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Modular and Cooperative Medical Devices and Related Systems and Methods

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(54) **MODULAR AND COOPERATIVE MEDICAL DEVICES AND RELATED SYSTEMS AND METHODS**

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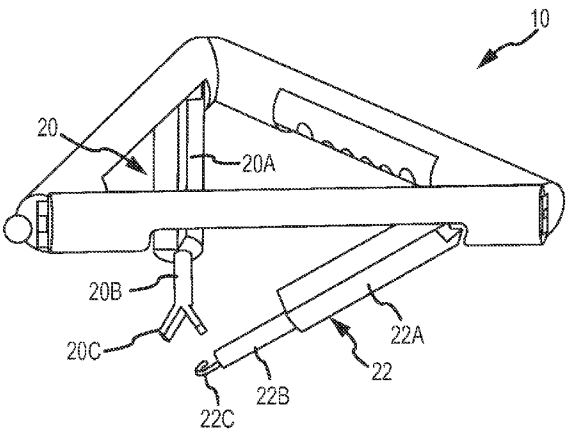
(57) **ABSTRACT**

The various embodiments disclosed herein relate to modular medical devices, including various devices with detachable modular components and various devices with pivotally attached modular components. Additional embodiments relate to procedures in which various of the devices are used cooperatively. Certain embodiments of the medical devices are robotic in vivo devices.

16 Claims, 10 Drawing Sheets



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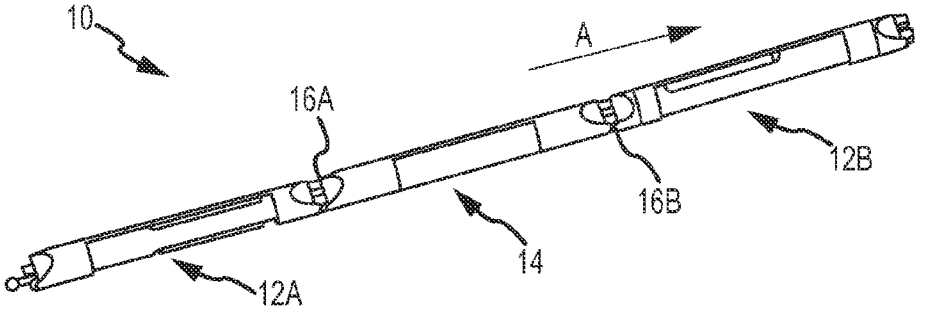

10
A
16A
12B
16B
14
12A

FIG.1A

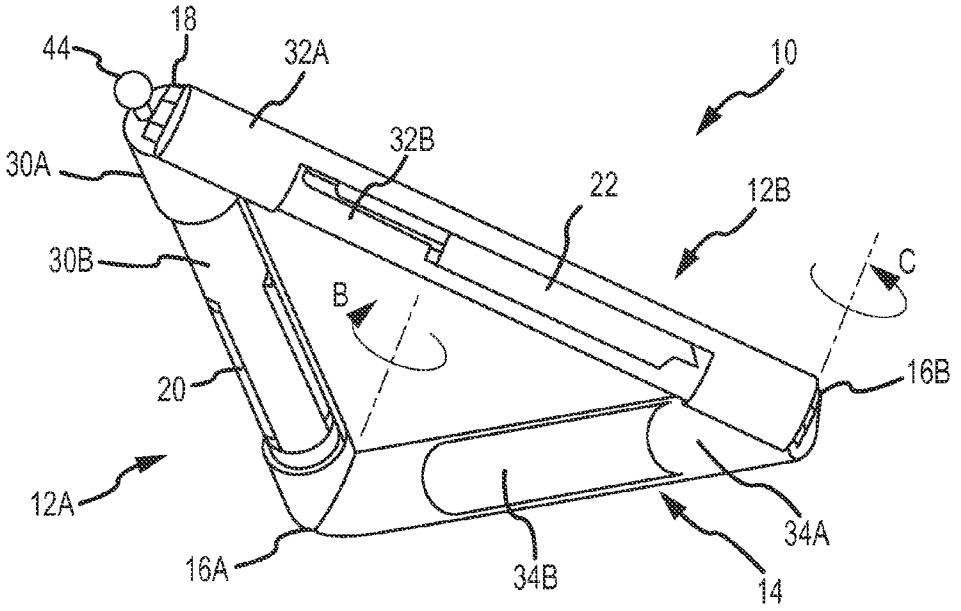

18
44
32A
10
32B
30A
22
12B
30B
C
B
20
16B
12A
34A
16A
34B
14

FIG.1B

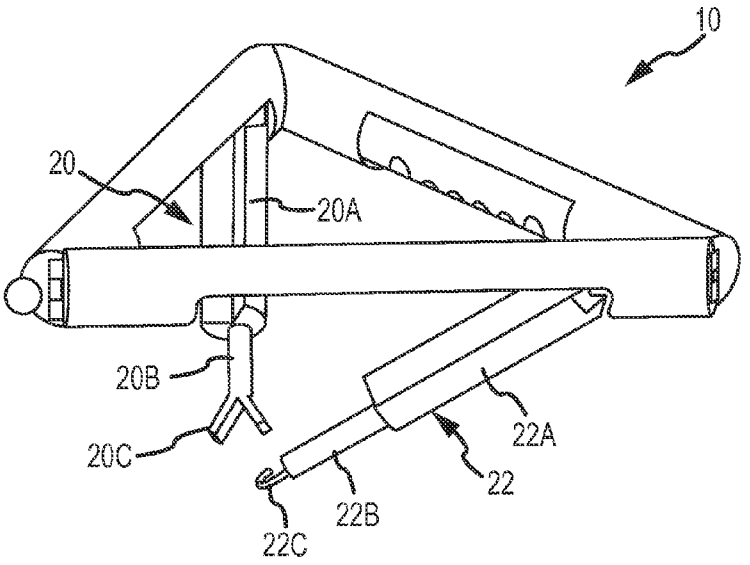


FIG.2A

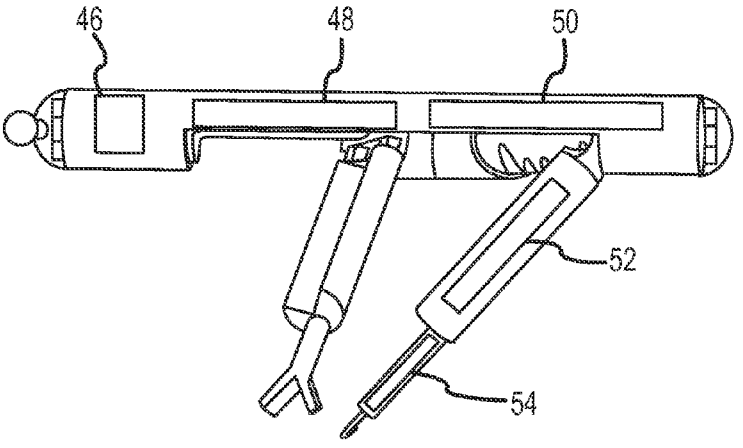


FIG.2B

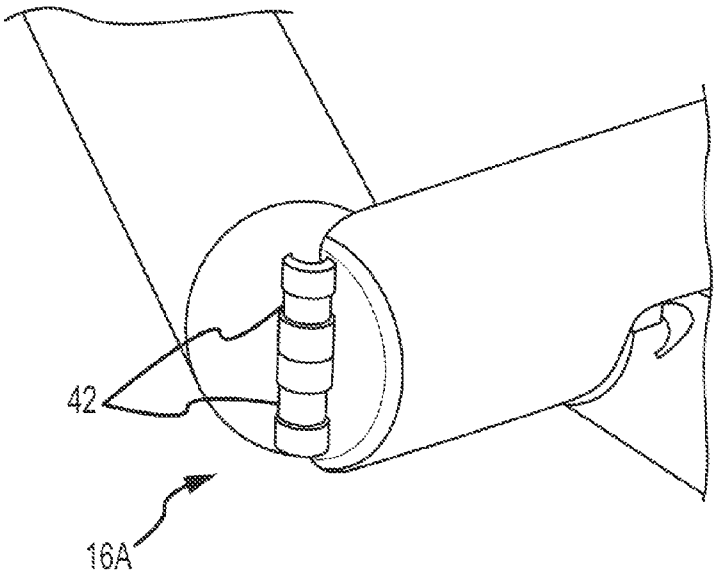


FIG.2C

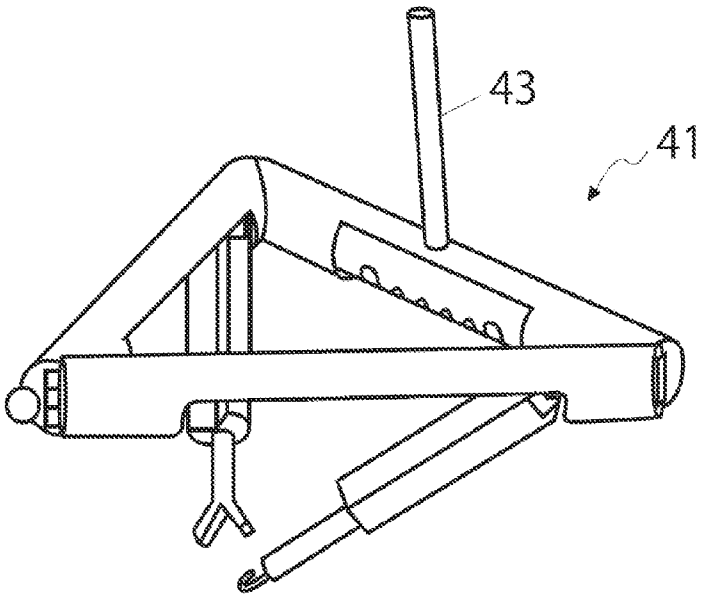


FIG. 2D

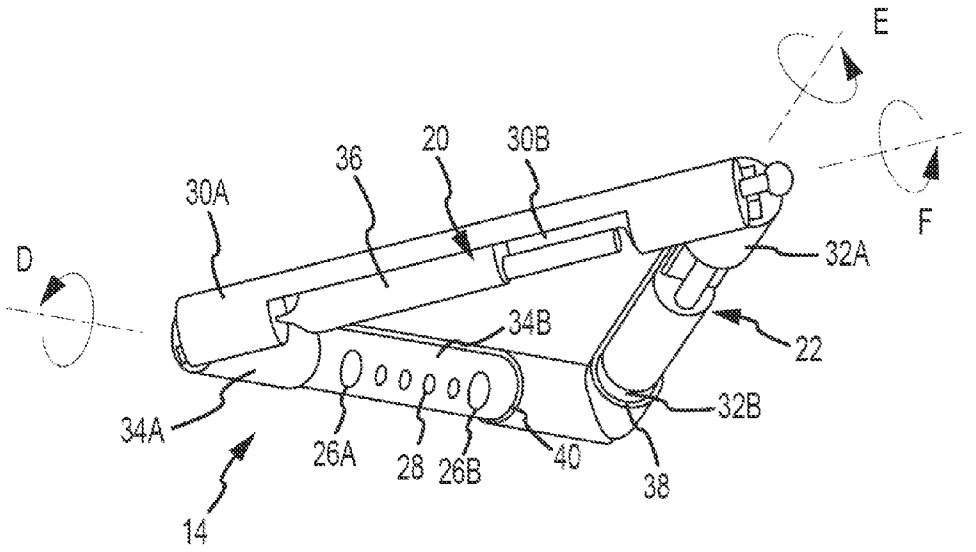


FIG.3

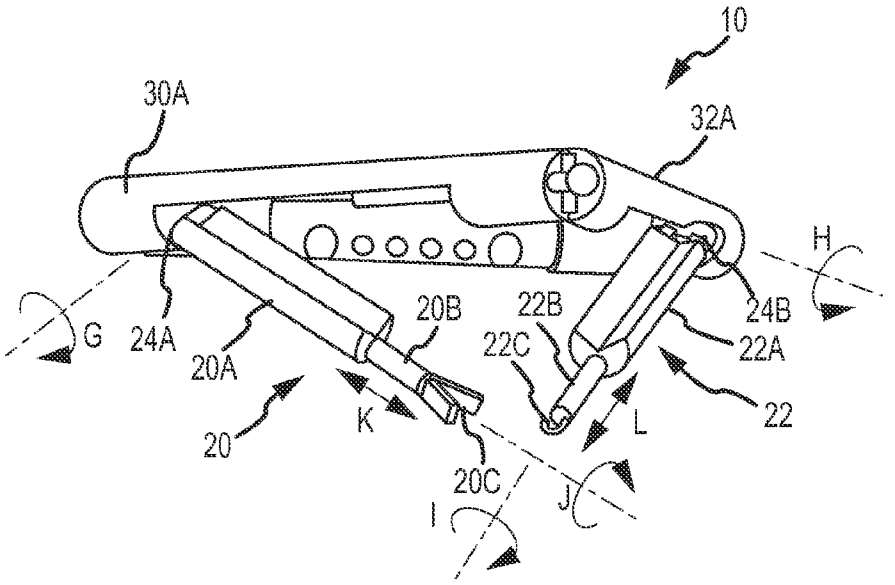
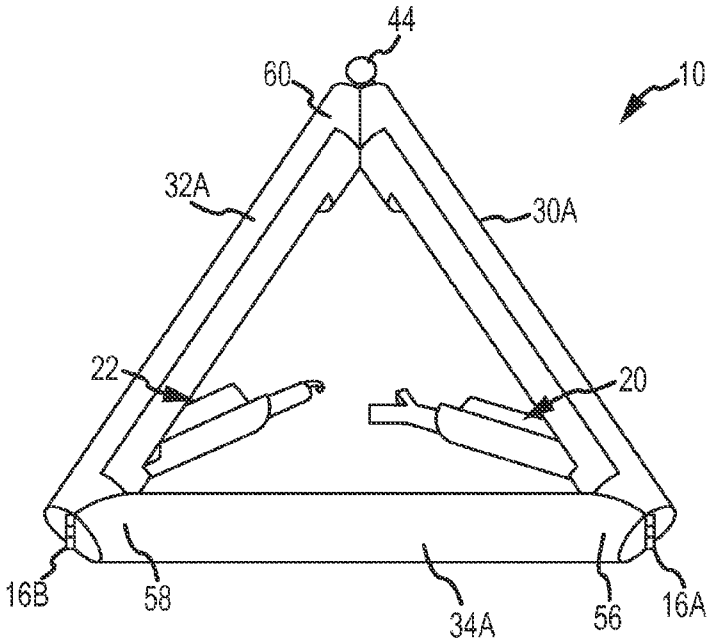

10
30A
32A
H
G
24A
20A
20B
22B
22C
24B
22A
22
20
K
L
20C
J
I

FIG.4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32A
30A
22
20
16B
58
34A
56
16A

FIG.5

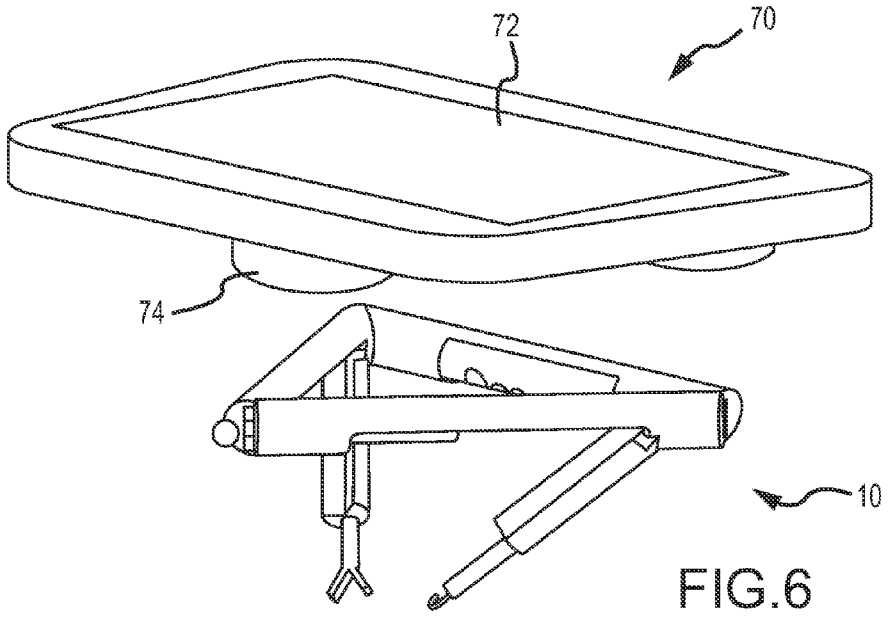


FIG.6

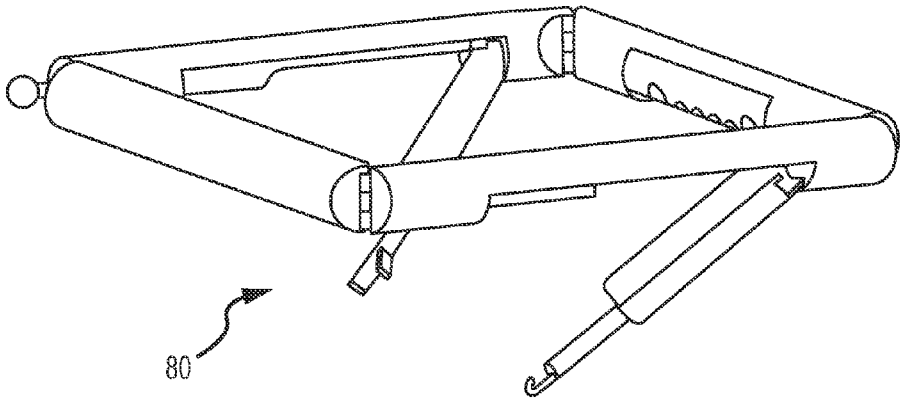


FIG.7

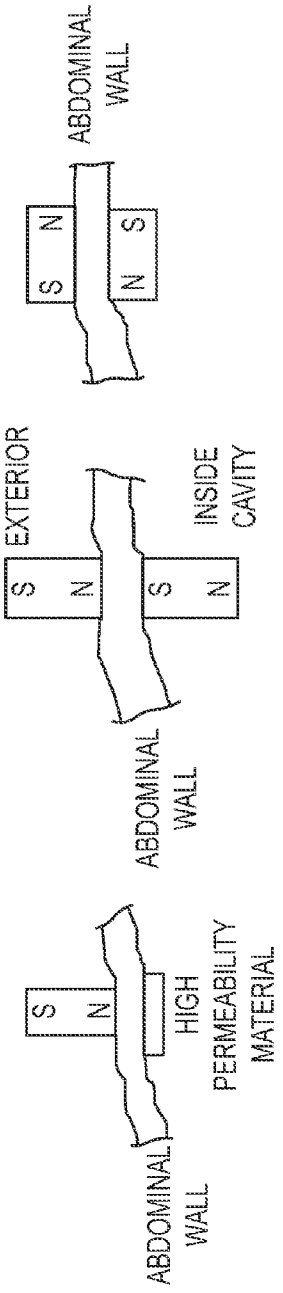
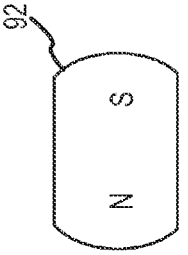


FIG.8A

FIG.8B

FIG.8C



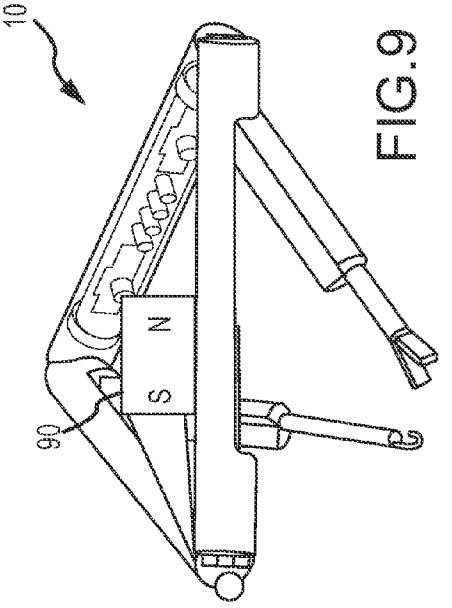


FIG.9

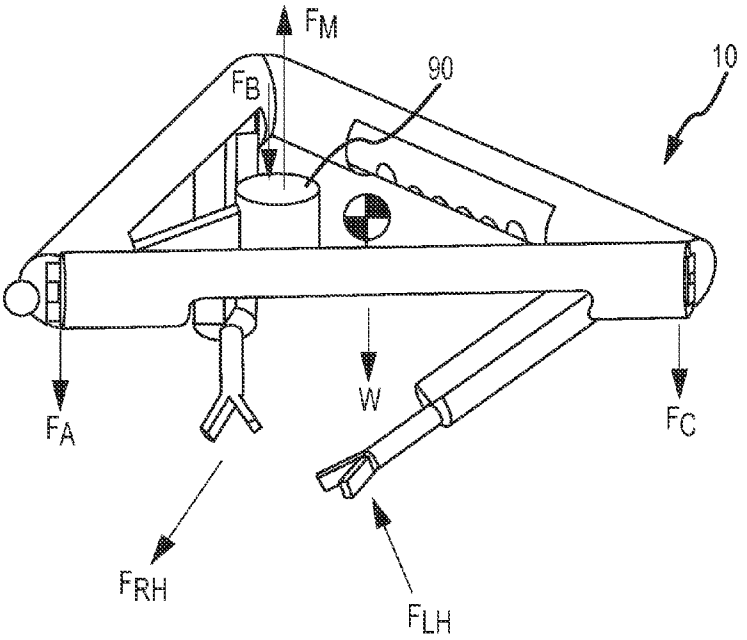


FIG.10

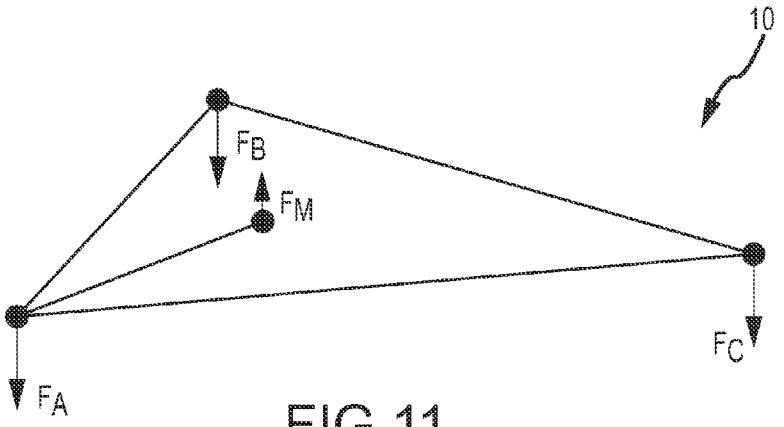
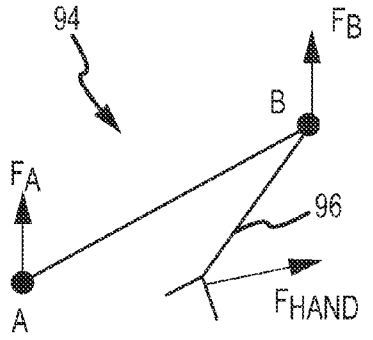
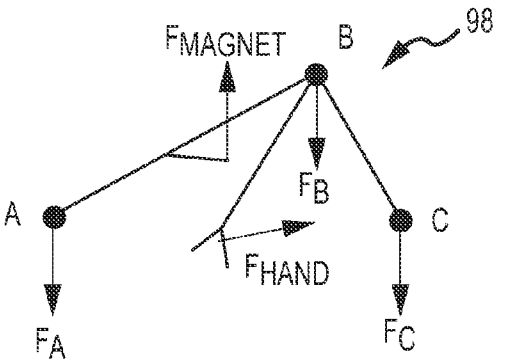


FIG.11



UNSTABLE

FIG.12A



STABLE

FIG.12B

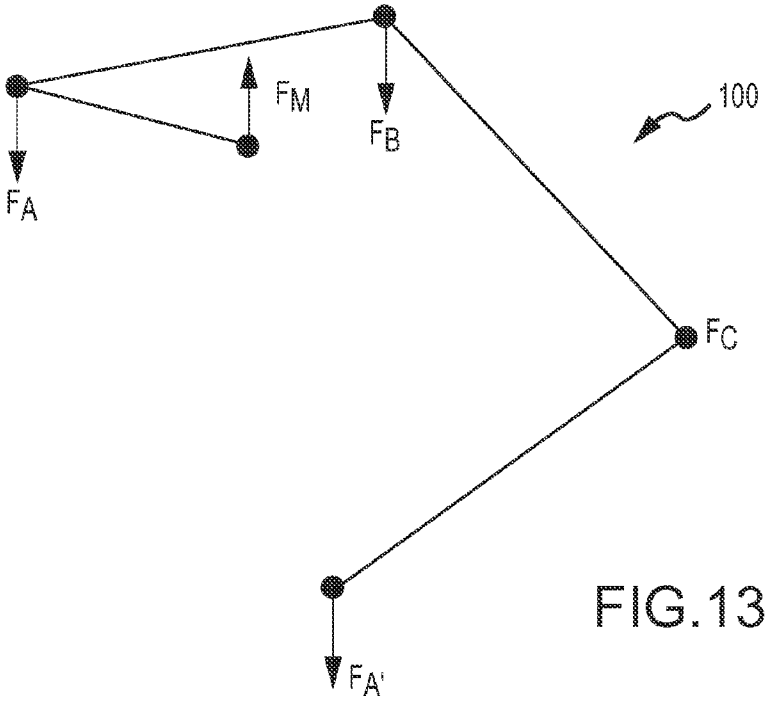


FIG.13

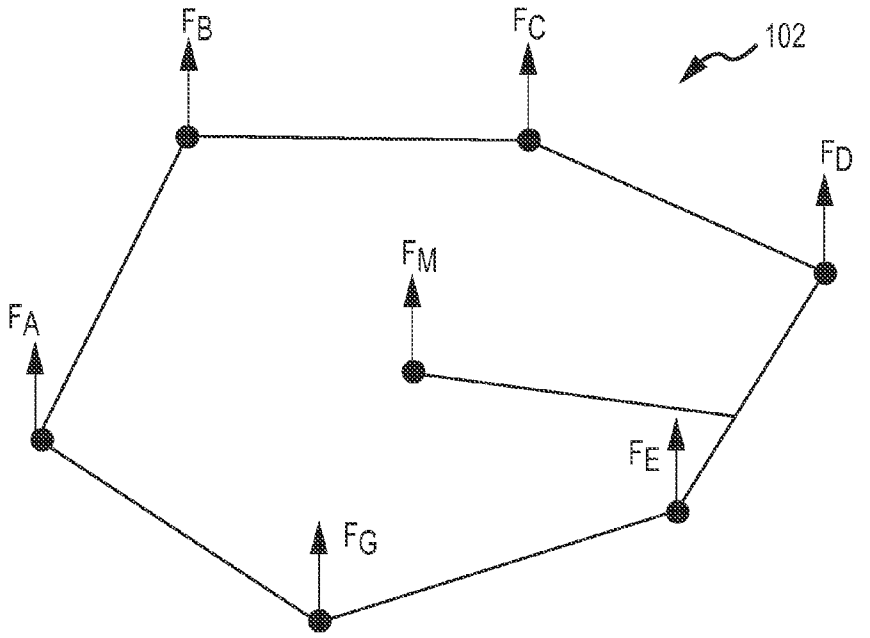


FIG.14

MODULAR AND COOPERATIVE MEDICAL DEVICES AND RELATED SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to Provisional Application No. 61/287,628, filed on Dec. 17, 2010, which is hereby incorporated herein by reference in it's entirety.

GOVERNMENT SUPPORT

This invention was made with government support under Grant No. R21EB5663-2, awarded by the National Institute of Biomedical Imaging and Bioengineering within the National Institutes of Health. Accordingly, the government has certain rights in the invention.

TECHNICAL FIELD

The embodiments disclosed herein relate to various medical devices and related components, including robotic and/or in vivo medical devices and related components. Certain embodiments include various modular medical devices, including modular in vivo and/or robotic devices. Other embodiments relate to modular medical devices in which the various modular components are segmented components or components that are coupled to each other. Further embodiment relate to methods of operating the above devices, including methods of using various of the devices cooperatively.

BACKGROUND

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures such as laparoscopy are preferred.

However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to 1) mobility restrictions resulting from using rigid tools inserted through access ports, and 2) limited visual feedback. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, Calif.) are also restricted by the access ports, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

There is a need in the art for improved surgical methods, systems, and devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective view of a modular medical device, according to another embodiment.

FIG. **1**B is a perspective bottom view of the device of FIG. **1**A.

FIG. **2**A is a perspective top view of the device of FIG. **1**A.

FIG. **2**B is a perspective side view of the device of FIG. **1**A.

FIG. **2**C is a perspective close-up view of a portion of the device of FIG. **1**A.

FIG. **2**D is a perspective view of another modular medical device, according to a further embodiment.

FIG. **3** is a perspective bottom view of the device of FIG. **1**A.

FIG. **4** is a perspective side view of the device of FIG. **1**A.

FIG. **5** is a top view of the device of FIG. **1**A.

FIG. **6** is a perspective view of modular medical device control and visualization system, according to one embodiment.

FIG. **7** is a perspective view of a modular medical device, according to one embodiment.

FIGS. **8**A-**8**C are schematic representations of various magnetic attachment mechanisms, according to various embodiments.

FIG. **9** is a perspective view of the device of FIG. **1**A.

FIG. **10** is a schematic representation of various forces associated with the device of FIG. **1**A, according to one embodiment.

FIG. **11** is a schematic representation of various forces associated with the device of FIG. **1**A, according to another embodiment.

FIG. **12**A is a schematic representation of various forces associated with a robotic device.

FIG. **12**B is a schematic representation of various forces associated with another robotic device, according to one embodiment.

FIG. **13** is a schematic representation of various forces associated with another robotic device, according to another embodiment.

FIG. **14** is a schematic representation of various forces associated with yet another robotic device, according to a further embodiment.

DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to various modular or combination medical devices, including modular in vivo and robotic devices and related methods and systems, while other embodiments relate to various cooperative medical devices, including cooperative in vivo and robotic devices and related methods and systems.

It is understood that the various embodiments of modular and cooperative devices and related methods and systems disclosed herein can be incorporated into or used with any other known medical devices, systems, and methods.

For example, the various embodiments disclosed herein may be incorporated into or used with any of the medical devices and systems disclosed in copending U.S. application Ser. No. 12/192,779 (filed on Aug. 15, 2008 and entitled "Modular and Cooperative Medical Devices and Related Systems and Methods"), Ser. No. 11/932,441 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/695,944 (filed on Apr. 3, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/947,097 (filed on Nov. 27, 2007 and entitled "Robotic Devices with Agent Delivery Components and Related Methods), Ser. No. 11/932,516 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/766,683 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Robotic Devices and Related Methods"), Ser. No. 11/766,720 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Surgical Robotic Devices and Related Methods"), Ser. No. 11/966,741 (filed on Dec. 28, 2007 and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation"), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled "Methods and Systems of Actuation in Robotic Devices"), 60/956,032 (filed on Aug. 15, 2007), 60/983,445 (filed on Oct. 29, 2007), 60/990,062 (filed on Nov. 26, 2007), 60/990,076 (filed on Nov. 26, 2007), 60/990,086 (filed on Nov. 26, 2007), 60/990,106 (filed on Nov. 26, 2007), 60/990,470 (filed on Nov. 27, 2007), 61/025,346 (filed on Feb. 1, 2008), 61/030,

588 (filed on Feb. 22, 2008), and 61/030,617 (filed on Feb. 22, 2008), all of which are hereby incorporated herein by reference in their entireties.

Certain device implementations disclosed in the applications listed above can be positioned within a body cavity of a patient, including certain devices that can be positioned against or substantially adjacent to an interior cavity wall, and related systems. An "in vivo device" as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned within a body cavity of a patient, including any device that is positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms "robot," and "robotic device" shall refer to any device that can perform a task either automatically or in response to a command.

Certain implementations disclosed herein relate to "combination" or "modular" medical devices that can be assembled in a variety of configurations. For purposes of this application, both "combination device" and "modular device" shall mean any medical device having modular or interchangeable components that can be arranged in a variety of different configurations. The modular components and combination devices disclosed herein also include segmented triangular or quadrangular-shaped combination devices. These devices, which are made up of modular components (also referred to herein as "segments") that are connected to create the triangular or quadrangular configuration, can provide leverage and/or stability during use while also providing for substantial payload space within the device that can be used for larger components or more operational components. As with the various combination devices disclosed and discussed above, according to one embodiment these triangular or quadrangular devices can be positioned inside the body cavity of a patient in the same fashion as those devices discussed and disclosed above.

FIGS. **1**A-**7** depict a multi-segmented medical device **10**, in accordance with one implementation. According to one embodiment, the device **10** is a robotic device **10** and further can be an in vivo device **10**. This device embodiment **10** as shown includes three segments **12**A, **12**B, **14**. Segments **12**A and **12**B are manipulator segments, while segment **14** is a command and imaging segment. Alternatively, the three segments can be any combination of segments with any combination of components and capabilities. For example, according to an alternative embodiment, the device could have one manipulator segment, one command and imaging segment, and a sensor segment. In a further alternative, the various segments can be any type of module, including any of those modules described above with respect to other modular components discussed herein.

As best shown in FIGS. **1**A and **1**B, segments **12**A, **12**B are rotatably coupled with the segment **14** via joints or hinges **16**A, **16**B. More specifically, segment **12**A is rotatable relative to segment **14** about joint **16**A around an axis as indicated by arrow B in FIG. **1**B, while segment **12**B is rotatable relative to segment **14** about joint **16**B around an axis as indicated by arrow C in FIG. **1**B.

In accordance with one embodiment, the device **10** has at least two configurations. One configuration is an extended or insertion configuration as shown in FIG. **1**A in which the three segments **12**A, **12**B, **14** are aligned along the same axis. The other configuration is a triangle configuration as shown in FIG. **1**B in which the manipulator segments **12**A, **12**B are each coupled to the segment **14** via the joints **16**A, **16**B and further are coupled to each other at a coupleable connection **18** at the ends of the segments **12**A, **12**B opposite the joints **16**A, **16**B.

As best shown in FIG. **2**A, each of the manipulator segments **12**A, **12**B in this particular embodiment has an operational arm **20**, **22** (respectively). Each arm **20**, **22** is moveably coupled to its respective segment **12**A, **12**B at a joint **24**A, **24**B (respectively) (as best shown in FIG. **4**). Further, segment **14** has a pair of imaging components (each also referred to herein as a "camera") **26**A, **26**B (as best shown in FIG. **3**).

In one embodiment, each arm **20**, **22** is configured to rotate at its joint **24**A, **24**B in relation to its segment **12**A, **12**B to move between an undeployed position in which it is disposed within its segment **12**A, **12**B as shown in FIG. **1**B and a deployed position as shown in FIG. **2**A. In one example, arm **20** is rotatable relative to segment **12**A about joint **24**A in the direction shown by G in FIG. **4**, while arm **22** is rotatable relative to segment **12**B about joint **24**B in the direction shown by H in FIG. **4**. Alternatively, the arms **20**, **22** are moveable in relation to the segments **12**A, **12**B in any known fashion and by any known mechanism.

According to one embodiment as best shown in FIG. **2**A, each arm **20**, **22** has three components: a proximal portion **20**A, **22**A, a distal portion **20**B, **22**B, and an operational component **20**C, **22**C coupled with the distal portion **20**B, **22**B, respectively. In this embodiment, the distal portion **20**B, **22**B of each arm **20**, **22** extends and retracts along the arm axis in relation to the proximal portion **20**A, **22**A while also rotating around that axis in relation to the proximal portion **20**A, **22**A. That is, distal portion **20**B of arm **20** can move back and forth laterally as shown by the letter K in FIG. **4** and further can rotate relative to the proximal portion **20**A as indicated by the letter J, while distal portion **22**B of arm **22** can move back and forth laterally as shown by the letter L in FIG. **4** and further can rotate relative to the proximal portion **22**A as indicated by the letter I.

In accordance with one implementation, the operational components **20**C, **22**C (also referred to herein as "end effectors") depicted in FIG. **2**A are a grasper **20**C and a cautery hook **22**C. It is understood that the operational component(s) used with the device **10** or any embodiment herein can be any known operational component for use with a medical device, including any of the operational components discussed above with other medical device embodiments and further including any operational components described in the applications incorporated above. Alternatively, only one of the two arms **20**, **22** has an operational component. In a further alternatively, neither arm has an operational component.

Alternatively, each arm **20**, **22** comprises one unitary component or more than two components. It is further understood that the arms **20**, **22** can be any kind of pivotal or moveable arm for use with a medical device which may or may not have operational components coupled or otherwise associated with them. For example, the arms **20**, **22** can have a structure or configuration similar to those additional arm embodiments discussed elsewhere herein or in any of the applications incorporated above. In a further alternative, the device **10** has only one arm. In a further alternative, the device **10** has no arms. In such alternative implementations, the segment(s) not having an arm can have other components associated with or coupled with the segment(s) such as sensors or other types of components that do not require an arm for operation.

As discussed above, the segment **14** of the embodiment depicted in FIG. **3** has a pair of cameras **26**A, **26**B. Alternatively, the segment **14** can have a single camera or more than two cameras. It is understood that any known imaging com-

ponent for medical devices, including in vivo devices, can be used with the devices disclosed herein and further can be positioned anywhere on any of the segments or on the arms of the devices.

In a further embodiment, the segment **14** as best shown in FIG. **3** can also include a lighting component **28**. In fact, the segment **14** has four lighting components **28**. Alternatively, the segment **14** can have any number of lighting components **28** or no lighting components. In a further alternative, the device **10** can have one or more lighting components positioned elsewhere on the device, such as one or both of segments **12**A, **12**B or one or more of the arms, etc.

In accordance with a further embodiment as best shown in FIGS. **1**B and **3**, each of the segments **12**A, **12**B, **14** has two cylindrical components—an outer cylindrical component and an inner cylindrical component—that are rotatable in relation to each other. More specifically, the segment **12**A has an outer cylindrical component **30**A and an inner cylindrical component **30**B that rotates relative to the outer component **30**A around an axis indicated by arrow F in FIG. **3**. Similarly, the segment **12**B has an outer cylindrical component **32**A and an inner cylindrical component **32**B that rotates relative to the outer component **32**A around an axis indicated by arrow E in FIG. **3**. Further, the segment **14** has an outer cylindrical component **34**A and an inner cylindrical component **34**B that rotates relative to the outer component **34**A around an axis indicated by arrow D in FIG. **3**.

In use, the embodiments having rotatable cylindrical components as described in the previous paragraph can provide for enclosing any arms, cameras, or any other operational components within any of the segments. Further, any segment having such rotatable components provide for two segment configurations: an open configuration and a closed configuration. More specifically, segment **12**A has an outer cylindrical component **30**A with an opening **36** as shown in FIG. **3** through which the arm **20** can move between its deployed and undeployed positions. Similarly, segment **12**B has an outer cylindrical component **32**A with an opening **38** as shown in FIG. **3** through which the arm **22** can move between its deployed and undeployed positions. Further, segment **14** has an outer cylindrical component **34**A with an opening **40** as shown in FIG. **3** through which the imaging component(s) **26**A, **26**B can capture images of a procedural or target area adjacent to or near the device **10**.

FIG. **1**B depicts the segments **12**A, **12**B, **14** in their closed configurations. That is, each of the inner cylindrical components **30**B, **32**B, **34**B are positioned in relation to the respective outer cylindrical component **30**A, **32**A, **34**A such that each opening **36**, **38**, **40**, respectively, is at least partially closed by the inner component **30**B, **32**B, **34**B such that the interior of each segment **12**A, **12**B, **14** is at least partially inaccessible from outside the segment.

More specifically, in the closed position, inner cylindrical component **30**B of segment **12**A is positioned in relation to outer cylindrical component **30**A such that the arm **20** is at least partially enclosed within the segment **12**A. According to one embodiment, the inner cylindrical component **30**B is configured such that when it is in the closed position as shown in FIG. **1**B, it closes off the opening **36** entirely. In a further embodiment, the inner cylindrical component **30**B in the closed position fluidically seals the interior of the segment **12**A from the exterior.

Similarly, in the closed position, inner cylindrical component **32**B of segment **12**B is positioned in relation to the outer cylindrical component **32**A such that the arm **22** is at least partially enclosed within the segment **12**B. According to one embodiment, the inner cylindrical component **32**B is configured such that when it is in the closed position as shown in FIG. **1**B, it closes off the opening **38** entirely. In a further embodiment, the inner cylindrical component **32**B in the closed position fluidically seals the interior of the segment **12**B from the exterior.

Further, in the closed position, inner cylindrical component **34**B of segment **14** is positioned in relation to the outer cylindrical component **34**A such that the imaging component(s) is not positioned within the opening **40**. According to one embodiment, the inner cylindrical component **34**B is configured such that when it is in the closed position as shown in FIG. **1**B, the imaging component(s) and any lighting component(s) are completely hidden from view and not exposed to the exterior of the segment **14**. In a further embodiment, the inner cylindrical component **34**B in the closed position fluidically seals the interior of the segment **14** from the exterior.

In contrast, FIGS. **2**A and **3** depict the segments **12**A, **12**B, **14** in their open configurations. In these configurations, each of the inner cylindrical components **30**B, **32**B, **34**B are positioned such that the openings **36**, **38**, **40** are open.

In use, according to one embodiment, the inner cylindrical components **30**B, **32**B, **34**B can thus be actuated to move between their closed and their open positions and thereby convert the device **10** between a closed or non-operational configuration (in which the operational components such as the arms **20**, **22** and/or the imaging components **26** and/or the lighting components **28** are inoperably disposed within the segments **12**A, **12**B, **14**) and an open or operational configuration (in which the operational components are accessible through the openings **36**, **38**, **40** and thus capable of operating). Thus, according to one implementation, the device **10** can be in its closed or non-operational configuration during insertion into a patient's body and/or to a target area and then can be converted into the open or operational configuration by causing the inner cylindrical components **30**B, **32**B, **34**B to rotate into the open configurations.

Alternatively, one or more or all of the segments do not have inner and outer components that rotate in relation to each other.

It is understood that the various embodiments of the device **10** disclosed herein include appropriate actuation components to generate the force necessary to operate the arms and/or the rotatable cylinders in the segments. In one embodiment, the actuation components are motors. For example, segment **12**A has a motor (not shown) operably coupled with the arm **20** and configured to power the movements of the arm **20**. Similarly, segment **12**B also has a motor (not shown) operably coupled with the arm **22** and configured to power the movements of the arm **20**. In further embodiments, each of the segments **12**A, **12**B, **14** also have motors (not shown) operably coupled to one or both of the inner and outer cylinder of each segment to power the rotation of the cylinders in relation to each other. In one embodiment, each segment can have one motor to power all drivable elements (arms, cylinders, etc.) associated with that segment. Alternatively, a separate motor can be provided for each drivable element.

In one embodiment, the joints **16**A, **16**B are configured to urge the segments **12**A, **12**B from the insertion configuration of FIG. **1**A into the triangular configuration of FIG. **1**B. That is, the joints **16**A, **16**B have torsion springs or some other known mechanism for urging the segments **12**A, **12**B to rotate around their joints **16**A, **16**B. For example, FIG. **2**C depicts one embodiment in which the joint **16**A has torsion springs **42** that are configured to urge segment **12**A toward the triangular configuration.

In use, in accordance with one implementation, the device **10** in the insertion configuration as shown in FIG. **1**A can be

inserted into a patient's body through an incision, a trocar port, or natural orifice in the direction indicated by arrow A. Alternatively, the device **10** can be inserted in the other direction as well. After insertion and/or as the device **10** enters the target area or procedural area in the patient's body, the joints **16**A, **16**B with the torsion springs (or other standard mechanisms) urge the segments **12**A, **12**B from their insertion position to their triangular position. As the segments **12**A, **12**B contact each other to form joint **18**, the two segments are coupled together with mating components that semi-lock the segments **12**A, **12**B together. That is, the two segments **12**A, **12**B can only be separated at the joint **18** by a force sufficient to overcome the semi-lock. Any such known mating component or coupling component, including any mechanical or magnetic mating component(s), can be incorporated into the device **10** for this purpose.

Thus, according to one embodiment, the device **10** can be in its insertion configuration during insertion into the patient. As the device **10** enters the target cavity and exits the port or incision, the torsion springs or other mechanisms at the joints **16**A, **16**B cause the two segments **12**A, **12**B to move toward each other until they couple to form the triangular configuration. The device **10** can then be attached to the abdominal wall by some method such as an external magnetic handle. Alternatively, the device **10** can be positioned anywhere in the cavity of the patient as desired by the user. The device **10** is then used to perform some sort of procedure.

Subsequently, when the procedure is complete, the device **10** can be retracted from the cavity. To do so, the surgeon uses a grasping or retrieval tool such as a Endo Babcock grasper made by Covidien in Mansfield, Mass., to attach to or otherwise grasp the ball **44** at the joint **18** and apply sufficient force to overcome the semi-lock of the joint **18**. Alternatively, any retrieval component can be positioned at the end of segment **12**A or elsewhere on the device **10** for grasping or otherwise coupling to for purposes of removing the device **10** from the patient's body. When the coupling of the semi-lock is overcome, the force urges the segments **12**A, **12**B away from each other, thereby making it possible for the surgeon to pull the ball **44** through a port or incision and out of the patient, thereby forcing the device **10** into its insertion configuration.

The multiple segments provided in the various embodiments of the device disclosed herein result in significantly more payload space than a single cylindrical body. The increased payload space results in increased capabilities for the device in the form of more, bigger, or more complex operational components, more, bigger, or more complex motors, magnets (as described below) and other similar benefits relating to the availability of more space for more, bigger, or more complex components. For example, FIG. **2**B depicts a side view of the device **10** according to one embodiment that shows the payload space available in segment **12**B. More specifically, segment **12**B and its coupled arm **22** have payload spaces **46**, **48**, **50**, **52**, **54** that can be used to accommodate motors, operational components, sensors, magnets (as described below) or any other type of component that could be useful for a procedural device. Similarly, each segment **12**A, **12**B, **14** can have such payload spaces. In addition, the segments **12**A, **12**B, **14** allow for maximization of the payload space available across the segments **12**A, **12**B, **14** by distributing the components such as motors, operational components, or magnets to maximize their effectiveness while minimizing the amount of space required by each such component. For example, it might maximize effectiveness of the device **10** while minimizing the utilized space to have one large motor in one segment that provides force for operation of components in more than one segment.

It is understood that various embodiments of the segmented devices disclosed herein are in vivo devices that can be inserted into and positioned within a patient's body to perform a procedure. In one embodiment, an external controller is also provided that transmits signals to the device **10** to control the device **10** and receives signals from the device **10**. In one embodiment, the controller communicates with the device **10** wirelessly. Alternatively, the controller and the device **10** are coupled via a flexible communication component such as a cord or wire (also referred to as a "tether") that extends between the device **10** and the controller.

It is also understood that various embodiments of the devices disclosed herein can be used in conjunction with known attachment components to attach or otherwise position the device near, against, or adjacent to an interior cavity wall inside the patient. In one embodiment, the attachment components are one or more magnets, disposed within the device, that communicate magnetically with one or more magnets positioned outside the patient's body. The device magnets can be positioned on or in the device in any suitable configuration. For example, the device magnets in one embodiment can be positioned within the segments **12**A, **12**B, **14** at positions **56**, **58**, **60** as shown in FIG. **5**. It is understood that the external magnets can be used outside the body to position and/or move the device **10** inside the body.

It is further understood that various embodiments of the devices disclosed herein can be used in conjunction with known visualization and control components, such as the console **70** depicted in FIG. **6**. The console **70** has a display **72** and magnets **74** and is positioned outside the patient such that the magnets **74** can be in magnetic communication with the device magnets (not shown) disposed within or otherwise coupled with the device **10**. The console **70** can be used to move the device **10** by moving the console **70** outside the body such that the device **10** is urged to move inside the body, because the console magnets **10** are magnetically coupled with the device magnets (not shown) within the device **10** such that the device **10** remains substantially fixed in relation to the console **70**. In addition, it is understood that the triangular (and quandrangular) devices disclosed and described in relation to FIGS. **1**A-**7** can be used in conjunction with any of the external controller or visualization components and systems disclosed and discussed above and in the applications incorporated above.

The segmented device **10**, according to one embodiment, provides greater stability and operability for the device **10** in comparison to other in vivo devices. That is, a device having more than one segment such as device **10** provides for a configuration with a larger "footprint" for the device **10**, thereby resulting in greater stability and leverage during use of the device **10**. For example, the device **10** with the triangular configuration in FIG. **6** that is urged against the interior cavity wall of the patient by the console magnets **74** has greater stability and leverage in comparison to a device that has a smaller "footprint." That is, the device **10** can have at least three magnets (not shown) disposed at the three corners of the triangular configuration such that when the device **10** is magnetically positioned against the interior cavity wall, the arms of the device **10** can apply greater force to the target tissues while maintaining the position of the device **10** than a corresponding single cylindrical device body.

It is understood that the device embodiments disclosed herein are not limited to a triangular configuration. FIG. **7** depicts a device **80** having a quadrangular configuration with four segments. Similarly, devices are contemplated herein having any number of segments ranging from two segments to any number of segments that can be used for a device that

can be positioned inside a patient's body. For example, a device incorporating the components and structures disclosed herein could have six or eight segments or more.

Several methods of attachment are possible for the triangle robot. A mechanical rod or elongate member having a cross-section of any shape or configuration could be used to support the robot. The elongate member could be rigid or flexible. One example of a rod **43** coupled to a robot **41** is depicted in FIG. **2**D, according to one embodiment. The robot could also be placed at the end of other instruments and manual tools as well as at the end of another robot.

In other embodiments, including some discussed above, the attachment mechanism includes magnets. Attaching the robot with magnets can be accomplished in many different ways; some are shown in FIGS. **8**A-**8**C. This can include a magnet external to the patient that is placed against the abdominal wall. This magnet then interacts with the robot to support the robot and hold it in place. The external magnet can interact with a high permeability material on the inside of the patient and attached to the robot as shown in FIG. **8**A. The roles could also be reversed and the high permeability material could also be external to the patient and the magnet could be internal.

The external magnet can also interact with a second magnet inside the patient and attached to the robot. This can be done so that opposite poles of the magnet attract using a single pole on each magnet (as shown in FIG. **8**B) or by using both poles on each magnet (as shown in FIG. **8**C).

The magnet (or high permeability material) associated with the robot does not even need to be attached to the robot. It only needs to interact in such a way as to create a force to stabilize the robot (this stability is described below). For example, when a piece of paper is attached to a refrigerator with a magnet, the magnet is not attached to the paper, but it does create a force that stabilizes the paper on the refrigerator. A similar approach could be used with the robot.

The methods of magnetic attachment described above can be used in many different combinations. For example, any number of magnets (0, 1, 2, 3, . . .) can be used to attach the robot. One obvious approach would be to place a magnet in each corner (or in each segment) of the triangle of the robot, with a trio of external magnets being used external to the patient. However, the triangle (or other open or closed polygons (from 2 sides on up)) is especially well suited to be supported by several different combinations of magnets. For example, a single magnet can be used inside the triangle since the shape of the triangle will provide multi axis support to react the force applied by this single magnet. This is further described in the next section. A "V" configuration or other polygon could give similar support.

Certain embodiments disclosed herein relate to maximization of stability of the various device embodiments while positioned inside the patient's body. Consider the triangle configuration of the in vivo robot **10** described above in detail and shown in FIG. **9**. This is one possible attachment method for the robot. Here a single magnet **90** is attached to the robot **10** so that it is attracted to a magnet **92** on the outside of the patient. The magnet **90** on the robot produces a force on the robot **10** in the upward direction.

A simplified Free Body Diagram (FBD) showing a simplified interpretation of the reaction forces is shown in FIG. **10**. Here, the magnet **90** produces an upward force on the body of the robot **10** (assumed rigid) F_m. The weight of the robot **10**, W, is also shown acting at the center of mass of the robot **10**. Each corner of the robot is labeled A, B, and C and reaction forces are shown at each corner (F_A, F_B, F_C). These reaction forces could occur along the length of each side in any distribution depending on the shape of the robot, stiffness of the abdominal wall, and other factors. However, for simplicity, these reaction forces are assumed to be lumped at each corner. Finally, end effector forces (F_{RH}, F_{LH}) are shown as the robot **10** applies forces to the tissue being manipulated during surgery. Also, any external applied moments or dynamic loads would also need to be included. This analysis could be extended to other robot configurations (e.g. a square robot with three manipulators), as will be described in further detail below.

The stability of the robot **10** in FIG. **10** created by the single magnet **90** can be determined using various mathematical techniques. One example of such techniques is set forth in Papadopoulos, E. and Rey, D., "A New Measure of Tipover Stability Margin for Mobile Manipulators," Proc. of the IEEE International Conference on Robotics and Automation, Minneapolis, Minn., April 1996 (which relates to the stability mathematics of large off-road vehicles). Similar techniques can be used to determine the stability of the robot **10**. The simplified version of this analysis is to take sum moments from all external forces (and moments) about each contact line for the robot. A first step in this example would be to sum the moments about the contact line AB (in FIG. **10**). If the resulting moment "pushes" the robot into the abdominal wall (such as would be caused by a large magnet force), the configuration is stable and the robot will not fall. If the resulting moment "peels" the robot away from the abdominal wall (such as would be caused by a small magnet force and a large robot weight), the robot would be unstable and would fall away from the abdominal wall. This would then need to be repeated for all contact lines (BC and CA in our example).

The above analysis shows that a single magnet can be used to hold the robot **10** in place.

A simplified example is shown in FIG. **11**. Here, the robot **10** is assumed mass-less and is not applying forces with its end effectors. It can be clearly seen that a large magnetic force, F_M, produces moment about the line AB that will cause the robot to rotate into the abdominal wall and therefore make a stable configuration for the robot. The same is true about lines BC and CA.

This example in FIG. **11** is further exemplified by the two possible configurations shown in FIGS. **12**A and **12**B. In this situation, the robot **94** in FIG. **12**A could be created by simply using one segment of the triangle configuration as shown back in FIG. **10** (with attachment magnets at A and B). In FIG. **12**A, there are two attachment points (A and B) that hold the robot **94** to the upper abdominal wall (one segment). When the robot's end effector (or hand) **96** applies a force in an arbitrary direction, there will be non-zero moments about the contact line AB. This will cause the robot **94** to rotate about the line AB and could result in some instability.

In contrast, FIG. **12** depicts a device **98** that contains additional structure as represented by point C. In this embodiment, hand forces (F_{Hand}) that produce a moment about the contact line AB can be balanced by a moment created by the reaction force at point C (F_C). Similarly, moments can be balanced and a stable configuration produced when other lines of contact are considered (BC & AC in this case, with other possibilities described below). Again, discrete points (A, B, & C) are described to simplify the description, but any line segment (AB for example) could be a continuous line of contact.

This stability based on one magnet can be recreated in several robot configurations. For example, FIG. **13** shows a configuration similar to FIG. **11**, but the "triangle" in FIG. **13** is in an "open" configuration **100** in which point A now becomes two points (A and A'). This configuration **100** will

also produce stability if the moments about all contact lines (AB, BC, CA' and A'A) "pushes" the robot into the abdominal wall rather than "peeling" it away.

FIG. **14** depicts another example of a multi-sided polygon **102** that uses a single magnet for stable attachment. The same analysis used above applies here and can be used to show that the robot **102** can be stable. In addition, the stability provided by a single magnet as described with the configurations discussed above can also occur for shapes other than polygons. For example, a "V" or "T" configuration could be used. The shapes could be open or closed.

It is understood that the concept of robot reaction forces (e.g. F_A, F_B, etc) occurring at a single point is an oversimplification for purposes of this discussion. These forces can occur at a continuum across any segment of any portion of the robot (or at discrete points).

In certain embodiments, different combinations of magnet "types" can also be used. For example, the robot could have a magnet at one corner of the robot and two pieces of high permeability material at the other two corners (or sides). Or the robot could have two magnets and one piece of high permeability material, or other combinations.

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

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

What is claimed is:

1. A segmented medical device, the system comprising:

(a) a first body segment configured to be disposed inside a cavity of a patient, the segment comprising
  (i) a first operational component associated with the first body segment; and
  (ii) a first mating component at a first end of the first body segment;

(b) a second body segment configured to be disposed inside the cavity of the patient, the segment comprising
  (i) a second operational component associated with the second body segment; and
  (ii) a first pivotal coupling at a first end of the second body segment, whereby the second body segment is pivotally coupled to a second end of the first body segment;

(c) a third body segment configured to be disposed inside the cavity of the patient, the segment comprising
  (i) a third operational component associated with the third body segment;
  (ii) a second pivotal coupling at a first end of the third body segment, whereby the third body segment is pivotally coupled to a second end of the second body segment; and
  (iii) a second mating component at a second end of the third body segment, the second mating component configured to be coupleable with the first mating component; and

(d) an attachment component associated with the segmented medical device, wherein the attachment component comprises a rod coupled to the segmented medical device, wherein the rod is configured to extend from the segmented medical device out of the cavity of the patient.

2. The segmented medical device of claim **1**, wherein the device is configured to move between an open position in which the first and second mating components are not coupled together and a closed position in which the first and second mating components are coupled.

3. The segmented medical device of claim **2**, wherein the first, second, and third body segments define an opening in the closed position.

4. The segmented medical device of claim **3**, wherein the attachment component is disposed in the opening.

5. The segmented medical device of claim **1**, wherein the first pivotal coupling and the second pivotal coupling comprise tensioned components configured to urge the first mating component and the second mating component toward each other.

6. The segmented medical device of claim **1**, wherein the first body segment comprises a first inner cylindrical component disposed within a first outer cylindrical component, wherein the first inner cylindrical component is rotatable in relation to the first outer cylindrical component.

7. The segmented medical device of claim **6**, wherein the first inner cylindrical component comprises a first inner opening and the first outer cylindrical component comprises a first outer opening, wherein the first inner cylindrical component and the first outer cylindrical component are rotatable such that the first inner opening and first outer opening align, thereby providing access to an interior portion of the first inner cylindrical component.

8. The segmented medical device of claim **7**, wherein the first operational component is configured to move between an undeployed position disposed within the interior portion of the first inner cylindrical component and a deployed position in which a portion of the first operational component is disposed outside of the first inner cylindrical component through the first inner opening and first outer opening.

9. A segmented medical device, the system comprising:

(a) a first body segment configured to be disposed inside a cavity of a patient, the segment comprising
  (i) a first operational component associated with the first body segment; and
  (ii) a first mating component at a first end of the first body segment;

(b) a second body segment configured to be disposed inside the cavity of the patient, the segment comprising
  (i) a second operational component associated with the second body segment; and
  (ii) a first pivotal coupling at a first end of the second body segment, whereby the second body segment is pivotally coupled to a second end of the first body segment;

(c) a third body segment configured to be disposed inside the cavity of the patient, the segment comprising
  (i) a third operational component associated with the third body segment;
  (ii) a second pivotal coupling at a first end of the third body segment, whereby the third body segment is pivotally coupled to a second end of the second body segment; and
  (iii) a second mating component at a second end of the third body segment, the second mating component configured to be coupleable with the first mating component; and

(d) an attachment component disposed in a substantially central location when the segmented medical device is in

a closed configuration in which the first and second mating components are coupled,

wherein the segmented medical device is configured to move between the closed configuration and an open configuration in which the first and second mating components are not coupled together.

10. The segmented medical device of claim **2**, wherein the first, second, and third body segments define an opening in the closed position, wherein the attachment component is disposed in the substantially central location in the opening.

11. The segmented medical device of claim **9**, wherein the attachment component comprises a single magnet disposed in a substantially central location when the segmented medical device is in a closed configuration.

12. The segmented medical device of claim **1**, wherein

(a) the first body segment comprises a first inner cylindrical component disposed within a first outer cylindrical component, wherein the first inner cylindrical component is rotatable in relation to the first outer cylindrical component;

(b) the second body segment comprises a second inner cylindrical component disposed within a second outer cylindrical component, wherein the second inner cylindrical component is rotatable in relation to the second outer cylindrical component; and

(c) the third body segment comprises a third inner cylindrical component disposed within a third outer cylindrical component, wherein the third inner cylindrical component is rotatable in relation to the third outer cylindrical component.

13. The segmented medical device of claim **12**, wherein

(a) the first inner cylindrical component comprises a first inner opening and the first outer cylindrical component comprises a first outer opening, wherein the first inner cylindrical component and the first outer cylindrical component are rotatable such that the first inner opening and first outer opening align, thereby providing access to an interior portion of the first inner cylindrical component;

(b) the second outer cylindrical component comprises a second outer opening, wherein the second inner cylindrical component and the second outer cylindrical component are rotatable such that the second operational component is accessible through the second outer opening; and

(c) the third inner cylindrical component comprises a third inner opening and the third outer cylindrical component comprises a third outer opening, wherein the third inner cylindrical component and the third outer cylindrical component are rotatable such that the third inner opening and third outer opening align, thereby providing access to an interior portion of the third inner cylindrical component.

14. The segmented medical device of claim **13**, wherein

(a) the first operational component is configured to move between an undeployed position disposed within the interior portion of the first inner cylindrical component and a deployed position in which a portion of the first operational component is disposed outside of the first inner cylindrical component through the first inner opening and first outer opening; and

(b) the third operational component is configured to move between an undeployed position disposed within the interior portion of the third inner cylindrical component and a deployed position in which a portion of the third operational component is disposed outside of the third inner cylindrical component through the third inner opening and third outer opening.

15. The segmented device of claim **14**, wherein the first operational component comprises a grasper and the second operational component comprises a cautery hook.

16. The segmented device of claim **1**, wherein the second operational component comprises at least one camera or at least one light.

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