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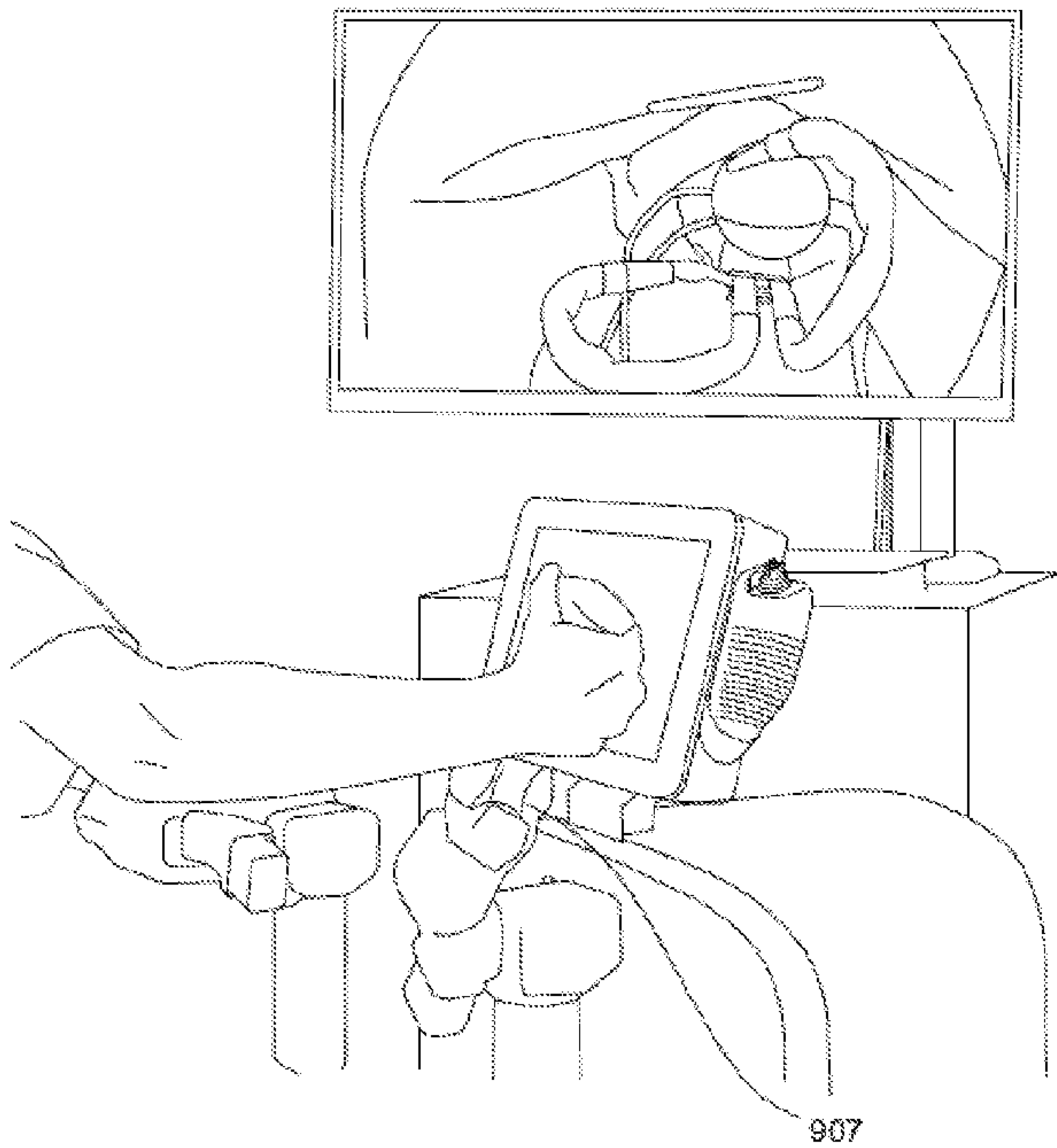


FIG. 14D

(57) Abstract: A surgical system, comprising an articulated mechanical arm with a plurality of arm joints, first and second user-input devices for controlling the arm, and a surgical end effector at the distal end of the arm, is operated initially in a retroflexing mode with the first user-input device is active to direct flexion and rotation of only a single given arm joints, and with the second user-input device is disabled. While in the retroflexing mode, a distal portion of the arm is retroflected by flexion and rotation of the single given arm joint. With the arm retroflected, the system is transitioned to surgical-operation mode which enables the second user-input device to flex and rotate any or all of the arm joints, to move the surgical end-effector to perform one or more surgical actions.

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DUAL CONTROL OF A MECHANICAL SURGICAL ARM

CROSS-REFERENCE TO RELATED APPLICATIONS

This invention claims the benefit of U.S. Provisional Patent Application No.
5 62/944,351 filed on December 5, 2019, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to surgical systems used in performing surgery, and
10 methods for using such systems, and particularly to controlling the bending and rotating of portions of articulated mechanical arms using multiple operating modes and input devices.

BACKGROUND

This section is intended to introduce the reader to various aspects of art that may be
15 related to various aspects of the present invention, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

20 It is well established that there are benefits of minimally invasive surgery. Instruments for such surgery typically have a surgical end effector located at the distal end of an articulated surgical arm (preferably with minimum diameter) that is inserted through a small opening (e.g., body wall incision, natural orifice) to reach a surgical site. In some instances, surgical instruments can be passed through a cannula and an endoscope can be
25 used to provide images of the surgical site.

Surgical instruments have been developed that utilize an end effector (e.g., a surgical tool such as for tissue fusing or cutting, or a measurement tool) for convenience,

accuracy, and wellbeing of the subject. In some cases, articulated surgical arms have one or more bending portions which are controlled remotely using various input devices (e.g., hand and foot controls) to ultimately control the location of the end effector and change its orientation with reference to the surgical arm's longitudinal axis. In some case, the surgical arm is capable of retroflected bending relative to the surgical arm longitudinal axis.

Clinical studies have demonstrated that the minimally invasive transvaginal approach to gynecological surgery is superior compared to the abdominal approach. Advantages include post-surgical recovery time, morbidity, infections, death rate, complications, blood loss and patient satisfaction. To this day, the policy of American College of Gynecology (ACOG) states that vaginal approaches to gynecological surgery are preferred whenever feasible. To enable a medical device entering trans-vaginally to perform gynecological surgery, articulated surgical arms are required to bend into a retroflected position.

The current state of the art is lacking devices and methods that can provide optimal control elements and methods of use to ensure that a preliminary retroflecting step is performed in a de-risked approach that does not affect the ergonomic comfort and convenience afforded by an input device optimized for arduous surgical procedures. Thus, there is a need for solutions which are suitable for restricting risk during retroflecting of surgical arms and provide maximal freedom of movement during surgical procedures while not impacting surgeon ergonomics.

SUMMARY OF THE INVENTION

A method is disclosed, according to embodiments, for operating a surgical system comprising (i) an articulated mechanical arm comprising a plurality of arm joints, and (ii) first and second user-input devices for controlling the arm, and (iii) a surgical end effector at the distal end of the arm. The method comprises: (a) commencing operation of the surgical system in a retroflexing mode wherein, with respect to flexing and rotation of the arm joints: (i) the first user-input device is active to direct flexion and rotation of only a given one of the arm joints, and (ii) the second user-input device is disabled; (b) while

in the retroflexing mode, retroflecting a distal portion of the articulated mechanical arm by flexion and rotation of the given one of the arm joints, responsive to electronic control-output from the first user-input device so as to bring the end effector to a retroflex operating position; (c) transitioning the surgical system from the retroflexing mode to a surgical-operation mode to enable the second user-input device with respect to flexing and rotating at least one of the arm joints of the arm other than the given one of the arm joints; and (d) while in the surgical-operation mode, effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the second user-input device, to thereby move the surgical end-effector to perform one or more surgical actions.

In some embodiments, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the single arm joint.

In some embodiments, the transitioning can include calibrating the input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, it can be that the first input device is configured for controlling actuation of the single arm joint and/or is not configured for controlling actuation of arm joints other than the single arm joint.

In some embodiments, the transitioning to the surgical-operation mode can be in response to and/or contingent upon detecting that the arm is in a retroflex position.

A surgical system according to embodiments comprises: (a) an articulated mechanical arm comprising a plurality of arm joints, and a surgical end effector at a distal end of the arm; and (b) first and second user-input devices for controlling the arm, wherein the surgical system is configured to operate, asynchronously, in (i) a retroflex mode in which a distal portion of the articulated mechanical arm is operative to be retroflected, responsive to electronic control-output from the first user-input device, so as to bring the end effector to a retroflex operating position, and in (ii) a surgical-operation mode in which at least two of the arm joints are operative to be flexed and rotated,

responsive to electronic control-output from the second user-input device, so as to thereby move the surgical end-effector to perform one or more surgical actions, such that: (A) while in the retroflexing mode, with respect to flexing and rotation of the arm joints, the first user-input device is active to direct flexion and rotation of only a given one of the arm joints, and the second user-input device is disabled, and (B) while in the surgical-operation mode, the second user-input device is enabled with respect to flexion and rotation of at least one of the arm joints of the arm other than the given one of the arm joints, in accordance with respective degrees of freedom of each arm joint.

10 In some embodiments, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the single arm joint.

In some embodiments, the surgical system can be configured such that transitioning includes calibrating the input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

15 In some embodiments, it can be that the first input device is configured for controlling actuation of the single arm joint and/or is not configured for controlling actuation of arm joints other than the single arm joint.

In some embodiments, the surgical system can be configured such that the transitioning to the surgical-operation mode can be in response to and/or contingent upon detecting that the arm is in a retroflex position.

20 A method is disclosed, according to embodiments, of operating a surgical system. According to the method, the surgical system comprises (i) a user-input device, and (ii) an articulated mechanical arm comprising a plurality of arm joints, and surgical end effector at a distal end of the arm. The method comprises: (a) commencing operation of the surgical system in a retroflexing mode wherein, with respect to flexing and rotation of the arm joints, the user-input device is active to direct flexion and rotation of only a given one of the arm joints; (b) while in the retroflexing mode, retroflexing a distal portion of the articulated mechanical arm by flexion and rotation of the given one of the arm joints, responsive to electronic control-output from the user-input device, so as to bring the end

effector to a retroflex operating position; (c) transitioning the surgical system from the retroflex mode to the surgical-operation mode to enable the user-input device with respect to flexing and rotating at least one of the arm joints of the arm other than the given one of the arm joints; and (d) while in the surgical-operation mode, effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the user-input device, to thereby move the surgical end-effector to perform one or more surgical actions.

In some embodiments of the method, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the given one of the arm joints. In some such embodiments, the restricting can be by disabling actuation of arm joints of the arm other than the given one of the arm joints.

In some embodiments, the user-input device can control the actuation of the plurality of arm joints in both the retroflexing mode and the surgical-operation mode.

In some embodiments, the user-input device can be precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other than the given one of the arm joints.

In some embodiments, the transitioning to the surgical-operation mode can be in response to and/or contingent upon detecting that the arm is in a retroflex position.

In some embodiments, the transitioning can include calibrating the user-input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, the method can additionally comprise, following the operating in the second mode, unflexing the distal end of the arm, so as to bring the arm to an unflexed position.

A surgical system is disclosed according to embodiments, comprising: (a) a user-input device; and (b) an articulated mechanical arm comprising (i) a plurality of arm joints and (ii) a surgical end effector at a distal end of the arm, wherein the surgical

system is configured to operate, asynchronously, in (A) a retroflexing mode in which a distal portion of the articulated mechanical arm is retroflected, responsive to electronic control-output from the user-input device, so as to bring the end effector to a retroflex operating position, and in (B) a surgical-operation mode in which at least two of the arm joints are flexed and rotated, responsive to electronic control-output from the user-input device, so as to thereby move the surgical end-effector to perform one or more surgical actions, such that (A) while in the retroflexing mode, with respect to flexing and rotation of the arm joints, the user-input device is active to direct flexion and rotation of only a given one of the arm joints, and (B) while in the surgical-operation mode, the user-input device is enabled with respect to flexion and rotation at least one of the arm joints of the arm other than the given one of the arm joints, in accordance with respective degrees of freedom of each arm joint.

In some embodiments, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the given one of the arm joints. In some such embodiments, the restricting can be by disabling actuation of arm joints of the arm other than the given one of the arm joints.

In some embodiments, the user-input device can be effective to control the actuation of the plurality of arm joints in both the retroflexing mode and the surgical-operation mode.

In some embodiments, the surgical system can be configured such that the user-input device can be precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other than the given one of the arm joints.

In some embodiments, the surgical system can be configured such that the transitioning to the surgical-operation mode can be in response to and/or contingent upon detecting that the arm is in a retroflex position.

In some embodiments, the surgical system can be configured such that the transitioning can include calibrating the user-input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, the surgical system can be additionally configured to effect unflexing the distal end of the arm, following the operating in the second mode, so as to bring the arm to an unflexed position.

A method is disclosed, according to embodiments, of operating a surgical system comprising (i) an articulated mechanical arm comprising a surgical end effector at a distal end thereof and a plurality of arm joints and (ii) an input-device array of one or more user-input devices, wherein the arm joints are configured to flex and rotate in response to an electronic control-output from one or more user-input devices of the input-device array. The method comprises: (a) commencing operation of the surgical system in a first operating mode defined with respect to a given single one of the arm joints, wherein the first operating mode precludes actuation of any arm joint of the arm that is not the given single arm joint, and permits controlling the actuation of the single arm joint to cause a flexion of and a rotation of the single arm joint; (b) while the surgical system is in the first operating mode, (i) retroflexing the distal end of the arm by flexion and rotation of the single arm joint, in response to control signals generated by one or more of the user-input devices of the input-device array, so as to bring the end effector to a retroflex operating position, and (ii) monitoring a status of the mechanical arm to detect whether or not the arm is in a retroflex position. The method additionally comprises: (c) in response to and contingent upon detecting that the arm is in a retroflex position, transitioning operation of the surgical system from the first operating mode to a second operating mode in which the system is enabled to control flexing and rotating of at least one first-mode-precluded arm joint in accordance with respective degrees of freedom of each arm joint; and (d) operating the surgical system in the second operating mode so as to perform a surgical action using the end effector.

In some embodiments, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the first operating mode, to restrict the actuation of arm joints other than the single arm joint. In some such methods, the restricting can be by disabling actuation of arm joints of the arm other the single arm joint. In some such embodiments, the input device can be precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other

than the single arm joint. In some such embodiments, the restricting can include disabling a capability of the first input device. In some such embodiments, it can be that (i) a first input device of the input-device array controls actuation of the single arm joint while the surgical system is in the first operating mode, and a second input device controls
5 actuation of the plurality of arm joints while the surgical system is in the second operating mode and/or (ii) the restricting is by providing a first input device that is configured for controlling actuation of the single arm joint and that is not configured for controlling actuation of arm joints other than the single arm joint.

10 In some embodiments, the transitioning can include calibrating the input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, it can be that a first input device of the input-device array controls actuation of the single arm joint while the surgical system is in the first operating mode, and/or that a second input device of the input-device array controls actuation of the
15 plurality of arm joints while the surgical system is in the second operating mode.

In some embodiments, the transitioning can include calibrating the second input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

20 In some embodiments, a single user-input device can control the actuation of the plurality of arm joints in both the first operating mode and the second operating mode.

In some embodiments of the method, the surgical system can additionally comprise a control console including a display screen, and at least one user-input device of the input-device array is disposed on or in proximity to the display screen.

25 In some embodiments, an additional user-input device for actuating linear advancement and retraction of the arm can be disposed upon, co-located with, or in proximity to, at least one user-input device of the input-device array.

In some embodiments, the retroflex operating position can be at, or in proximity to, a surgical worksite.

In some embodiments, the operating in the second mode can be with the arm in the retroflex position.

In some embodiments, the method can additionally comprise, following the operating in the second mode: unflexing the distal end of the arm, so as to bring the arm
5 to an unflexed position.

According to embodiments, a surgical system for use with a surgical end effector and configured to operate, asynchronously, in a first operating mode and a second operating mode, comprises: (a) an input-device array of one or more user-input devices; and (b) an articulated mechanical arm comprising a surgical end effector at the distal end
10 thereof, and a plurality of arm joints configured to flex and rotate in response to a control signal generated by one or more input devices of the input-device array, wherein: (i) the first operating mode is defined with respect to a given single one of the arm joints, wherein the first operating mode precludes actuation of any arm joint of the arm that is not the given single arm joint, and permits controlling the actuation of the single arm
15 joint to cause a flexion and a rotation of the single arm joint, (ii) the system is configured to retroflex the distal end of the arm while in the first operating mode by actuating the single arm joint to cause a flexion of and a rotation of the single arm joint, in response to an electronic control-output from one or more of the user-input devices of the input-device array, so as to bring the surgical end effector to a retroflex operating position, (iii)
20 the second operating mode is defined with respect to the plurality of arm joints, wherein the second operating mode enables controlling the actuation of at least one of the first-mode-precluded arm joints in accordance with respective degrees of freedom of each arm joint, and (iv) the system is configured to transition from the first operating mode to the second operating mode in response to and contingent upon a detection that the arm is in a
25 retroflex position, and, while in the second operating mode, perform a surgical action using the end effector.

In some embodiments, the surgical system can additionally comprise control circuitry effective, while the surgical system is in the first operating mode, to restrict the actuation of arm joints other than the single arm joint. In some such embodiments, the
30 restricting can be by disabling actuation of arm joints of the arm other than the single arm

joint. In some such embodiments, the input device can be precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other than the single arm joint. In some such embodiments, the restricting can include disabling a capability of the first input device. In some such embodiments, it can be that (i) a first
5 input device of the input-device array controls actuation of the single arm joint while the surgical system is in the first operating mode, and a second input device controls actuation of the plurality of arm joints while the surgical system is in the second operating mode and/or (ii) the restricting is by providing a first input device that is configured for controlling actuation of the single arm joint and that is not configured for
10 controlling actuation of arm joints other than the single arm joint.

In some embodiments, the system can be configured such that the transitioning can include calibrating the input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, it can be that a first input device of the input-device array
15 is effective to control actuation of the single arm joint while the surgical system is in the first operating mode, and/or that a second input device of the input-device array is effective to control actuation of the plurality of arm joints while the surgical system is in the second operating mode.

In some embodiments, the system can be configured such that the transitioning
20 can include calibrating the second input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.

In some embodiments, a single user-input device can be effective to control the actuation of the plurality of arm joints in both the first operating mode and the second operating mode.

25 In some embodiments, the surgical system can additionally comprise a control console including a display screen, and at least one user-input device of the input-device array is disposed on or in proximity to the display screen.

In some embodiments, an additional user-input device for actuating linear advancement and retraction of the arm can be disposed upon, co-located with, or in proximity to, at least one user-input device of the input-device array.

5 In some embodiments, the retroflex operating position can be at, or in proximity to, a surgical worksite.

In some embodiments, the operating in the second mode can be with the arm in the retroflex position.

10 In some embodiments, the surgical system can be additionally configured to effect unflexing the distal end of the arm, following the operating in the second mode, so as to bring the arm to an unflexed position. A method is disclosed, according to embodiments, of operating a surgical system that comprises (i) an articulated mechanical arm comprising a plurality of arm joints, and a surgical end effector at a distal end of the arm, and (ii) an input-device array of one or more user-input devices for controlling the arm. The method comprises: (a) retroflexing a distal portion of the articulated mechanical arm
15 by flexion and rotation of a given one of arm joints, responsive to electronic control-output from the input-device array, so as to bring the end effector to a retroflex operating position without flexing or rotating any of the arm joints other than the given one of the arm joints; and (b) in response to and contingent upon detecting that the arm is in a retroflex position, effect flexing and rotating of at least two of the arm joints in
20 accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the input-device array, to thereby move the surgical end-effector to perform one or more surgical actions.

In some embodiments of the method, the surgical system can additionally comprise control circuitry effective to restrict the actuation of arm joints other than the
25 given one of the arm joints during the retroflexing.

In some embodiments, the method can additionally comprise, following the performing the one or more surgical actions, unflexing the distal end of the arm, so as to bring the arm to an unflexed position.

According to embodiments, a surgical system comprises: (a) an articulated mechanical arm comprising (i) a plurality of arm joints and (ii) a surgical end effector at a distal end of the arm, and (b) an input-device array of one or more user-input devices for controlling the arm, wherein the surgical system is configured: (i) to retroflect a distal portion of the articulated mechanical arm by flexion and rotation of a given one of arm joints, responsive to electronic control-output from the input-device array, so as to bring the end effector to a retroflex operating position without flexing or rotating any of the arm joints other than the given one of the arm joints, and (ii) to effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint in response to and contingent upon detecting that the arm is in a retroflex position, and responsively to electronic control-output from the input-device array, to thereby move the surgical end-effector to perform one or more surgical actions.

In some embodiments, the surgical system can additionally comprise control circuitry effective to restrict the actuation of arm joints other than the given one of the arm joints during the retroflexing.

In some embodiments of the method, the surgical system can additionally comprise control circuitry effective to restrict the actuation of arm joints other than the given one of the arm joints during the retroflexing.

In some embodiments, the method can additionally comprise, following the performing the one or more surgical actions, unflexing the distal end of the arm, so as to bring the arm to an unflexed position.

A method is disclosed, according to embodiments, of using a surgical system. The method comprises: (a) providing an articulated mechanical arm having a surgical end effector at a distal end thereof, the arm comprising a plurality of arm segments connected serially by a corresponding plurality of arm joints configured to flex and rotate in response to an electronic control-output from a user-input device, wherein the providing is such that the end effector is displaced; (b) maneuvering the end effector to a retroflex operating position while operating in a first input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a speed of at least one of (i) a flexion of an arm joint and (ii) a rotation of an arm joint; (c) in response to and

contingent upon detecting that the end effector is in the retroflex operating position, transitioning from operating in the first input mode to operating in a second input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a corresponding displacement of at least one arm segment; and (d) after the
5 transitioning and while operating in the second input mode, performing a surgical action using the end effector.

In some embodiments, a single user-input device can be used in both the first input mode and the second input mode.

In some embodiments, it can be that a first input device is used in the first input
10 mode, and/or that a second input device is used in the second input mode.

In some embodiments, an additional user-input device can be used for actuating linear advancement and retraction of the arm.

In some embodiments, the retroflex operating position can be at, or in proximity to, a surgical worksite.

15 According to embodiments, a surgical system for use with a surgical end effector comprises: (a) an articulated mechanical arm having a surgical end effector at a distal end thereof, the arm comprising a plurality of arm segments connected serially by a corresponding plurality of arm joints configured to flex and rotate in response to an electronic control-output from a user-input device; and (b) an array of one or more input
20 devices for controlling the arm, wherein the surgical system is configured: (i) to operate, asynchronously, in (A) a first input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a speed of a flexion and of a rotation of an arm joint, and in (B) a second input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a corresponding displacement of at
25 least one arm segment; (ii) while operating in the first input mode, to maneuver the end effector to a retroflex operating position during a first stage in which the end effector is displaced; and (iii) while operating in the second input mode, to perform a surgical action using the end effector.

In some embodiments, the system can be configured such that a single user-input device can be used in both the first input mode and the second input mode.

In some embodiments, the system can be configured such that a first input device is used in the first input mode, and/or that a second input device is used in the second
5 input mode.

In some embodiments, the system can be configured such that an additional user-input device can be used for actuating linear advancement and retraction of the arm.

In some embodiments, the retroflex operating position can be at, or in proximity to, a surgical worksite.

10

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which the dimensions of components and features shown in the figures are chosen for convenience and clarity of presentation and not necessarily to
15 scale. In the drawings:

Fig. 1 is a schematic illustration of a surgical system according to embodiments of the present invention.

Fig. 2A is a schematic perspective view of a surgical system comprising a mechanical surgical arm according to embodiments of the present invention.

20 Fig. 2B shows a distal portion of a mechanical surgical arm according to embodiments of the present invention.

Figs. 3-C show the distal portion of a mechanical surgical arm in a variety of flexed and retroflexed positions, according to embodiments of the present invention.

25 Figs. 4 and 5 show the distal portion of a mechanical surgical arm with a variety of arm curve-shapes, according to embodiments of the present invention.

Fig. 6 shows a flowchart of a method for operating surgical mechanical arms using two operating modes, according to embodiments of the present invention.

Fig. 7 is a schematic illustration of a control console for a surgical system with input devices positioned in proximity thereto, according to embodiments of the present invention.

Fig. 8 is a schematic illustration of a user-input device according to embodiments
5 of the present invention.

Fig. 9 is a chart illustrating an exemplary scheme for using an input-device to control flexion and rotation of an arm joint, according to embodiments of the present invention.

Fig. 10 is a schematic illustration of an articulated user-input device according to
10 embodiments of the present invention.

Fig. 11 is a schematic view of a handle member of the user-input device of Fig. 10 according to embodiments of the present invention.

Figs. 12A-B illustrate an exemplary graphical aid for use in aligning the respective positions of a mechanical surgical arm and an articulated user-input device,
15 according to embodiments of the present invention.

Fig. 13 shows a sample screen display for use in aligning the respective positions of a mechanical surgical arm and an articulated user-input device, according to embodiments of the present invention.

Figs. 14A-E show time-consecutive images showing exemplary control of
20 surgical mechanical arms using a plurality of different input devices, according to embodiments of the present invention.

Fig. 15 shows a block diagram of a surgical system according to embodiments of the present invention.

Fig. 16 shows a flowchart of a method for operating a surgical system in two
25 different operating modes, according to embodiments of the present invention.

Fig. 17A shows a flowchart of a method for dual control of surgical arms, according to embodiments of the present invention.

Figs. 17B and 17C are schematic illustrations of control consoles comprising dual control means, according to embodiments of the present invention.

FIG. 18 is a flowchart of a method of using haptic handles to control one or more surgical arms, according to embodiments of the present invention.

5

DETAILED DESCRIPTION OF EMBODIMENTS

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

Embodiments disclosed herein relate to controlling one or more surgical mechanical arms, i.e., articulated mechanical arms, using a plurality of different operating modes and/or a plurality of different input devices.

Whenever 'arm' is used herein or in the appended claims, it means an articulated, mechanical arm that is part of a surgical system or electrosurgical system and used for performing or helping to perform surgical (including electrosurgical) actions inside a human subject's body. 'Surgical actions' when unspecified can include any medical or surgery-related or diagnostic action taken inside the human body, including, but not exhaustively: cutting tissue, dissecting tissue, manipulating tissue, suturing tissue, retracting tissue, fusing tissue, taking measurements, and imaging. It can be desirable that a surgical arm be sized and/or shaped for insertion into a human body. For example, an arm can be sized and/or shaped for insertion through a laparoscopic port and/or for

performing laparoscopic surgery. For example, an arm can be sized and/or shaped for insertion through a natural body orifice, e.g. vagina, anus, trachea, esophagus, ear canal.

An arm may include an end effector, which is used herein to mean a tool or device used in connection with surgery, electrosurgery, diagnosis or imaging when
5 deployed within a human body. An end effector may be supplied as part of an arm, i.e., already mounted, mechanical attached and/or integrated with the power and communications conveyances of the arm; in some embodiments an arm an end effector may be provided separately for assembly and/or integration into a working unit before or even during a surgical operation, i.e., before insertion into a subject's body. In any case,
10 terms such as 'an arm comprising an end effector' and 'an arm configured for use with an end effector', etc., should be understood as equivalent for the purposes of this disclosure and the claims appended thereto.

An 'input device', or, equivalently, a 'user-input device', as used herein can be any device capable of receiving a user input, i.e., an input received from a user of a
15 surgical system. Input devices can include, for example but not exhaustively: buttons, switches, toggles, wheels, knobs, small sticks such as thumbsticks (alternatively called nipples), and joysticks (whether articulated or not). Disclosure of specific device-type for any specific input device is not intended to exclude the substitution of other types of input devices for the specific input devices. Input devices can be standalone, grouped on
20 a single control member or on a small number of control members, disposed upon another input device, or co-located, e.g., on or in proximity to a control console, display screen, etc. Input devices can be operated by a user employing one or more fingers, thumbs, hands or feet. Additionally or alternatively, and without limitation, input devices can be eye- or hand- motion operated, voice-operated, or controlled by facial expressions.

25 Arms and input devices, as well as other aspects and features of the present invention may be understood in combination with any of the teachings of co-pending US Patent Application Ser. No. 16/121,704 filed on Sep. 5, 2018 and published as US Patent Publication US20190000574A1 which is hereby incorporated by reference herein in its entirety.

A 'handle', or, equivalently a 'handle-member', is used herein generally to describe a hand-operated user-input device or a hand-operated portion of a user-input device, and in some embodiments to describe a hand-grasped or finger-grasped user-input device or portion thereof. Drawings and accompanying descriptions of handles and hand-operated user-input devices in this disclosure are provided as illustrative examples, and such drawings and accompanying descriptions are not to be understood as limiting the scope of the embodiments as pertains to handle/handle-member design, connectivity and functionality.

For the present disclosure, 'module' and/or 'electrical circuitry' or 'electronic circuitry' and/or control circuitry' and/or element and/or unit and/or controller and/or module and/or sensor and/or detector may include any combination of analog and/or digital circuitry and/or software/computer readable code module and/or firmware and/or hardware elements including but not limited to a digital computer, CPU, volatile or non-volatile memory, field programmable logic array (FPLA) elements, hard-wired logic elements, field programmable gate array (FPGA) elements, and application-specific integrated circuit (ASIC) elements. Any instruction set architecture may be used including but not limited to reduced instruction set computer (RISC) architecture and/or complex instruction set computer (CISC) architecture.

In different embodiments, any computation or analysis procedure may be performed using any combination of analog and/or digital circuitry and/or software/computer readable code module and/or firmware and/or hardware elements including but not limited to a digital computer, CPU, volatile or non-volatile memory, field programmable logic array (FPLA) elements, hard-wired logic elements, field programmable gate array (FPGA) elements, and application-specific integrated circuit (ASIC) elements. Any instruction set architecture may be used including but not limited to reduced instruction set computer (RISC) architecture and/or complex instruction set computer (CISC) architecture.

Referring now to the figures, Fig. 1 shows a schematic illustration of a surgical system **100** according to embodiments. The system **100** of Fig. 1 includes two surgical

mechanical arms **102**. In other examples of a surgical system, a single surgical arm is provided. In other examples, more than two (e.g., 3 or 4) surgical arms are provided. Surgical mechanical arms **102** are preferably sized and/or shaped for insertion into a human body or patient **106**. Each of the surgical mechanical arms **102** is actuated by a respective
5 motor unit **108**. The surgical arms **102** and/or motor units **108** are supported in this simplified illustrative example by attachment to a patient support **116**, e.g., a bed, but may also be supported by a patient side cart or any other suitable equipment.

Power to the arms **102** and the motor units **108** can be supplied by an electrosurgical generator **112** in embodiments in which the surgical system is used in electrosurgery. As
10 known in the art of electrosurgery, an electrosurgical generator supplies high-frequency (e.g. radio frequency) alternating polarity, electric current. An electrosurgical generator **112** can be configured to supply different frequencies and/or power levels, for example, suitable for cutting and/or coagulating and/or sealing and/or desiccating and/or fulgurating tissue. Power is supplied to the motor units **108** via one or more cables **114** which are
15 configured to transfer radio frequency electrosurgical power.

Movement of the surgical arms **102** is controlled at a control console **118**. Movement is in response to signals generated by one or more input devices. Control console **118** includes a plurality of user interfaces including one or more of: input devices, e.g., input device arms **120** where the control console is configured to generate control
20 signals based upon movement of the input device arms **120**; display screen **128** configured to receive user input and/or display, for example, system-status information or imaging of a surgical zone, for example, to display images collected by a camera inserted into patient **106** using one of surgical arms **102** or display arm position and orientation; and one or more additional user interfaces **130** (e.g. button, switch, etc.).

25 Control console **118** includes a processor (not shown) configured to receive signals from a user input/s and to send control signals to motor units **108** and/or electrosurgical generator **112**. Foot pedal **126** and/or electrosurgical generator **112** include/s a processor (not shown) configured to receive control signals (e.g. generated by a user pressing on a portion/s of the foot pedal **126**) to vary electrical power supplied to motor units **108** based

on the control signals. Foot pedal control signals do not necessarily pass through a control unit processor.

As will be explained in greater detail hereinbelow, in one control mode, the movement of input device arms **120** controls movement of a respective surgical device arm **102**. A user **124** can position and/or move an input arm **120** by grasping an input device arm handle **127**. Input arms are one form of input device, and are shown here for illustrative purposes. In other embodiments, other types or forms of input devices can be used.

Referring now to Figs. 2A-B, an arm unit **104** includes a proximal end which is shaped for acceptance by the motor unit **108**, and a distal end where an end effector **174** such as the illustrated multi-jaw grasper (shown only as a non-limiting illustrative example) is attached to the arm **102**.

The use of the relative terms ‘proximal’ and distal are in accordance with the arrows shown in Fig. 2A and are used in this manner throughout this disclosure and the appended claims: as shown, the distal end of the arm **102** at which the end effector **174** is disposed is the end furthest removed from the motor unit **108** and which is the first portion of the arm to be inserted in a human subject **19**. The proximal end, therefore, is the end opposite the distal end, closest to the motor unit **108**. The term ‘distal portion’ as used herein means any portion of the arm **102** which includes the distal end/tip (optionally including the end effector **174**) and less than half the length of the arm **102**. In Fig. 2B, a bendable portion **170** of the arm **102**, i.e., a portion that contains one or more bendable joints, is located along the length of the arm, closer to the distal end. The bendable portion **170** can comprise a series of ‘stacked links’ **199** that enable flexibility for the outer contour/surface of the arm **102**; an example of a plurality of stacked links **199** in a bendable portion **170** of an arm **102** is illustrated in Fig. 2B.

As used herein, an ‘operating mode’ or its equivalent ‘mode’ (which can be used in conjunction with various non-limiting descriptive words, e.g., ‘retroflexing mode’, ‘surgical-operating mode,’ etc.) means an operating regime imposed on the use of a surgical system or an arm, either by hardware, firmware or software design or by control circuitry of the surgical system or in other ways. To clarify: The word ‘operating’ in ‘operating mode’ means ‘working’ or ‘functioning/al’ and describes the operating of,

e.g., an arm, and does not mean the performance of surgery, i.e., an ‘operating mode’ may happen to include the performance of surgery but not necessarily. The imposed operating regime can include, and not exhaustively, restricting or not restricting certain actions or certain portions of the surgical system that perform one or more actions, and
5 the restricting or not restricting can include and/or can be equivalent to enabling or disabling, locking or unlocking, and precluding or permitting or similar words and phrases. In some embodiments herein, a mode is dedicated or directed to accomplishing a single goal, for example retroflecting a distal portion of an arm, and may be limited to one or more specific time periods. In other embodiments, a mode can incorporate an
10 unlimited number of goals and actions and unlimited or undefined time periods.

Operation of the surgical system can be differentiated between different modes, in various ways, as further described hereinbelow. For example, the differentiation can be on the basis of (and not exhaustively): having a different input device (or multiple input devices) dedicated to each mode; having various restrictions or limitations on specific
15 arm movements and/or on specific arm joints and segments; having different translation schemes for displacement of input devices or control elements of input devices to arm movements, e.g., displacement-to-speed vs. displacement-to-displacement, whether the translation from user inputs to arm movements is robotic/semi-autonomous or tele-operated; and whether the manipulation of the input device addresses (via the mechanics
20 and electronics of the surgical system) the flexing and rotating of arm joints directly, or indirectly by addressing the displacements of arm segments which in turn causes the necessary flexions and rotations to occur in order to displace the arm segments as directed. The differentiations can be used in combination, and they can vary from arm to arm in a multi-arm system. In some embodiments, the differentiations can change while
25 the system is in a given mode.

Some differentiations between modes can be implemented in more than one way. As a non-limiting example, if the differentiation between modes involves restricting or limiting certain arm movements (e.g., flexing and rotating of certain joints) or permitting only certain arm movements, the differentiation can be implemented by using different
30 input devices for each mode, or by using one input device in both modes but enforcing,

on the one input device, a software or hardware restriction that can be user-switchable or system-enforced. Regardless of whether an embodiment calls for one input device or more, a software-implemented or hardware-implemented solution may actively permit the actuation of a single given arm joint, or may actively prevent or preclude the
5 actuation of any arm joint (of the same arm) that is not the single arm joint.

It should be noted that wherever actuation or movement of a singular ‘arm’ (as opposed to the plural ‘arms’ is discussed herein, this is for convenience only and is not intended to indicate whether or not a second arm (or other multiple arms) is/are being likewise or otherwise actuated or moved. Each arm can be controlled and actuated
10 independently of any other arms by a respective input device. On the other hand, wherever an ‘arm’ (singular) is disclosed as being restricted or limited as to actuation or movement, e.g., when in an operating mode characterized by such a limitation or restriction, the limitation or restriction may apply equally to both/all arms of a surgical system. In some embodiments, however, a restriction or limitation may apply to one or
15 more given arms while other arms are not restricted or limited at all, or not restricted or limited in the same way.

In embodiments in which two different operating modes are employed, a first operating mode is typically used when introducing or exiting and/or navigating the surgical arm or arms into or out of the body (or from a first point to a second point within
20 the body) and more specifically towards or away from a target surgical site. The second operating mode is typically used when performing surgical actions (e.g. dissecting tissue, manipulating tissue, suturing tissue, taking measurements, imaging, etc.). The ‘navigating’ of the first mode may include retroflexing the arm or arms so as to put at least a portion of the arm or a distal portion thereof in a retroflex position or,
25 equivalently, to put an end effector in a retroflex operating position (working position).

It can be desirable to have a clearly defined transition or ‘handoff’ from one operating mode to another. In some embodiments, the transition includes a handoff from one input device (or plurality of input devices) to another. In other embodiments, the transition is entirely concerned with changing control aspects that are differentiated
30 between one mode and another wherein the tasks assigned to both modes can be

accomplished by a single input device, or by the same input devices. A transition can be initiated and managed by the surgical system, or it can be initiated by a user.

In a non-limiting example with respect to a transition from a first mode to a second mode, a transition may include ending restrictions or limitations imposed during first-mode operation, such as limiting joint flexion and rotation to a given single arm joint of any particular arm, e.g. the elbow joint. Additionally or alternatively, a transition can include enabling the actuation of arm joints that were disabled (or not specifically enabled) in the first-mode operation, i.e., in addition to the single given joint that was enabled in the first mode. Enablement can include enablement of joints to move unrestrictedly in accordance with respective degrees of freedom of each joint. For example, if a given arm joint is only configured for rotation and not flexion, the enablement will enable it only for rotation. Additionally or alternatively, a transition can enable actuation of all arm joints. Additionally or alternatively, a transition can change a processing of control-outputs from user-input devices from a displacement-to-velocity translation to a displacement-to-displacement translation. In further non-limiting examples, the transition can be implemented automatically by control circuitry in response to an event, it can be implemented based on a user input such as, for example, a depressed button or a rotated switch, or it can be implemented by noting that a user has ceased using a first input device and begun using a second input device. In a further non-limiting example, the transition is a user interface-based mediated transitioning.

In a non-limiting example with respect to a transition from a second mode to a first mode, a transition may include restoring restrictions or limitations removed during a transition to second-mode operation, such as limiting joint flexion and rotation to a given single arm joint of any particular arm, e.g. the elbow joint. Additionally or alternatively, a transition can include disabling the actuation of arm joints that were enabled for the second-mode operation. Additionally or alternatively, a transition can change back a processing of control-outputs from user-input devices from a displacement-to-displacement translation to a displacement-to-velocity translation. In further non-limiting examples, the transition can be implemented based on a user input such as, for example, a depressed button or a rotated switch, or it can be implemented by noting that a user has

ceased using an input device dedicated to second-mode operation and begun using a different input device that is dedicated to first-mode operation.

In embodiments, and especially in embodiments in which the input device employed in the second mode is avatar-like and translates input arm displacements to surgical arm displacements, transitioning from a first operating mode to a second operating mode can include an alignment calibration. In an alignment calibration, which is discussed in further detail with respect to Figs. 12A-12B, the orientation of the surgical arm, including the 'internal' orientation of arm elements (e.g., arm joints and/or arm segments) with respect to each other is modified so as to match a 'shape' or 'curve' which describes the corresponding orientation of the input arm which will take over actuation control of the surgical arm in the transition to the second operating mode. There is not necessarily a corresponding alignment calibration in the case of transitioning back from the second operating to the first operating mode.

Translation of user inputs to arm movements (flexion and rotation) can be accomplished in various ways. For example, the displacement (or the force of displacement) of an input device or of a control element of an input device can be translated to a velocity (e.g., velocity, speed, angular velocity) of arm movement. It can be desirable in a first mode that includes insertion/extraction and retroflexing (or retroflexing/unflexing) to use this type of translation. These limited and, in some embodiments, less precise, movements can be conducive to being performed not in a tele-operated or avatar mode but to simpler robotic or semi-autonomous mode. In contrast, the movements required in a second mode dedicated to performing various surgical actions may be more conducive to a controlled displacement-displacement translation, where displacement of an input device or a control element of an input device is suitably translated to displacement of arm segments and indirectly to rotation and flexing of joints. For example, in the second mode, it can be desirable to ensure that the articulation of an articulatable input device corresponds in internal orientation (i.e., segment-to-segment orientation) to the surgical arm, so that the translation of displacement to displacement is more intuitive, ergonomic and precise.

It can be desirable, in a first mode, to restrict arm movements to flexing and/or rotating a single given arm joint of an arm (or of each arm). This can be suitably implemented by configuring the surgical system to receive, from the input device used in the first mode, inputs which directly address the flexing and rotating of specific arm joints such as the single given arm joint that is permitted (in the operating mode) to be actuated. In other words, the user is 'controlling', via the input device and suitable control circuitry, the arm joint itself. The movement intended to be actuated in this case is specifically a flexion and/or rotation of the arm joint. Regardless of whether the actual arm movements are performed semi-autonomously in response to the user's control inputs, the user understands that she is controlling the actuation of the joint. The attending displacement and reorientation of the end effector is a presumably intended consequence of the control of the joint.

In contrast, it can be desirable, in a second mode, and especially in embodiments in which the input device employed in the second mode is avatar-like and translates input arm displacements to surgical arm displacements, for the surgical system to receive and process inputs which directly address the displacement of arm segments. The flexing and rotating of arm joints are then indirectly addressed by the surgical system by controlling the arm joints to flex and rotate to the extent necessary for achieving the required arm segment displacement and reorientation. In other words, the user is 'controlling' the displacement and reorientation of arm segments (or of the end effector which for the purpose of this discussion plays a role similar to that of any arm segment in that controlling its position and orientation is a user goal), and the control circuitry of the surgical system uses this information to determine the necessary flexion and rotation of each affected arm joint. In an embodiment, an avatar-like input arm can be manipulated by a user into a shape or configuration that anticipates or drives the intended shape of the surgical arm post-manipulation.

In an exemplary first operating mode, surgical arm movement can be at least partially limited or restricted, and certain types of movements can be precluded while others are permitted. For clarity, 'movement' of an arm can include displacement and/or

reorientation of any portion of the arm, such as, for example, one or more segment members of the arm.

The terms ‘elbow joint’, ‘wrist joint’ and ‘shoulder joint’ where used herein refer to particular joints of a mechanical arm, according to a specific implementation in which the arm comprises three actuatable joints. In such a case, the joint nearest a distal-end effector is known as the ‘wrist joint’, the middle joint of the three is the ‘elbow joint’ and the most proximal joint is known as the ‘shoulder joint’. In some embodiments, a wrist joint is limited to rotation only, i.e., is not configured to flex. The various joints are shown in Fig. 3A, which is discussed hereinbelow.

The meaning of the term ‘joint’ unless otherwise specified and as used in this disclosure and in the appended claims in the case of arm joints, i.e., joints of an arm, means any actuatable member capable of causing a flexion (e.g., planar bending) and/or a rotation. It should be noted that articulatable/avatar-like input arms (a type of input device) can also have joints, and they are referred to as ‘joint members’ of the input devices. Typically, arm segments are non-actuatable (with respect to flexing/rotating) members of an arm which can be joined serially by actuatable arm joints, where the term ‘joined serially’ means only that a joint is interposed between two consecutive segment members. A joint can be actuated, e.g., mechanically and/or electronically, to cause a flexion of one arm segment (and every portion of the arm disposed distally therefrom) relative to a base arm segment (2181 In Fig. 3A) or another (adjacent) arm segment, and/or to cause a rotation of one arm segment (and every portion of the arm disposed distally therefrom) relative to the base arm segment or another arm segment. In some embodiments, a joint includes multiple components, and in some examples can include both a flexion-facilitating component (or sub-assembly and a rotation-facilitating component (or sub-assembly). For the sake of readability, a combination of such components is referred to herein, in combination, as a joint or an arm joint.

In embodiments, arm movements may be limited according to types of articulations (e.g., rotations vs. flexions), speed of movement, which portions of the surgical arm can move, etc. Movement of the surgical arm during the first operating mode can be restricted to movement of a given single arm joint -- an elbow joint only --

(including, for example, flexion and/or rotation of the elbow joint) and to linear movement of the surgical arm as a single unit (including, for example, linearly advancing and retracting the arm). It can be desirable to limit arm movements during the first operating mode to facilitate introducing the surgical arms with minimized volume
5 through a narrow path and to the target surgical site.

It can also be desirable to limit arm movements during the first operating mode to facilitate retroflexing of the arm in a minimum volume so as to avoid collision and potential tissue damage within the human body. Fig. 3A is a simplified schematic side view of a surgical mechanical arm **102** in different configurations, explained here for
10 illustrative purposes. The dashed line **2177** represents an obstacle, for example patient tissue. Movements of the arm **102** when retroflexing are preferably controlled to prevent contact or collision of the arm **102** (and especially end effector **174**) with the obstacle **2177**. Three scenarios, respectively labeled **A**, **B** and **C** are illustrated in Fig. 3. Arm **102** comprises proximal segment **2181** and distal bendable portion **170**. Bendable portion
15 **2179** comprises shoulder joint **2101** and elbow joint **2103**, which are labeled variously as **2101a**, **2101bc**, **2103a**, **2103b** and **2103c** so as to indicate to which one or more of the scenarios (**A**, **B** or **C**) the instance of the joint is relevant. For example, joint **2103a** is the elbow joint position in scenario **A**. Thus, scenario **A** involves the bending of only elbow joint **2103a** (shoulder joint **2101a** remains unactuated and unbent), and specifically one
20 can see that the bending of only elbow joint **2101a** does not cause a collision between end effector **174** and the obstacle **2177**. On the other hand, in Scenario **B**, in which only the shoulder joint **2101b** is bent, there is a collision between end effector **174** with the obstacle **2177**. The difference between the collision/no-collision results of Scenarios **A** and **B** is because the portion of the arm **102** distal from the elbow joint **2103** is shorter
25 than the portion of the arm distal from the shoulder joint **2101**. The wrist joint **2105** of arm **102** in Fig. 3A is not involved in any of the three scenarios, as being designed or configured in the non-limiting example of Fig. 3A to rotate but not flex. In scenario **C**, which is a continuation of scenario **A**, it can be seen that flexing shoulder joint **2101c** after the flexion of elbow joint **2103a** (now **2103c**) can facilitate the continued avoidance
30 of collision between end effector **174** and obstacle **2177**.

Fig. 3B illustrates examples of elbow joint **2103** flexion from an unflexed orientation to various post-flexion orientations ranging from less than 90° to more than 180° relative to proximal arm base segment **2181**.

In embodiments, the flexion range of movement for an elbow joint is $>90^\circ$, $>120^\circ$, $>140^\circ$, $>160^\circ$, $>180^\circ$, $>190^\circ$, $>200^\circ$ or about $210^\circ \pm 10^\circ$. In some embodiments, an end-effector **174** is capable of being positioned at $>90^\circ$, $>120^\circ$, $>140^\circ$, $>160^\circ$, $>180^\circ$, $>190^\circ$, $>200^\circ$ or about $210^\circ \pm 10^\circ$ relative to the base **2181** of the arm **102**. In some embodiments, an end-effector **174** is able to be parallel to the base **2181** of the arm **102** or alternatively reach the base **2181** of the arm **102** when fully flexed. In addition, the Elbow Rotation joint range of motion shall be at least 200° , at least 250° , at least 300° , at least 310° , at least 320° , at least 330° , at least 350° or about 360° . Fig. 3C shows an arm **102** with flexion of elbow joint **2103** of more than 180° rotated from the unflexed orientation indicated in Fig. 3B, so as to bring the arm **102** to a retroflex configuration or, equivalently, retroflex position, and so as to deliver end effector **174** to a retroflex operation position.

In some embodiments, the retroflexion of a surgical arm can be done automatically, i.e., by arranging the arm to respond to a single or limited number of electronic control-outputs by flexing and/or rotating a single arm joint until a pre-programmed retroflex position of the arm and/or of an end effector at the distal end of the arm is achieved.

Fig. 4 shows, in front perspective, an arm **102** with elbow joint **2103** flexed similarly to elbow joint **2103a** in scenario **A** of Fig. 3B, and subsequently rotated – i.e., elbow joint **2103** in Fig. 4 is both flexed and rotated. The rotation of any arm joint can be independent of the flexion of the same arm joint. In some embodiments, the flexion and rotation can be simultaneous, and in other embodiments, a restriction of non-simultaneity can be enforced, for example by hardware design or by a software component of control circuitry governing the actuation of the joint.

Fig. 5 shows, in front perspective, an arm **102** with elbow joint **2103** flexed and rotated similar to that of Fig. 4, and with shoulder joint **2101** flexed so as to form, together with elbow joint **2101**, a complex “S” shape. In some embodiments, such as

those typified by scenario C of Fig. 3B, the shoulder joint **2101** is preferably actuated to flex and rotate only after the flexing of the elbow joint **2103** has ‘cleared’ the obstacle **2177**.

Referring now to Fig. 6, a flowchart of a general method is shown for controlling surgical mechanical arms using different operating modes, according to some embodiments.

A process for example as described herein may be implemented for various types of operations such as gynecologic, laparoscopic, otorhinolaryngology (ear, nose and throat) surgeries, carried out, at least in part, using one or more surgical mechanical arms inserted into the body of a patient.

As discussed hereinabove, the surgical mechanical arms can be operated according to a plurality of operating modes. Optionally, the operating modes are selected in accordance with a surgical step to be performed and/or in accordance with a current stage of the surgery.

Different operating modes can be characterized by different ways of translating user inputs (movements of input devices or control elements of input devices), i.e., by manipulation of user-input devices, into respective movements of the surgical mechanical arms. Additionally or alternatively, different operating modes can be characterized by different restrictions on surgical arm articulation, for example, limiting articulation (e.g. flexion) of one or more surgical arm joints; limiting a range of movement; or limiting arm articulation to selected degrees of freedom. Additionally or alternatively, different operating modes can be characterized by different types of feedback to the user, for example, feedback sensed by a user controlling the surgical arms via one or more input devices.

In some embodiments, selecting and/or switching between operating modes is controlled by a user, e.g. a surgeon. Optionally, selection of operating modes can be carried out via a user interface of the system, for example via a touch screen and/or via buttons or other input devices disposed on or in proximity to another input device, or a control console or display screen. Additionally or alternatively, selecting operating modes

can be automatic, for example, carried out by suitable control circuitry, such as by a system controller or processor. In some embodiments, selecting and/or switching an operating mode is triggered by and contingent upon: one or more of, and not exhaustively: identifying the current ‘anatomical’ position of the surgical arm or of the end effector of the arm, for example, by using electromechanical instruments such as encoders or other sensors (NOT SHOWN) associated with the actuators and/or motors (e.g. of **104** or **108**) of the arms, or by accessing and analyzing images of arm **102** obtained by a camera – through image processing or visually, upon identifying a current position of the input device, upon performing a certain articulation of the surgical arms, upon receiving an indication of one or more position sensors of the surgical arms, upon a timed indication, for example by setting a time point by which an operating mode is changed.

The flowchart in Fig. 6 describes a method of operating surgical mechanical arms using two operating modes, according to some embodiments.

The method includes:

Step **S01**: inserting and navigating surgical arm(s) to a predetermined location in a first operating mode.

In a first operating mode, the surgical arms are introduced into the body and navigated to a selected anatomical location and/or to a selected arm position. The surgical arms may be introduced to the body via a natural body orifice (e.g., the vagina, anus, trachea, esophagus, ear canal) and/or via an incision.

In some embodiments, in the first operating mode, arm articulation is limited. For example, one or more arm joints can be restricted or precluded from articulating (flexing and rotating). In an example, the arm comprises 3 joints: a shoulder joint, an elbow joint and a wrist joint that rotates but doesn’t flex, and one or two of the joints are prevented from articulating. In a specific example, only movement of the elbow joint is allowed, e.g. flexion, extension and/or rotation of the elbow joint, while the shoulder and wrist joint are restricted from moving.

It can also be that while in the first operating mode, the arm as a whole is allowed to move linearly (including only linearly), such as to be advanced or retracted in a one-dimensional movement.

5 In some embodiments, restriction of arm movement is achieved mechanically, for example by one or more locks (e.g. solenoid locks) affecting actuation of the arm joints. Additionally or alternatively, restriction of arm movement can be achieved by suitable circuitry, for example, by implementing software control functions that limit the extent of movement and/or the type of movement.

10 In some embodiments, limiting an extent of arm movement and/or restricting certain types of movement is performed in accordance with a current arm position, as indicated, for example, by one or more position sensors of the arm. In some embodiments, limiting an extent of arm movement and/or restricting certain types of movement is performed in accordance with a current anatomical location of the arms, for example as visualized by optical means (e.g. a camera introduced into the body,
15 optionally along with the surgical arms).

Step **S02**: articulate surgical arm(s) to a base position in the first operating mode

Still in the first operating mode, the surgical arm(s) is(are) articulated to a base position. In some embodiments, the base position comprises a retroflected position of the arms, for example, when the arms are flexed by at least 120 degrees, at least 150 degrees,
20 at least 180 degrees or intermediate, larger or smaller angles. In some embodiments, the base position is one in which the arms are positioned to allow a user to perform surgical acts from a selected orientation (e.g. corresponding to an abdominal orientation) which the user may be more comfortable or familiar with.

In some embodiments, control of surgical arm movement in the first operating
25 mode comprises robotic control. Optionally, manipulation of an input device by a user in the first operating mode involves only limited types of user movement, for example, limited movement of an input device along a defined axis and/or pressing of buttons. In an example, moving the input device along a first defined axis actuates rotation of selected arm joint, e.g. elbow; moving the input device along a second defined axis

actuates flexion of a selected arm joint, e.g. elbow; pushing one or more buttons actuates linear advancement or retraction of the surgical arm.

In some embodiments, manipulation of an input device by a user in the first operating mode is translated to the speed of movement of the surgical arm. For example,
5 when the user moves an input device relative to the rest position of the input device, the extent to which the input device was moved relative to its rest position sets the relative speed of movement of the surgical arm.

Step **S03** Transition to a second operating mode, then carrying out surgical actions using the surgical arm(s)

10 In a second operating mode, the user carries out surgical acts via the surgical arms, for example grasping tissue, dissecting tissue, moving tissue, suturing tissue. In some embodiments, the second operating mode is initiated at the end of step **S02**, once the arms have been moved into a selected base position, for example, a retroflected position.

15 In some embodiments, the user switches an input device when transferring from the first operating mode to the second operating mode. Alternately, the user uses the same input device for both the first or navigation operating mode and the second or surgical operating mode.

In some embodiments, at the second operating mode, surgical arm movement is
20 not as restricted as in the first operating mode. In an example, all arm joints (shoulder, elbow, wrist) are allowed to articulate, e.g. bend and/or rotate. In some embodiments, the extent and/or speed of arm movement during the second operating mode is limited based on safety considerations, for example, not to damage surrounding tissue, not to perform a movement at a speed that is too high and may risk damage.

25 In some embodiments, control of the surgical arms at the second operating mode involves tele-operated control. Optionally, displacement of an input device by the user is mimicked by a respective displacement of the surgical arm. Optionally, the speed of displacement of an input device by the user is reflected in the respective speed of surgical arm movement.

Step **S04** Transition back to the first operating mode, then retract the surgical arm(s) from the body

In accordance with some embodiments, optionally when the surgical acts have been accomplished, the arms are retracted outwardly from the patient body. In some
5 embodiments, retraction is performed in the first operating mode. Optionally, before and/or during retraction, the arms are straightened.

Retracting in the first operating mode may be advantageous as it limits the extent and/or type of arm movement, thereby potentially reducing damage to tissues surrounding an anatomical passage (e.g. the vagina) through which the arms are retracted.

10 Referring now to Fig. 7, a control console **118** can comprise a display screen **407**, with input devices **405** positioned in proximity thereto – on opposite sides of screen **407** in the non-limiting example of Fig. 7.

Each of the input devices **405** (in the form of ‘thumbsticks’) comprises a nipple-type controller **409** suitable for manipulation by a user’s thumb. In embodiments, the extent
15 of movement of the nipple **409** relative to a central rest position can be translated to a velocity of a chosen surgical arm movement, as discussed hereinabove. In one example, the further the nipple **409** is pushed away from its central rest position, the higher the resulting speed of the movement of the surgical arm. In another example, the more force is applied to the nipple **409**, the higher the resulting speed of the movement of the surgical
20 arm.

In some embodiments, when controlling the surgical arms via the thumbsticks **405**, one or more of the surgical arm joints (e.g. a shoulder joint, a wrist joint) are restricted from movement, and only flexion and/or rotation of the elbow joint are enabled. In some embodiments, linear movement of the surgical arm (as a single body) is also enabled, for
25 example to advance or retract the arm. In some embodiments, movement of the nipple **409** actuates flexion and/or rotation of the elbow joint. In some embodiments, linear movement of the arm **102** is actuated by separate actuators, for example using another pair of input devices such as input devices **406**, **408** which are implemented as push buttons disposed, in the illustrated example of Fig. 7, along the body of the input devices

(thumbstick assembly) **405** themselves. In other examples the push buttons **406**, **408** can be provided independently, or on (or in closer proximity to) the display screen **407**. In an example, button **406** advances the surgical arm distally (e.g. in an abdominal direction) and button **408** retracts the surgical arm proximally. In embodiments, input devices **406**,
5 **408** may be used while in a first mode in which flexing and rotating arm joints that are not the elbow joint is precluded, as the linear motion does not require any flexing or rotating.

In some embodiments, during use of the thumbsticks **405**, other input devices such as avatar-input arms **411** provided for use in the second mode without any first-mode restrictions, are locked at a rest position, for example by solenoid locks. In some
10 embodiments, the rest position of the input arms **411** is selected as the retroflected position of the surgical arm **102**, so that once the surgical arms **102** have been retroflected (e.g. using the thumbsticks), a user may pick up the avatar input arms **411** and continue the procedure directly. In some embodiments, when the avatar-like input arms **411** are enabled while in the second mode, operation of the thumbsticks is disabled.

15 In some embodiments, during insertion of the surgical arms **102** into the body of a patient **106**, the surgical arms are straight, i.e., unflexed. In some cases insertion is via a cannula. At the same time, the avatar input arms are at a rest position, which can be a locked position and which can be a retroflected position. Optionally, following retroflexion of the surgical arms using the thumbsticks **405**, the surgeon may release the
20 thumbsticks **405** and moves her hands to the avatar input arms **411**. Once the avatar input arms **411** are grasped and optionally lifted by the surgeon, control over the surgical arms **102** can be automatically transferred or transitioned from the first user-input device **405** to the second **411**, and the surgeon may continue the procedure using the avatar input arms **411**.

25 In some embodiments, when one or more avatar input arm joints are locked by solenoid locks, lifting of the avatar input arm by the surgeon automatically releases the solenoid locks. Additionally or alternatively, manual locks of the avatar input arm joints are released, for example via a sensor that detects an avatar input arm position.

In some embodiments, the system (e.g. a system processor) is configured to
30 recognize one or more positions of the input devices, for example a current position of the

thumbsticks and/or a current position of the avatar input arms, and optionally to present the position on the user interface screen. In some embodiments, identifying a position is assisted by the use of position sensors.

Fig. 8 shows an image of an example of a thumb-operated input device **501** comprising a gripping handle **503** and, optionally, a textured surface to facilitate gripping, such as a surface comprising ridges **505**. One or more control buttons **507** can be disposed along the gripping handle **503**. For example, the thumbstick input device **501** of Fig. 8 comprises two control buttons **507** – one for actuating linear advancement of the surgical arm distally, and one for actuating linear retraction of the arm proximally.

In some embodiments, thumbstick **501** comprises a nipple **509**, extending for example from a proximal end of the gripping handle **503**. In some embodiments, nipple **509** is shaped and/or sized for a user's thumb. In some embodiments, nipple **509** comprises a rounded profile. In some embodiments, a proximal surface of the nipple **509** is formed with circumferential protrusions **511**. The circumferential protrusions may assist in maintaining the thumb placed on the nipple **509**, potentially preventing or reducing sliding of the thumb away from the nipple **509**.

In some embodiments, the nipple **509** moves in a spring-like manner. Optionally, after pushing the nipple **509** away from its initial rest position (e.g a central position, in which the nipple **509** is centrally aligned with long axis **513** of the thumbstick), the nipple springs back to its central position.

Fig. 9 is a schematic diagram illustrating an example of control of the thumb-operated input **501**, according to some embodiments. In some embodiments, moving ('displacing') the nipple **509** with respect to first axis actuates a first type of surgical arm movement, for example a flexion; and displacing the nipple **509** with respect to a second axis actuates a second type of surgical arm movement, for example rotation.

In some embodiments, the thumbsticks **501** are used during the first operation mode, when at least some of the joints are restricted, for example, the shoulder and wrist joints **2101**, **2105**. Optionally, displacing the nipple **509** along the Y-axis generates flexion of an elbow joint **2103** of the surgical arm **102**; and displacing the nipple **509**

along the axis generates rotation of the elbow joint. In some embodiments, actuation of simultaneous bending and rotation can be achieved by pushing the nipple relative to both axes, for example, diagonally relative to the center.

Referring now to Figs. 10 and 11, side and front view images are shown of an exemplary avatar-like input arm **701** comprising multiple joints for actuating respective movement of surgical arm joints: as illustrated the joints include a shoulder joint **703**, an elbow joint **705** and a wrist rotation knob **707** for controlling a wrist joint **2105** of a surgical arm **102**.

In some embodiments, the avatar input arm can comprise additional input devices, such as button or lever **709**, which can control operation of a surgical tool (as end effector **174**) of the surgical arm **102**.

Other input devices disposed on the exemplary input arm **701** of Figs. 10-11 include a pause-resume button **711** and buttons **713**, **715** respectively for actuating linear advancement and retraction of the arm **102**. A user may use the buttons **713**, **715** on the avatar input arm and/or the buttons **406**, **408** disposed on the thumbstick **405** to actuate linear advancement and/or retraction. Additionally or alternatively, linear movement of the arm may be actuated via a screen interface of the control console (e.g. via a touch screen interface).

In some embodiments, a set of two avatar input arms are provided, for controlling left and right arms respectively. For example, a first avatar input arm **701** can control a first motor unit **108** associated with a first surgical arm **102** (e.g. a “right” arm) and a second avatar input arm **701** can control a second motor unit **108** associated with a second surgical arm **102** (e.g. a “left” arm). In some embodiments, any or all of input arms **120**, **411** and **701** can be the same.

In a prior art example, a first mode and a second mode both use the same input device, an avatar-like input arm. The input arm is used in a restricted mode for retroreflecting the arm as explained hereinabove, at which point a transition is made to fully enabled use in the second mode. However, at this point, the input arm, or at least a handle member (e.g., handle member **702** of Fig. 10) may have been flipped around by as much as 180° or more

than 180° in accordance with the angle of flexion employed in the retroflexion. This means that (a) the handle **702** is uncomfortably ‘upside down’ from the perspective of the surgeon, and (b) the coordinate system used by the surgical system is ‘backwards’. The surgeon’s perspective has switched from looking ‘distally’ to retroflex the arm, to looking
5 ‘proximally’ to perform a surgery with arm in a retroflex position, and as a result a displacement vector or reorientation arc of a segment member is not translated to a corresponding (e.g., parallel) displacement vector or reorientation arc in the same x-y-z space.

It is now disclosed that transitioning from a first input device of an array of one or
10 more input devices to a second input device of the array when transitioning from the first mode to the second mode can overcome the aforementioned shortcomings. The handle member **702** of the second input device (the avatar-like input arm **701**) can be placed in advance in an orientation that is not ‘upside down’ from the surgeon’s perspective; the retroflexing can performed with an input device (e.g., input device **501/405**), the use of
15 which does not include or require that the handle member **702** of the second input device be moved, or if moved then not moved more than the 90° that might be a ‘tipping point’ to becoming ‘upside down’ from the surgeon’s perspective. Moreover, the control circuitry controlling the second input device (the input arm **701**) can be set (e.g., programmed) to use a ‘direct’ coordinate translation matrix, one in which a displacement vector of a segment
20 member of the input arm is translated to a corresponding (e.g., parallel or, at minimum, retaining the same sign in each of the x, y and z directions or at least two out of three directions) displacement vector of the corresponding surgical arm segment, and/or in which a reorientation arc of a segment member of the input arm is translated to a corresponding reorientation arc of the corresponding surgical arm segment.

25 It can therefore be desirable to ensure a handoff (transition) from a first mode to the second mode, in which control of arm movement transfers from a first input device (such as the ‘thumbsticks’ detailed hereinabove) to an avatar-like input arm, that ensures ergonomic comfort and convenience based on the optimally oriented handle member and directly translatable (input arm to surgical arm) coordinate translation matrix.

It should be noted that the exemplary design of the input device **701** and handle member **702** is provided for illustrative purposes, while in other examples and in other embodiments, input devices and handle members can be designed and implemented in different ways. For example, in some embodiments a handle member can be physically detached from an input device of which it is functionally a part. As another example, in some embodiments, an avatar-like or joystick-like input device be wholly or almost wholly or mostly comprised of a hand-operated and/or hand-graspable handle member. As another example, in some embodiments, a handle member can incorporate multiple operating functions in its design by including, and not exhaustively, buttons, switches, toggles, wheels, knobs, and/or small sticks such as thumbsticks so as to ‘combine’ multiple input devices and their respective functions into what appears visually to be a single input device. The repeated presentation herein of the input device **701** and handle member **702** of Fig. 10 is for convenience and easier comprehension, and should not be understood as a limitation of input device and handle member design.

We now refer to Figs. 12A and 12B. In embodiments, alignment of an input device such as the avatar input arm with the current position of the surgical mechanical arm is performed. In an example, alignment is performed when the user switches between different input devices, for example when switching from thumb operated input to the avatar input arm. In another example, alignment of an input device with the surgical arm position is performed upon initialization of the system, for example at the beginning or prior to surgery. In another example, an alignment of the input device with the current position of the surgical mechanical arm is performed when resuming control following a pause. Optionally, in the paused mode, movement of the input device does not actuate relative movement of the surgical mechanical arm, and upon resuming control, it may be required to adjust a position of the input arm so that it matches the current position of the surgical mechanical arm, to continue operation in a smooth, non-interrupted manner.

In some embodiments, resumed control is gained in an automatic or semi-automatic manner. For example, a user performs a selected articulation of the input device (e.g. straightens an elbow joint of the avatar input arm) and control of the surgical arm is resumed.

In Figs. 12A and 12B, the relative position of an input device (i.e., input arm) is represented using a cross shaped diagram **801**. In some embodiments, there are two sets of crosses, one for the shoulder joint and one for the elbow joint. In some embodiments, the cross represents a specific single joint (e.g. a shoulder joint, an elbow joint) of the surgical mechanical arm. In some embodiments, each line of the slot represents a different type of articulation, for example, the horizontal line **803** represents rotation of the joint; the vertical **805** line represents flexion of the joint. During use, a user manipulates the input device according to the joint position indicated at the cross by the two colored dots **807**. As the position of the input device (in response to manipulation by the user) becomes closer to that of the surgical mechanical arm, the colored dots move closer to the center of the cross (see FIG. 12B). Optionally, once sufficient alignment between the input device position and the surgical arm position is obtained, the dots change color, for example, from red to green as indicated in Figs. 12A-B.

In embodiments, the control apparatus of Figs. 12A and 12B can be used in an alignment calibration as part of a transitioning from a first mode using a first input device to a second mode using the avatar-like input arm. In these embodiments, the first input device can be used to adjust the position of the surgical arm so as to align with a fixed position of the input arm.

FIG. 13 is an example of a screen displayed to the user during alignment, according to some embodiments. In the shown example, a first input device (such as corresponding with the right avatar arm) is shown to be properly aligned with the first surgical arm, as indicated for example by the checkmarks **809** at the position of both the elbow and shoulder joints, and/or by the locked lock **811**. A second input device (such as corresponding with the left arm) is shown at a position in which it is not yet aligned with the surgical arm. The joint position is represented by the two cross shaped diagrams, for example as described hereinabove, and the lock is unlocked.

In some embodiments, during alignment, certain articulations and/or functions are disabled, for example, the speed of the surgical arm is limited; electrosurgery functions are disabled; and/or other functions.

Figs. 14A-E show a set of images showing exemplary control of surgical mechanical arms using a plurality of different input devices, according to some embodiments. Two arms are shown in the non-limiting example of Figs. 14A-E, and in other examples there can be a single arm or more than 2 arms.

5 Fig. 14A shows control of two surgical mechanical arms **901** during introducing of the arms into a model **903** simulating access to the body via the vagina, according to some embodiments. In this example, control of the surgical arms **901** during advancing of the arms into the body (e.g. through the vaginal canal) is via thumb-operated input, including a set of thumbsticks **905** for example as described hereinabove.

10 Fig. 14B shows manipulation of the surgical arms, via the thumbsticks **905**, into a retroflected position. In the shown example, the arms are flexed (e.g. by 120, 150, 180, 210 degrees or intermediate, larger or smaller angles) to obtain the retroflected position.

FIG. 14C shows the surgical arms in a retroflex position. Following retroflexion, a user may, in some examples, switch the input device used, for example by releasing the
15 thumbsticks and picks up avatar input arms. At this point, alignment of the avatar input arms with current a position of the surgical arms can be performed, for example as described in Figs. 12A-B and 13.

Figs. 14D and 14E show maneuvering of the surgical arms using a set of avatar input arms **907**, according to some embodiments. It can be seen that the respective positions
20 of the surgical arms correspond to the positions of the input arms.

The block diagram of Fig. 15 shows articulated arm **102**, input-device array **1500**, and detector **1520**. The skilled artisan will appreciate that not every element appearing in Fig. 15 is required in every embodiment. Although input-device array **1500** as illustrated in Fig. 15 shows two user input devices **1510A** (e.g. thumbstick **501**), **1510B** (e.g.
25 joystick **701**), the skilled artisan will appreciate that in different embodiments fewer or more user-input devices may be provided. In an example, the joystick **701** can be both the first user-input device **1510A** and the second user-input device **1510B**; in other words, the first user-input device **1510A** and the second user-input device **1510B** can be the same single user-input device. In implementations in which the first user-input device

1510A and the second user-input device **1510B** are the same single user-input device, then it is typically the more versatile or flexible device such as the joystick **701**. The term user-input device relates to a device for converting input received by a user into electronic output and/or signals. Examples of user-input devices include but are not
 5 limited to joysticks, touch screens, thumbsticks, mouse, keyboards, gesture detection devices (e.g. including a camera [not shown]). Unless specified otherwise, the term “array” relates to one or more of an item.

As shown in the example of Fig. 15, articulated arm **102** has one or more objects **1530** mounted at a distal end thereof. The object(s) **1530** can be provided with the arm
 10 **102** or can be added or exchanged separately. Examples of such objects **1530** include but are not limited to end effectors, e.g., surgical end effectors. Relevant surgical tools can include, and not exhaustively: an endoscope for diagnostic/surgical feedback, surgical end effector tools such as a needle driver (e.g., large needle driver, curved needle driver), mono and bipolar instruments (e.g., monopolar scissors, bipolar forceps), clip applicators
 15 (e.g., large and medium clip applicators), vessel sealers, graspers or dissectors (e.g., Maryland dissectors, Tenaculum forceps, micro forceps, long tip forceps, grasping retractors, Fundus graspers, Crocodile graspers, Cadiere forceps,), scissors (e.g., Potts Scissors, curved scissors), hooks (e.g., cautery hook)., and spatulas (e.g., cautery spatula).

As discussed elsewhere, in some embodiments arm **102** and/or object(s) **1530**
 20 operate responsive to electronic control output of one or more of the control device(s). The terms ‘control output’ and ‘control signal’ are used synonymously. In different embodiments, the control output may be sent to arm **102** and/or to a controller thereof via wired and/or wireless communication.

Also illustrated in Fig. 15 is detector **1520**. As discussed elsewhere, in some
 25 embodiments a mode transition from a first operating mode of surgical system **999** to a second operating mode of surgical system **999** is responsive to and/or contingent upon output of detector **1520**. Surgical system **999** can be functionally equivalent to surgical system **100** shown in Fig. 1. In one non-limiting example, detector **1520** detects whether or not a portion (e.g. distal portion) of arm **102** is retroflexed and/or in a retroflex
 30 position. In one example, a camera may acquire an image of arm **102** and detector **1520**

the camera and image-processing circuitry. In another example, encoders (not shown) or other electromechanical sensors (e.g. of **104** or **108**) may be used for monitoring and detecting to track e.g. orientation of joint(s) of arm **102**. Other examples may relate to magnetic or capacitive detector(s) or position detection based upon, e.g. (e.g. time-of-flight) triangulation using ultrasound and/or light.

‘Monitoring’ and ‘detecting’ as used in this disclosure and in the claims appended thereto are actions (and/or functions and/or potential actions and/or capabilities) which can be undertaken by one or more components of a surgical system, by one or more users, or any combination of system components and humans users. Descriptive language used herein with respect to automated or machine monitoring or detecting is meant as non-limiting, and in any such embodiment, user intervention can be a part of the design and/or a part of the operation. In some embodiments, user intervention is required for safety reasons. In a non-limiting example, one or more sensors relays information about a surgical arm or one of its components to a display screen to which a user is trained and/or positioned to monitor an arm curve-shape and detect, without or without automated or semi-automated visual aids, when an arm is in a desired position and orientation, e.g., is retroflected at a surgical worksite. In another non-limiting example, the monitoring and/or detecting is communicated to a user in a non-visual way, such as, and not exhaustively, by audible announcement, by haptic feedback, or by a locking of a control or input device. Obviously, any of these types of communications can be combined with visual information as well.

The skilled artisan will also appreciate that the additional elements may be provided in the surgical system **999**, and that not every component of every element is illustrated in Fig. 15 is required in every embodiment.

Reference is now made to Fig. 16. In step **S101**, surgical system **999** is operated in a first operating mode. In step **S121**, surgical system **999** is operated in a second operating mode. As discussed elsewhere, in different embodiments the first and/or second operating mode may relate to specific capabilities of and/or specific restrictions on one or more of the input devices. Alternatively or additionally, the first and/or second operating mode may relate to specific capabilities of and/or specific restrictions on one or more of

elements of the arm **102** and/or objects **1530**. Examples of such elements include joints and articulators. Alternatively or additionally, the first and/or second operating mode may relate to a relationship between operation of one or more input devices **1510** and arm **102** or one or more components thereof – e.g. whether or not a configuration of an input
 5 device **1510** or component thereof is translated into a speed or a position of arm **102** or component thereof.

While surgical system **999** is operated in the first mode in step **S101**, one or more operations are performed. In one example, when surgical system is operated in the first mode, a distal portion of arm **102** is retroflexed, possibly starting from an unflexed and/or
 10 straight position but not necessarily so. In another example, when the surgical system **999** is operated in the first mode, a distal portion of arm **102** is brought so a curve shape thereof, e.g. the curve shape in 3D or a planar projection thereof, matches a pre-determined curve shape, for example, one that is. useful for commencing surgical operations such as a retroflex shape or an “S” curve-shape.

15 Step **S109** relates to monitoring and may be performed concurrent with step **S101**. For example, step **S109** may be performed at least in part by detector **1520**. In some embodiments, the monitoring of step **S109** may include determining whether or not the arm is in a retroflex position.

Step **S113** relates to mode-transition trigger events – i.e. a detectable event whose
 20 detection triggers a mode-transition of surgical system **999** from the first mode of step **S101** to the second mode of step **S121**. One example of step **S113** is as follows: in response to, and contingent upon a detecting, e.g. by detector **1520**, that arm **102** is in a retroflex position, i.e., a detecting that the arm **102** has transitioned from a non-retroflex position to a retroflex position, the surgical system **999** transitions from the first to the
 25 second operating mode. As discussed hereinabove, the transition can include an alignment calibration of the surgical arm **102** with an input arm **701**.

The transitioning of step **S117** may, for example, be triggered by and/or in response to and/or contingent upon detecting that the arm **102** has retroflected, or that an end effector **1530** is in a retroflex position.

Discussion of First mode of S101 vs Second mode of Step S121

In some embodiments, step **S101** may provide the one or more of the following features, singly or in combination:

(A1) the configuration of arm **102** or at least a distal section thereof is controlled
 5 by user input device **1510A** and can be responsive to electronic control-output from the user input device **1510A**. In some embodiments, user input device **1510A** can be a first user-input device, such as a thumbstick **501**, and in other embodiments user input device **1510A** can be a single same user-input device **1510A/1510B** such as a joystick **701**.

(A2) while the surgical system is in the first mode (e.g. to perform the retroflexing),
 10 configuration of the arm is controlled by output of a user input device (e.g. a thumbstick device **501**) such that a magnitude (i.e. magnitude of the displacement from a base position and/or initial and/or starting and/or center position) as opposed to a speed of the displacement) of a displacement of an user input device or of a displaceable portion (e.g. located on tiltable nipple **409** or **509**) thereof is translated to a speed of a flexion and/or of
 15 a rotation of an arm joint such as elbow **2103**;

(A3) while the surgical system is in the first mode (e.g. to perform the retroflexing), configuration of the arm is controlled by output of a user input device such that a position of an element of user input device selected from a plurality of candidate positions (e.g. defined by multiple possible tilt angles of the nipple or equivalent) of the element of the
 20 user input device (e...g. thumbstick) specifies (e.g. commands) a target-velocity for movement of an element of the arm selected from a plurality of candidate velocities (e.g. the greater the tilt of the nipple, the greater the velocity);

(A4) while the surgical system is in the first mode, configuration of the arm is controlled by output of a user input device such that the controlling user input device has
 25 multiple positions or configurations, wherein (i) for a subset of the multiple positions or configurations, each one specifies movement in the same flexion plane or rotational direction, (ii) a first position or configuration specifies/commands a first speed and (iii) a second position or configuration specifies (e.g. commands) a second speed which exceeds the first speed.

(A5) control circuitry of the surgical system is effective, while the surgical system is in the first operating mode, to restrict the actuation of arm joints other than the single arm joint.

Second operating mode: In some embodiments, step **S121** may provide the one or
5 more of the following features, singly or in combination:

(B1) the configuration of arm **102** or at least a distal section thereof is controlled by user-input device **1510B** (e.g. joystick **701**) – e.g. responsive to control output from the user input device **1510B**;

(B2) while the surgical system is in the second mode, e.g., to perform the surgical
10 operation, a configuration of the arm **102** is controlled by output of user-input device **1510B** such that a magnitude of a displacement of the given input device or of a displaceable portion thereof is translated to a corresponding displacement of at least one portion of the arm and/or of at least one arm segment of the arm - for example, in Fig.
10 a displacement of shoulder element **703** of joystick **701** may be translated into a
15 corresponding displacement of shoulder joint **2101** of arm **102** and/or for example, in Fig.
10 a displacement of elbow element **705** of joystick **701** may be translated into a corresponding displacement of elbow joint **2103** of arm **102**;

(B3) while the surgical system (e.g. to perform the surgical operation) is in the second mode, a configuration of the arm is controlled by output of the user control device
20 such that a magnitude of a displacement of a the given input device or of a displaceable portion specifies (e.g. completely specifies ; e.g. commands) a destination position of an arm element (i.e. different from a currently prevailing position) and/or a destination configuration (e.g. different from a currently prevailing configuration) of the arm.

First and Second operating mode: In some embodiments, steps **S101** and **S121** may
25 collectively provide the one or more of (e.g. any combination of) following salient features:

(C1) In some embodiments, a first input device **1510A** (e.g. thumbstick) of the input-device array **1500** controls actuation of the single arm joint (e.g. elbow **2103**) while the surgical system is in the first operating mode, and a second input device **1510B** (e.g. joystick) of the input-device array **1500** controls actuation of the plurality of arm joints

(e.g. elbow **2103** and shoulder **2101**) while the surgical system is in the second operating mode.

(C2) In some embodiments, the array of input devices includes first **1510A** (e.g. thumbstick **501**) and second **1510B** (e.g. joystick **701**) input devices; (ii) the first input
 5 device is configured for controlling actuation of the single arm joint (e.g. elbow **2103**) and is not configured for controlling actuation of arm joints (e.g. shoulder **2101**, etc) other than the single arm joint (e.g. elbow **2103**); (iii) the second input device controls actuation of the plurality of arm joints (e.g. both elbow **2103** and shoulder **2101**) while in the second operating mode; (iv) the control circuitry is effective, while the surgical system is in the
 10 first operating mode, to achieve the restricting by permitting control of the arm **102** by the first input device **1510A** while disabling control of the arm by the second input device **1510B**. Thus, the transition from the first operating mode to second operating mode (e.g. into step **S121**) may ‘handoff’ control from the first **1510A** to the second **1510B** user input devices.

15 (C3) In some embodiments, both user-input devices **1510A**, **1510B** are the same user-input device, e.g., a joystick **701** or similar articulated device, i.e., a device having segment members and segment joints that correspond to arm segments and arm joints of an arm **102**.

A number of embodiments of Fig. 16 are now described. The skilled artisan will
 20 appreciate that these embodiments are not required to be mutually exclusive – the embodiments or features thereof may be combined. In some embodiments, not all of the features and/or method steps need be present.

A first embodiment of Fig. 16

A first embodiments relates to a method of operating a surgical system comprising (i) an
 25 input-device array of one or more user-input devices and (ii) an articulated mechanical arm comprising a surgical end effector at a distal end thereof and a plurality of arm joints configured to flex and rotate in response to an electronic control-output from said user-input device, the method comprising: (a) commencing operation of the surgical system in a first operating mode **S101** defined with respect to a given single one (e.g. elbow **2103**)

of the arm joints, wherein the first mode precludes actuation of any arm joint (e.g. including shoulder **2101**) of the arm that is not the given single arm joint, and permits controlling the actuation of the single arm (e.g. elbow **2103**) joint to cause a flexion of and a rotation of the single arm joint (e.g. elbow **2103**); (b) while the surgical system is in the first operating mode (e.g. of **S101**), (i) retroflexing the distal end of the arm by flexion and rotation of the single arm joint (e.g. elbow **2103**), in response to control signals generated by one or more of the user-input devices (e.g. thumbstick **501**), so as to bring the end effector **174** to a retroflex operating position, and (ii) monitoring a status (e.g. **S109**) of the mechanical arm **102** to detect whether or not the arm is in a retroflex position; (c) in response to and contingent upon (in step **S113**) detecting that the arm **102** is in a retroflex position, transitioning operation (e.g. 'yes branch' from **S113** to **S121**) of the surgical system from the first mode to a second mode in which the system is enabled to control flexing and rotating of at least one first-mode-precluded arm joint (e.g. elbow **2103**) in accordance with respective degrees of freedom of each arm joint; and (d) operating the surgical system in the second mode (e.g. in **S121**) so as to perform a surgical action using the end effector.

A second embodiment of Fig. 16

A method of operating a surgical system comprising (i) first **1510A** (e.g. thumbstick **501**) and second **1510B** (e.g. joystick **701**) user-input devices, and (ii) an articulated mechanical arm **102** comprising a plurality of arm joints (e.g. elbow **2103** and shoulder **2101**), and a surgical end effector **174** at the distal end of the arm, the method comprising: (a) commencing operation of the surgical system in a retroflexing mode (e.g. first mode of **S101**) wherein, with respect to flexing and rotation of the arm joints: (i) the first **1510A** (e.g. thumbstick **501**) user-input device is active to direct flexion and rotation of only a given one of the arm joints, and (ii) the second **1510B** (e.g. joystick **701**) user-input device is disabled; (b) while in the retroflexing mode by flexion and rotation of the given one (e.g. elbow **2103**) of the arm joints, retroflexing a distal portion of the articulated mechanical arm, responsive to electronic control-output from the first user-input device **1510A** so as to bring the end effector to a retroflex operating position; (c) transitioning the surgical system from the retroflexing mode to a surgical-operation mode to enable the second user-input device **1510B** with respect to flexing and rotating at least one (e.g. shoulder **2101**) of

the arm joints of the arm other than the given one (e.g. elbow **2103**) of the arm joints; and
 (d) while in the surgical-operation mode, effect flexing and rotating of at least two of the
 arm joints (e.g. shoulder and elbow) in accordance with respective degrees of freedom of
 each arm joint, responsive to electronic control-output from the second user-input device
 5 **1510B**, to thereby move the surgical end-effector to perform one or more surgical actions.

A third embodiment of Fig. 16

A method of operating a surgical system that comprises (i) an input-device array **1500** of
 one or more user-input devices, and (ii) an articulated mechanical arm **102** comprising a
 plurality of arm joints (e.g. shoulder **2101** and elbow **2103**, and a surgical end effector **1764**
 10 at a distal end of the arm, the method comprising: (a) commencing operation of the surgical
 system in a retroflexing mode (e.g. **S101**) wherein, with respect to flexing and rotation of
 the arm joints, the input-device array is active to direct flexion and rotation of only a given
 one (e.g. elbow **2103**) of the arm joints; (b) while in the retroflexing mode, retroflexing a
 distal portion of the articulated mechanical arm by flexion and rotation of the given one of
 15 arm joints, responsive to electronic control-output from the input-device array, so as to
 bring the end effector to a retroflex operating position; (c) transitioning the surgical system
 from the retroflex mode to the surgical-operation mode to enable the input-device array
 with respect to flexing and rotating of the arm joints other than the given one of the arm
 joints; and (d) while in the surgical-operation mode, effect flexing and rotating of at least
 20 two (e.g. at least both elbow **2103** and shoulder **2101**) of the arm joints in accordance with
 respective degrees of freedom of each arm joint, responsive to electronic control-output
 from the input-device array, to thereby move the surgical end-effector to perform one or
 more surgical actions.

A fourth embodiment of Fig. 16

25 A method of operating a surgical system comprising (i) a user-input device (e.g. joystick
701), and (ii) an articulated mechanical arm **102** comprising a plurality of arm joints, and
 surgical end effector at a distal end of the arm, the method comprising: (a) commencing
 operation of the surgical system in a retroflexing mode (e.g. **S101**) wherein, with respect
 to flexing and rotation of the arm joints, the user-input device is active to direct flexion and
 30 rotation of only a given one (e.g. elbow) of the arm joints; (b) while in the retroflexing

mode, retroflecting a distal portion of the articulated mechanical arm by flexion and rotation of the given one of the arm joints, responsive to electronic control-output from the user-input device, so as to bring the end effector to a retroflex operating position; (c) transitioning the surgical system from the retroflex mode to the surgical-operation mode
5 (e.g. **121**) to enable the user-input device with respect to flexing and rotating at least one of the arm joints of the arm other than the given one of the arm joints; and (d) while in the surgical-operation mode, effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the user-input device, to thereby move the surgical end-effector to
10 perform one or more surgical actions.

A fifth embodiment of Fig. 16

A method of using a surgical system, the method comprising: (a) providing an articulated mechanical arm capable of displacing a surgical end effector **174** at a distal end thereof, the arm comprising a plurality of arm segments connected (e.g. serially) by a
15 corresponding plurality of arm joints (e.g. elbow and shoulder) configured to flex and rotate in response to an electronic control-output from a user-input device; (b) maneuvering the end effector to a retroflex operating position while operating in a first input mode in which a displacement of an input device (e.g. **1510A** such as thumbstick) or of a displaceable portion thereof is translated to a speed of a flexion and/or of a rotation of an arm joint; (c)
20 in response to and contingent upon detecting that the end effector is in the retroflex operating position, transitioning from operating in the first input mode to operating in a second input mode in which a displacement of an input device (e.g. **1510B** such as joystick) or of a displaceable portion thereof is translated to a corresponding displacement of at least one arm segment; and (d) after the transitioning and while operating in the second input
25 mode, performing a surgical action using the end effector.

The present invention has been described using detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the present
30 invention utilize only some of the features or possible combinations of the features.

Variations of embodiments of the present invention that are described and embodiments of the present invention comprising different combinations of features noted in the described embodiments will occur to persons skilled in the art to which the invention pertains.

Additional Discussion

5 According to an aspect of some embodiments there is provided a method of controlling via one or more input device, one or more surgical mechanical arms insertable into a body of a patient, each surgical mechanical arm comprising a plurality of movable joints; the method comprising: in a first mode of operation, navigating the surgical mechanical arms into the patient's body; in a second mode of operation, carrying out
10 surgical acts using the surgical mechanical arms; wherein in the first mode of operation movement of each of the surgical mechanical arms is restricted to movement of a single joint out of the plurality of joints , and to linear movement of the surgical mechanical arm as a single unit.

 In some embodiments, navigating comprises retroflecting the surgical mechanical
15 arms within the patient's body.

 In some embodiments, in the first mode of operation the surgical mechanical arms are controlled by thumb operated input.

 In some embodiments, in the second mode of operation the surgical arms are controlled by avatar input arms.

20 In some embodiments, the surgical mechanical arms are controlled by haptic handles during both the first and the second modes of operation.

 In some embodiments, in the first mode of operation manipulation of the input device by a user is translated to a speed of movement of the surgical mechanical arm, and in the second mode of operation displacement of the input device by the user is translated
25 to a relative displacement of the surgical mechanical arm.

 In some embodiments, in the second mode of operation a clutch-like mode is enabled, disconnecting control of the surgical arm by the one or more input device.

In some embodiments, there is provided a control console for control of one or more surgical mechanical arms, comprising: thumb operated input for controlling the first mode of operation; hand operated input for controlling the second mode of operation; and a screen interface.

5 In some embodiments, the thumb operated input comprises a nipple engagable by the user's thumb; whereby pushing of the nipple from a central rest position actuates respective movement of the surgical mechanical arm; and wherein a speed of the movement is affected by an extent in which the nipple was pushed relative to its rest position.

10 In some embodiments, in the second mode of operation manipulation of the hand operated input by a user is translated to a similar articulation of the surgical arm.

According to an aspect of some embodiments there is provided a method for operating a patient, comprising: introducing one or more surgical arms through the vagina into the abdominal cavity; bending the one or more surgical arms to a retroflected position, wherein during introducing and bending, articulation of the one or more surgical arms is limited to linear movement and to movement of a single arm joint only; and operating within the abdominal cavity using the one or more surgical arms in the retroflected position.

20 In some embodiments, wherein during linear movement the surgical arm moves as a single unit, and wherein movement of a single arm joint comprises flexion and extension of an elbow joint.

A general aspect of some embodiments of the invention relates to control of one or more surgical mechanical arms using a first mode of operation for navigation of the arms to a selected location and position within the patient's body, and a second mode of operation for performing surgical acts within the selected location. In some embodiments, control at the first mode involves translating a user (e.g. surgeon) manipulation of an input arm (e.g. an avatar arm, a joystick) into a respective articulation of the surgical arm, whereby the speed of movement of the surgical arm changes as the extent of manipulation of the input arm relative to a rest position of the input arm changes.

In some embodiments, control at the second mode involves translating a user manipulation of an input arm into a respective position of the surgical arm, for example so that the position is set directly according to the input arm position (e.g. identical articulation). In some embodiments, a user's displacement of the input arm is translated
 5 to a relative displacement command to the surgical arm. In some embodiments, the second mode includes a different control, for example one in which a user's extent of manipulation of the input arm is in a different proportion to similar movement carried out by the surgical arm.

In some embodiments, movement of the surgical arm at the first mode is
 10 restricted, for example providing only for flexion and/or extension of an elbow joint of the surgical arm, and for linear movement of the surgical arm as a single unit. Optionally, other joints of the surgical arm (e.g. shoulder joint, wrist joint) are held stationary, optionally locked in position. Alternatively, at least a partial, limited movement of one or more other joints is allowed.

In some embodiments, introducing of the surgical arms into the body (e.g. through the vagina), navigation of the arms (e.g. into the abdomen) and optionally retroflexion of the surgical arms is carried out when the surgical arms are controlled using the first operation mode. A potential advantage of restricting articulation of the surgical arm during introducing of the arm and/or during retroflexion of the arm may
 15 include reducing a bending radius of the surgical arm, thereby reducing a likelihood of encountering surrounding obstacles such as the inner abdominal wall. Another potential advantage of restricting articulation of the surgical arm during navigation and/or retroflexion processes may include improved control over the surgical arms. In some embodiments, the first operation mode (speed control mode) allows a user to
 20 continuously control movement of the surgical arms, even during retroflexion of the arms, when relative directions (e.g. upwards and downwards) are reversed.

In some embodiments, a system configured for controlling the surgical arms at both modes includes dual control means, including two different sets of controls. In some embodiments, a first control set is used for insertion of the surgical arms into the body,
 30 and a second control set is used for performing surgical acts inside the body.

Alternatively, both sets are used for at least one of the stages (insertion and surgery); alternatively, only one set is used for both stages.

In some embodiments, the first mode is controlled by a set of thumbsticks. Optionally, an extent of pushing of a nipple of each thumbstick relative to a central rest
5 position of the nipple affects a speed in which an arm articulation takes place. Optionally, the nipple springs back to its rest position when the user lifts their thumb. In some embodiments, the second operation mode is controlled using a set of avatar input arms, manipulated by the user's hands.

Additionally or alternatively, a set of haptic handles (including for example 2
10 handles, one for control of each surgical arm) are used for carrying out both modes of operation. Optionally, at the first mode of operation, the handles are set to provide counter resistance to user movement, optionally spring-like resistance, in response to moving the arm away from its rest position. Optionally, at the second mode of operation, the haptic
handles are set (for example pre-programmed) to provide selected or changing resistance
15 in response to manipulation by the user.

Additional discussion

We now refer to Figs. 17A-C.

In some embodiments, control of the one or more surgical arms is achieved via one or more input arms, joysticks, control handles, and/or other means suitable for
20 manipulation by a user (e.g. a surgeon) which is then translated into a matching articulation of the surgical arm(s).

In the example described herein, as referred to in the flowchart of FIG.17A, some embodiments include dual-control of the surgical arms. In some embodiments, a first user input (in this example, thumbsticks **4005** of Fig. 17B) is used for introducing the surgical
25 arms into the patient body, for example through the vagina, and then for retroflecting the surgical arms (**4001**). In some embodiments, retroflecting (for example, bending backwards) of the surgical arms within the patient body is performed to reduce an area within which the surgical arm is located. Optionally, retroflecting is performed during a surgical procedure to avoid obstacles such as certain organs or portions thereof, for

example, an inner wall of the abdomen. Optionally, retroflecting is performed to position the surgical arms at an orientation in which a laparoscopic surgeon is familiar with, for carrying out the operation.

In some embodiments, a second user input, in this example in the form of input
5 arms **4011** (e.g. avatar joysticks) is then used for performing the rest of the surgical procedure (**4003**).

In some embodiments, thumbsticks **4005** are positioned adjacent the control console screen **4007**, for example on opposing sides of the screen. In some embodiments, each of the thumbsticks **4005** comprises a nipple type controller **4009** shaped and sized for
10 the user's thumb. In some embodiments, the nipple of the thumbsticks is at rest position when centered, and is configured to spring back to the rest position upon release of the thumb. In some embodiments, the extent of movement of the nipple relative to its central rest position determines a resulting velocity of the surgical arm movement. For example,
15 of the movement of the surgical arm (and vice versa- the closer the nipple is to its central rest position, the lower the velocity of the arm).

In some embodiments, when controlling the surgical arms via the thumbsticks, one or more of the surgical arm joints (e.g. a shoulder joint, a wrist joint) are restricted from movement. In some embodiments, all surgical arm joints except an elbow joint are
20 prevented from moving, and only flexion and/or rotation of the elbow joint are enabled. In some embodiments, linear movement of the surgical arm (as a single body) is also enabled, for example to advance or retract the arm. In some embodiments, movement of the nipple actuates flexion and/or rotation of the elbow joint. In some embodiments, linear movement of the arm is actuated by separate actuators, for example using push buttons such as **4006**,
25 **4008**, configured for example along a body of the thumbstick **4005**. In an example, button **4006** advances the surgical arm distally (e.g. into the abdomen); button **4008** retracts the surgical arm proximally.

In some embodiments, during use of the thumbsticks, the input arms **4011** are locked at a rest position, for example by solenoid locks. In some embodiments, the rest
30 position of the input arms is selected as the retroflected position. Optionally, this position

allows the surgeon to continue the procedure directly following retroflexion using the thumbsticks. In some embodiments, when the input arms are operated, operation of the thumbsticks is disabled.

5 A potential advantage of using the thumbsticks for navigation into the body and for retroflexing the surgical arms while selected arm joints such as the shoulder joint remain stationary may include reducing a bending radius of the surgical arm, thereby reducing a likelihood of encountering surrounding obstacles such as the inner abdominal wall. Another potential advantage of using the thumbsticks for navigation and/or retroflexion processes may include improved control over the surgical arms, for example as compared
10 to navigating and retroflexing with the input arms in which the ergonomics of the handle may be less suitable for supporting the rotational movement that the surgeon needs to perform while holding the handle in order to carry out retroflexion.

In some embodiments, during introducing of the surgical arms into the body the surgical arms are straight (optionally to provide for insertion via a cannula), while the input
15 arms are at a rest, locked, retroflexed position. Optionally, following retroflexion of the surgical arms using the thumbsticks, the surgeon releases the thumbsticks and moves their hands to the input arms. Once the input arms are grasped and optionally lifted by the surgeon, control over the surgical arms is automatically gained, and the surgeon may continue the procedure using the input arms. In some embodiments, when one or more
20 input arm joints are locked by solenoid locks, lifting of the input arm by the surgeon automatically releases the solenoid locks. Additionally or alternately, manual locks of the input arm joints are released, for example via a sensor that detects an input arm position.

In some embodiments, the system (e.g. a system processor) is configured to recognize one or more positions of the input arms, for example when the input arms are at
25 their rest position, and optionally display to the current position to the user.

We now refer to Fig. 18. In some embodiments, haptic handles which provide force feedback to the user (a suitable example of which being the ‘omega.7’ haptic device available from Force Dimension of Nyon, Switzerland) are used throughout the operation for controlling movement and articulation of the surgical arms. In some embodiments, the
30 haptic handles are set to provide counter resistance for preventing the user from moving

in directions that are not supported by the surgical arm, for example bending the elbow joint of the surgical arm backwards; touching a joint (e.g. an elbow joint) with a different segment of the same arm; and/or other. In some embodiments, the handles are set to provide counter resistance which varies in accordance with a current anatomical position and/or orientation of the surgical arms. In an example, resistance may be increased if the user attempts a disallowed anatomical area, such as an organ that should be avoided.

In some embodiments, the haptic handles are programmed to operate according to various control modes. Optionally, the control mode is selected in accordance with a current stage in the surgical operation. In some embodiments, switching between different modes is performed via one or more of a screen interface, one or more buttons on the control console or handles, a foot pedal, and/or other.

In some embodiments, during a first stage of the procedure, during which the surgical arms are introduced into the patient body and optionally retroflected, the haptic handles are used in “speed-control” mode (**5001**). Optionally, in the speed-control mode, relative movement of a handle with respect to the handle rest position sets the speed in which the surgical arm is moved. As the user moves the handle further away from the rest position, the speed is raised, and vice versa. For example, movement of the handle to the right of its rest position may result in rotation of an arm joint (e.g. elbow joint) to the right, at a speed determined according to the distance of the handle from its rest position. In some embodiments, in the speed-control mode, the haptic handles are set to provide an elastic (spring-like) counter resistance to the movement of the user. In some embodiments, in the speed control mode, a control algorithm is applied, converting a current configuration of the haptic handle into speed commands issued to the actuators (e.g. motors) of the surgical arm, such as to increase a rotation speed of one or more motor gears.

A potential advantage of using the speed control mode during introducing and optionally retroflecting the surgical arms in the body may include that during retroflecting the directions are reversed (e.g. upwards/downwards), yet that change can be ignored and the motion can be naturally continued, since the resulting movement of the surgical arms is limited and what changes is the speed of movement.

In some embodiments, during a second stage of the surgical procedure, optionally during the rest of the procedure, the haptic handles are set to “position- control” mode (5003). Optionally, in the position control mode, a spatial position of the handles sets a respective position of the surgical arms. In the position control mode, a user’s displacement
5 of the haptic handle is translated to a relative displacement command to the surgical arm. In some embodiments, converting the displacement of the haptic handle is controlled according to an algorithm. In some embodiments, control is according to known algorithms (e.g. the Inverse Jacobian algorithm). Additionally or alternatively, in some embodiments, control is according to custom algorithms. In an example, a custom algorithm is set to scale
10 the user’s motion, such as to increase accuracy of movement. Such scaling may include amplifying the movement required on the user end by a selected coefficient to produce a similar non-amplified movement of the surgical arm. For example, the for the arm to move a distance X , the user will need to move the handle by $A * X$ ($A > 1$). In another example, an algorithm is selected to filter signals, for example filtering using a low-pass filter to reduce
15 user hand tremors.

In some embodiments, in the position control mode, a clutch mechanism is provided, allowing a user to temporarily disconnect from the surgical arm (such that movement of the input haptic handle no longer controls the surgical arm). Optionally, when disconnected, the user may freely re-position the haptic handle. In an example, the user re-
20 positions the haptic handle to a position and/or orientation in which it is more comfortable for the user to carry out and control the next movement.

In some embodiments, the extent of resistance sensed by the user in response to movement of the handles is selected and controlled. In an example, a floating mode is set, in which the user substantially does not encounter resistance and is free to move the handle
25 in all directions. Additionally or alternatively, a level of resistance sensed by the user is adjusted, for example so that the user senses a high resistance in response to one movement and a low or no resistance in response to another movement.

In some embodiments, the amount of resistance is controlled based on the anatomical location of the surgical arms. For example, a high resistance may be set where
30 obstacles (e.g. the abdominal wall) are found near the surgical arm. In a specific example,

if an obstacle is found on the right of the surgical arm, the user may encounter high resistance in response to moving the handle to the right; if no obstacles are found on the left of the arm, the user may encounter low or no resistance in response to moving the handle to the left. Optionally, the extent of resistance is defined by setting system
5 definitions such as producing wall type resistance, rubber like resistance, sand type resistance and/or other.

Any feature or combination of features described in the present document may be combined with any feature or combination of features described in US Patent Application Ser. No. 16/121,704 filed on Sep. 5, 2018 and published as US Patent Publication
10 US20190000574A1; US Patent Application Ser. No. 16/377,280 filed on April 8, 2019 and published as US Patent Publication US201902314445; US Patent Application Ser. No. 15/915,237 filed on March 8, 2018 and published as US Patent Publication US20180256246A1; and US Patent Application Ser. No. 15/454,123 filed on Mar. 9, 2017 and published as US Patent Publication US20170258539A1; U.S. patent application Ser.
15 No. 15/501,862 filed on Feb. 6, 2017 and published as US Patent Publication US20170239005A1; all of which are hereby incorporated by reference herein as if fully set forth in their entirety.

In the description and claims of the present disclosure, each of the verbs, "comprise", "include" and "have", and conjugates thereof, are used to indicate that the
20 object or objects of the verb are not necessarily a complete listing of members, components, elements or parts of the subject or subjects of the verb. As used herein, the singular form "a", "an" and "the" include plural references unless the context clearly dictates otherwise. For example, the term "a marking" or "at least one marking" may include a plurality of markings.

25

CLAIMS

1. A method of operating a surgical system comprising (i) an articulated mechanical arm comprising a plurality of arm joints, and (ii) first and second user-input devices for
5 controlling the arm, and (iii) a surgical end effector at the distal end of the arm, the method comprising:
 - a. commencing operation of the surgical system in a retroflexing mode wherein, with respect to flexing and rotation of the arm joints: (i) the first user-input device is active to direct flexion and rotation of only a given one of the arm
10 joints, and (ii) the second user-input device is disabled;
 - b. while in the retroflexing mode, retroflecting a distal portion of the articulated mechanical arm by flexion and rotation of the given one of the arm joints, responsive to electronic control-output from the first user-input device so as to bring the end effector to a retroflex operating position;
 - 15 c. transitioning the surgical system from the retroflexing mode to a surgical-operation mode to enable the second user-input device with respect to flexing and rotating at least one of the arm joints of the arm other than the given one of the arm joints; and
 - d. while in the surgical-operation mode, effect flexing and rotating of at least two
20 of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the second user-input device, to thereby move the surgical end-effector to perform one or more surgical actions.
2. The method of claim 1, wherein the surgical system additionally comprises control
25 circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the single arm joint.

3. The method of either one of claims 1 or 2, wherein the transitioning includes calibrating the input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.
4. The method of any one of claims 1 to 3, wherein the first input device is configured
5 for controlling actuation of the single arm joint and is not configured for controlling actuation of arm joints other than the single arm joint.
5. The method of any one of claims 1 to 4, wherein the transitioning to the surgical-operation mode is in response to and contingent upon detecting that the arm is in a retroflex position.
- 10 6. A surgical system comprising:
 - a. an articulated mechanical arm comprising a plurality of arm joints, and a surgical end effector at a distal end of the arm; and
 - b. first and second user-input devices for controlling the arm,wherein the surgical system is configured to operate, asynchronously, in (i) a
15 retroflex mode in which a distal portion of the articulated mechanical arm is operative to be retroflected, responsive to electronic control-output from the first user-input device, so as to bring the end effector to a retroflex operating position , and in (ii) a surgical-operation mode in which at least two of the arm joints are operative to be flexed and rotated, responsive to electronic control-output from the
20 second user-input device, so as to thereby move the surgical end-effector to perform one or more surgical actions, such that:
 - A. while in the retroflexing mode, with respect to flexing and rotation of the arm joints, the first user-input device is active to direct flexion and rotation of only a given one of the arm joints, and the second
25 user-input device is disabled, and
 - B. while in the surgical-operation mode, the second user-input device is enabled with respect to flexion and rotation of at least one of the

arm joints of the arm other than the given one of the arm joints, in accordance with respective degrees of freedom of each arm joint.

7. A method of operating a surgical system, the surgical system comprising (i) a user-input device, and (ii) an articulated mechanical arm comprising a plurality of arm joints, and surgical end effector at a distal end of the arm, the method comprising:

- a. commencing operation of the surgical system in a retroflexing mode wherein, with respect to flexing and rotation of the arm joints, the user-input device is active to direct flexion and rotation of only a given one of the arm joints;
- b. while in the retroflexing mode, retroflexing a distal portion of the articulated mechanical arm by flexion and rotation of the given one of the arm joints, responsive to electronic control-output from the user-input device, so as to bring the end effector to a retroflex operating position;
- c. transitioning the surgical system from the retroflex mode to the surgical-operation mode to enable the user-input device with respect to flexing and rotating at least one of the arm joints of the arm other than the given one of the arm joints; and
- d. while in the surgical-operation mode, effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the user-input device, to thereby move the surgical end-effector to perform one or more surgical actions.

8. The method of claim 7, wherein the surgical system additionally comprises control circuitry effective, while the surgical system is in the retroflexing mode, to restrict the actuation of arm joints other than the given one of the arm joints.

9. The method of claim 8, wherein the restricting is by disabling actuation of arm joints of the arm other than the given one of the arm joints.

10. The method of any one of claims 7 to 9, wherein the user-input device controls the actuation of the plurality of arm joints in both the retroflexing mode and the surgical-operation mode.

11. The method of any one of claim 7 to 10, wherein the user-input device is precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other than the given one of the arm joints.
12. The method of any one of claims 7 to 11, wherein the transitioning to the surgical-
5 operation mode is in response to and contingent upon detecting that the arm is in a retroflex position.
13. The method of any one of claims 7 to 12, wherein the transitioning includes calibrating the user-input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm.
- 10 14. The method of any one of claims 7 to 13, additionally comprising, following the operating in the second mode: unflexing the distal end of the arm, so as to bring the arm to an unflexed position.
15. A surgical system comprising:
- a. a user-input device; and
 - 15 b. an articulated mechanical arm comprising (i) a plurality of arm joints and (ii) a surgical end effector at a distal end of the arm,
- wherein the surgical system is configured to operate, asynchronously, in (A) a retroflexing mode in which a distal portion of the articulated mechanical arm is retroflected, responsive to electronic control-output from the user-input device, so
20 as to bring the end effector to a retroflex operating position, and in (B) a surgical-operation mode in which at least two of the arm joints are flexed and rotated, responsive to electronic control-output from the user-input device, so as to thereby move the surgical end-effector to perform one or more surgical actions, such that:
- 25 A. while in the retroflexing mode, with respect to flexing and rotation of the arm joints, the user-input device is active to direct flexion and rotation of only a given one of the arm joints, and
 - B. while in the surgical-operation mode, the user-input device is enabled with respect to flexion and rotation at least one of the arm joints of the

arm other than the given one of the arm joints, in accordance with respective degrees of freedom of each arm joint.

16. A method of operating a surgical system comprising (i) an articulated mechanical arm comprising a surgical end effector at a distal end thereof and a plurality of arm joints and (ii) an input-device array of one or more user-input devices, wherein the arm joints are configured to flex and rotate in response to an electronic control-output from one or more user-input devices of the input-device array, the method comprising:

- a. commencing operation of the surgical system in a first operating mode defined with respect to a given single one of the arm joints, wherein the first operating mode precludes actuation of any arm joint of the arm that is not the given single arm joint, and permits controlling the actuation of the single arm joint to cause a flexion of and a rotation of the single arm joint;
- b. while the surgical system is in the first operating mode,
 - i. retroflexing the distal end of the arm by flexion and rotation of the single arm joint, in response to control signals generated by one or more of the user-input devices of the input-device array, so as to bring the end effector to a retroflex operating position, and
 - ii. monitoring a status of the mechanical arm to detect whether or not the arm is in a retroflex position;
- c. in response to and contingent upon detecting that the arm is in a retroflex position, transitioning operation of the surgical system from the first operating mode to a second operating mode in which the system is enabled to control flexing and rotating of at least one first-mode-precluded arm joint in accordance with respective degrees of freedom of each arm joint; and
- d. operating the surgical system in the second operating mode so as to perform a surgical action using the end effector.

17. The method of claim 16, wherein the surgical system additionally comprises control circuitry effective, while the surgical system is in the first operating mode, to restrict the actuation of arm joints other than the single arm joint.
18. The method of claim 17, wherein the restricting is by disabling actuation of arm joints
5 of the arm other than the single arm joint.
19. The method of claim 17, wherein the input device is precluded from generating or transmitting control outputs that would control actuation of arm joints of the arm other than the single arm joint.
20. The method of claim 17, wherein the restricting includes disabling a capability of the
10 first input device.
21. The method of claim 17 wherein (i) a first input device of the input-device array controls actuation of the single arm joint while the surgical system is in the first operating mode, and a second input device controls actuation of the plurality of arm joints while the surgical system is in the second operating mode and (ii) the restricting
15 is by providing a first input device that is configured for controlling actuation of the single arm joint and that is not configured for controlling actuation of arm joints other than the single arm joint.
22. The method of any one of claims 16 to 21, wherein the transitioning includes calibrating the input device with respect to at least one of a position and an
20 orientation of the end effector or of a distal portion of the arm.
23. The method of any one of claims 16 to 22, wherein a first input device of the input-device array controls actuation of the single arm joint while the surgical system is in the first operating mode, and a second input device of the input-device array controls actuation of the plurality of arm joints while the surgical system is in the second
25 operating mode.
24. The method of claim 23, wherein the transitioning includes calibrating the second input device with respect to at least one of a position and an orientation of the end effector or of a distal portion of the arm

25. The method of claim 16, wherein a single user-input device controls the actuation of the plurality of arm joints in both the first operating mode and the second operating mode.
26. The method of any one of claims 16 to 25, wherein the surgical system additionally
5 comprises a control console including a display screen, and at least one user-input device of the input-device array is disposed on or in proximity to the display screen.
27. The method of any one of claims 16 to 26, wherein an additional user-input device for actuating linear advancement and retraction of the arm is disposed upon, co-located with, or in proximity to, at least one user-input device of the input-device array.
- 10 28. The method of any one of claims 16 to 27, wherein the retroflex operating position is at, or in proximity to, a surgical worksite.
29. The method of any one of claims 16 to 28, wherein the operating in the second mode is with the arm in the retroflex position.
30. The method of any one of claims 16 to 29, additionally comprising, following the
15 operating in the second mode: unflexing the distal end of the arm, so as to bring the arm to an unflexed position.
31. A surgical system for use with a surgical end effector and configured to operate, asynchronously, in a first operating mode and a second operating mode, the system comprising:
- 20 a. an input-device array of one or more user-input devices; and
- b. an articulated mechanical arm comprising a surgical end effector at the distal end thereof, and a plurality of arm joints configured to flex and rotate in response to a control signal generated by one or more input devices of the input-device array,
- wherein:
- 25 iii. the first operating mode is defined with respect to a given single one of the arm joints, wherein the first operating mode precludes actuation of any arm joint of the arm that is not the given single arm joint, and permits controlling

the actuation of the single arm joint to cause a flexion and a rotation of the single arm joint,

- iv. the system is configured to retroflex the distal end of the arm while in the first operating mode by actuating the single arm joint to cause a flexion of and a rotation of the single arm joint, in response to an electronic control-output from one or more of the user-input devices of the input-device array, so as to bring the surgical end effector to a retroflex operating position,
- v. the second operating mode is defined with respect to the plurality of arm joints, wherein the second operating mode enables controlling the actuation of at least one of the first-mode-precluded arm joints in accordance with respective degrees of freedom of each arm joint, and
- vi. the system is configured to transition from the first operating mode to the second operating mode in response to and contingent upon a detection that the arm is in a retroflex position, and, while in the second operating mode, perform a surgical action using the end effector.

32. A method of operating a surgical system that comprises (i) an articulated mechanical arm comprising a plurality of arm joints, and a surgical end effector at a distal end of the arm, and (ii) an input-device array of one or more user-input devices for controlling the arm, the method comprising:

- a. retroflexing a distal portion of the articulated mechanical arm by flexion and rotation of a given one of arm joints, responsive to electronic control-output from the input-device array, so as to bring the end effector to a retroflex operating position without flexing or rotating any of the arm joints other than the given one of the arm joints; and
- b. in response to and contingent upon detecting that the arm is in a retroflex position, effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint, responsive to electronic control-output from the input-device array, to thereby move the surgical end-effector to perform one or more surgical actions.

33. The method of claim 32, wherein the surgical system additionally comprises control circuitry effective to restrict the actuation of arm joints other than the given one of the arm joints during the retroflexing.

34. The method of either one of claims 32 or 33, additionally comprising, following the performing the one or more surgical actions: unflexing the distal end of the arm, so as to bring the arm to an unflexed position.

35. A surgical system comprising:

- a. an articulated mechanical arm comprising (i) a plurality of arm joints and (ii) a surgical end effector at a distal end of the arm, and
- b. an input-device array of one or more user-input devices for controlling the arm, wherein the surgical system is configured:
 - i. to retroflect a distal portion of the articulated mechanical arm by flexion and rotation of a given one of arm joints, responsive to electronic control-output from the input-device array, so as to bring the end effector to a retroflex operating position without flexing or rotating any of the arm joints other than the given one of the arm joints; and
 - ii. to effect flexing and rotating of at least two of the arm joints in accordance with respective degrees of freedom of each arm joint in response to and contingent upon detecting that the arm is in a retroflex position, and responsively to electronic control-output from the input-device array, to thereby move the surgical end-effector to perform one or more surgical actions.

36. A method of using a surgical system, the method comprising:

- a. providing an articulated mechanical arm having a surgical end effector at a distal end thereof, the arm comprising a plurality of arm segments connected serially by a corresponding plurality of arm joints configured to flex and rotate in response to an electronic control-output from a user-input device, wherein the providing is such that the end effector is displaced;

- b. maneuvering the end effector to a retroflex operating position while operating in a first input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a speed of at least one of (i) a flexion of an arm joint and (ii) a rotation of an arm joint;
 - 5 c. in response to and contingent upon detecting that the end effector is in the retroflex operating position, transitioning from operating in the first input mode to operating in a second input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a corresponding displacement of at least one arm segment; and
 - 10 d. after the transitioning and while operating in the second input mode, performing a surgical action using the end effector.
37. The method of claim 36, wherein a single user-input device is used in both the first input mode and the second input mode.
38. The method of claim 36, wherein a first input device is used in the first input mode,
15 and a second input device is used in the second input mode.
39. The method of any one of claims 36 to 38, wherein an additional user-input device is used for actuating linear advancement and retraction of the arm.
40. The method of any one of claims 36 to 39, wherein the retroflex operating position is at, or in proximity to, a surgical worksite.
- 20 41. A surgical system for use with a surgical end effector, the system comprising:
- a. an articulated mechanical arm having a surgical end effector at a distal end thereof, the arm comprising a plurality of arm segments connected serially by a corresponding plurality of arm joints configured to flex and rotate in response to an electronic control-output from a user-input device; and
 - 25 b. an array of one or more input devices for controlling the arm,
- wherein the surgical system is configured:

- 5 i. to operate, asynchronously, in (A) a first input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a speed of a flexion and of a rotation of an arm joint, and in (B) a second input mode in which a displacement of an input device or of a displaceable portion thereof is translated to a corresponding displacement of at least one arm segment,
- ii. while operating in the first input mode, to maneuver the end effector to a retroflex operating position during a first stage in which the end effector is displaced, and
- 10 iii. while operating in the second input mode, to perform a surgical action using the end effector.

15

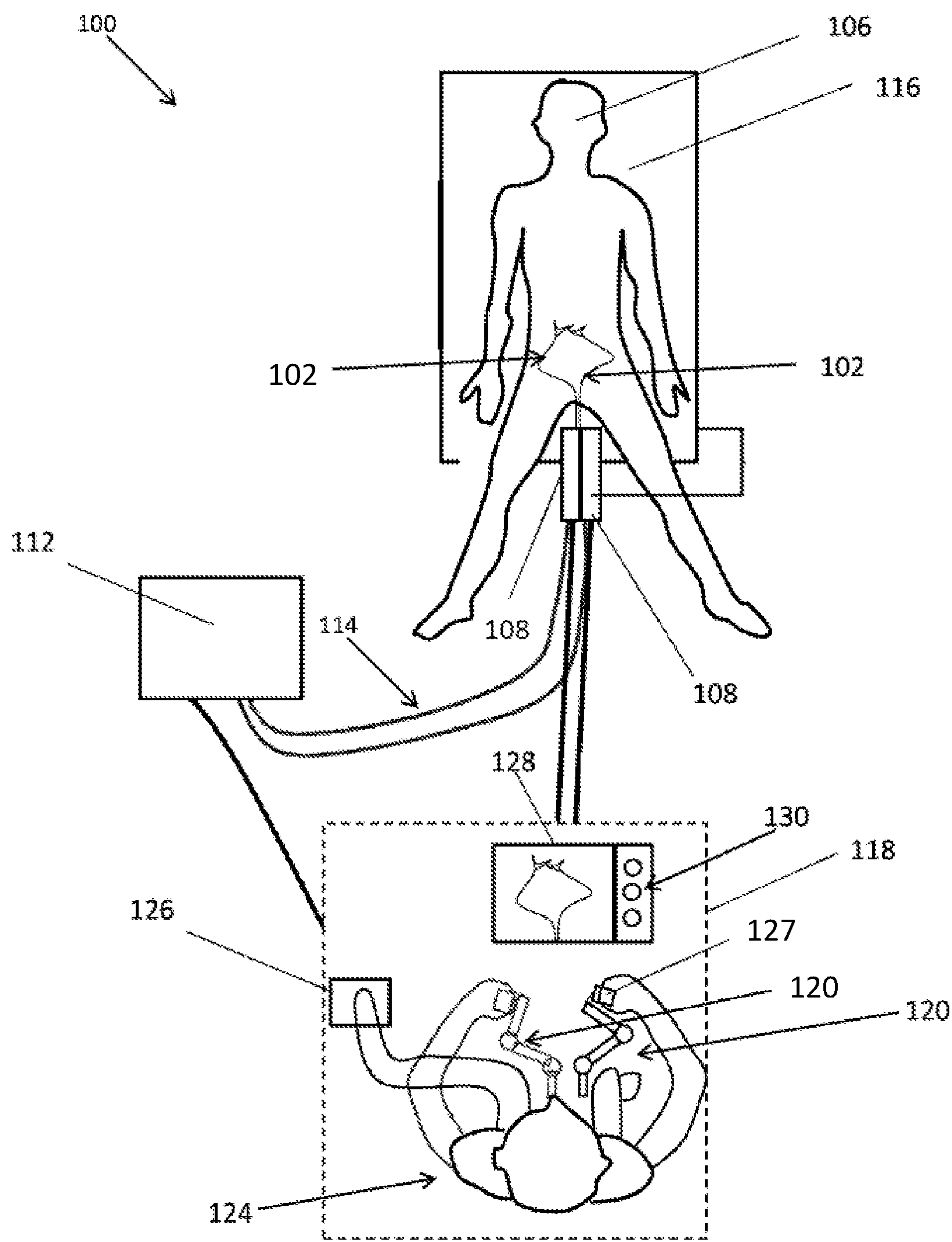


FIG. 1

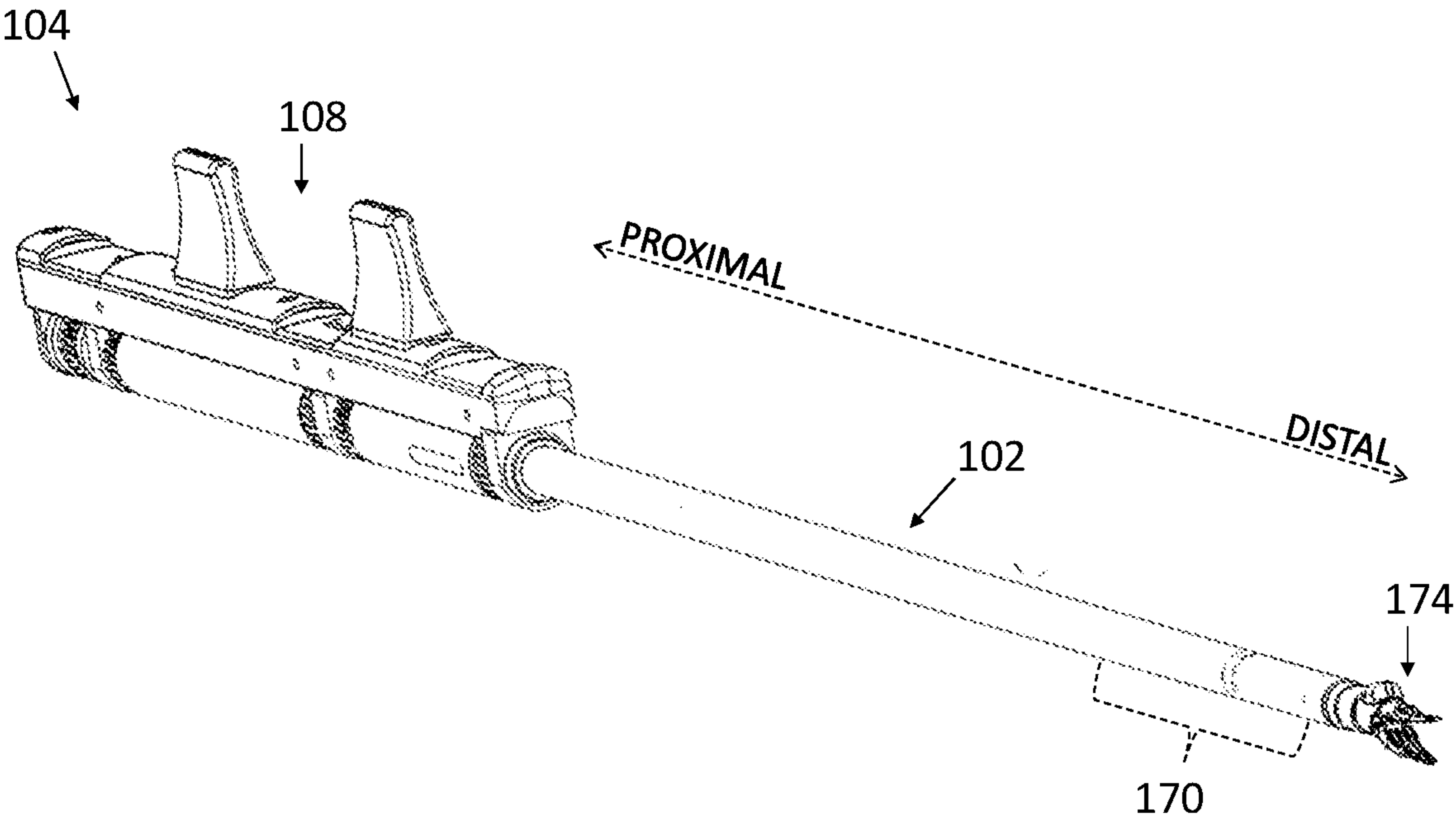


FIG. 2A

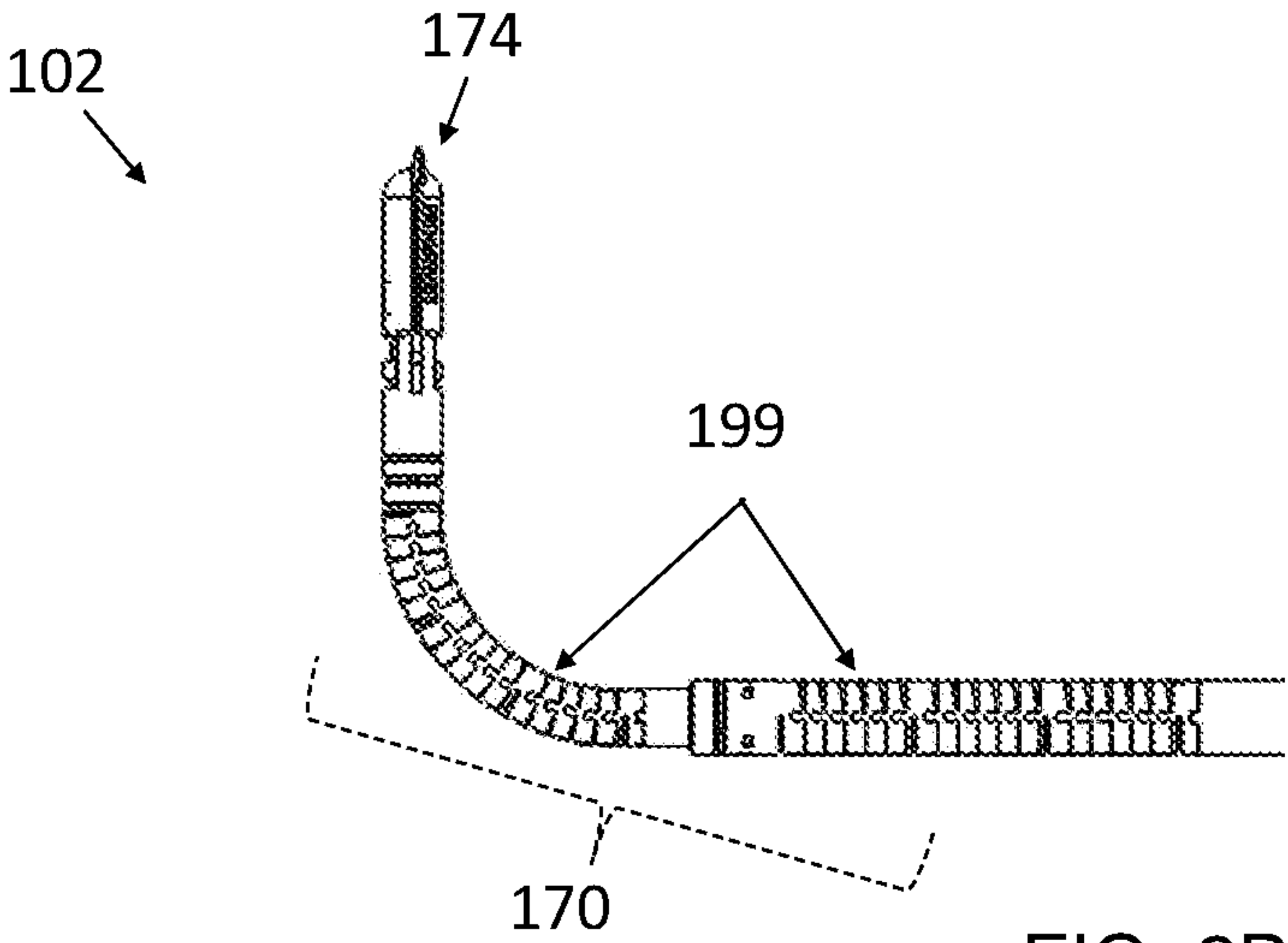


FIG. 2B

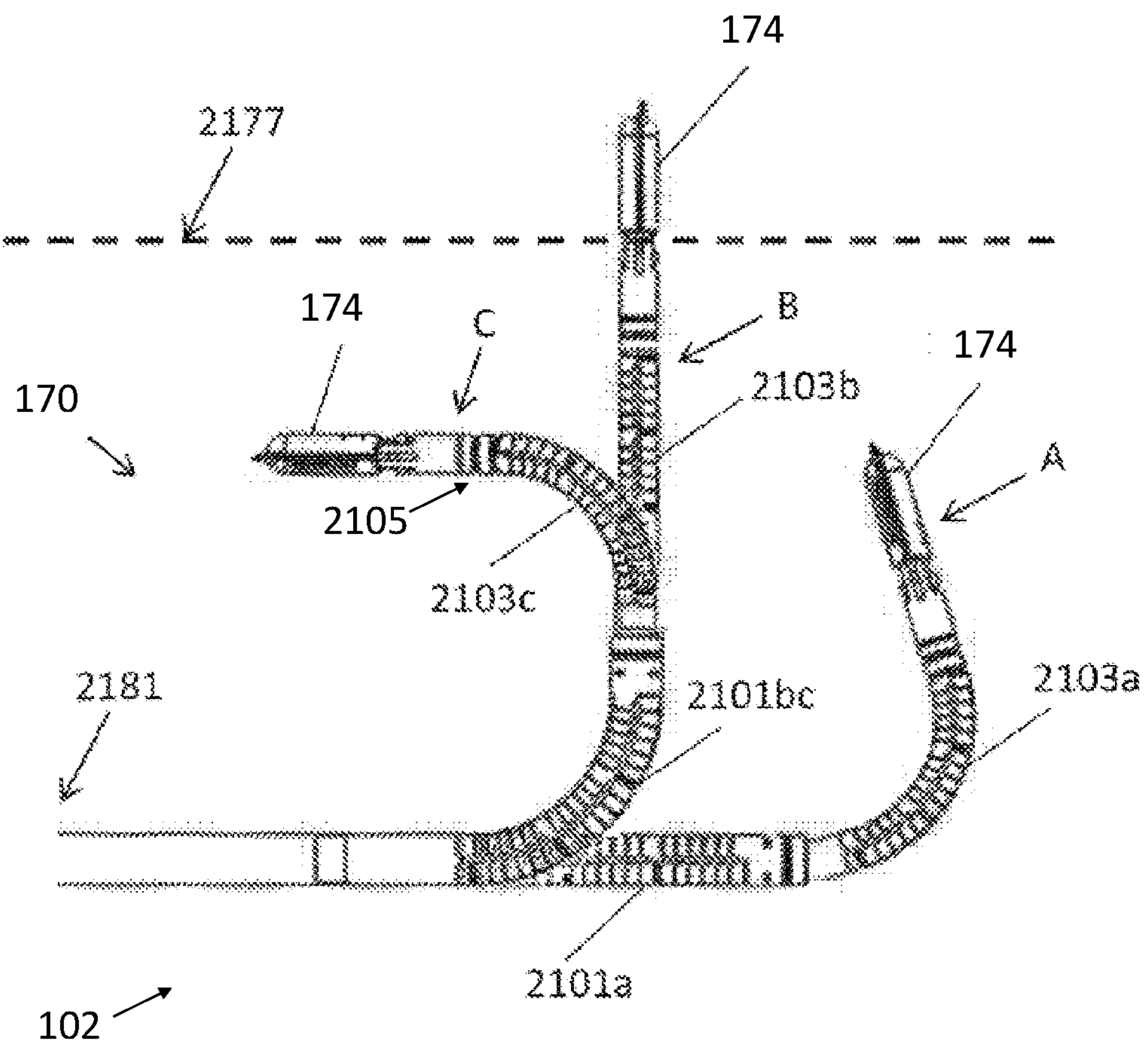


FIG. 3A

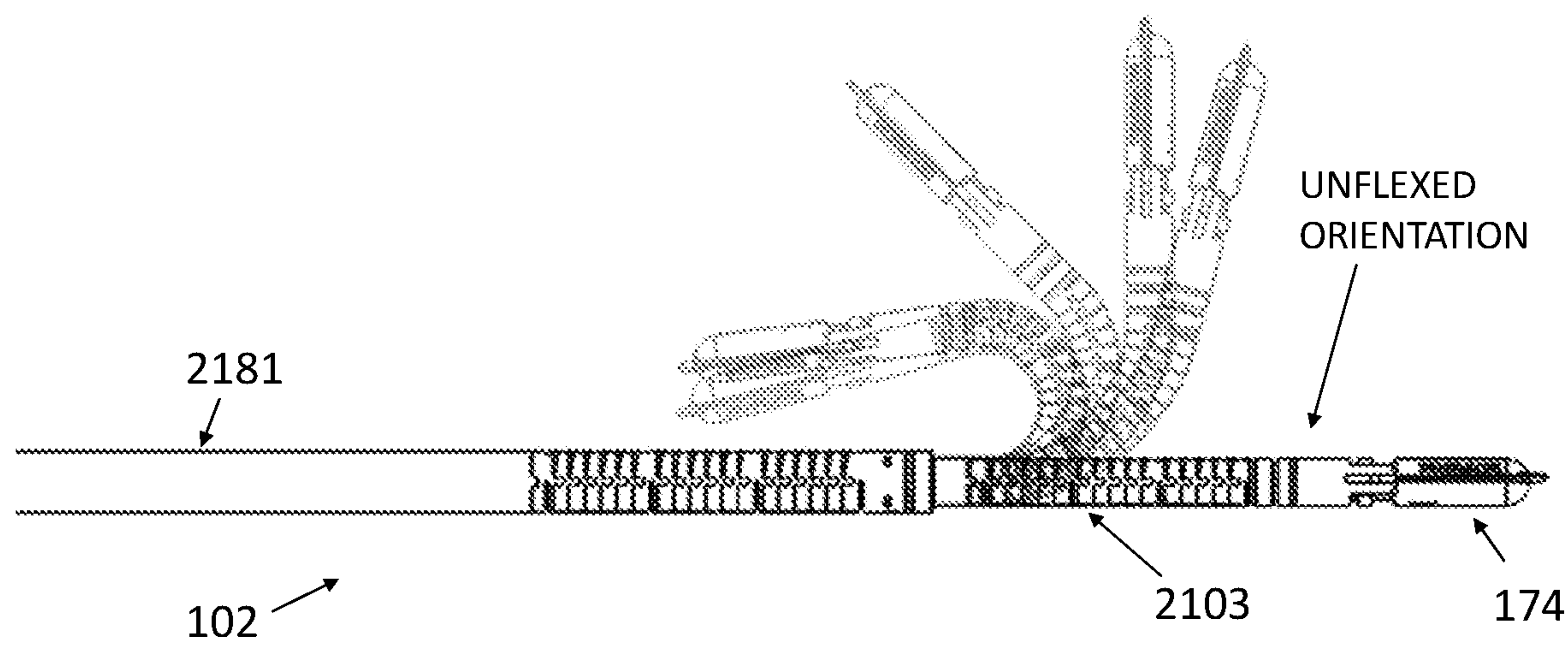


FIG. 3B

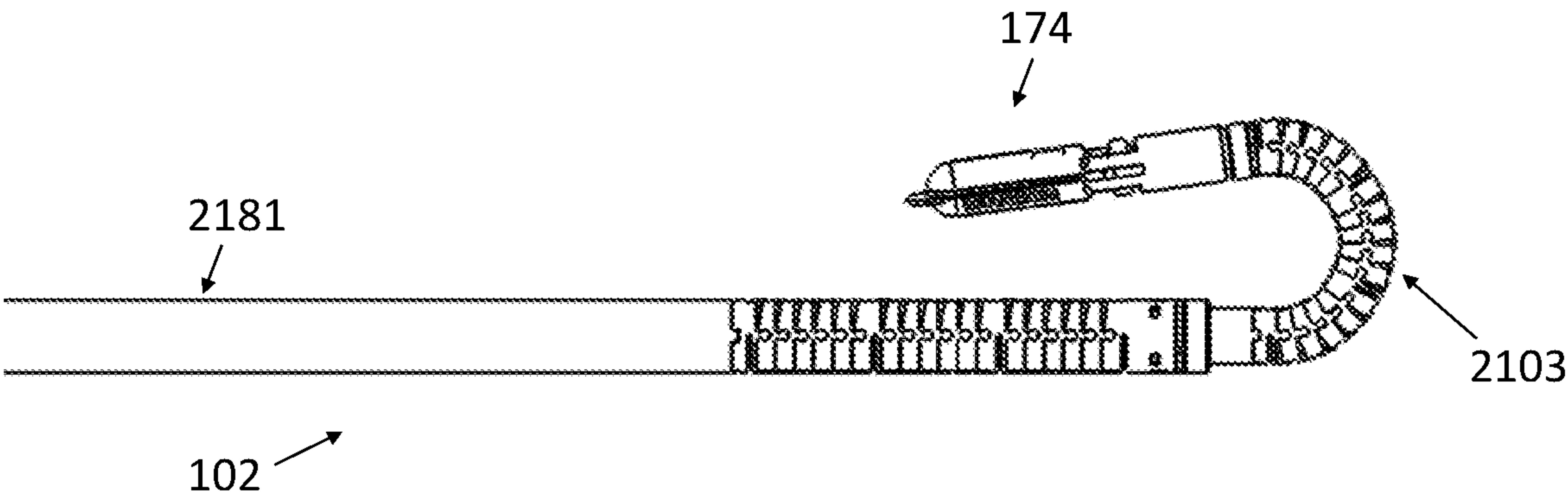


FIG. 3C

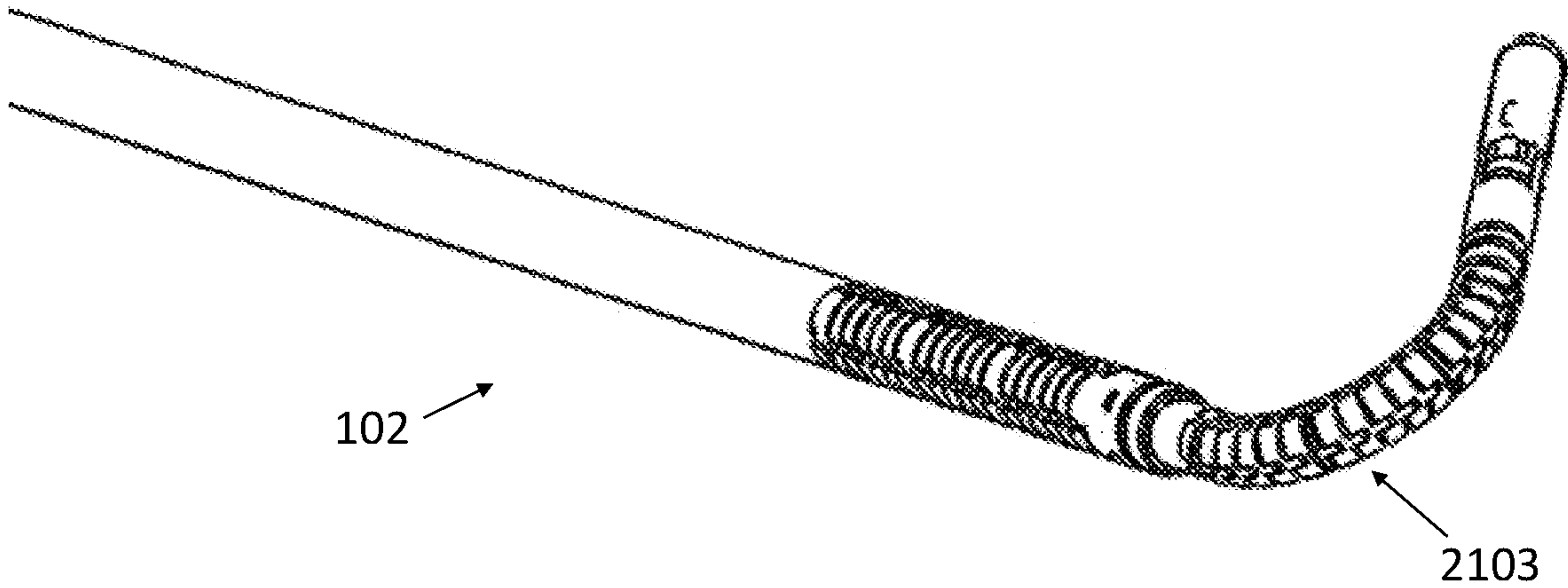


FIG. 4

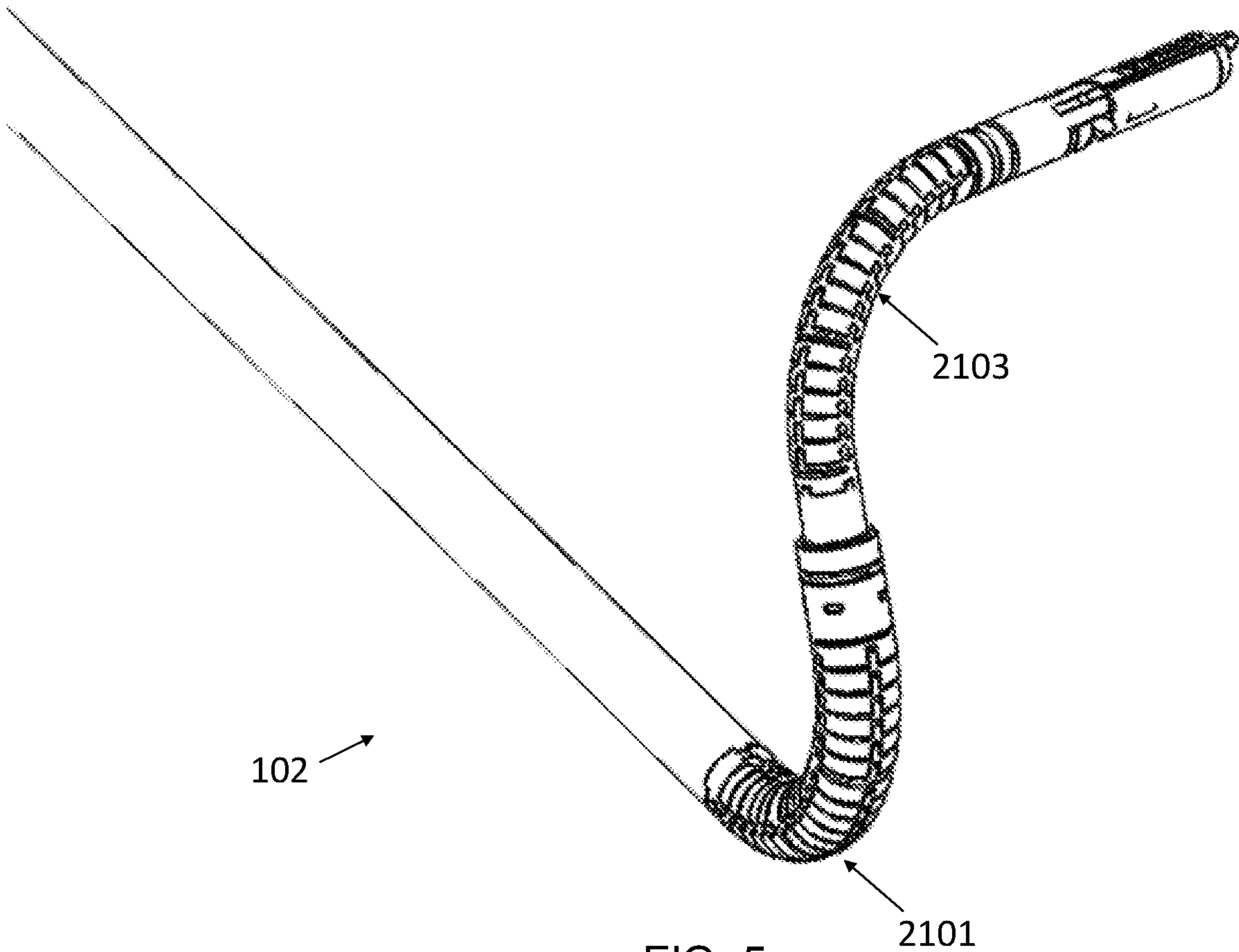


FIG. 5

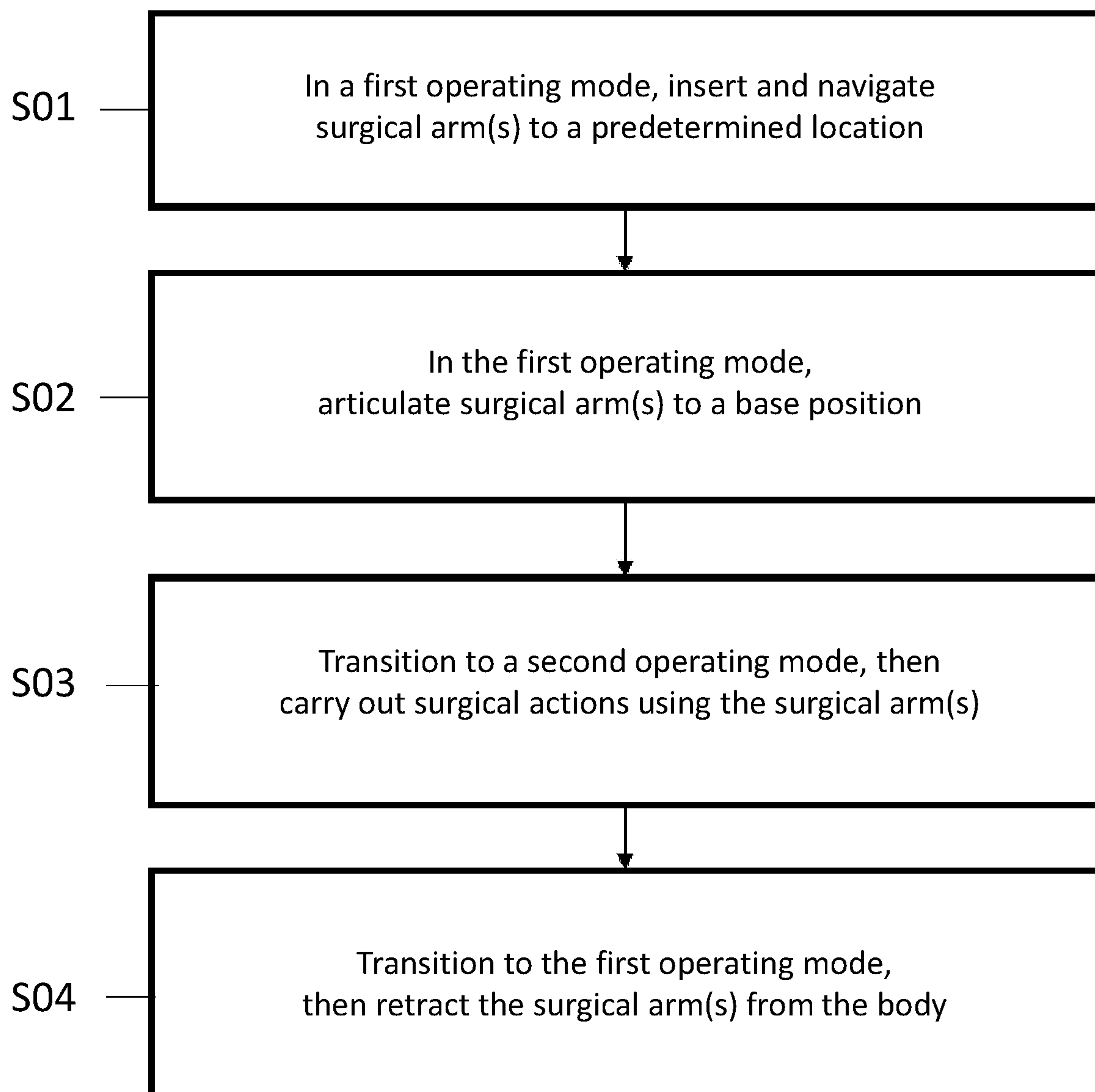


FIG. 6

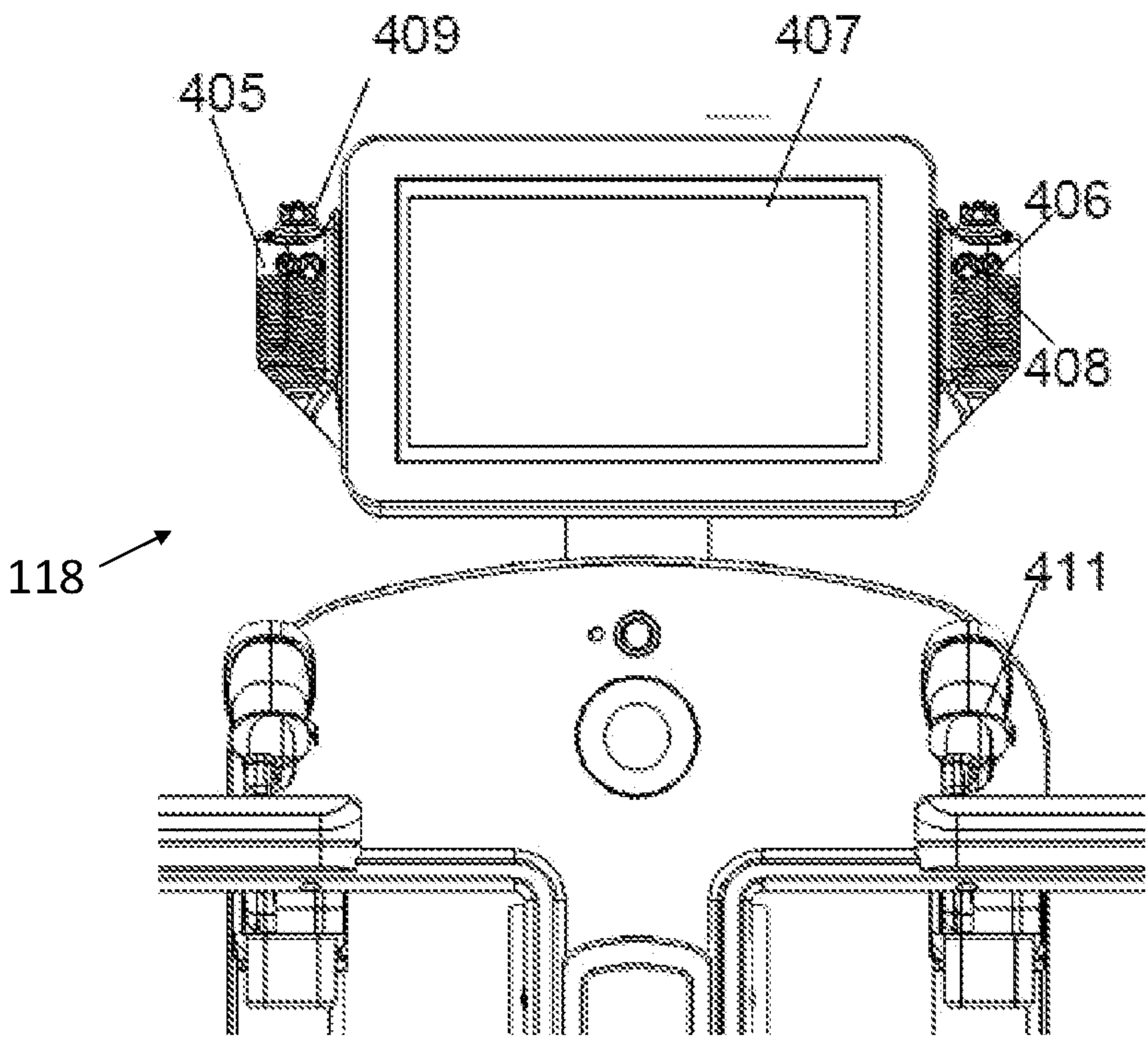


FIG. 7

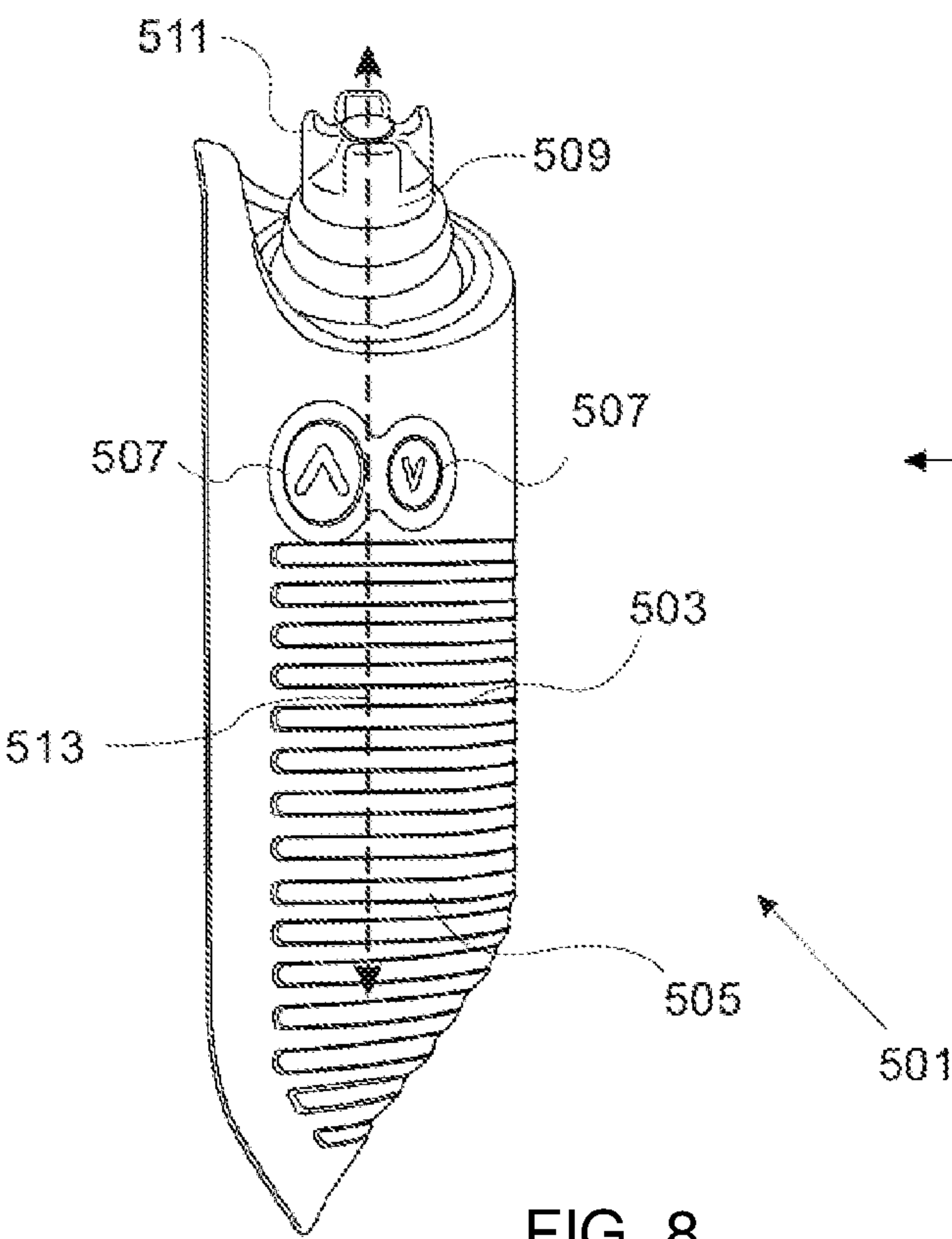


FIG. 8

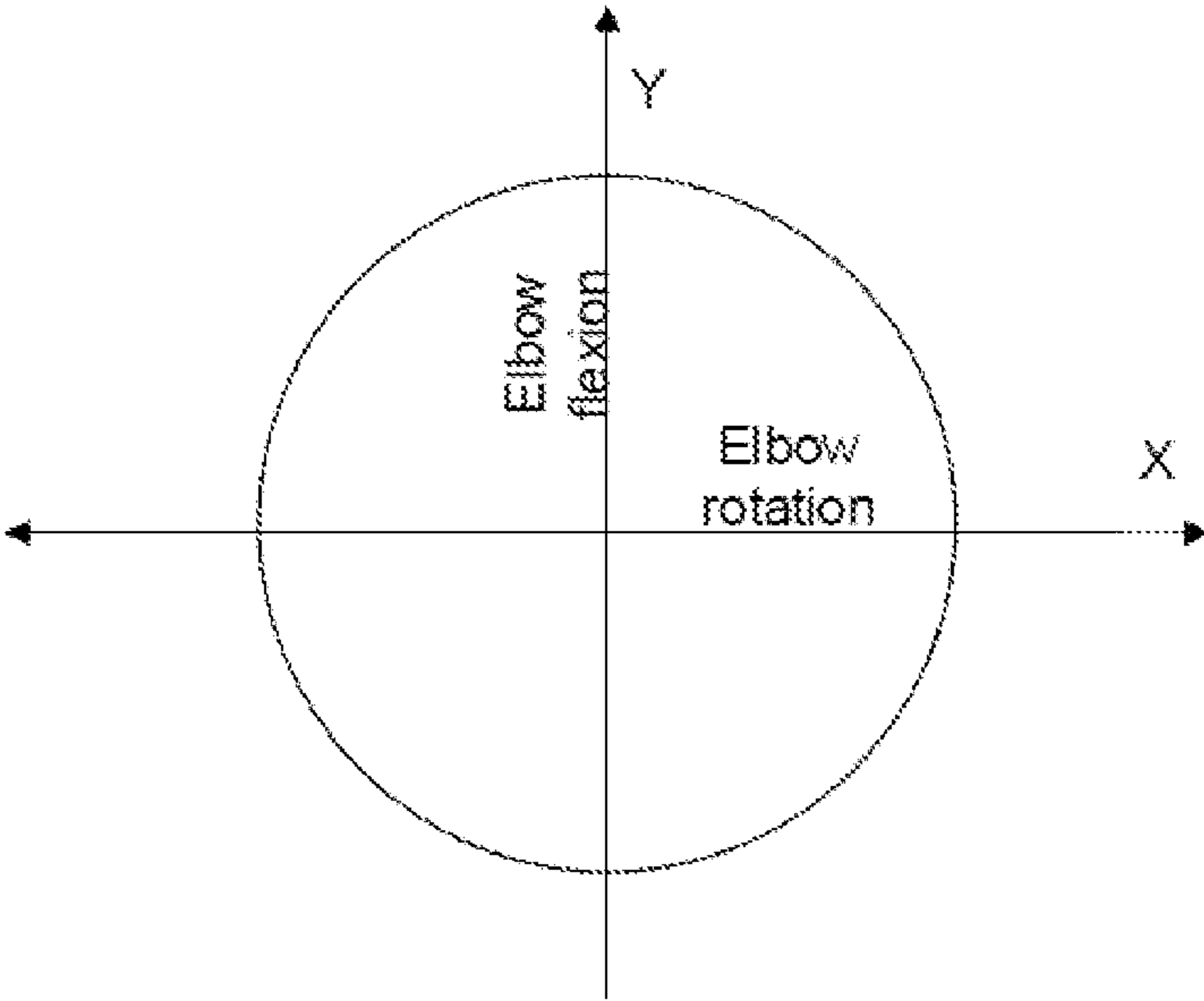


FIG. 9

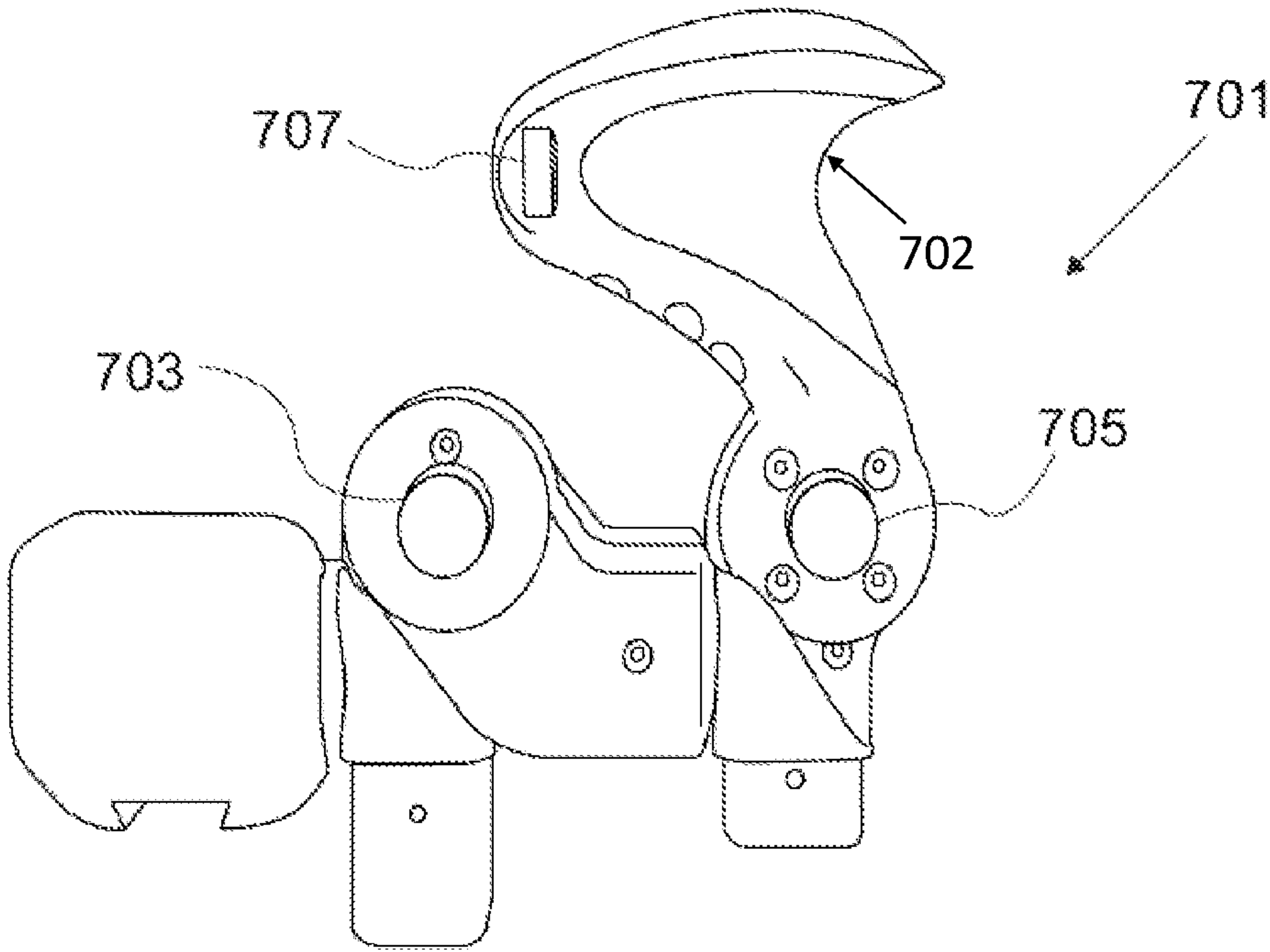


FIG. 10

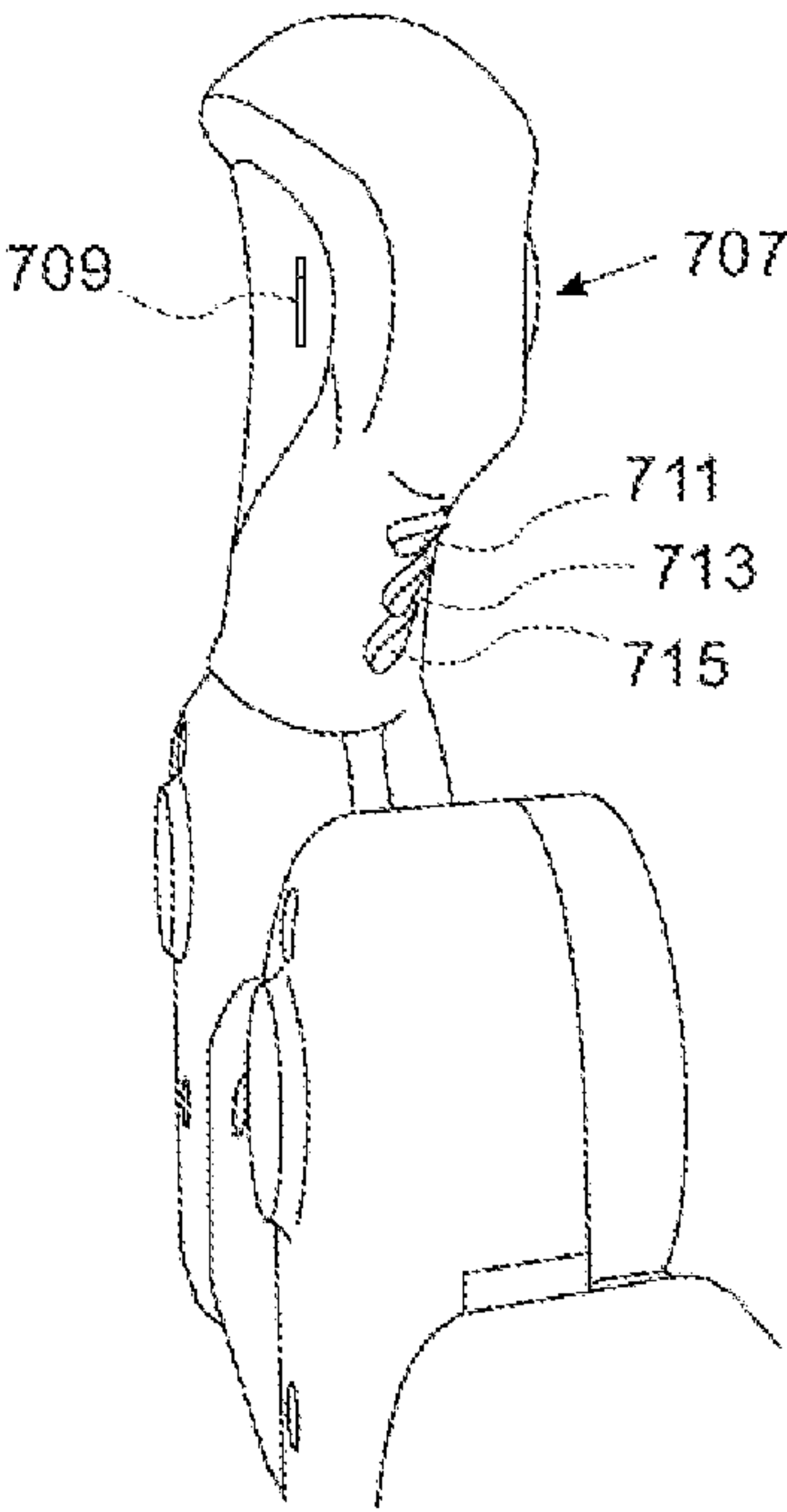


FIG. 11

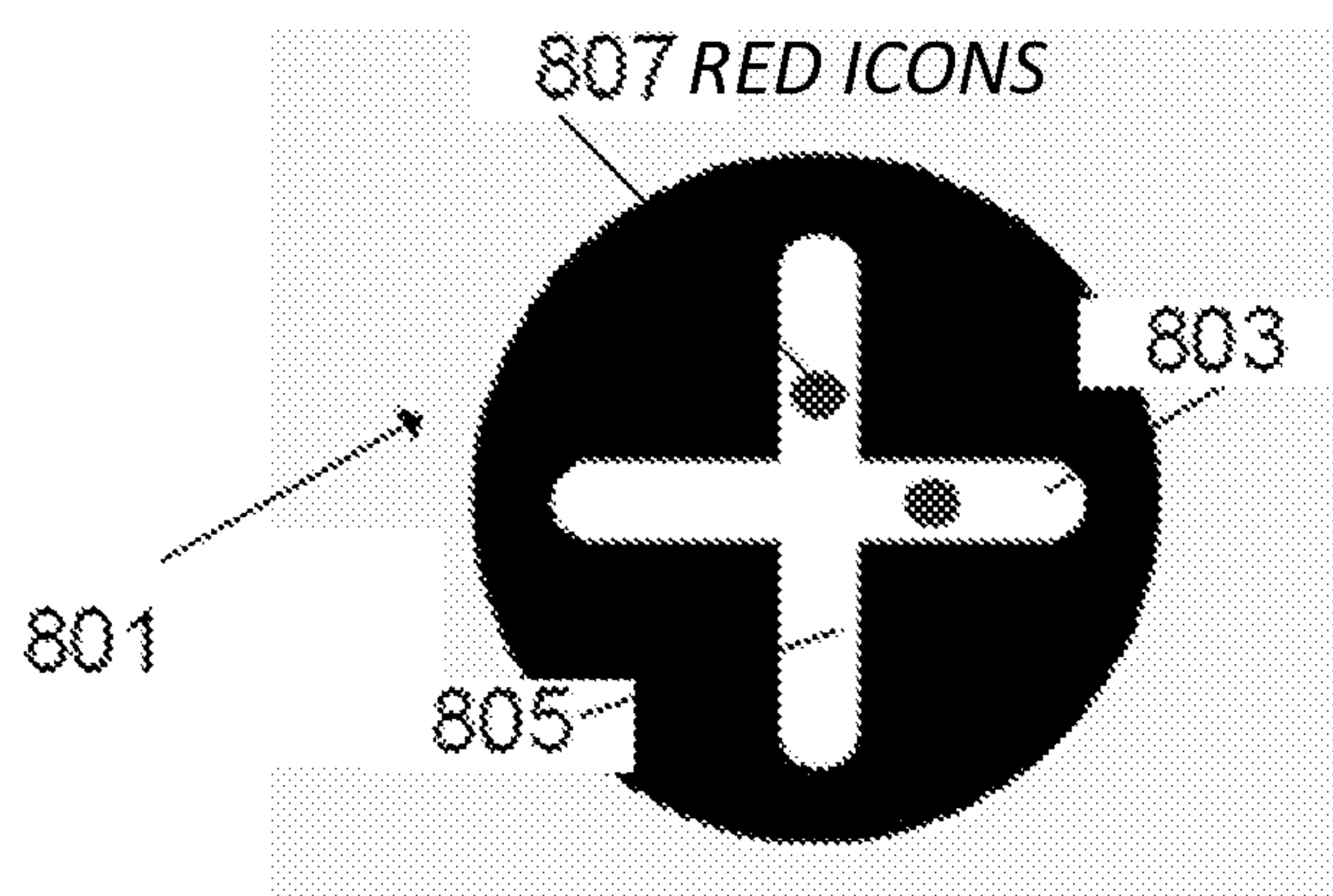


FIG. 12A

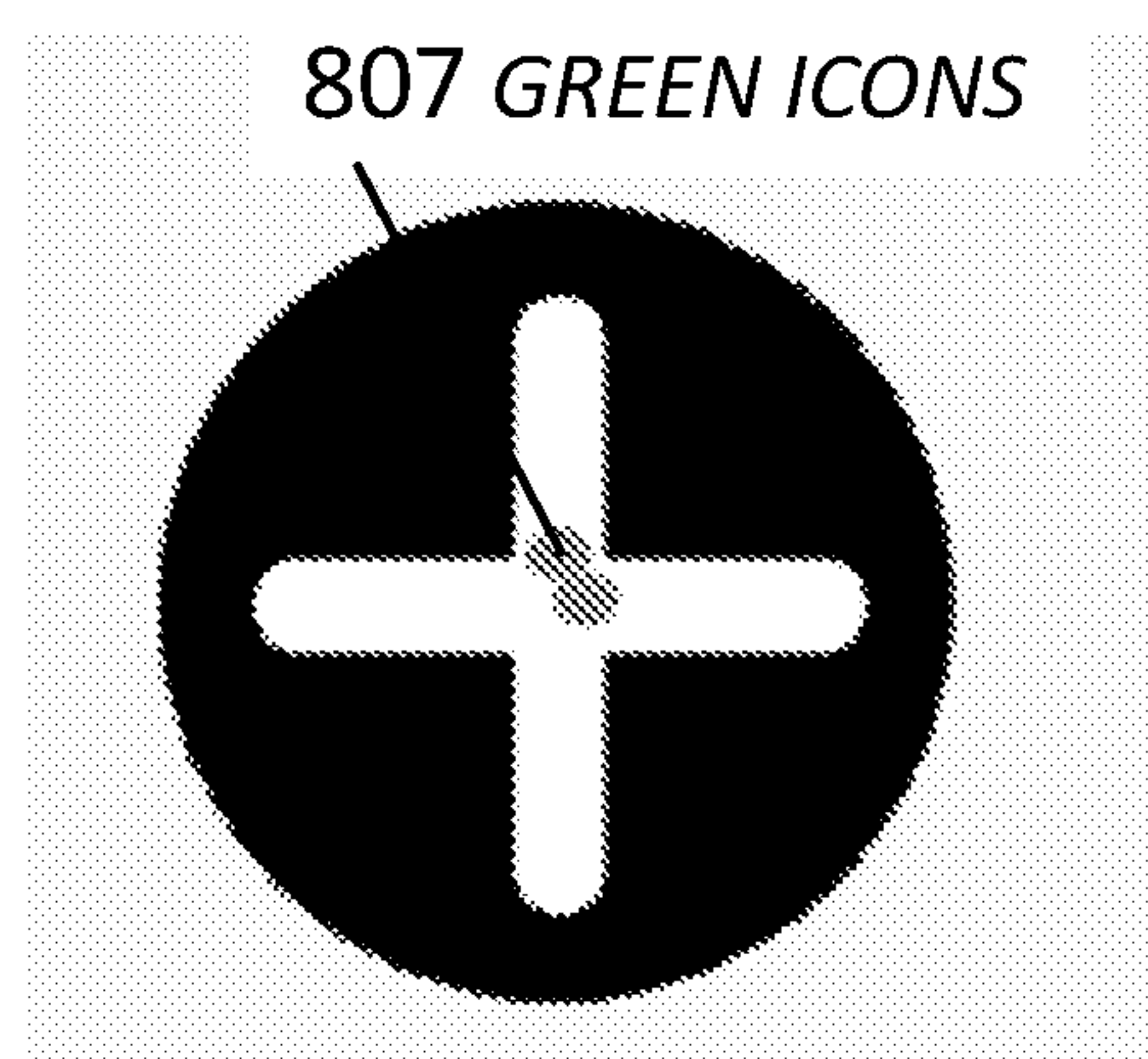


FIG. 12B

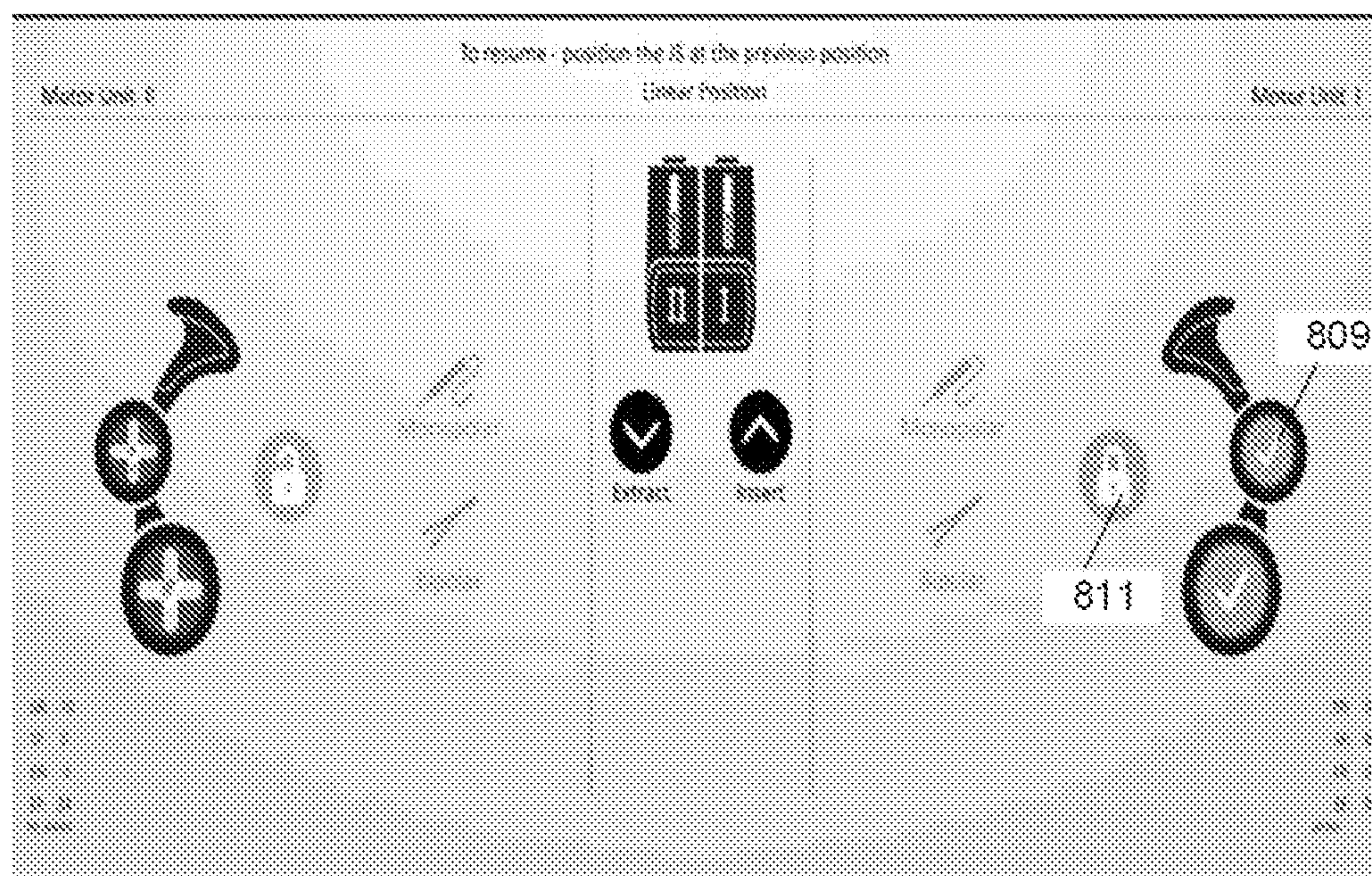


FIG. 13

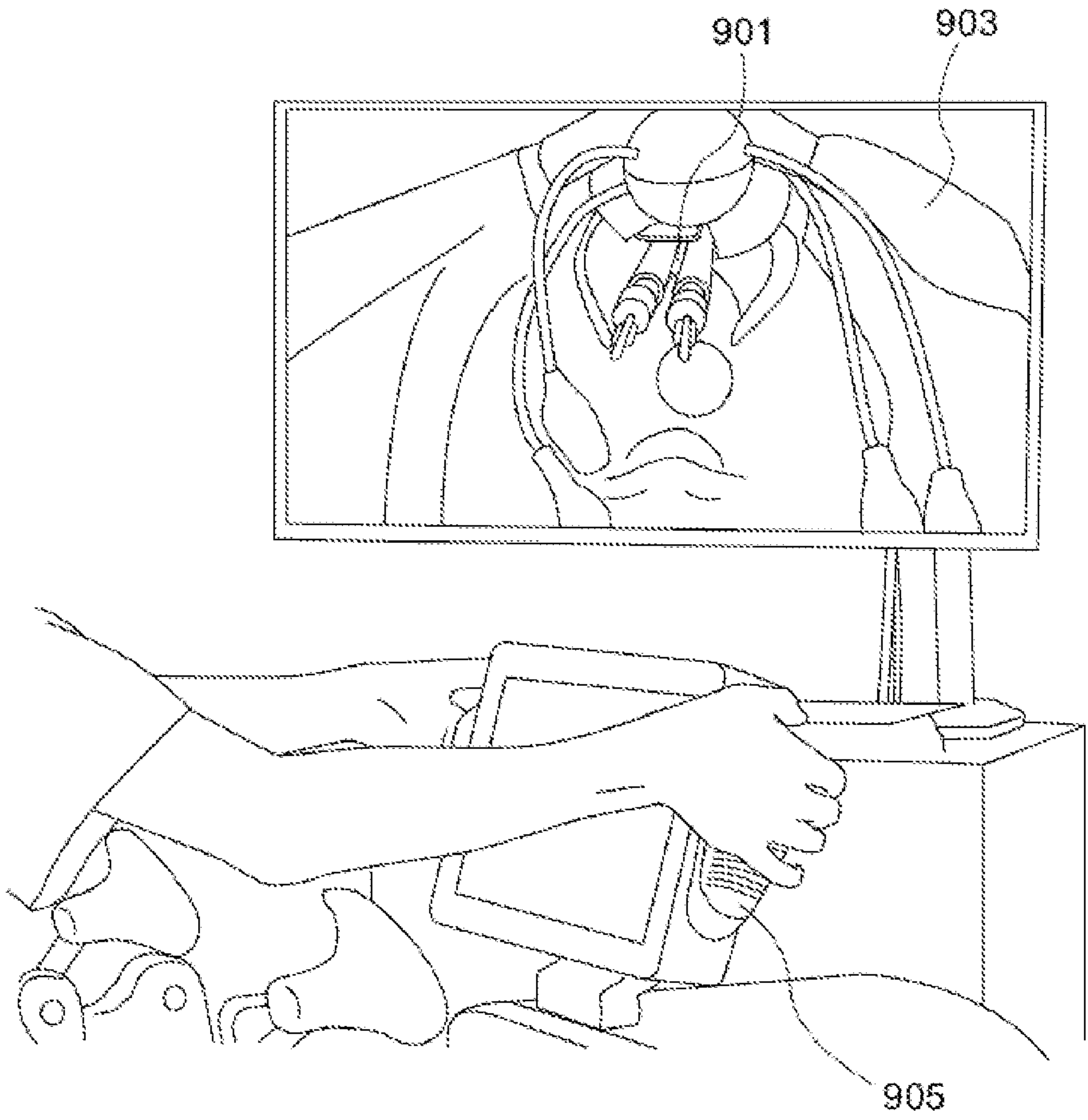


FIG. 14A

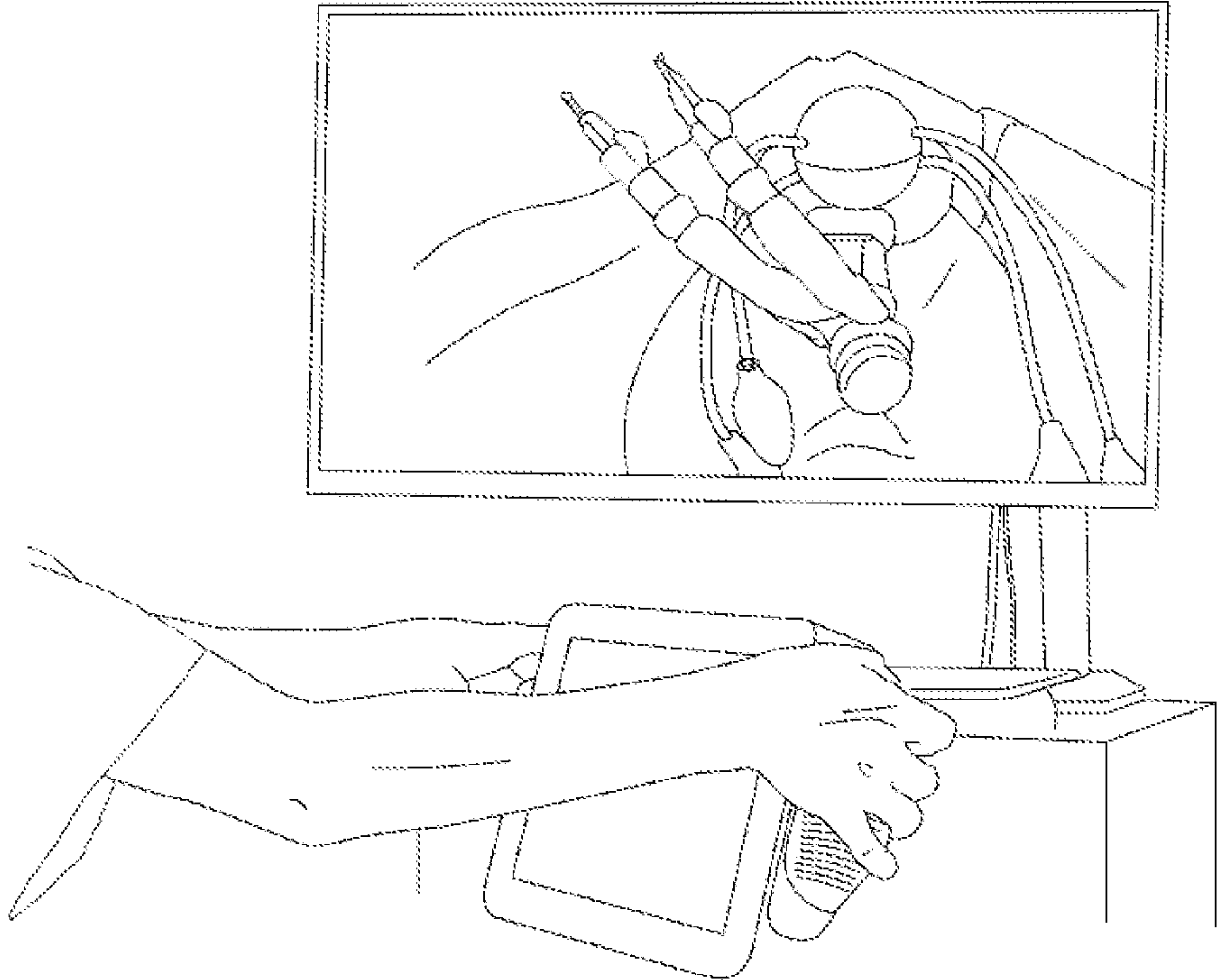


FIG. 14B

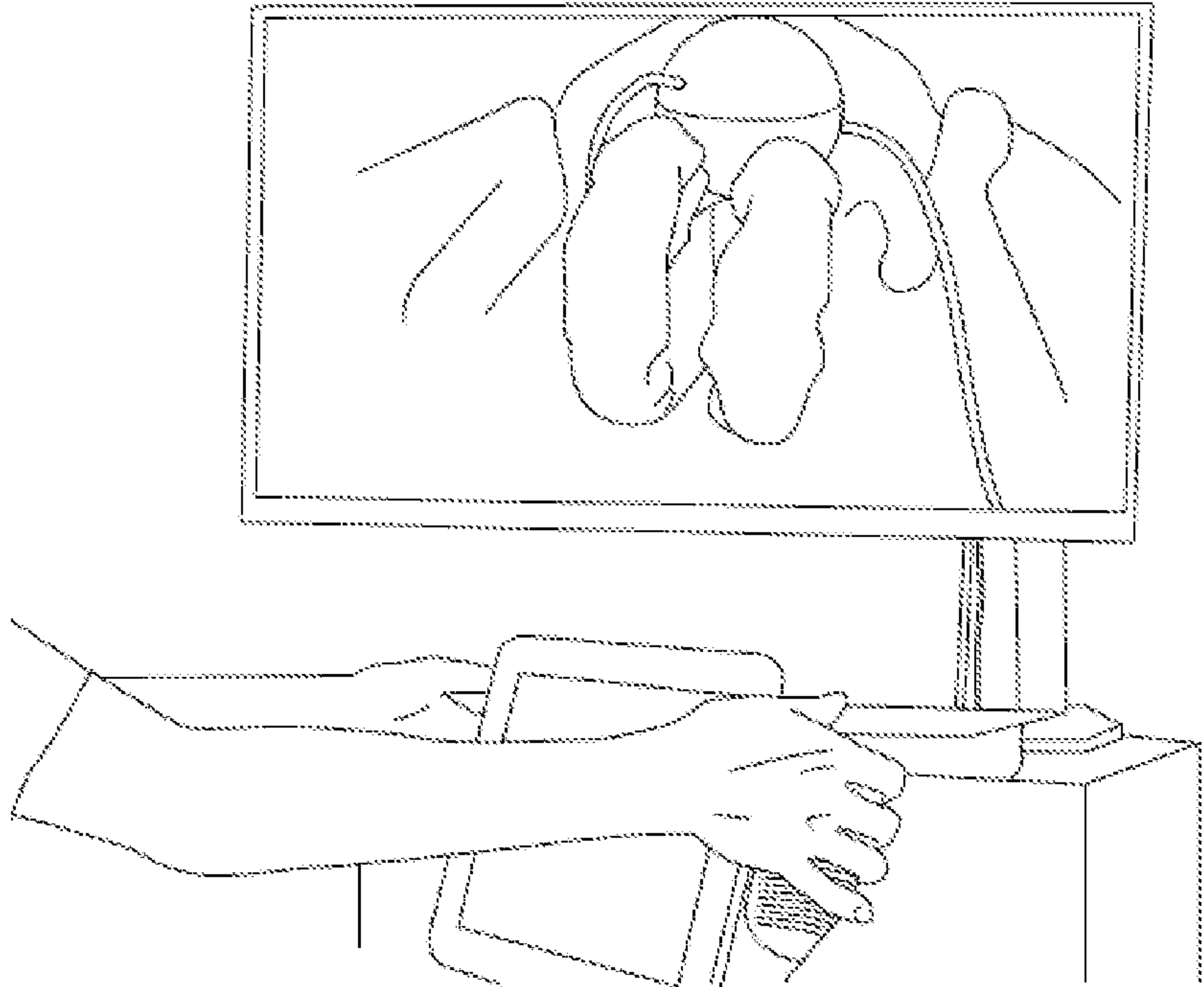


FIG. 14C

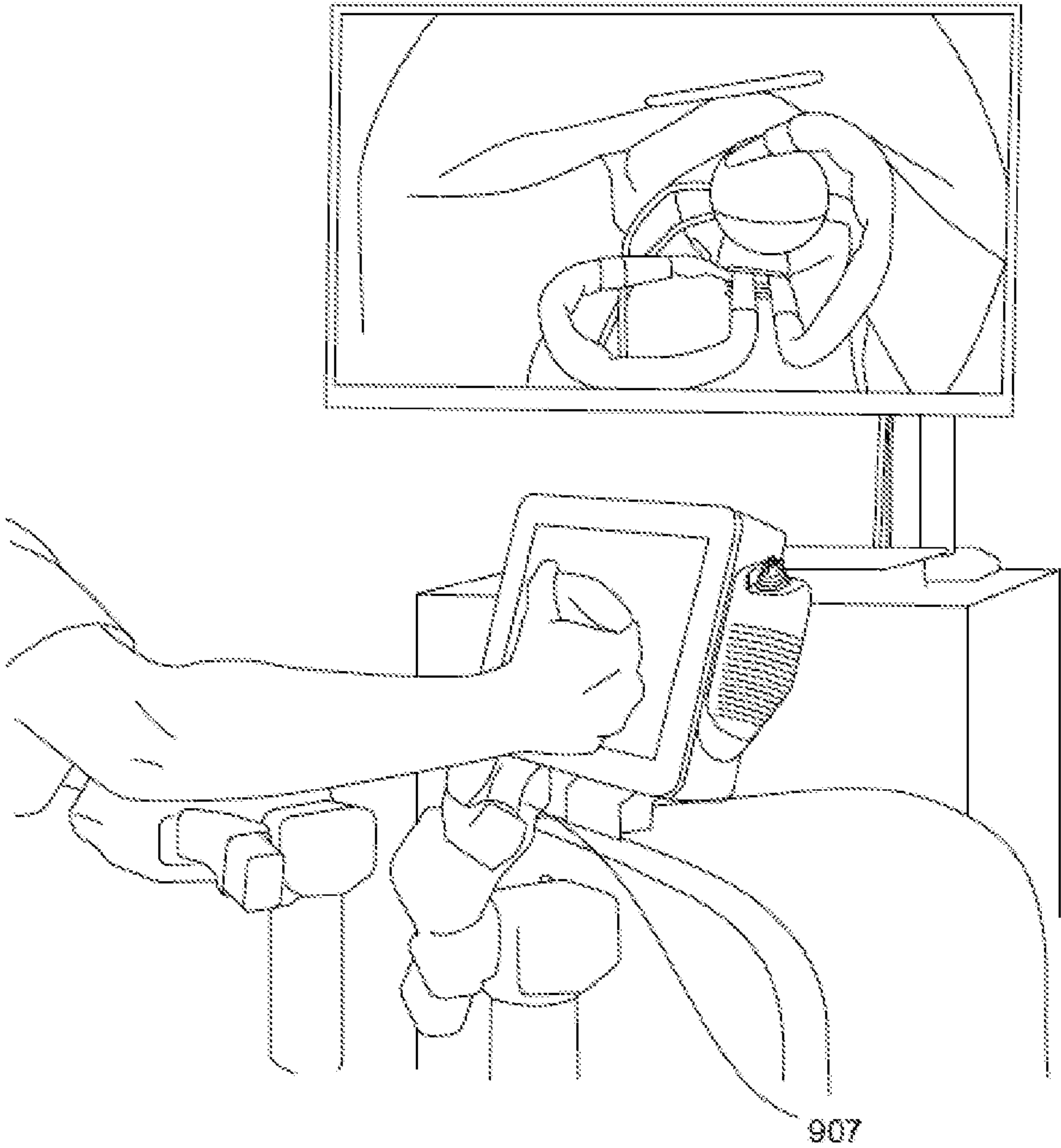


FIG. 14D

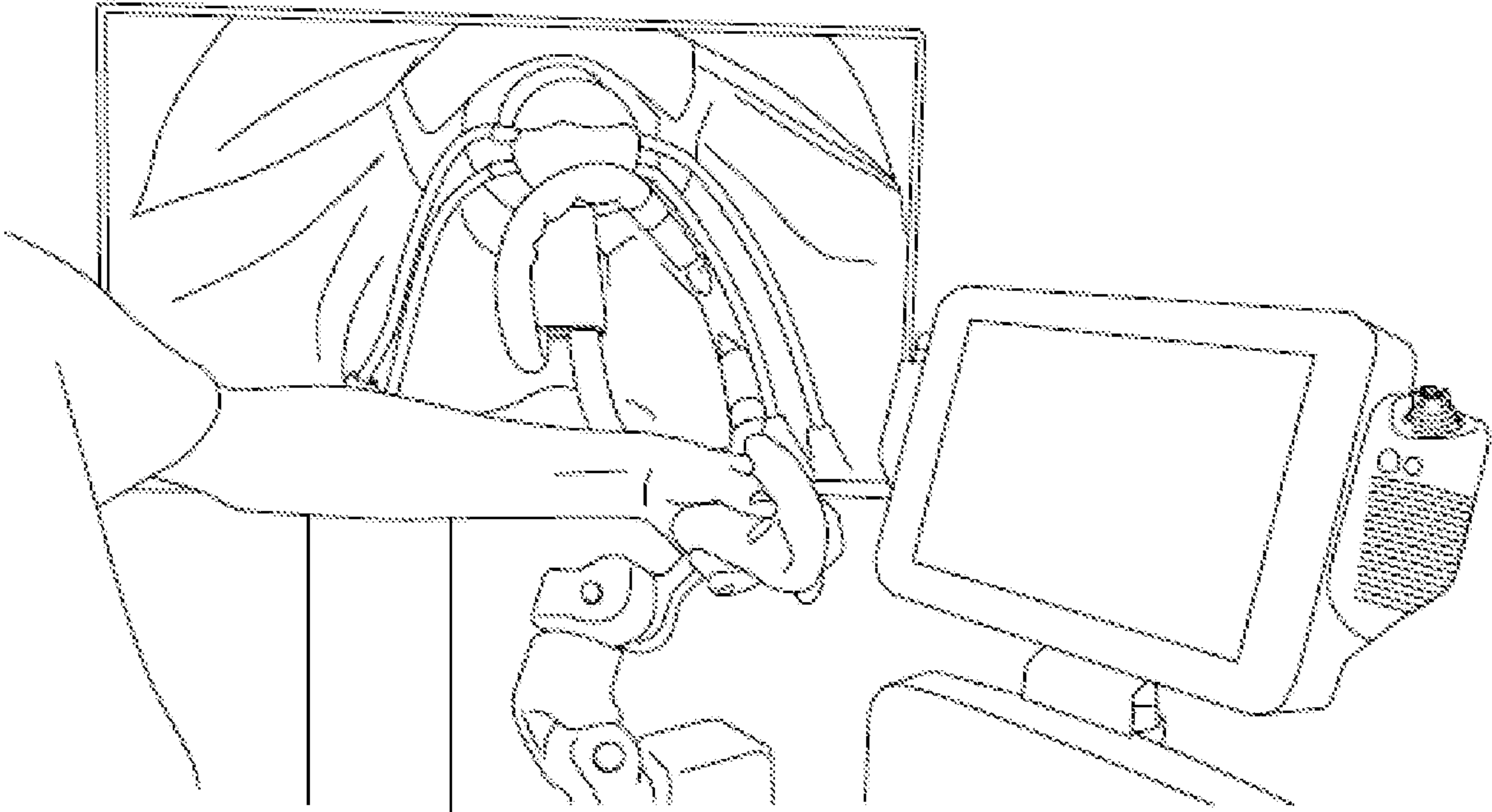


FIG. 14E

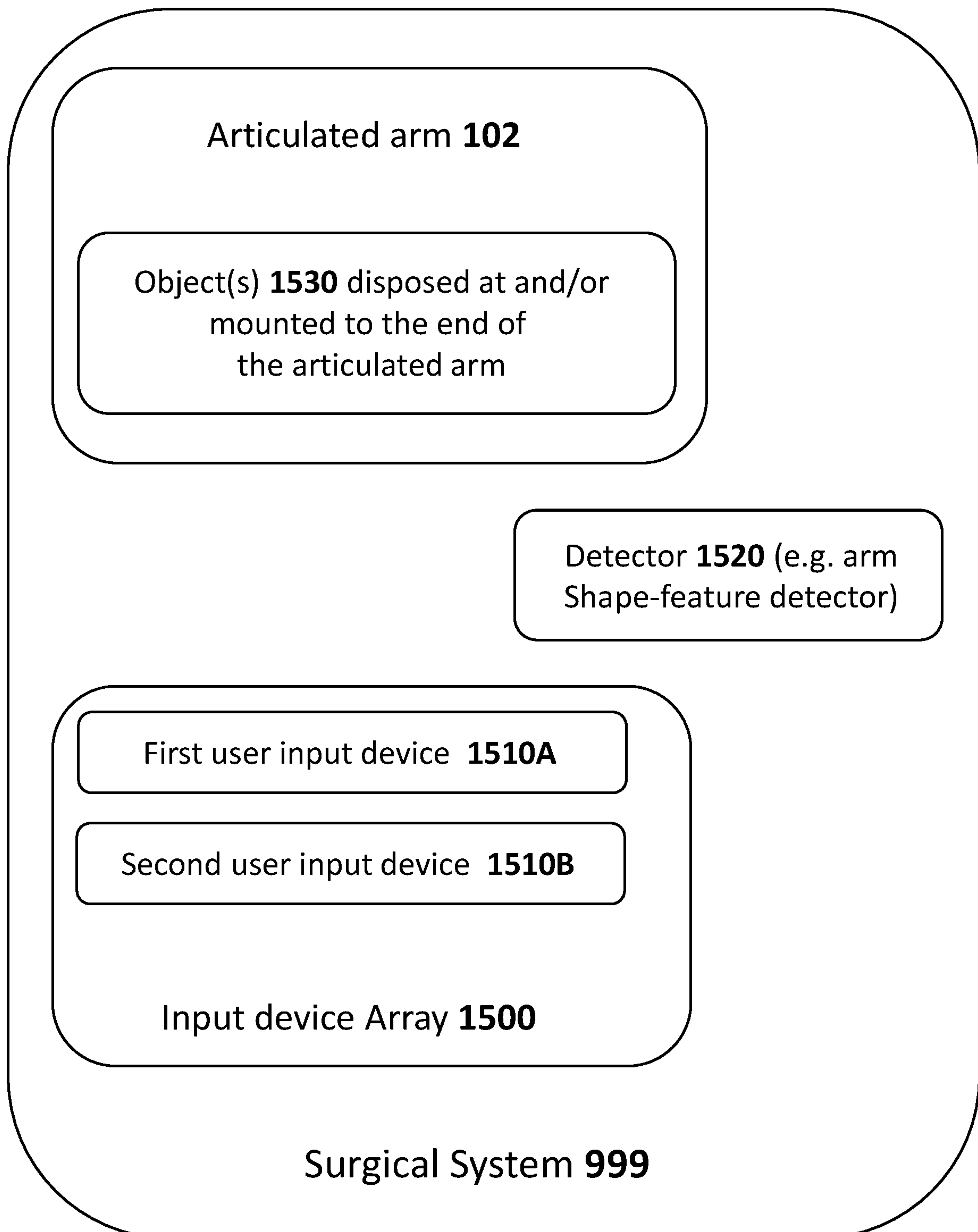


FIG. 15

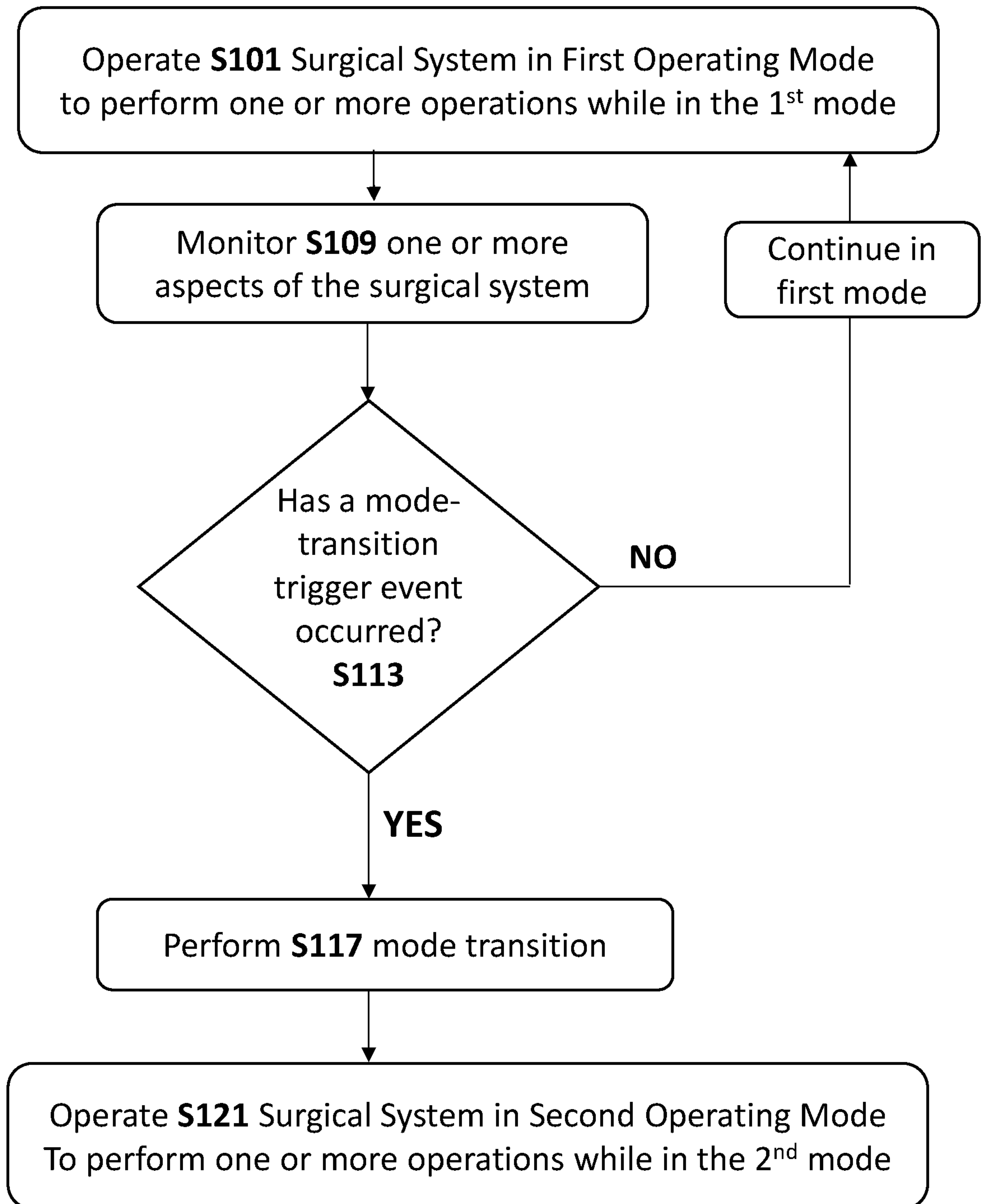


FIG. 16

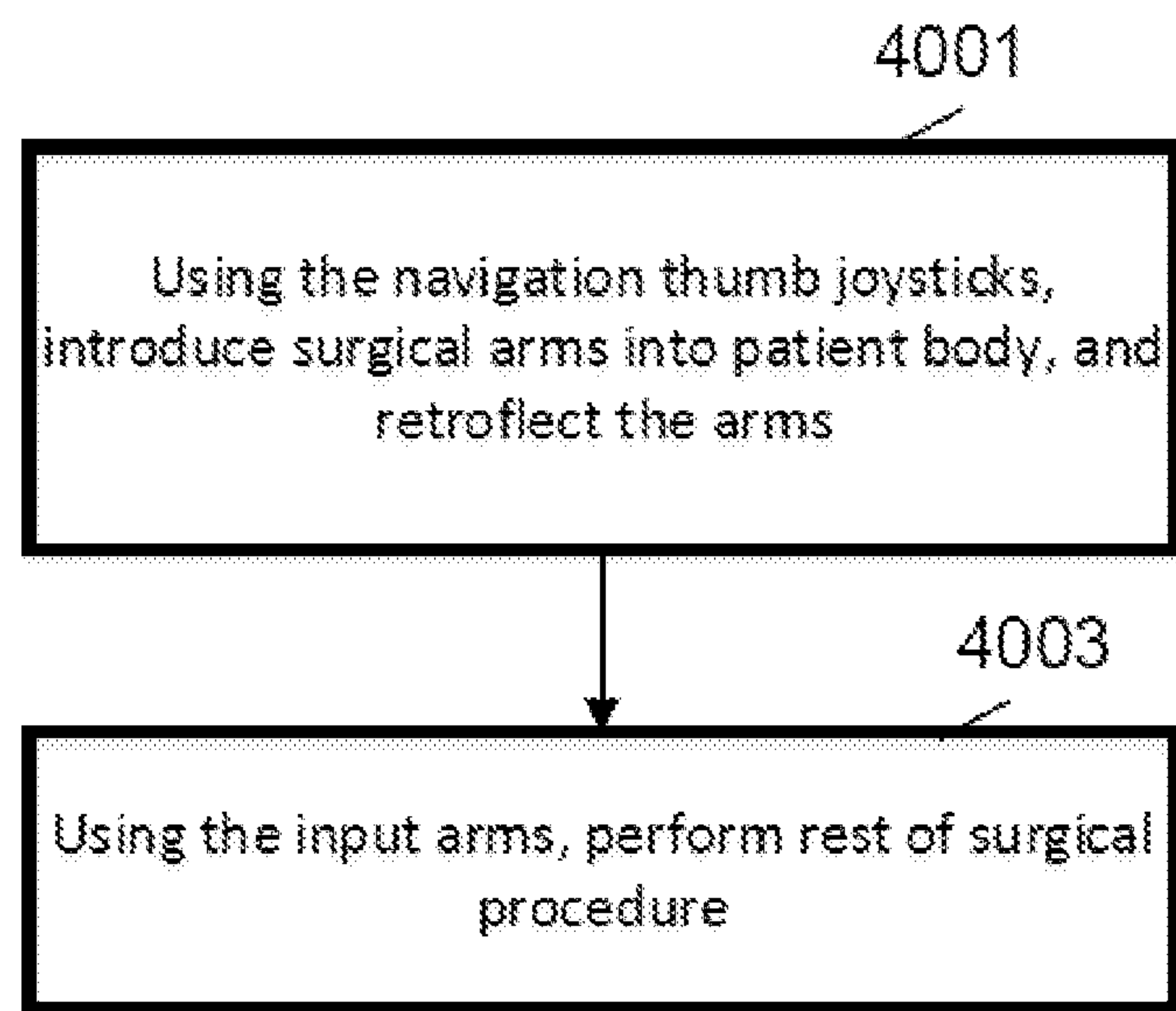


FIG. 17A

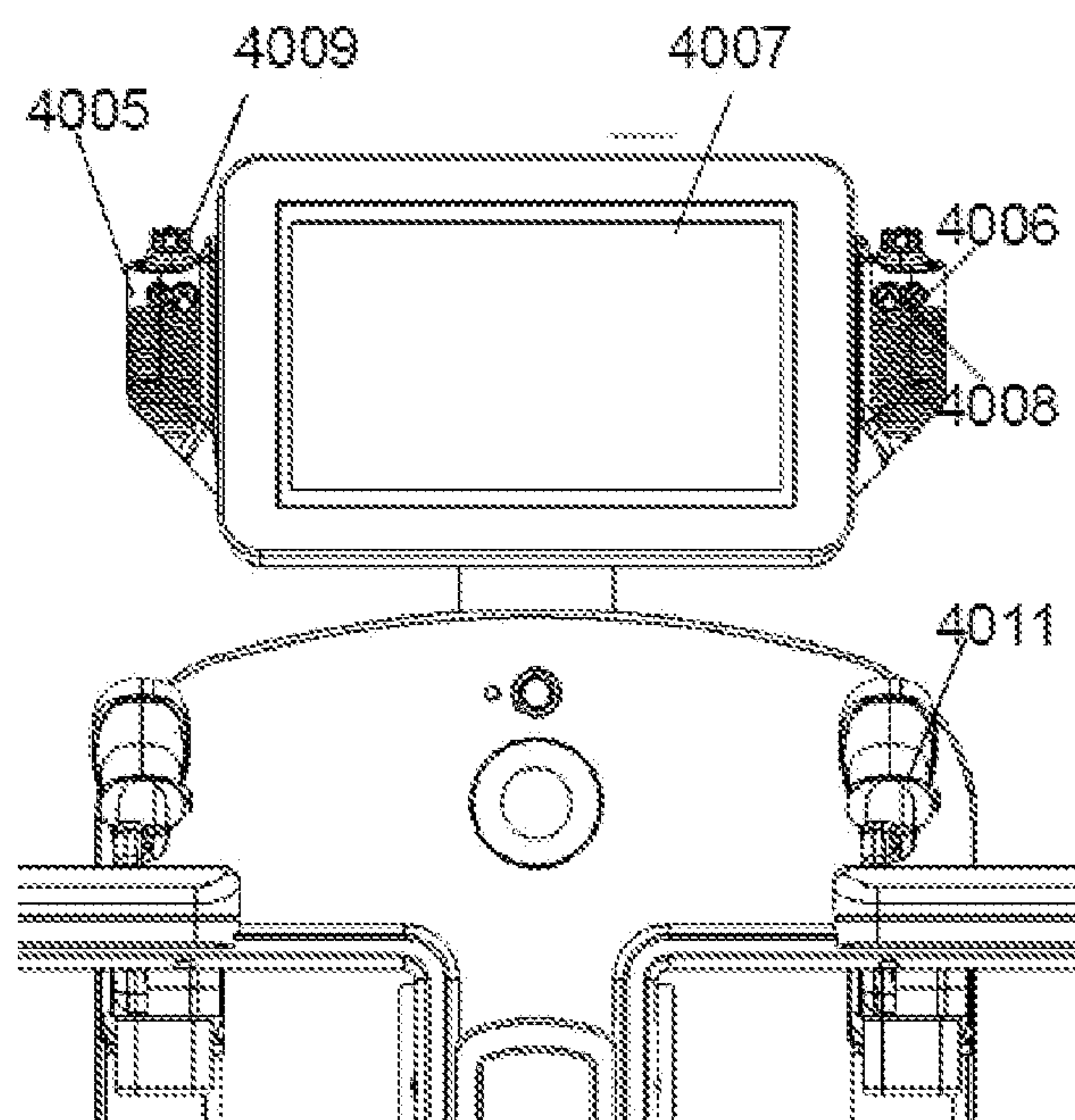


FIG. 17B

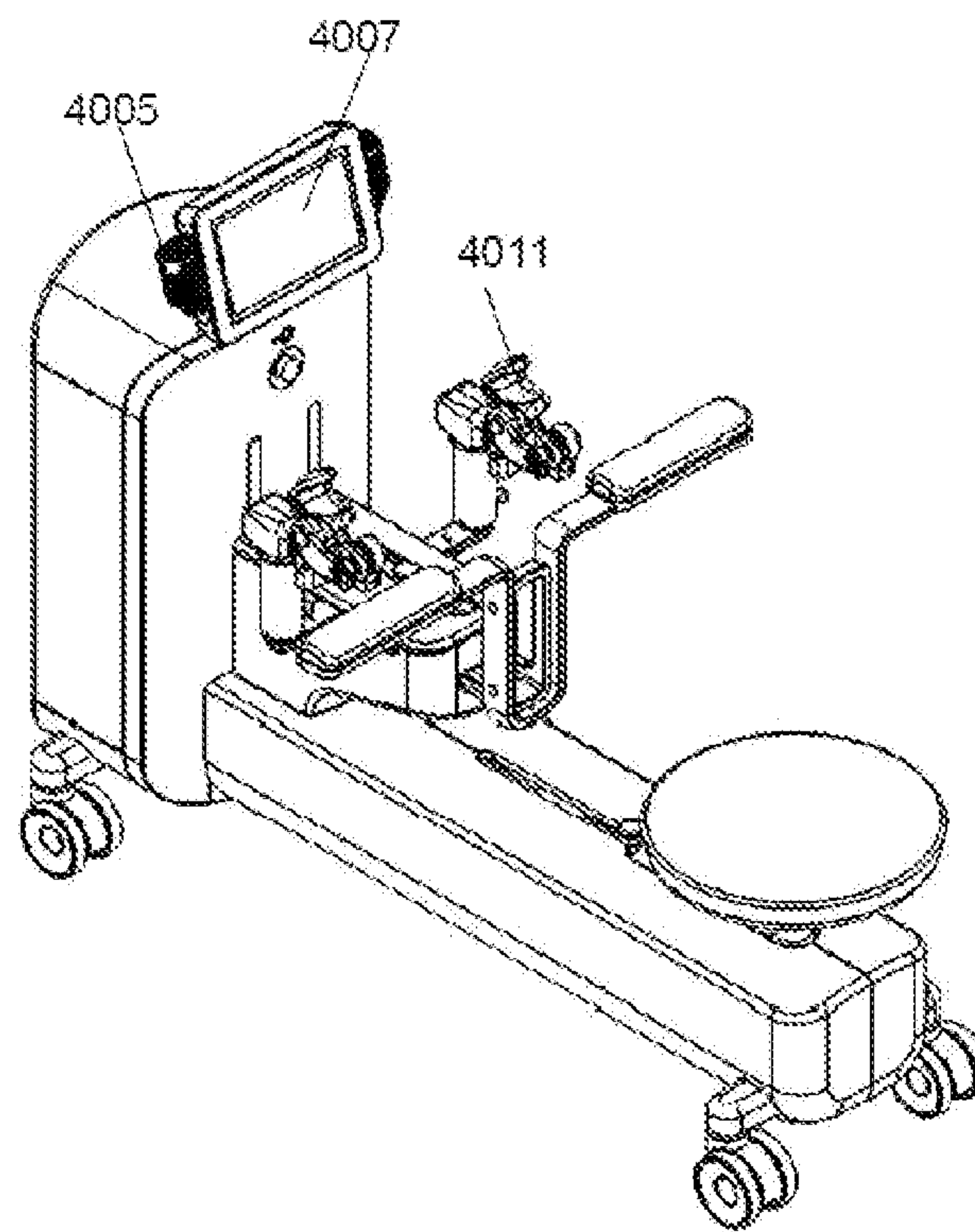


FIG. 17C

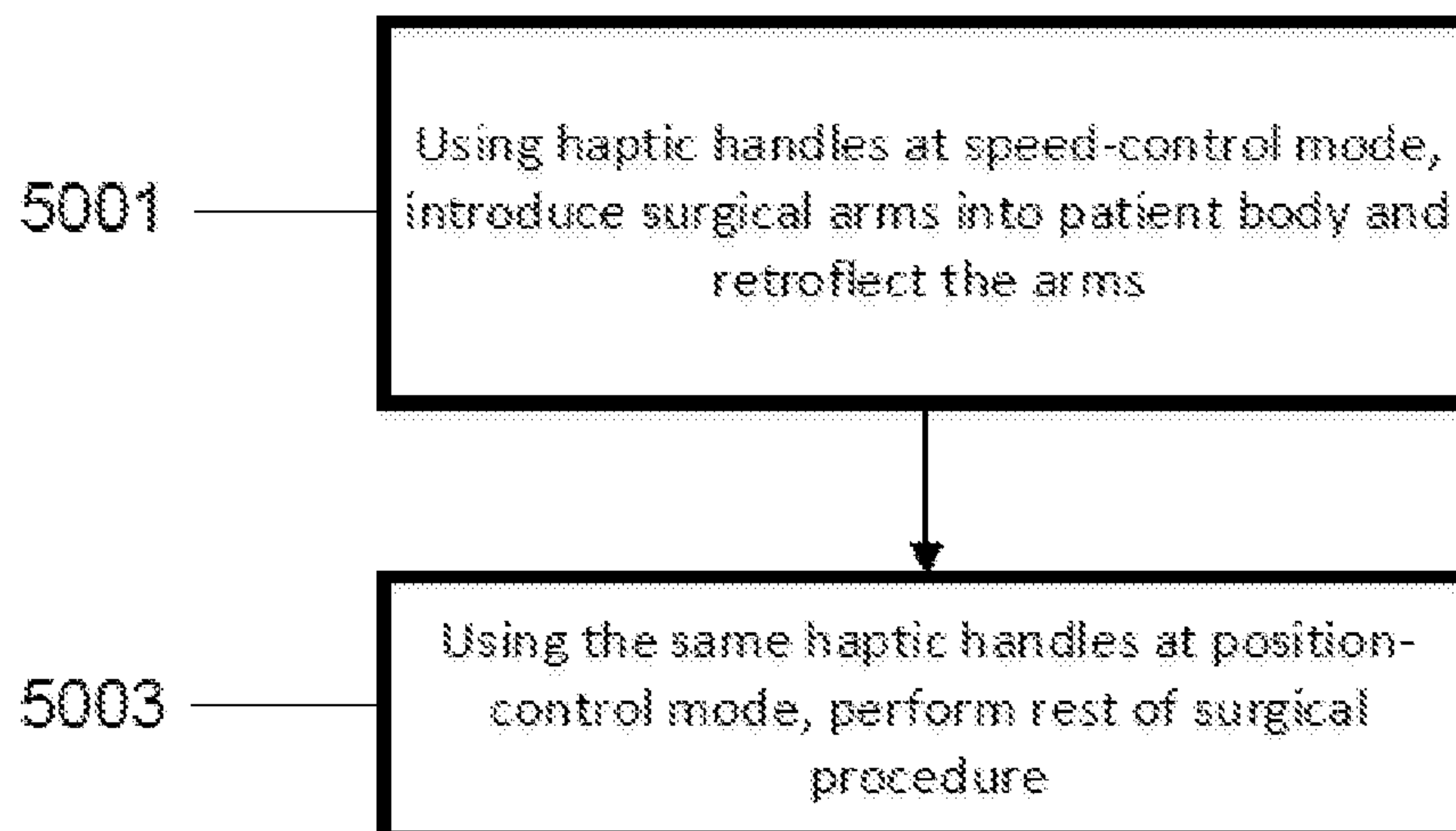


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2020/061506

A. CLASSIFICATION OF SUBJECT MATTER See extra sheet. According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) See extra sheet. Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Databases consulted: Esp@cenet, Derwent Innovation, Orbit, Similari (AI-based) Search terms used: articulate, joint, vertebre, segment, section, arm, input, device, joystick, keyboard, console, preclude, restrict, disable, stop, block, prevent, avoid, pause, actuate, active, action, bend, flex, rotate, move, surgical.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019231445 A1 MEMIC INNOVATIVE SURGERY LTD 01 Aug 2019 (2019/08/01) para.[0324], [0334], [0336], [0338], [0361], [0373]-[0376], [0379], [0385], [0401], [0495]-[0506], [0544], [0546], [0548], [0588]; fig. 1, 2, 21, 22	1-41
X	US 2015327940 A1 OLYMPUS CORP 19 Nov 2015 (2015/11/19) para.[0011], [0021], [0041]-[0048], [0051], [0056], [0057], [0064], [0073], [0094]-[0098]; claim 1; fig. 1, 3, 7	7,10,13-16,22,25,26, 28-32,34-37,40,41
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "D" document cited by the applicant in the international application "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 17 Mar 2021		Date of mailing of the international search report 18 Mar 2021
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Email address: pctoffice@justice.gov.il		Authorized officer AHARONY Meytal Telephone No. 972-73-3927138

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2020/061506

Patent document cited search report			Publication date	Patent family member(s)			Publication Date
US	2019231445	A1	01 Aug 2019	US	2019231445	A1	01 Aug 2019
				CA	2957362	A1	04 Mar 2017
				CA	2957620	A1	10 Mar 2016
				CA	2957622	A1	10 Mar 2016
				CA	2957624	A1	10 Mar 2016
				CA	2960354	A1	09 Sep 2017
				CA	2997849	A1	09 Sep 2018
				CN	106714655	A	24 May 2017
				CN	106714655	B	29 Dec 2020
				DK	3188645	T3	13 Jul 2020
				DK	3188682	T3	01 Feb 2021
				DK	3190942	T3	13 Jul 2020
				DK	3219283	T3	22 Feb 2021
				EP	3188645	A2	12 Jul 2017
				EP	3188645	A4	11 Jul 2018
				EP	3188645	B1	15 Apr 2020
				EP	3188682	A2	12 Jul 2017
				EP	3188682	A4	09 May 2018
				EP	3188682	B1	04 Nov 2020
				EP	3190942	A1	19 Jul 2017
				EP	3190942	A4	25 Jul 2018
				EP	3190942	B1	17 Jun 2020
				EP	3219283	A1	20 Sep 2017
				EP	3219283	B1	02 Dec 2020
				EP	3738541	A1	18 Nov 2020
				EP	3750502	A1	16 Dec 2020
				EP	3753518	A1	23 Dec 2020
				ES	2801149	T3	08 Jan 2021
				ES	2803579	T3	28 Jan 2021
				HR	P20201017	T1	16 Oct 2020

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2020/061506

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
	HR	P20201018 T1	16 Oct 2020
	IL	250896 D0	30 Apr 2017
	IL	250896 A	30 Sep 2020
	IL	251293 D0	29 Jun 2017
	IL	251293 A	30 Jun 2019
	IL	276723 D0	30 Sep 2020
	JP	2017533057 A	09 Nov 2017
	JP	6626110 B2	25 Dec 2019
	JP	2020058815 A	16 Apr 2020
	LT	3188645 T	10 Jul 2020
	LT	3188682 T	25 Jan 2021
	LT	3190942 T	10 Jul 2020
	LT	3219283 T	10 Mar 2021
	SI	3188645 T1	31 Aug 2020
	SI	3190942 T1	30 Oct 2020
	US	2017112583 A1	27 Apr 2017
	US	9788911 B2	17 Oct 2017
	US	2017119483 A1	04 May 2017
	US	9820822 B2	21 Nov 2017
	US	2017071687 A1	16 Mar 2017
	US	10022197 B2	17 Jul 2018
	US	2017112581 A1	27 Apr 2017
	US	10052165 B2	21 Aug 2018
	US	2017135776 A1	18 May 2017
	US	10070930 B2	11 Sep 2018
	US	2018256267 A1	13 Sep 2018
	US	10299866 B2	28 May 2019
	US	2017258539 A1	14 Sep 2017
	US	10463438 B2	05 Nov 2019
	US	2019167364 A1	06 Jun 2019
	US	10470831 B2	12 Nov 2019

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2020/061506

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
		US 2019167363 A1	06 Jun 2019
		US 10500003 B2	10 Dec 2019
		US 2017258538 A1	14 Sep 2017
		US 10617481 B2	14 Apr 2020
		US 2017071688 A1	16 Mar 2017
		US 2017231701 A1	17 Aug 2017
		US 2017239005 A1	24 Aug 2017
		US 2018256265 A1	13 Sep 2018
		US 2018256266 A1	13 Sep 2018
		US 2018256268 A1	13 Sep 2018
		US 2019000574 A1	03 Jan 2019
		US 2020138533 A1	07 May 2020
		US 2020170736 A1	04 Jun 2020
		US 2020268458 A1	27 Aug 2020
		US 2020289225 A1	17 Sep 2020
		WO 2016035084 A2	10 Mar 2016
		WO 2016035084 A3	21 Apr 2016
		WO 2016035085 A2	10 Mar 2016
		WO 2016035085 A3	06 May 2016
		WO 2016035086 A2	10 Mar 2016
		WO 2016035086 A3	06 May 2016
		WO 2017037723 A1	09 Mar 2017
US 2015327940 A1	19 Nov 2015	US 2015327940 A1	19 Nov 2015
		US 10307212 B2	04 Jun 2019
		CN 104936548 A	23 Sep 2015
		CN 104936548 B	14 Jul 2017
		EP 2948092 A1	02 Dec 2015
		EP 2948092 A4	30 Nov 2016
		JP 2016504067 A	12 Feb 2016
		JP 6072283 B2	01 Feb 2017

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/IB2020/061506

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
		WO 2014115901 A1	31 Jul 2014

A. CLASSIFICATION OF SUBJECT MATTER:

IPC (20210101) A61B 34/00, A61B 34/35, A61B 34/37, A61B 17/00, A61B 34/30, A61B 90/00, B25J 18/04, B25J 18/06
CPC (20160201) A61B 34/74, A61B 34/25, A61B 34/35, A61B 34/37, A61B 34/70, A61B 2017/00199, A61B 17/00234, A61B 2017/00398, A61B 2017/00973, A61B 2034/301, A61B 2034/302, A61B 2034/305, A61B 2090/035, B25J 18/04, B25J 18/06

B. FIELDS SEARCHED:

* Minimum documentation searched (classification system followed by classification symbols)

IPC (20210101) A61B 34/00, A61B 34/35, A61B 34/37, A61B 17/00, A61B 34/30, A61B 90/00, B25J 18/04, B25J 18/06
CPC (20160201) A61B 34/74, A61B 34/25, A61B 34/35, A61B 34/37, A61B 34/70, A61B 2017/00199, A61B 17/00234, A61B 2017/00398, A61B 2017/00973, A61B 2034/301, A61B 2034/302, A61B 2034/305, A61B 2090/035, B25J 18/04, B25J 18/06