor electronics **114**—including components such as a central processing unit, data bus, control circuitry, and memory—and related actuators such as motors to move the robotic arm **102**. The electronics **114** in the base **101** may also process and transmit control signals communicated from the command console.

In some embodiments, the base **101** includes wheels **115** to transport the surgical robotic system **100**. Mobility of the surgical robotic system **100** helps accommodate space constraints in a surgical operating room as well as facilitate appropriate positioning and movement of surgical equipment. Further, the mobility allows the robotic arms **102** to be configured such that the robotic arms **102** do not interfere with the patient, physician, anesthesiologist, or any other equipment. During procedures, a user may control the robotic arms **102** using control devices such as the command console.

In some embodiments, the robotic arm **102** includes set up joints that use a combination of brakes and counter-balances to maintain a position of the robotic arm **102**. The counter-balances may include gas springs or coil springs. The brakes, e.g., fail safe brakes, may include mechanical and/or electrical components. Further, the robotic arms **102** may be gravity-assisted passive support type robotic arms.

Each robotic arm **102** may be coupled to an instrument device manipulator (IDM) **117** using a mechanism changer interface (MCI) **116**. The IDM **117** can be removed and replaced with a different type of IDM, for example, a first type of IDM manipulates an endoscope, while a second type of IDM manipulates a laparoscope. The MCI **116** includes connectors to transfer pneumatic pressure, electrical power, electrical signals, and optical signals from the robotic arm **102** to the IDM **117**. The MCI **116** can be a set screw or base plate connector. The IDM **117** manipulates surgical instruments such as the endoscope **118** using techniques including direct drive, harmonic drive, geared drives, belts and pulleys, magnetic drives, and the like. The MCI **116** is interchangeable based on the type of IDM **117** and can be customized for a certain type of surgical procedure. The robotic **102** arm can include a joint level torque sensing and a wrist at a distal end, such as the KUKA AG® LBR5 robotic arm.

The endoscope **118** is a tubular and flexible surgical instrument that is inserted into the anatomy of a patient to capture images of the anatomy (e.g., body tissue). In particular, the endoscope **118** includes one or more imaging devices (e.g., cameras or sensors) that capture the images. The imaging devices may include one or more optical components such as an optical fiber, fiber array, or lens. The optical components move along with the tip of the endoscope **118** such that movement of the tip of the endoscope **118** results in changes to the images captured by the imaging devices. While an endoscope is used as the primary example throughout, it is understood that the surgical robotic system **100** may be used with a variety of surgical instruments.

In some embodiments, robotic arms **102** of the surgical robotic system **100** manipulate the endoscope **118** using elongate movement members. The elongate movement members may include pull-wires, also referred to as pull or push wires, cables, fibers, or flexible shafts. For example, the robotic arms **102** actuate multiple pull-wires coupled to the endoscope **118** to deflect the tip of the endoscope **118**. The pull-wires may include both metallic and non-metallic materials such as stainless steel, Kevlar, tungsten, carbon fiber,

and the like. The endoscope **118** may exhibit nonlinear behavior in response to forces applied by the elongate movement members. The nonlinear behavior may be based on stiffness and compressibility of the endoscope **118**, as well as variability in slack or stiffness between different elongate movement members.

The surgical robotic system **100** includes a controller **120**, for example, a computer processor. The controller **120** includes a calibration module **125**, image registration module **130**, and a calibration store **135**. The calibration module **125** can characterize the nonlinear behavior using a model with piecewise linear responses along with parameters such as slopes, hystereses, and dead zone values. The surgical robotic system **100** can more accurately control an endoscope **118** by determining accurate values of the parameters. In some embodiments, some or all functionality of the controller **120** is performed outside the surgical robotic system **100**, for example, on another computer system or server communicatively coupled to the surgical robotic system **100**.

II. Command Console

FIG. **2** illustrates a command console **200** for a surgical robotic system **100** according to one embodiment. The command console **200** includes a console base **201**, display modules **202**, e.g., monitors, and control modules, e.g., a keyboard **203** and joystick **204**. In some embodiments, one or more of the command module **200** functionality may be integrated into a base **101** of the surgical robotic system **100** or another system communicatively coupled to the surgical robotic system **100**. A user **205**, e.g., a physician, remotely controls the surgical robotic system **100** from an ergonomic position using the command console **200**.

The console base **201** may include a central processing unit, a memory unit, a data bus, and associated data communication ports that are responsible for interpreting and processing signals such as camera imagery and tracking sensor data, e.g., from the endoscope **118** shown in FIG. **1**. In some embodiments, both the console base **201** and the base **101** perform signal processing for load-balancing. The console base **201** may also process commands and instructions provided by the user **205** through the control modules **203** and **204**. In addition to the keyboard **203** and joystick **204** shown in FIG. **2**, the control modules may include other devices, for example, computer mice, track pads, trackballs, control pads, video game controllers, and sensors (e.g., motion sensors or cameras) that capture hand gestures and finger gestures.

The user **205** can control a surgical instrument such as the endoscope **118** using the command console **200** in a velocity mode or position control mode. In velocity mode, the user **205** directly controls pitch and yaw motion of a distal end of the endoscope **118** based on direct manual control using the control modules. For example, movement on the joystick **204** may be mapped to yaw and pitch movement in the distal end of the endoscope **118**. The joystick **204** can provide haptic feedback to the user **205**. For example, the joystick **204** vibrates to indicate that the endoscope **118** cannot further translate or rotate in a certain direction. The command console **200** can also provide visual feedback (e.g., pop-up messages) and/or audio feedback (e.g., beeping) to indicate that the endoscope **118** has reached maximum translation or rotation.

In position control mode, the command console **200** uses a three-dimensional (3D) map of a patient and pre-determined computer models of the patient to control a surgical instrument, e.g., the endoscope **118**. The command console **200** provides control signals to robotic arms **102** of the surgical robotic system **100** to manipulate the endoscope **118** to a target location. Due to the reliance on the 3D map, position control mode requires accurate mapping of the anatomy of the patient.

In some embodiments, users **205** can manually manipulate robotic arms **102** of the surgical robotic system **100** without using the command console **200**. During setup in a surgical operating room, the users **205** may move the robotic arms **102**, endoscopes **118**, and other surgical equipment to access a patient. The surgical robotic system **100** may rely on force feedback and inertia control from the users **205** to determine appropriate configuration of the robotic arms **102** and equipment.

The display modules **202** may include electronic monitors, virtual reality viewing devices, e.g., goggles or glasses, and/or other means of display devices. In some embodiments, the display modules **202** are integrated with the control modules, for example, as a tablet device with a touchscreen. Further, the user **205** can both view data and input commands to the surgical robotic system **100** using the integrated display modules **202** and control modules.

The display modules **202** can display 3D images using a stereoscopic device, e.g., a visor or goggle. The 3D images provide an "endo view" (i.e., endoscopic view), which is a computer 3D model illustrating the anatomy of a patient. The "endo view" provides a virtual environment of the patient's interior and an expected location of an endoscope **118** inside the patient. A user **205** compares the "endo view" model to actual images captured by a camera to help mentally orient and confirm that the endoscope **118** is in the correct—or approximately correct—location within the patient. The "endo view" provides information about anatomical structures, e.g., the shape of an intestine or colon of the patient, around the distal end of the endoscope **118**. The display modules **202** can simultaneously display the 3D model and computerized tomography (CT) scans of the anatomy the around distal end of the endoscope **118**. Further, the display modules **202** may overlay pre-determined optimal navigation paths of the endoscope **118** on the 3D model and CT scans.

In some embodiments, a model of the endoscope **118** is displayed with the 3D models to help indicate a status of a surgical procedure. For example, the CT scans identify a lesion in the anatomy where a biopsy may be necessary. During operation, the display modules **202** may show a reference image captured by the endoscope **118** corresponding to the current location of the endoscope **118**. The display modules **202** may automatically display different views of the model of the endoscope **118** depending on user settings and a particular surgical procedure. For example, the display modules **202** show an overhead fluoroscopic view of the endoscope **118** during a navigation step as the endoscope **118** approaches an operative region of a patient.

III. Instrument Device Manipulator

FIG. **3** illustrates a perspective view of an instrument device manipulator (IDM) **300** for a surgical robotic system, and FIG. **4** is a side view of the IDM **300**, according to one embodiment. The IDM **300** is configured to attach a surgical tool to a robotic surgical arm in a manner that allows the surgical tool to be continuously rotated or "rolled" about an axis of the surgical tool. The IDM **300** includes a base **302** and a surgical tool holder assembly **304**. The surgical tool holder assembly **304** further includes an outer housing **306**, a surgical tool holder **308**, an attachment interface **310**, a passage **312**, and a plurality of torque couplers **314**. The IDM **300** may be used with a variety of surgical tools (not shown in FIG. **3**), which may include a housing and an

elongated body, and which may be for a laparoscope, an endoscope, or other types of end-effectors of surgical instruments.

The base **302** removeably or fixedly mounts the IDM **300** to a surgical robotic arm of a surgical robotic system. In the embodiment of FIG. **3**, the base **302** is fixedly attached to the outer housing **306** of the surgical tool holder assembly **304**. In alternate embodiments, the base **302** may be structured to include a platform which is adapted to rotatably receive the surgical tool holder **308** on the face opposite from the attachment interface **310**. The platform may include a passage aligned with the passage **312** to receive the elongated body of the surgical tool and, in some embodiments, an additional elongated body of a second surgical tool mounted coaxially with the first surgical tool.

The surgical tool holder assembly **304** is configured to secure a surgical tool to the IDM **300** and rotate the surgical tool relative to the base **302**. Mechanical and electrical connections are provided from the surgical arm to the base **302** and then to the surgical tool holder assembly **304** to rotate the surgical tool holder **308** relative to the outer housing **306** and to manipulate and/or deliver power and/or signals from the surgical arm to the surgical tool holder **308** and ultimately to the surgical tool. Signals may include signals for pneumatic pressure, electrical power, electrical signals, and/or optical signals.

The outer housing **306** provides support for the surgical tool holder assembly **304** with respect to the base **302**. The outer housing **306** is fixedly attached to the base **302** such that it remains stationary relative to the base **302**, while allowing the surgical tool holder **308** to rotate freely relative to the outer housing **306**. In the embodiment of FIG. **3**, the outer housing **306** is cylindrical in shape and fully circumscribes the surgical tool holder **308**. The outer housing **306** may be composed of rigid materials (e.g., metals or hard plastics). In alternate embodiments, the shape of the housing may vary.

The surgical tool holder **308** secures a surgical tool to the IDM **300** via the attachment interface **310**. The surgical tool holder **308** is capable of rotating independent of the outer housing **306**. The surgical tool holder **308** rotates about a rotational axis **316**, which co-axially aligns with the elongated body of a surgical tool such that the surgical tool rotates with the surgical tool holder **308**.

The attachment interface **310** is a face of the surgical tool holder **308** that attaches to the surgical tool. The attachment interface **310** includes a first portion of an attachment mechanism that reciprocally mates with a second portion of the attachment mechanism located on the surgical tool, which will be discussed in greater detail with regards to FIGS. **8**A and **8**B. The attachment interface **310** comprises a plurality of torque couplers **314** that protrude outwards from the attachment interface **310** and engage with respective instrument inputs on the surgical tool. In some embodiments, a surgical drape, coupled to a sterile adapter, may be used to create a sterile boundary between the IDM **300** and the surgical tool. In these embodiments, the sterile adapter may be positioned between the attachment interface **310** and the surgical tool when the surgical tool is secured to the IDM **300** such that the surgical drape separates the surgical tool and the patient from the IDM **300** and the surgical robotics system.

The passage **312** is configured to receive the elongated body of a surgical tool when the surgical tool is secured to the attachment interface **310**. In the embodiment of FIG. **3**, the passage **312** is co-axially aligned with the longitudinal axis of the elongated body of the surgical tool and the rotational axis **316** of the surgical tool holder **308**. The passage **312** allows the elongated body of the surgical tool to freely rotate within the passage **312**. This configuration allows the surgical tool to be continuously rotated or rolled about the rotational axis **316** in either direction with minimal or no restrictions.

The plurality of torque couplers **314** are configured to engage and drive the components of the surgical tool when the surgical tool is secured to the surgical tool holder **308**. Each torque coupler **314** is inserted into a respective instrument input located on the surgical tool. The plurality of torque couplers **314** may also serve to maintain rotational alignment between the surgical tool and the surgical tool holder **308**. As illustrated in FIG. **3**, each torque coupler **314** is shaped as a cylindrical protrusion that protrudes outwards from the attachment interface **310**. Notches **318** may be arranged along the outer surface area of the cylindrical protrusion. In some embodiments, the arrangement of the notches **318** creates a spline interface. The instrument inputs on the surgical tool are configured to have a complementary geometry to the torque couplers **314**. For example, while not shown in FIG. **3**, the instrument inputs of the surgical tool may be cylindrical in shape and have a plurality of ridges that reciprocally mate with the plurality of notches **318** on each torque coupler **314** and thus impart a torque on the notches **318**. In alternate embodiments, the top face of the cylindrical protrusion may include the plurality of notches **318** configured to mate with a plurality of ridges in respective instrument inputs. In this configuration, each torque coupler **314** fully engages with its respective instrument input.

Additionally, each torque coupler **314** may be coupled to a spring that allows the torque coupler to translate. In the embodiment of FIG. **3**, the spring causes each torque coupler **314** to be biased to spring outwards away from the attachment interface **310**. The spring is configured to create translation in an axial direction, i.e., protract away from the attachment interface **310** and retract towards the surgical tool holder **308**. In some embodiments, each torque coupler **314** is capable of partially retracting into the surgical tool holder **308**. In other embodiments, each torque coupler **314** is capable of fully retracting into the surgical tool holder **308** such that the effective height of each torque coupler is zero relative to the attachment interface **310**. In the embodiment of FIG. **3**, the translation of each torque coupler **314** is actuated by an actuation mechanism, which will be described in further detail with regards to FIGS. **7-8**. In various embodiments, each torque coupler **314** may be coupled to a single spring, a plurality of springs, or a respective spring for each torque coupler.

In addition, each torque coupler **314** is driven by a respective actuator that causes the torque coupler to rotate in either direction. Thus, once engaged with an instrument input, each torque coupler **314** is capable of transmitting power to tighten or loosen pull-wires within a surgical tool, thereby manipulating a surgical tool's end-effectors. In the embodiment of FIG. **3**, the IDM **300** includes five torque couplers **314**, but the number may vary in other embodiments depending on the desired number of degrees of freedom for a surgical tool's end-effectors. In some embodiments, a surgical drape, coupled to a sterile adapter, may be used to create a sterile boundary between the IDM **300** and the surgical tool. In these embodiments, the sterile adapter may be positioned between the attachment interface **310** and the surgical tool when the surgical tool is secured to the IDM

300, and the sterile adapter may be configured to transmit power from each torque coupler **314** to the respective instrument input.

The embodiment of the IDM **300** illustrated in FIG. **3** may be used in various configurations with a surgical robotic system. The desired configuration may depend on the type of surgical procedure being performed on a patient or the type of surgical tool being used during the surgical procedure. For example, the desired configuration of the IDM **300** may be different for an endoscopic procedure than for a laparoscopic procedure.

In a first configuration, the IDM **300** may be removeably or fixedly attached to a surgical arm such that the attachment interface **310** is proximal to a patient during the surgical procedure. In this configuration, hereinafter referred to as "front-mount configuration," the surgical tool is secured to the IDM **300** on a side proximal to the patient. A surgical tool for use with the front-mount configuration is structured such that the elongated body of the surgical tool extends from a side that is opposite of the attachment interface of the surgical tool. As a surgical tool is removed from the IDM **300** in a front-mount configuration, the surgical tool will be removed in a proximal direction to the patient.

In a second configuration, the IDM **300** may be removeably or fixedly attached to a surgical arm such that the attachment interface **310** is distal to a patient during the surgical procedure. In this configuration, hereinafter referred to as "back-mount configuration," the surgical tool is secured to the IDM **300** on a side distal to the patient. A surgical tool for use with the back-mount configuration is structured such that the elongated body of the surgical tool extends from the attachment interface of the surgical tool. This configuration increases patient safety during tool removal from the IDM **300**. As a surgical tool is removed from the IDM **300** in a back-mount configuration, the surgical tool will be removed in a distal direction from the patient.

Certain configurations of a surgical tool may be structured such that the surgical tool can be used with an IDM in either a front-mount configuration or a back-mount configuration. In these configurations, the surgical tool includes an attachment interface on both ends of the surgical tool. For some surgical procedures, the physician may decide the configuration of the IDM depending on the type of surgical procedure being performed. For instance, the back-mount configuration may be beneficial for laparoscopic procedures wherein laparoscopic tools may be especially long relative to other surgical instruments. As a surgical arm moves about during a surgical procedure, such as when a physician directs a distal end of the surgical tool to a remote location of a patient (e.g., a lung or blood vessel), the increased length of laparoscopic tools causes the surgical arm to swing about a larger arc. Beneficially, the back-mount configuration decreases the effective tool length of the surgical tool by receiving a portion of the elongated body through the passage **312** and thereby decreases the arc of motion required by the surgical arm to position the surgical tool.

FIGS. **5-6** illustrate perspective exploded views of an example surgical tool **500** secured to the instrument device manipulator **300** of FIG. **3**, according to one embodiment. The surgical tool **500** includes a housing **502**, an elongated body **504**, and a plurality of instrument inputs **600**. As previously described, the elongated body **504** may be a laparoscope, an endoscope, or other surgical instrument having end-effectors. As illustrated, the plurality of torque couplers **314** protrude outwards from the attachment interface **310** to engage with the instrument inputs **600** of the surgical tool. The structure of the instrument inputs **600** can be seen in FIG. **6**, wherein the instrument inputs **600** have corresponding geometry to the torque couplers **314** to ensure secure surgical tool engagement.

During a surgical procedure, a surgical drape may be used to maintain a sterile boundary between the IDM **300** and an outside environment (i.e., an operating room). In the embodiments of FIGS. **5-6**, the surgical drape comprises a sterile adapter **506**, a first protrusion **508**, and a second protrusion **510**. While not shown in FIGS. **5-6**, a sterile sheet is connected to the sterile adapter and the second protrusion and drapes around the IDM **300** to create the sterile boundary.

The sterile adapter **506** is configured to create a sterile interface between the IDM **300** and the surgical tool **500** when secured to the IDM **300**. In the embodiment of FIGS. **5-6**, the sterile adapter **506** has a disk-like geometry that covers the attachment interface **310** of the IDM **300**. The sterile adapter **506** comprises a central hole **508** that is configured to receive the elongated body **504** of the surgical tool **500**. In this configuration, the sterile adapter **506** is positioned between the attachment interface **310** and the surgical tool **500** when the surgical tool **500** is secured to the IDM **300**, creating the sterile boundary between the surgical tool **500** and the IDM **300** and allowing the elongated body **504** to pass through the passage **312**. In certain embodiments, the sterile adapter **506** may be capable of rotating with the surgical tool holder **308**, transmitting the rotational torque from the plurality of torque couplers **314** to the surgical tool **500**, passing electrical signals between the IDM **300** and the surgical tool **500**, or some combination thereof.

In the embodiment of FIGS. **5-6**, the sterile adapter **506** further comprises a plurality of couplers **512**. A first side of a coupler **512** is configured to engage with a respective torque coupler **314** while a second side of a coupler **512** is configured to engage with a respective instrument input **600**. Similar to the structure of the plurality of torque couplers **314**, each coupler **512** is structured as a cylindrical protrusion including a plurality of notches. Each side of the coupler **512** has complementary geometry to fully engage with the respective torque coupler **314** and the respective instrument input **600**. Each coupler **512** is configured to rotate in a clockwise or counter-clockwise direction with the respective torque coupler **314**. This configuration allows each coupler **512** to transfer rotational torque from the plurality of torque couplers **314** of the IDM **300** to the plurality of instrument inputs **600** of the surgical tool **500**, and thus control the end-effectors of the surgical tool **500**.

The first protrusion **508** and the second protrusion **510** are configured to pass through the passage **312** of the IDM **300** and mate with each other inside the passage **312**. Each protrusion **508**, **510** is structured to allow the elongated body **504** to pass through the protrusion and thus the passage **312**. The connection of the first protrusion **508** and the second protrusion **510** creates the sterile boundary between the IDM **300** and the outside environment (i.e., an operating room). The surgical drape is discussed in further detail with regards to FIGS. **13-16**.

IV. Surgical Tool Disengagement

FIG. **7** illustrates a zoomed-in, perspective view of an actuation mechanism for engagement and disengagement of a surgical tool **500** from a sterile adapter **506** of a surgical drape, according to one embodiment. Due to the configuration of the IDM **300** as described with regards to FIG. **3**, the axis of surgical tool insertion into the patient during a surgical procedure is the same as the axis of surgical tool removal. To ensure patient safety during surgical tool

removal, the surgical tool **500** can be de-articulated from the sterile adapter **506** and the IDM **300** before removing the surgical tool **500**. In the embodiment of FIG. **7**, the plurality of couplers **512** are configured to translate in an axial direction, i.e., protract away from and retract towards the sterile adapter **506**. The translation of the plurality of couplers **512** is actuated by the actuation mechanism which ensures de-articulation of the surgical tool **500** by disengaging the plurality of couplers **512** from the respective instrument inputs **600**. The actuation mechanism includes a wedge **702** and a pusher plate **704**.

The wedge **702** is a structural component that activates the pusher plate **704** during the process of surgical tool disengagement. In the embodiment of FIG. **7**, the wedge **702** is located within the housing **502** of the surgical tool **500** along the outer perimeter of the housing **502**. As illustrated, the wedge **702** is oriented such that contact with the pusher plate **704** causes the pusher plate **704** to depress into the sterile adapter **506** if the housing **502** of the surgical tool **500** is rotated clockwise relative to the sterile adapter **506**. In alternate embodiments, the wedge **702** may be configured such that the housing **502** of the surgical tool **500** is rotated counter-clockwise rather than clockwise. Geometries other than a wedge may be employed, such as an arch-shaped ramp, given that the structure is able to depress the pusher plate when rotating.

The pusher plate **704** is an actuator that disengages the plurality of couplers **512** from the surgical tool **500**. Similar to the plurality of torque couplers **314**, each of the couplers **512** may be coupled to one or more springs that bias each coupler **512** to spring outwards away from the sterile adapter **506**. The plurality of couplers **512** are further configured to translate in an axial direction, i.e., protract away from and retract into the sterile adapter **506**. The pusher plate **704** actuates the translational movement of the couplers **512**. As the pusher plate **704** is depressed by the wedge **702**, the pusher plate **704** causes the spring or plurality of springs coupled to each coupler **512** to compress, resulting in the couplers **512** retracting into the sterile adapter **506**. In the embodiment of FIG. **7**, the pusher plate **704** is configured to cause simultaneous retraction of the plurality of couplers **512**. Alternate embodiments may retract the couplers **512** in a specific sequence or a random order. In the embodiment of FIG. **7**, the pusher plate **704** causes the plurality of couplers **512** to partially retract into the sterile adapter **506**. This configuration allows a surgical tool **500** to be de-articulated from the sterile adapter **506** before the surgical tool **500** is removed. This configuration also allows a user to de-articulate the surgical tool **500** from the sterile adapter **506** at any desired time without removing the surgical tool **500**. Alternate embodiments may fully retract the plurality of couplers **512** into the sterile adapter **506** such that the effective height of each coupler **512** measured is zero. In some embodiments, the pusher plate **704** may cause the plurality of torque couplers **314** to retract synchronously with the plurality of respective couplers **512**.

FIGS. **8**A and **8**B illustrate a process of engaging and disengaging a surgical tool from a sterile adapter, according to one embodiment. FIG. **8**A illustrates a sterile adapter **506** and a surgical tool **500** in a secured position, such that the two components are secured together and the plurality of couplers **512** are fully engaged with respective instrument inputs **600** of the surgical tool **500**. To achieve the secured position as illustrated in FIG. **8**A, the elongated body **504** (not shown) of the surgical tool **500** is passed through the central hole **508** (not shown) of the sterile adapter **506** until mating surfaces of the surgical tool **500** and the sterile adapter **506** are in contact, and the surgical tool **500** and the sterile adapter **506** are secured to each other by a latching mechanism. In the embodiments of FIGS. **8**A and **8**B, the latching mechanism comprises a ledge **802** and a latch **804**.

The ledge **802** is a structural component that secures the latch **804** in the secured position. In the embodiment of FIG. **8**A, the ledge **802** is located within the housing **502** of the surgical tool **500** along the outer perimeter of the housing **502**. As illustrated in FIG. **8**A, the ledge **802** is oriented such that it rests below a protrusion on the latch **804**, preventing the latch **804** and thereby the sterile adapter **506** from pulling away from the surgical tool **500** due to the sprung-up nature of the plurality of couplers **512**, as described with regards to FIG. **7**.

The latch **804** is a structural component that mates with the ledge **802** in the secured position. In the embodiment of FIG. **8**A, the latch **804** protrudes from the mating surface of the sterile adapter **506**. The latch **804** comprises a protrusion that is configured to rest against the ledge **802** when the surgical tool **500** is secured to sterile adapter **506**. In the embodiment of FIG. **8**A, the housing **502** of the surgical tool **500** is capable of rotating independent of the rest of the surgical tool **500**. This configuration allows the housing **502** to rotate relative to the sterile adapter **506** such that the ledge **802** is secured against the latch **804**, thereby securing the surgical tool **500** to the sterile adapter **502**. In the embodiment of FIG. **8**A, the housing **502** is rotated counter-clockwise to achieve the secured position, but other embodiments may be configured for clockwise rotation. In alternate embodiments, the ledge **802** and the latch **804** may have various geometries that lock the sterile adapter **506** and the surgical tool **500** in the secured position.

FIG. **8**B illustrates the sterile adapter **506** and the surgical tool **500** in an unsecured position, in which the surgical tool **500** may be removed from the sterile adapter **506**. As previously described, the housing **502** of the surgical tool **500** is capable of rotating independent of the rest of the surgical tool **500**. This configuration allows the housing **502** to rotate even while the plurality of couplers **512** are engaged with the instrument inputs **600** of the surgical tool **500**. To transition from the secured position to the unsecured position, a user rotates the housing **502** of the surgical tool **500** clockwise relative to the sterile adapter **506**. During this rotation, the wedge **702** contacts the pusher plate **704** and progressively depresses the pusher plate **704** as it slides against the angled plane of the wedge **702**, thereby causing the plurality of couplers **512** to retract into the sterile adapter **506** and disengage from the plurality of instrument inputs **600**. Further rotation causes the latch **804** to contact an axial cam **806**, which is structured similar to wedge **702**. As the latch **804** contacts the axial cam **806** during rotation, the axial cam **806** causes the latch **804** to flex outwards away from the surgical tool **500** such that the latch **804** is displaced from the ledge **802**. In this unsecured position, the plurality of couplers **512** are retracted, and the surgical tool **500** can be removed from the sterile adapter **506**, in the embodiment of FIG. **8**B. In other embodiments, the axial cam **806** may have various geometries such that rotation causes the latch **804** to flex outwards.

In alternate embodiments, the direction of rotation of the housing **502** of the surgical tool **500** may be configured as counter-clockwise rotation to unsecure the latch **804** from the ledge **802**. Additionally, alternate embodiments may include similar components but the location of the components may be switched between the sterile adapter **506** and the surgical tool **500**. For example, the ledge **802** may be located on the sterile adapter **506** while the latch **804** may be

located on the surgical tool **500**. In other embodiments, an outer portion of the sterile adapter **506** may be rotatable relative to the plurality of couplers **512** rather than the housing **502** of the surgical tool **500**. Alternate embodiments may also include a feature to lock the rotation of the housing **502** of the surgical tool **502** when the housing **502** is fully rotated relative to the instrument inputs **600**. This configuration prevents rotation of the surgical tool if the instrument inputs **600** have been de-articulated from the couplers **512**. In some embodiments, the retraction and protraction of the couplers **512** may be coupled with a respective retraction and protraction of the torque couplers **314**, such that a coupler **512** engaged with a torque coupler **314** will translate together.

FIGS. **9**A and **9**B illustrate a process of surgical tool engagement and disengagement of a surgical tool from a sterile adapter, according to another embodiment. In the embodiment of FIGS. **9**A and **9**B, a sterile adapter **900** may include an outer band **902** that secures the surgical tool **904** to the sterile adapter **900**. As illustrated in FIGS. **9**A and **9**B, the surgical tool **902** comprises a ramp **906** on the outer surface of the housing **908**. The ramp **906** includes a notch **910** that is configured to receive a circular protrusion **912**, which is positioned on an inner surface of the outer band **902** of the sterile adapter **900**. The outer band **902** is capable of rotating independent of and relative to the sterile adapter **900** and the surgical tool **904**. As the outer band **902** rotates in a first direction, the circular protrusion **912** glides up the surface of the ramp **906** until the circular protrusion **912** is nested within the notch **910**, thereby securing the sterile adapter **900** and the surgical tool **904** together. Rotation of the outer band **902** in a second direction causes the sterile adapter **900** and the surgical tool **904** to unsecure from each other. In certain embodiments, this mechanism may be coupled with a de-articulation of the plurality of couplers **914** on the sterile adapter **900**, as described with regards to FIGS. **7**-**8**.

Alternate embodiments of surgical tool disengagement may include additional features, such as an impedance mode. With an impedance mode, the surgical robotics system may control whether the surgical tool can be removed from the sterile adapter by a user. The user may initiate the disengagement mechanism by rotating the outer housing of the surgical tool and unsecuring the surgical tool from the sterile adapter, but the surgical robotics system may not release the couplers from the instrument inputs. Only once the surgical robotics system has transitioned into the impedance mode are the couplers released and the user can remove the surgical tool. An advantage of keeping the surgical tool engaged is that the surgical robotics system can control the end-effectors of the surgical tool and position them for tool removal before the surgical tool is removed to minimize damage to the surgical tool. To activate an impedance mode, the pusher plate **704** may have a hard-stop such that the pusher plate can be depressed up to a certain distance. In some embodiments, the hard-stop of the pusher plate may be adjustable such that the hard-stop coincides with the maximum amount of rotation of the housing of the surgical tool. Thus, once the full rotation is reached, the hard-stop is also met by the pusher plate. A plurality of sensors may detect these events and trigger the impedance mode.

Certain situations may require emergency tool removal during a surgical procedure in which the impedance mode may not be desirable. In some embodiments, the hard-stop of the pusher plate may have compliance, such that the hard-stop may yield in an emergency situation. The hard-stop of the pusher plate may be coupled to a spring, allowing the hard-stop to yield in response to additional force. In other embodiments, the hard-stop of the pusher plate may be rigid such that emergency tool removal occurs by removing the latch that secures the surgical tool to the sterile adapter.

V. Roll Mechanism

FIG. **10**A illustrates a perspective view of a mechanism for rolling a surgical tool holder **308** within an instrument device manipulator **300**, according to one embodiment. As illustrated in FIG. **10**A, the attachment interface **310** is removed to expose the roll mechanism. This mechanism allows the surgical tool holder **308** to continuously rotate or "roll" about the rotational axis **316** in either direction. The roll mechanism comprises a stator gear **1002** and a rotor gear **1004**.

The stator gear **1002** is a stationary gear configured to mate with the rotor gear **1004**. In the embodiment of FIG. **10**A, the stator gear **1002** is a ring-shaped gear comprising gear teeth along the inner circumference of the ring. The stator gear **1002** is fixedly attached to the outer housing **306** behind the attachment interface **310**. The stator gear **1002** has the same pitch as the rotor gear **1004**, such that the gear teeth of the stator gear **1002** are configured to mate with the gear teeth of the rotor gear **1004**. The stator gear **1002** may be composed of rigid materials (e.g., metals or hard plastics).

The rotor gear **1004** is a rotating gear configured to induce rotation of the surgical tool holder **308**. As illustrated in FIG. **10**A, the rotor gear **1004** is a circular gear comprising gear teeth along its outer circumference. The rotor gear **1004** is positioned behind the attachment interface **310** and within the inner circumference of the stator gear **1002** such that the gear teeth of the rotor gear **1004** mate with the gear teeth of the stator gear. As previously described, the rotor gear **1004** and the stator gear **1002** have the same pitch. In the embodiment of FIG. **10**A, the rotor gear **1004** is coupled to a drive mechanism (e.g., a motor) that causes the rotor gear **1004** to rotate in a clockwise or counter-clockwise direction. The drive mechanism may receive signals from an integrated controller within the surgical tool holder assembly **304**. As the drive mechanism causes the rotor gear **1004** to rotate, the rotor gear **1004** travels along the gear teeth of the stator gear **1002**, thereby causing the surgical tool holder **308** to rotate. In this configuration, the rotor gear **1004** is capable of continuously rotating in either direction and thus allows the surgical tool holder **308** to achieve infinite roll about the rotational axis **316**. Alternate embodiments may use similar mechanisms to allow for infinite roll, such as a configuration of a ring gear and a pinion gear.

FIG. **10**B illustrates a cross-sectional view of an instrument device manipulator **300**, according to one embodiment. As illustrated in FIB. **10**B, the roll mechanism is coupled with a plurality of bearing **1006**. A bearing is a mechanical component that reduces friction between moving parts and facilitates rotation around a fixed axis. One bearing alone is capable of supporting the radial or torsional loading as the surgical tool holder **308** rotates within the outer housing **306**. In the embodiment of FIG. **10**B, the IDM **300** includes two bearings **1006***a*, **1006***b* fixedly attached to the surgical tool holder **308** such that a plurality of components (such as balls or cylinders) within the bearings **1006** contacts the outer housing **306**. A first bearing **1006***a* is secured at a first end behind the attachment interface **310** and a second bearing **1006***b* is secured at a second end. This configuration improves rigidity and support between the first end and the second end of the surgical tool holder **308** as the surgical tool holder **308** rotates within the outer housing **306**. Alternate

embodiments may include additional bearings that provide additional support along the length of the surgical tool holder.

FIG. **10**B also illustrates sealing components within the IDM **300**, according to one embodiment. The IDM **300** comprises a plurality of O-rings **1008** and a plurality of gaskets **1010** which are configured to seal a junction between two surfaces to prevent fluids from entering the junction. In the embodiment of FIG. **10**B, the IDM includes O-rings **1008***a*, **1008***b*, **1008***c*, **1008***d*, **1008***e* between junctions of the outer housing and gaskets **1010***a*, **1010***b* between junctions within the surgical tool holder **308**. This configuration helps to maintain sterility of the components within the IDM **300** during a surgical procedure. Gaskets and O-rings are typically composed of strong elastomeric materials (e.g., rubber).

VI. Electrical Componentry

FIG. **11**A illustrates a partially exploded, perspective view of the internal components of an instrument device manipulator and certain electrical components thereof, according to one embodiment. The internal components of the surgical tool holder **308** include a plurality of actuators **1102**, a motor, a gearhead (not shown), a torque sensor (not shown), a torque sensor amplifier **1110**, a slip ring **1112**, a plurality of encoder boards **1114**, a plurality of motor power boards **1116**, and an integrated controller **1118**.

The plurality of actuators **1102** drive the rotation of each of the plurality of torque couplers **314**. In the embodiment of FIG. **11**A, an actuator, such as **1102***a* or **1102***b*, is coupled to a torque coupler **314** via a motor shaft. The motor shaft may be a keyed shaft such that it includes a plurality of grooves to allow the motor shaft to securely mate to a torque coupler **314**. The actuator **1102** causes the motor shaft to rotate in a clockwise or counter-clockwise direction, thereby causing the respective torque coupler **314** to rotate in that direction. In some embodiments, the motor shaft may be torsionally rigid but spring compliant, allowing the motor shaft and thus the torque coupler **314** to rotate and to translate in an axial direction. This configuration may allow the plurality of torque couplers **314** to retract and protract within the surgical tool holder **308**. Each actuator **1102** may receive electrical signals from the integrated controller **1118** indicating the direction and amount to rotate the motor shaft. In the embodiment of FIG. **11**A, the surgical tool holder **308** includes five torque couplers **314** and thus five actuators **1102**.

The motor drives the rotation of the surgical tool holder **308** within the outer housing **306**. The motor may be structurally equivalent to one of the actuators, except that it is coupled to the rotor gear **1004** and stator gear **1002** (see FIG. **10**A) for rotating the surgical tool holder **308** relative to the outer housing **306**. The motor causes the rotor gear **1004** to rotate in a clockwise or counter-clockwise direction, thereby causing the rotor gear **1004** to travel about the gear teeth of the stator gear **1002**. This configuration allows the surgical tool holder **308** to continuously roll or rotate without being hindered by potential wind-up of cables or pull-wires. The motor may receive electrical signals from the integrated controller **1118** indicating the direction and amount to rotate the motor shaft.

The gearhead controls the amount of torque delivered to the surgical tool **500**. For example, the gearhead may increase the amount of torque delivered to the instrument inputs **600** of the surgical tool **500**. Alternate embodiments may be configured such that the gearhead decreases the amount of torque delivered to the instrument inputs **600**.

The torque sensor measures the amount of torque produced on the rotating surgical tool holder **308**. In the embodiment shown in FIG. **11**A, the torque sensor is capable of measuring torque in the clockwise and the counter-clockwise direction. The torque measurements may be used to maintain a specific amount of tension in a plurality of pull-wires of a surgical tool. For instance, some embodiments of the surgical robotics system may have an auto-tensioning feature, wherein, upon powering on the surgical robotics system or engaging a surgical tool with an IDM, the tension on the pull-wires of the surgical tool will be pre-loaded. The amount of tension on each pull-wire may reach a threshold amount such that the pull-wires are tensioned just enough to be taut. The torque sensor amplifier **1110** comprises circuitry for amplifying the signal that measures the amount of torque produced on the rotating surgical tool holder **308**. In some embodiments, the torque sensor is mounted to the motor.

The slip ring **1112** enables the transfer of electrical power and signals from a stationary structure to a rotating structure. In the embodiment of FIG. **11**A, the slip ring **1112** is structured as a ring including a central hole that is configured to align with the passage **312** of the surgical tool holder **308**, as is also shown in an additional perspective view of the slip ring **1112** in FIG. **11**B. A first side of the slip ring **1112** includes a plurality of concentric grooves **1120** while a second side of the slip ring **1112** includes a plurality of electrical components for the electrical connections provided from the surgical arm and the base **302**, as described with regards to FIG. **3**. The slip ring **1112** is secured to the outer housing **306** of the surgical tool holder **308** at a specific distance from the outer housing **306** to allocate space for these electrical connections. The plurality of concentric grooves **1120** are configured to mate with a plurality of brushes **1122** attached to the integrated controller. The contact between the grooves **1120** and the brushes **1122** enables the transfer of electrical power and signals from the surgical arm and base to the surgical tool holder.

The plurality of encoder boards **1114** read and process the signals received through the slip ring from the surgical robotic system. Signals received from the surgical robotic system may include signals indicating the amount and direction of rotation of the surgical tool, signals indicating the amount and direction of rotation of the surgical tool's end-effectors and/or wrist, signals operating a light source on the surgical tool, signals operating a video or imaging device on the surgical tool, and other signals operating various functionalities of the surgical tool. The configuration of the encoder boards **1114** allows the entire signal processing to be performed completely in the surgical tool holder **308**. The plurality of motor power boards **1116** each comprises circuitry for providing power to the motors.

The integrated controller **1118** is the computing device within the surgical tool holder **308**. In the embodiment of FIG. **11**A, the integrated controller **1118** is structured as a ring including a central hole that is configured to align with the passage **312** of the surgical tool holder **308**. The integrated controller **1118** includes a plurality of brushes **1122** on a first side of the integrated controller **1118**. The brushes **1122** contact the slip ring **1112** and receive signals that are delivered from the surgical robotics system through the surgical arm, the base **302**, and finally through the slip ring **1112** to the integrated controller **1118**. As a result of the received signals, the integrated controller **1118** is configured to send various signals to respective components within the surgical tool holder **308**. In some embodiments, the functions of the encoder boards **1114** and the integrated control-

ler **1118** may be distributed in a different manner than is described here, such that the encoder boards **1114** and the integrated controller **1118** may perform the same functions or some combination thereof.

FIG. **11**B illustrates a partially exploded, perspective view of the internal components of an instrument device manipulator and certain electrical components thereof, according to one embodiment. The embodiment of FIG. **11**B includes two encoder boards **1114***a* and **1114***b*, a torque sensor amplifier **1110**, and three motor power boards **1116***a*, **1116***b*, and **1116***c*. These components are secured to the integrated controller **1118** and protrude outwards, extending perpendicularly from the integrated controller **1118**. This configuration provides room for the plurality of actuators **1102** and motor to be positioned within the electrical boards.

As discussed with regards to FIG. **11**A, the slip ring **1112** is secured at a specific distance from the outer housing **306**. To ensure correct space allocation between the slip ring **1112** and the outer housing **306** for the electrical connections from the surgical arm and base **302** to the slip ring **1112**, in the embodiment of FIG. **11**B, the slip ring **1112** is supported by a plurality of alignment pins, a plurality of coil springs, and a shim. The slip ring **1112** includes a hole **1124** on each side of the center hole of the slip ring **1112** that is configured to accept a first side of an alignment pin while a second side of the alignment pin is inserted into a respective hole in the outer housing **306**. The alignment pins may be composed of rigid materials (e.g., metal or hard plastics). The plurality of coil springs are secured around the center of the slip ring **1112** and configured to bridge the space and maintain contact between the slip ring **1112** and the outer housing **306**. The coil springs may beneficially absorb any impact to the IDM **300**. The shim is ring-shaped spacer that is positioned around the center hole of the slip ring **1112** to add further support between the slip ring **1112** and the outer housing **306**. In addition, these components provide stability to the slip ring **1112** as the plurality of brushes **1122** on the integrated controller **1118** contact and rotate against the plurality of concentric grooves **1120**. In alternate embodiments, the number of alignment pins, coil springs, and shims may vary until the desired support between the slip ring **1112** and the outer housing **306** is achieved.

FIG. **12** illustrates a zoomed-in, perspective view of electrical components of an instrument device manipulator **300** for roll indexing the surgical tool holder **308**, according to one embodiment. Roll indexing monitors the position of the surgical tool holder **308** relative to the outer housing **306** such that the position and orientation of the surgical tool **500** is continuously known by the surgical robotics system. The embodiment of FIG. **12** includes a micro switch **1202** and a boss **1204**. The micro switch **1202** and the boss **1204** are secured within the surgical tool holder **308**. The boss **1204** is a structure on the outer housing **306** that is configured to contact the micro switch **1202** as the surgical tool holder **308** rotates, thus activating the micro switch each time there is contact with the boss **1204**. In the embodiment of FIG. **12**, there is one boss **1204** that serves as a single reference point for the micro switch **1202**.

VII. Surgical Drape

FIG. **13** illustrates a cross-sectional view of a surgical drape for an instrument device manipulator for a surgical robotics system, according to one embodiment. The surgical drape **1300** provides a sterile boundary for the IDM, the surgical arm, and other portions of the surgical robotics system during a surgical procedure. In the embodiment of FIG. **13**, the surgical drape **1300** is configured for use with an IDM that includes a passage configured to receive an elongated body of a surgical tool when the surgical tool is attached to the IDM, such as IDM **300**. The surgical drape **1300** comprises a sterile sheet **1302**, a first protrusion **1304**, and a second protrusion **1306**.

The sterile sheet **1302** creates and maintains a sterile environment for portions of the surgical robotics system during a surgical procedure. In the embodiment of FIG. **13**, the sterile sheet **1302** is configured to cover the IDM **300**, the surgical arm, and portions of the surgical robotics system. The sterile sheet **1302** may be composed of a variety of materials, such as plastics (e.g., polypropylene), paper, and other materials that may be resistant to fluids.

The first protrusion **1304** is a cylindrical tube configured to receive an elongated body of a surgical tool, such as elongated body **504** of surgical tool **500**. In the embodiment of FIG. **13**, the first protrusion **1304** is connected to a first portion of the sterile sheet **1302**, and a first end of the first protrusion **1304** is configured to be inserted into a first end of the passage **312**. The first end of the first protrusion **1304** includes a mating interface **1308** that is configured to mate with a reciprocal mating interface **1310** on the second protrusion **1306**. The first protrusion **1304** may be composed of rigid materials (e.g., metals or hard plastics).

The second protrusion **1306** is a cylindrical tube configured to receive an elongated body of a surgical tool, such as elongated body **504** of surgical tool **500**. In the embodiment of FIG. **13**, the second protrusion **1306** is connected to a second portion of the sterile sheet **1302**, and a first end of the second protrusion **1306** is configured to be inserted into a second end of the passage **312**, such that the first protrusion **1304** and the second protrusion **1306** are inserted into opposite ends of the passage **312**. The first end of the second protrusion **1306** includes a reciprocal mating interface **1310** that is configured to removeably couple with the mating interface **1308** on the first protrusion **1304** inside the passage **312**. When coupled to each other, the mating interface **1308** and the reciprocal mating interface **1310** create a sterile junction. The second protrusion **1306** may be composed of rigid materials (e.g., metals or hard plastics). In alternate embodiments, coupling mechanisms may include hook-and-loop fasteners, friction-fit tubes, threaded tubes, and other suitable coupling mechanisms.

FIG. **14** illustrates a cross-sectional view of reciprocal mating interfaces of a surgical drape for a surgical tool holder, according to one embodiment. As described with regards to FIG. **13**, the first end of the first protrusion **1304** includes a mating interface **1308**. The mating interface **1308** is structured as two concentric tubes with a crevice between the concentric tubes, as shown by the cross-section in FIG. **14**, wherein the crevice is a ring configured to receive an end of another tube. In the embodiment of FIG. **14**, the reciprocal mating interface **1310** at the first end of the second protrusion **1306** is structured as a tube that tapers such that the diameter at the first end of the tube is smaller relative to the rest of the tube. The tapered end facilitates easy insertion of the reciprocal mating interface **1310** into the mating interface **1308**. In addition, it is possible for the inner surfaces of the first protrusion **1304** and the second protrusion **1306** to contact an unsterile surface while the outer surfaces are able to remain sterile. The junction between the mating interface **1308** and the reciprocal mating interface **1310** when secured to each other creates a convoluted path by enveloping the first end of the second protrusion **1306** into the crevice. This configuration ensures that any surfaces of the first protrusion **1304** or the second protrusion **1306** that contacted an unsterile surface are enveloped within the junction. This configuration further ensures that any fluids

may not be able to travel across the junction between the inner surfaces and the outer surfaces and that a sterile environment is maintained for the IDM and other portions of the surgical robotics system. In some embodiments, the junction between the mating interface **1308** and the reciprocal mating interface **1310** may further comprise a gasket to prevent fluids from penetrating the junction.

In some embodiments of the surgical drape, the surgical drape **1300** may further include a plurality of sterile adapters **1400** that provide a sterile boundary between the IDM and the outside environment or the surgical tool. In certain embodiments, the sterile adapter **1400** is configured to accommodate a rotating interface of an IDM, such as IDM **300**. In the embodiment of FIG. **14**, the sterile adapter **1400** comprises an outer ring **1402** and an inner disk **1404**. The outer ring **1402** is connected to the sterile sheet **1302**, and the inner disk **1404** is connected to the first protrusion **1304**, as illustrated in FIG. **14**. The inner disk **1404** is rotatably secured within the outer ring **1402**. In the embodiment of FIG. **14**, the sterile adapter **1400** covers the attachment interface **310** of the IDM **300** such that the sterile adapter **1400** is positioned between the attachment interface **310** and a surgical tool **500** when the surgical tool **500** is secured to the IDM **300**. This configuration of the sterile adapter **1400** may allow the inner disk **1404** or the outer ring **1402** to freely rotate with the rotation of the IDM **300** and the surgical tool **500**. The outer ring **1402** and the inner disk **1404** may be composed of rigid materials (e.g., metals or hard plastics). In alternate embodiments, portions of the inner disk may be a membrane that covers the plurality of torque couplers of the IDM.

FIG. **15** illustrates a cross-sectional view of sterile adapters of a surgical drape for an instrument device manipulator, according to one embodiment. As described in regards to FIG. **14**, the surgical drape **1300** may include a plurality of sterile adapters, such as **1400** and **1406**, that are configured to accommodate a rotating interface of an IDM **300**. In the embodiment of FIG. **15**, a sterile adapter **1400**, **1406** is positioned at each end of the IDM **300**. A sterile adapter **1406** that is configured to cover the end of the IDM **300** without the attachment interface **310** may vary in structure from a sterile adapter **1400** that is configured to cover the attachment interface **310**, i.e., the sterile adapter may not need structures to accommodate for the plurality of torque couplers **314**. In alternate embodiments, portions of the first protrusion **1304** or the second protrusion **1306** may include a rotatable component, such as a roller bearing or a similar inner disk and outer ring mechanism as previously described, such that rotation occurs within the passage **312** rather than at a sterile adapter. This configuration may improve stability during rotation of the surgical tool holder **308** due to the smaller diameter of the protrusion compared to the diameter of the inner disk **1402**. This configuration may also eliminate the need for an additional sterile adapter **1406** at the end of the IDM **300** without the attachment interface **310**.

FIG. **16** illustrates a cross-sectional view of a surgical drape for an instrument device manipulator, according to an additional embodiment. As illustrated in FIG. **16**, the surgical drape **1300** provides a sterile boundary for the IDM and the surgical arm. The embodiment of FIG. **16** illustrates the inner disk **1404** through which respective torque couplers **314** may protrude.

VIII. Power and Data Transmission

FIG. **17** illustrates an optical interface for power and data transmission between a surgical tool and an instrument device manipulator, according to one embodiment. In certain embodiments, surgical tools may have capabilities that require power and/or data transmission, such as a camera or a light source that operates at the proximal end of the elongated body of the surgical tool. Other features may include tracking sensors or tension sensors. Surgical tools with such features may use cable connections to the rest of the platform for power and/or data transmission and thus hinder the surgical tool's capability to roll. To achieve infinite roll for these surgical tools, power and/or data transmission may occur through inductive power and an optical interface.

In the embodiment of FIG. **17**, the IDM **1700** includes a power transmitter, and the surgical tool includes a power receiver. The power transmitter inductively transmits power to the power receiver across the attachment interface **310** without the need for direct connections. In the embodiment of FIG. **17**, a plurality of coils are secured within the IDM **1700** perpendicular to the attachment interface **310** and centered along the rotational axis of the IDM **1700**. The coils are coupled to the integrated controller and configured to receive signals to transmit power. The coils may be of various diameters centered around the passage **312** of the IDM **1700**. A larger diameter may improve the power transmission capabilities. The surgical tool **1704** may include a battery to support the instrument operation in the event that the wireless power transmission is interrupted. In some embodiments, the power transmitter may have shielding to prevent transferring heat to nearby metal components and interfering with the motors in the IDM **1700**. Possible shielding materials include mu-metals.

In the embodiment of FIG. **17**, the optical interface is between the mating surfaces of the IDM **1700** and the surgical tool **1704**. The IDM **1700** and the surgical tool **1704** each include a plurality of optical transmitters, such as **1706***a*, **1706***b*, and a plurality of optical receivers, such as **1708***a*, **1708***b*. In the embodiment of FIG. **17**, there is at least one pair for the connection between the surgical tool **1704** to the IDM **1700** for transferring data such as imaging data, and at least one pair for the connection between the IDM **1700** to the surgical tool **1704**. In addition, a wireless point-to-point data connection can be used for high bandwidth communication from the IDM **1700** to the surgical robotic system. In some embodiments, the power transmitter may be an LED, which would require the sterile sheet across the attachment interface to be composed of a material transparent to the LED light. Alternate embodiments may use RFID technology or physical connections between the IDM **1700** and surgical tool **1704** for data transmission.

In some embodiments, the optical transmitters **1706** and optical receivers **1708** are symmetrically oriented with respect to the plurality of instrument inputs **1710** and the plurality of torque couplers **1712**, respectively, such that the surgical tool **1704** may be attached to the surgical tool holder **1702** in any orientation. Once the surgical tool **1704** is attached to the surgical tool holder **1702**, an optical transmitter **1706** of the surgical tool **1704** may be configured to transmit a signal to an optical receiver **1708**. The signal can be used to determine the rotational orientation of the surgical tool **1704** with respect to the surgical tool holder **1702**. Once the rotational orientation of the surgical tool **1704** has been determined, the optical data flow can be fully established and the actuators for the torque couplers **1712** can be accurately controlled.

IX. Alternative Considerations

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs through the disclosed principles herein. Thus,

while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

As used herein any reference to "one embodiment" or "an embodiment" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. For example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context unless otherwise explicitly stated.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

What is claimed is:

1. A surgical instrument manipulation system comprising:

a surgical arm configured to secure to a base;

a surgical tool holder assembly comprising:

a surgical tool holder having a first opening and a second opening, the first opening and second opening connected by a passage therethrough, and

an attachment interface on a first end of the surgical tool holder; and

a surgical tool comprising:

a reciprocal attachment interface on a first face of the surgical tool,

an attachment mechanism configured to releasably attach the reciprocal attachment interface to the attachment interface of the surgical tool holder, and

an elongated body extending from the first face of the surgical tool, the elongated body capable of passing through the passage of the surgical tool holder and extending through the second opening when the surgical tool is attached to the surgical tool holder.

2. The system of claim **1**, wherein the surgical arm is operable by a surgical robotics system.

3. The system of claim **1**, wherein the surgical tool holder assembly further comprises an outer housing having a disk-like geometry.

4. The system of claim **1**, wherein the surgical tool holder assembly comprises at least one motor configured to rotate the surgical tool holder relative to an outer housing.

5. The system of claim **4**, wherein the passage, the elongated body of the surgical tool, and a rotational axis of the surgical tool holder assembly are co-axially aligned.

6. The system of claim **5**, wherein the passage allows the elongated body of the surgical tool to continuously rotate about the rotational axis.

7. The system of claim **1**, wherein the attachment interface comprises a plurality of torque couplers that protrudes outward from a surface of the attachment interface.

8. The system of claim **7**, wherein the reciprocal attachment interface comprises a plurality of instrument inputs that are configured to reciprocally mate with the plurality of torque couplers.

9. The system of claim **8**, wherein the drive mechanism for each torque coupler is configured to cause the torque coupler to rotate and thereby rotate the respective instrument input.

10. The system of claim **9**, wherein the plurality of drive mechanisms are arranged in a ring formation around the passage.

11. The system of claim **7**, wherein each of the plurality of torque couplers is coupled to a drive mechanism.

12. The system of claim **1**, wherein the elongated body is one of the following: a steerable tool for endoscopic applications or a rigid tool for laparoscopic applications.

13. The system of claim **1**, further comprising a surgical drape configured to create a sterile boundary between the surgical tool holder assembly and the surgical tool.

14. The system of claim **13**, wherein the surgical drape comprises a sterile adapter that is positioned between the surgical tool holder and the surgical tool attached to the surgical tool holder via the attachment interface, the sterile adapter configured to rotatably secure to the surgical tool holder.

15. The system of claim **14**, wherein the sterile adapter is capable of transmitting data, power, and electrical signals between the surgical tool holder and the surgical tool.

16. A method for attaching a surgical tool to a surgical tool holder assembly, the method comprising:

passing an elongated body of the surgical tool through a passage of the surgical tool holder assembly, the surgical tool holder having a first opening and a second opening, the first opening and second opening connected by the passage therethrough;

advancing the elongated body of the surgical tool through the passage of the surgical tool holder until an attachment mechanism of the surgical tool secures the surgical tool to the surgical tool holder assembly and a distal end of the elongated body extends through the second opening;

operating the surgical tool using the surgical tool holder assembly;

releasing the surgical tool from the surgical tool holder assembly; and

removing the elongated body of the surgical tool from the passage.

17. The method of claim **16**, wherein operating the surgical tool using the surgical tool holder assembly comprises rotating the surgical tool relative to an outer housing of the surgical tool holder assembly.

18. The method of claim 16, wherein the surgical tool holder assembly comprises an attachment interface that mates with a reciprocal attachment interface on the surgical tool via the attachment mechanism.

19. The method of claim 18, wherein the elongated body of the surgical tool extends from the reciprocal attachment interface of the surgical tool.

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摘要(译)

器械装置操纵器（IDM）附接到机器人系统的外科手术臂并且包括外科工具保持器和外壳。手术工具保持器包括附接接口，该附接接口能够将外科手术工具固定在前安装构造中（其中附接接口位于与外科手术工具的细长主体相对的面上）或后安装构造（其中附接接口）与手术工具的细长主体位于同一面上。手术工具架可以在外壳内连续旋转。在后部安装配置中，外科工具保持器可具有通道，该通道接收工具的细长主体并允许细长主体绕旋转轴线自由旋转。手术单将IDM和机械臂与工具分开，同时允许电信号和/或光信号在其间通过。