

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
30 December 2009 (30.12.2009)

(10) International Publication Number
WO 2009/158164 A1

- (51) **International Patent Classification:**
A61B 19/00 (2006.01)
- (21) **International Application Number:**
PCT/US2009/046234
- (22) **International Filing Date:**
4 June 2009 (04.06.2009)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
12/163,087 27 June 2008 (27.06.2008) US
- (71) **Applicant (for all designated States except US):** INTUITIVE SURGICAL, INC. [US/US]; 1266 Kifer Road, Bldg. 101, Sunnyvale, CA 94086 (US).
- (72) **Inventors:** MUSTAFA, Tabish; 650 N. Shoreline Blvd., Apt. 25, Mountain View, CA 94043 (US). DIOLAITI, Nicola; 460 Channing Avenue, Apt. D, Palo Alto, California 94301 (US). LARKIN, David, Q.; 913 Woodland Avenue, Menlo Park, California 94025 (US).
- (74) **Agents:** NGUYEN, Frank et al.; Intuitive Surgical, Inc., 1266 Kifer Road Bldg. 101, Sunnyvale, CA 94086 (US).
- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR),

[Continued on next page]

(54) **Title:** MEDICAL ROBOTIC SYSTEM PROVIDING AN AUXILIARY VIEW OF ARTICULATABLE INSTRUMENTS EXTENDING OUT OF A DISTAL END OF AN ENTRY GUIDE

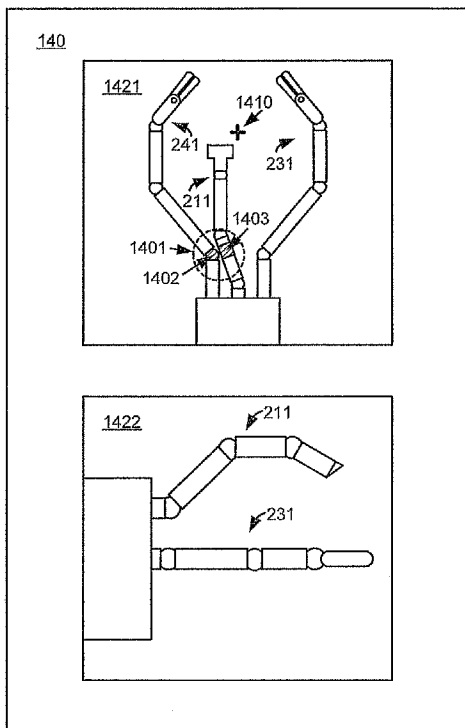


fig.14

(57) **Abstract:** A medical robotic system (100) includes an entry guide (200) with surgical tools (231, 241) and a camera (211) extending out of its distal end. To supplement the view provided by an image captured by the camera, an auxiliary view including articulating arms of the surgical tools and/or camera is generated from sensed or otherwise determined information about their positions and orientations and displayed on a display screen (140) from the perspective of a specified viewing point.

WO 2009/158164 A1

OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG). **Published:**

— with international search report (Art. 21(3))

MEDICAL ROBOTIC SYSTEM PROVIDING AN AUXILIARY VIEW OF
ARTICULATABLE INSTRUMENTS EXTENDING OUT OF A DISTAL END OF AN
ENTRY GUIDE

FIELD OF THE INVENTION

[0001] The present invention generally relates to medical robotic systems and in particular, to a medical robotic system providing an auxiliary view of articulatable instruments extending out of a distal end of an entry guide.

BACKGROUND OF THE INVENTION

[0002] Medical robotic systems such as teleoperative systems used in performing minimally invasive surgical procedures offer many benefits over traditional open surgery techniques, including less pain, shorter hospital stays, quicker return to normal activities, minimal scarring, reduced recovery time, and less injury to tissue. Consequently, demand for such medical robotic systems is strong and growing.

[0003] One example of such a medical robotic system is the da Vinci[®] Surgical System from Intuitive Surgical, Inc., of Sunnyvale, California, which is a minimally invasive robotic surgical system. The da Vinci[®] Surgical System has a number of robotic arms that move attached medical devices, such as an image capturing device and Intuitive Surgical's proprietary EndoWrist[®] articulating surgical instruments, in response to movement of input devices by a surgeon viewing images captured by the image capturing device of a surgical site. Each of the medical devices is inserted through its own minimally invasive incision into the patient and positioned to perform a medical procedure at the surgical site. The incisions are placed about the patient's body so that the surgical instruments may be used to cooperatively perform the medical procedure and the image

capturing device may view it without their robotic arms colliding during the procedure.

[0004] To perform certain medical procedures, it may be advantageous to use a single entry aperture, such as a minimally invasive incision or a natural body orifice, to enter a patient to perform a medical procedure. For example, an entry guide may first be inserted, positioned, and held in place in the entry aperture. Instruments such as an articulatable camera and a plurality of articulatable surgical tools, which are used to perform the medical procedure, may then be inserted into a proximal end of the entry guide so as to extend out of its distal end. Thus, the entry guide provides a single entry aperture for multiple instruments while keeping the instruments bundled together as it guides them toward the work site.

[0005] Since the entry guide generally has a relatively small diameter in order to fit through a minimally invasive incision or a natural body orifice, a number of problems may arise while teleoperating the surgical tools to perform the medical procedure and the camera to view it. For example, because the camera is bundled with the surgical tools, it is limited in its positioning relative to the surgical tools and consequently, its view of the surgical tools.

[0006] Thus, although the tips of the articulatable surgical tools may be kept in the field of view of the camera, controllable linkages which facilitate the articulatability of the surgical tools may not be in the field of view of the camera. As a consequence, the controllable linkages of the surgical tools may inadvertently collide with each other (or with a link of the camera) during the performance of a medical procedure and as a result, cause harm to the patient or otherwise adversely impact the performance of the medical procedure.

[0007] Also, since the articulatable camera is generally incapable of viewing its own controllable linkage, operator movement of the camera is especially a concern where collisions with the surgical tool links are to be avoided. Further, when intuitive control is provided to assist the operator in teleoperatively moving the surgical tools and camera, the motions of the linkages required to produce such intuitive motions of the tips of the tools and camera may not be obvious or intuitive to the operator, thus making it even more difficult for the operator to avoid collisions between linkages that are outside the field of view of the camera.

OBJECTS AND SUMMARY OF THE INVENTION

[0008] Accordingly, one object of one or more aspects of the present invention is a method that provides an auxiliary view to an operator to assist the operator in performing a medical procedure on a patient using a medical robotic system having articulatable instruments extending out of a distal end of an entry guide inserted through a single entry aperture in the patient.

[0009] Another object of one or more aspects of the present invention is a method implemented in such a medical robotic system that provides a visual indication to an operator that indicates when controllable linkages of the articulatable instruments may collide.

[0010] Another object of one or more aspects of the present invention is a method implemented in a medical robotic system that provides a visual indication to an operator that indicates when joints and/or links and/or portions thereof of the articulatable instruments are nearing an undesirable or desirable event or condition.

[0011] Another object of one or more aspects of the present invention is a method implemented in such a medical robotic system that improves an operator's understanding of the configuration of the linkages of the articulatable instruments that are outside of the field of view of a camera.

[0012] These and additional objects are accomplished by the various aspects of the present invention, wherein briefly stated, one aspect is a method for providing a computer generated view, comprising: receiving information of states of one or more articulatable instruments extending out of a distal end of an entry guide; generating a view using the received information and forward kinematics of the one or more

articulatable instruments; and displaying the generated view on a display screen.

[0013] Another aspect is a medical robotic system comprising: an entry guide; a plurality of instruments extending through and out of a distal end of the entry guide; a plurality of sensors adapted to sense states of articulating elements of the plurality of instruments; a display screen; and a controller configured to receive information including the sensed states of the articulating elements from the plurality of sensors, generate a view using the received information, and display the generated view on the display screen.

[0014] Additional objects, features and advantages of the various aspects of the present invention will become apparent from the following description of its preferred embodiment, which description should be taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** illustrates a top view of an operating room employing a medical robotic system utilizing aspects of the present invention.

[0016] **FIG. 2** illustrates a block diagram of components for controlling and selectively associating device manipulators to left and right hand-manipulatable input devices in a medical robotic system utilizing aspects of the present invention.

[0017] **FIGS. 3-4** respectively illustrate top and side views of an articulatable camera and a pair of articulatable surgical tools extending out of a distal end of an entry guide as used in a medical robotic system utilizing aspects of the present invention.

[0018] **FIG. 5** illustrates a perspective view of an entry guide and its four degrees-of-freedom movement as used in a medical robotic system utilizing aspects of the present invention.

[0019] **FIG. 6** illustrates a cross-sectional view of an entry guide with passages defined therein that extend between its proximal and distal ends as used in a medical robotic system utilizing aspects of the present invention.

[0020] **FIG. 7** illustrates a block diagram of interacting components of an entry guide manipulator as used in a medical robotic system utilizing aspects of the present invention.

[0021] **FIG. 8** illustrates a block diagram of interacting components of an articulatable instrument manipulator and an articulatable instrument as used in a medical robotic system utilizing aspects of the present invention.

[0022] **FIG. 9** illustrates a flow diagram of a method for providing a computer generated auxiliary view, utilizing aspects of the present invention.

[0023] **FIG. 10** illustrates a data and processing flow diagram to determine instrument link positions and orientations using instrument joint positions and forward kinematics, as used in a medical robotic system utilizing aspects of the present invention.

[0024] **FIG. 11** illustrates a data and processing flow diagram to determine instrument joint positions using a sensed instrument tip position and inverse kinematics, as used in a medical robotic system utilizing aspects of the present invention.

[0025] **FIGS. 12-13** respectively illustrate top and side auxiliary views as generated and displayed on a display screen by a method implemented in a medical robotic system utilizing aspects of the present invention.

[0026] **FIG. 14** illustrates top and side auxiliary views as generated and displayed in separate windows on a display screen by a method implemented in a medical robotic system utilizing aspects of the present invention.

[0027] **FIG. 15** illustrates an auxiliary view displayed adjacent to an image captured by the articulatable camera on a monitor in a medical robotic system utilizing aspects of the present invention.

[0028] **FIG. 16** illustrates an auxiliary side view of an articulatable camera having a frustum as generated and displayed by a method implemented in a medical robotic system utilizing aspects of the present invention on a display screen.

[0029] **FIG. 17** illustrates a combined display of an auxiliary view of a pair of articulatable surgical tools from a viewing point of a camera, along with an image captured by the camera, as generated and displayed by a method implemented in a medical robotic system utilizing aspects of the present invention on a display screen.

[0030] **FIG. 18** illustrates a flow diagram of a method for providing auxiliary viewing modes that correspond to device control modes in a medical robotic system, utilizing aspects of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0031] **FIG. 1** illustrates, as an example, a top view of an operating room in which a medical robotic system **100** is being utilized by a Surgeon **20** for performing a medical procedure on a Patient **40** who is lying face up on an operating table **50**. One or more Assistants **30** may be positioned near the Patient **40** to assist in the procedure while the Surgeon **20** performs the procedure teleoperatively by manipulating input devices **108, 109** on a surgeon console **10**.

[0032] In the present example, an entry guide (EG) **200** is inserted through a single entry aperture **150** into the Patient **40**. Although the entry aperture **150** is a minimally invasive incision in the present example, in the performance of other medical procedures, it may instead be a natural body orifice. The entry guide **200** is held and manipulated by a robotic arm assembly **130**.

[0033] As with other parts of the medical robotic system **100**, the illustration of the robotic arm assembly **130** is simplified in **FIG. 1**. In one example of the medical robotic system **100**, the robotic arm assembly **130** includes a setup arm and an entry guide manipulator. The setup arm is used to position the entry guide **200** at the entry aperture **150** so that it properly enters the entry aperture **150**. The entry guide manipulator is then used to robotically insert and retract the entry guide **200** into and out of the entry aperture **150**. It may also be used to robotically pivot the entry guide **200** in pitch, roll and yaw about a pivot point located at the entry aperture **150**. An example of such an entry guide manipulator is the entry guide manipulator **202** of **FIG. 2** and an example of the four degrees-of-freedom movement that it manipulates the entry guide **200** with is shown in **FIG. 5**.

[0034] The console **10** includes a 3-D monitor **104** for displaying a 3-D image of a surgical site to the Surgeon, left and right hand-manipulatable input devices **108, 109**, and a processor (also referred to herein as a "controller") **102**. The input devices **108, 109** may include any one or more of a variety of input devices such as joysticks, gloves, trigger-guns, hand-operated controllers, or the like. Other input devices that are provided to allow the Surgeon to interact with the medical robotic system **100** include a foot pedal **105**, a conventional voice recognition system **160** and a Graphical User Interface (GUI) **170**.

[0035] An auxiliary display screen **140** is coupled to the console **10** (and processor **102**) for providing auxiliary views to the Surgeon to supplement those shown on the monitor **104**. A second auxiliary display screen **140'** is also coupled to the console **10** (and processor **102**) for providing auxiliary views to the Assistant(s). An input device **180** is also coupled to the console to allow the Assistant(s) to select between available auxiliary views for display on the second auxiliary display screen **140'**.

[0036] The console **10** is usually located in the same room as the Patient so that the Surgeon may directly monitor the procedure, is physically available if necessary, and is able to speak to the Assistant(s) directly rather than over the telephone or other communication medium. However, it will be understood that the Surgeon can also be located in a different room, a completely different building, or other remote location from the Patient allowing for remote surgical procedures. In such a case, the console **10** may be connected to the second auxiliary display screen **140'** and input device **180** through a network connection such as a local area network, wide area network, or the Internet.

[0037] As shown in **FIGS. 3-4**, the entry guide **200** has articulatable instruments such as articulatable surgical tools **231, 241** and an articulatable stereo camera **211** extending out of its distal end. Although only two tools **231, 241** are shown, the entry guide **200** may guide additional tools as required for performing a medical procedure at a work site in the Patient. For example, as shown in **FIG. 4**, a passage **351** is available for extending another articulatable surgical tool through the entry guide **200** and out through its distal end. Each of the surgical tools **231, 241** is associated with one of the input devices **108, 109** in a tool following mode. The Surgeon performs a medical procedure by manipulating the input devices **108, 109** so that the controller **102** causes corresponding movement of their respectively associated surgical tools **231, 241** while the Surgeon views the work site in 3-D on the console monitor **104** as images of the work site are being captured by the articulatable camera **211**.

[0038] Preferably, input devices **108, 109** will be provided with at least the same degrees of freedom as their associated tools **231, 241** to provide the Surgeon with telepresence, or the perception that the input devices **108, 109** are integral with the tools **231, 241** so that the Surgeon has a strong sense of directly controlling the tools **231, 241**. To this end, the monitor **104** is also positioned near the Surgeon's hands so that it will display a projected image that is oriented so that the Surgeon feels that he or she is actually looking directly down onto the work site and images of the tools **231, 241** appear to be located substantially where the Surgeon's hands are located.

[0039] In addition, the real-time image on the monitor **104** is preferably projected into a perspective image such that the Surgeon can manipulate the end effectors **331, 341** of the tools **231, 241** through their corresponding input devices **108, 109** as if viewing the work site in substantially true presence. By

true presence, it is meant that the presentation of an image is a true perspective image simulating the viewpoint of an operator that is physically manipulating the end effectors **331, 341**.

Thus, the processor **102** may transform the coordinates of the end effectors **331, 341** to a perceived position so that the perspective image being shown on the monitor **104** is the image that the Surgeon would see if the Surgeon was located directly behind the end effectors **331, 341**.

[0040] The processor **102** performs various functions in the system **100**. One important function that it performs is to translate and transfer the mechanical motion of input devices **108, 109** through control signals over bus **110** so that the Surgeon can effectively manipulate devices, such as the tools **231, 241**, camera **211**, and entry guide **200**, that are selectively associated with the input devices **108, 109** at the time. Another function is to perform various methods and controller functions described herein.

[0041] Although described as a processor, it is to be appreciated that the processor **102** may be implemented in practice by any combination of hardware, software and firmware. Also, its functions as described herein may be performed by one unit or divided up among different components, each of which may be implemented in turn by any combination of hardware, software and firmware. Further, although being shown as part of or being physically adjacent to the console **10**, the processor **102** may also comprise a number of subunits distributed throughout the system.

[0042] For additional details on the construction and operation of various aspects of a medical robotic system such as described herein, see, e.g., U.S. Pat. No. 6,493,608 "Aspects of a Control System of a Minimally Invasive Surgical Apparatus," and U.S. Pat. No. 6,671,581 "Camera Referenced Control in a

Minimally Invasive Surgical Apparatus," which are incorporated herein by reference.

[0043] **FIG. 2** illustrates, as an example, a block diagram of components for controlling and selectively associating device manipulators to the input devices **108, 109**. Various surgical tools such as graspers, cutters, and needles may be used to perform a medical procedure at a work site within the Patient. In this example, two surgical tools **231, 241** are used to robotically perform the procedure and the camera **211** is used to view the procedure. The tools **231, 241** and camera **211** are inserted through passages in the entry guide **200**. As described in reference to **FIG. 1**, the entry guide **200** is inserted into the Patient through entry aperture **150** using the setup portion of the robotic arm assembly **130** and maneuvered by the entry guide manipulator (EGM) **202** of the robotic arm assembly **130** towards the work site where the medical procedure is to be performed.

[0044] Each of the devices **231, 241, 211, 200** is manipulated by its own manipulator. In particular, the camera **211** is manipulated by a camera manipulator (ECM) **212**, the first surgical tool **231** is manipulated by a first tool manipulator (PSM1) **232**, the second surgical tool **241** is manipulated by a second tool manipulator (PSM2) **242**, and the entry guide **200** is manipulated by an entry guide manipulator (EGM) **202**. So as to not overly encumber the figure, the devices **231, 241, 211, 200** are not shown, only their respective manipulators **232, 242, 212, 202** are shown in the figure.

[0045] Each of the instrument manipulators **232, 242, 212** is a mechanical assembly that carries actuators and provides a mechanical, sterile interface to transmit motion to its respective articulatable instrument. Each instrument **231, 241, 211** is a mechanical assembly that receives the motion from its manipulator and, by means of a cable transmission, propagates

the motion to its distal articulations (e.g., joints). Such joints may be prismatic (e.g., linear motion) or rotational (e.g., they pivot about a mechanical axis). Furthermore, the instrument may have internal mechanical constraints (e.g., cables, gearing, cams, belts, etc.) that force multiple joints to move together in a pre-determined fashion. Each set of mechanically constrained joints implements a specific axis of motion, and constraints may be devised to pair rotational joints (e.g., joggle joints). Note also that in this way the instrument may have more joints than the available actuators.

[0046] In contrast, the entry guide manipulator **202** has a different construction and operation. A description of the parts and operation of the entry guide manipulator **202** is described below in reference to **FIG. 7**.

[0047] In this example, each of the input devices **108, 109** may be selectively associated with one of the devices **211, 231, 241, 200** so that the associated device may be controlled by the input device through its controller and manipulator. For example, by placing switches **258, 259** respectively in tool following modes "T2" and "T1", the left and right input devices **108, 109** may be respectively associated with the first and second surgical tools **231, 241**, which are telerobotically controlled through their respective controllers **233, 243** (preferably implemented in the processor **102**) and manipulators **232, 242** so that the Surgeon may perform a medical procedure on the Patient while the entry guide **200** is locked in place.

[0048] When the camera **211** or the entry guide **200** is to be repositioned by the Surgeon, either one or both of the left and right input devices **108, 109** may be associated with the camera **211** or entry guide **200** so that the Surgeon may move the camera **211** or entry guide **200** through its respective controller (**213** or **203**) and manipulator (**212** or **202**). In this case, the

disassociated one(s) of the surgical tools 231, 241 is locked in place relative to the entry guide 200 by its controller. For example, by placing switches 258, 259 respectively in camera positioning modes "C2" and "C1", the left and right input devices 108, 109 may be associated with the camera 211, which is telerobotically controlled through its controller 213 (preferably implemented in the processor 102) and manipulator 212 so that the Surgeon may position the camera 211 while the surgical tools 231, 241 and entry guide 200 are locked in place by their respective controllers 233, 243, 203. If only one input device is to be used for positioning the camera, then only one of the switches 258, 259 is placed in its camera positioning mode while the other one of the switches 258, 259 remains in its tool following mode so that its respective input device may continue to control its associated surgical tool.

[0049] On the other hand, by placing switches 258, 259 respectively in entry guide positioning modes "G2" and "G1", the left and right input devices 108, 109 may be associated with the entry guide 200, which is telerobotically controlled through its controller 203 (preferably implemented in the processor 102) and manipulator 202 so that the Surgeon may position the entry guide 200 while the surgical tools 231, 241 and camera 211 are locked in place relative to the entry guide 200 by their respective controllers 233, 243, 213. As with the camera positioning mode, if only one input device is to be used for positioning the entry guide, then only one of the switches 258, 259 is placed in its entry guide positioning mode while the other one of the switches 258, 259 remains in its tool following mode so that its respective input device may continue to control its associated surgical tool.

[0050] The selective association of the input devices 108, 109 to other devices in this example may be performed by the Surgeon using the GUI 170 or the voice recognition system 160 in

a conventional manner. Alternatively, the association of the input devices **108**, **109** may be changed by the Surgeon depressing a button on one of the input devices **108**, **109** or depressing the foot pedal **105**, or using any other well known mode switching technique.

[0051] **FIGS. 3-4** respectively illustrate, as examples, top and right side views of a distal end of the entry guide **200** with the camera **211** and surgical tools **231**, **241** extending outward. As shown in a perspective view of a simplified (not to scale) entry guide **200** in **FIG. 5**, the entry guide **200** is generally cylindrical in shape and has a longitudinal axis X' running centrally along its length. The pivot point, which is also referred to as a remote center "RC", serves as an origin for both a fixed reference frame having X , Y and Z axes as shown and an entry guide reference frame having X' , Y' and Z' axes as shown. When the system **100** is in the entry guide positioning mode, the entry guide manipulator **202** is capable of pivoting the entry guide **200** in response to movement of one or more associated input devices about the Z axis (which remains fixed in space) at the remote center "RC" in yaw ψ . In addition, the entry guide manipulator **202** is capable of pivoting the entry guide **200** in response to movement of the one or more input devices about the Y' axis (which is orthogonal to the longitudinal axis X' of the entry guide **200**) in pitch θ , capable of rotating the entry guide **200** about its longitudinal axis X' in roll Φ , and linearly moving the entry guide **200** along its longitudinal axis X' in insertion/retraction or in/out "I/O" directions in response to movement of the one or more associated input devices. Note that unlike the Z -axis which is fixed in space, the X' and Y' axes move with the entry guide **200**.

[0052] As shown in **FIG. 7**, the entry guide manipulator (EGM) **202** has four actuators **701-704** for actuating the four degrees-of-freedom movement of the entry guide **200** (i.e., pitch θ , yaw

ψ , roll Φ , and in/out I/O) and four corresponding assemblies 711-714 to implement them.

[0053] Referring back to FIGS. 3-4, the articulatable camera 211 extends through passage 321 and the articulatable surgical tools 231, 241 respectively extend through passages 431, 441 of the entry guide 200. The camera 211 includes a tip 311 (which houses a stereo camera connected to a camera controller and a fiber-optic cable connected to an external light source), first, second, and third links 322, 324, 326, first and second joint assemblies (also referred to herein simply as "joints") 323, 325, and a wrist assembly 327. The first joint assembly 323 couples the first and second links 322, 324 and the second joint assembly 325 couples the second and third links 324, 326 so that the second link 324 may pivot about the first joint assembly 323 in pitch and yaw while the first and third links 322, 326 remain parallel to each other.

[0054] The first and second joints 323, 325 are referred to as "joggle joints", because they cooperatively operate together so that as the second link 324 pivots about the first joint 323 in pitch and/or yaw, the third link 326 pivots about the second joint 325 in a complementary fashion so that the first and third links 322, 326 always remain parallel to each other. The first link 322 may also rotate around its longitudinal axis in roll as well as move in and out (e.g., insertion towards the work site and retraction from the worksite) through the passage 321. The wrist assembly 327 also has pitch and yaw angular movement capability so that the camera's tip 311 may be oriented up or down and to the right or left, and combinations thereof.

[0055] The joints and links of the tools 231, 241 are similar in construction and operation to those of the camera 211. In particular, the tool 231 includes an end effector 331 (having jaws 338, 339), first, second, and third links 332, 334, 336,

first and second joint assemblies 333, 335, and a wrist assembly 337 that are driven by actuators such as described in reference to FIG. 8 (plus an additional actuator for actuating the end effector 331). Likewise, the tool 241 includes an end effector 341 (having jaws 348, 349), first, second, and third links 342, 344, 346, first and second joint assemblies 343, 345, and a wrist assembly 347 that are also driven by actuators such as described in reference to FIG. 8 (plus an additional actuator for actuating the end effector 341).

[0056] FIG. 8 illustrates, as an example, a diagram of interacting parts of an articulatable instrument (such as the articulatable camera 211 and the articulatable surgical tools 231, 241) and its corresponding instrument manipulator (such as the camera manipulator 212 and the tool manipulators 232, 242). Each of the instruments includes a number of actuatable assemblies 821-823, 831-833, 870 for effectuating articulation of the instrument (including its end effector), and its corresponding manipulator includes a number of actuators 801-803, 811-813, 860 for actuating the actuatable assemblies.

[0057] In addition, a number of interface mechanisms may also be provided. For example, pitch/yaw coupling mechanisms 840, 850 (respectively for the joggle joint pitch/yaw and the wrist pitch/yaw) and gear ratios 845, 855 (respectively for the instrument roll and the end effector actuation) are provided in a sterile manipulator/instrument interface to achieve the required range of motion of the instrument joints in instrument joint space while both satisfying compactness constraints in the manipulator actuator space and preserving accurate transmissions of motion across the interface. Although shown as a single block 840, the coupling between the joggle joint actuators 801, 802 (differentiated as #1 and #2) and joggle joint pitch/yaw assemblies 821, 822 may include a pair of coupling mechanisms - one on each side of the sterile interface (i.e., one on the

manipulator side of the interface and one on the instrument side of the interface). Likewise, although shown as a single block **850**, the coupling between the wrist actuators **812**, **813** (differentiated as #1 and #2) and wrist pitch/yaw joint assemblies **832**, **833** may also comprise a pair of coupling mechanisms - one on each side of the sterile interface.

[0058] Both the joggle joint pitch assembly **821** and the joggle joint yaw assembly **822** share the first, second and third links (e.g., links **322**, **324**, **326** of the articulatable camera **211**) and the first and second joints (e.g., joints **322**, **325** of the articulatable camera **211**). In addition to these shared components, the joggle joint pitch and yaw assemblies **821**, **822** also include mechanical couplings that couple the first and second joints (through joggle coupling **840**) to the joggle joint pitch and yaw actuators **801**, **802** so that the second link may controllably pivot about a line passing through the first joint and along an axis that is latitudinal to the longitudinal axis of the first link (e.g., link **322** of the articulatable camera **211**) and the second link may controllably pivot about a line passing through the first joint and along an axis that is orthogonal to both the latitudinal and longitudinal axes of the first link.

[0059] The in/out (I/O) assembly **823** includes the first link (e.g., link **322** of the articulatable camera **211**) and interfaces through a drive train coupling the in/out (I/O) actuator **803** to the first link so that the first link is controllably moved linearly along its longitudinal axis by actuation of the I/O actuator **803**. The roll assembly **831** includes the first link and interfaces through one or more gears (i.e., having the gear ratio **845**) that couple a rotating element of the roll actuator **811** (such as a rotor of a motor) to the first link so that the first link is controllably rotated about its longitudinal axis by actuation of the roll actuator **811**.

[0060] The instrument manipulator (e.g., camera manipulator 212) includes wrist actuators 812, 813 that actuate through wrist coupling 850 pitch and yaw joints 832, 833 of the wrist assembly (e.g., wrist 327 of the articulatable camera 211) so as to cause the instrument tip (e.g., camera tip 311) to controllably pivot in an up-down (i.e., pitch) and side-to-side (i.e., yaw) directions relative to the wrist assembly. The grip assembly 870 includes the end effector (e.g., end effector 331 of the surgical tool 231) and interfaces through one or more gears (i.e., having the gear ratio 855) that couple the grip actuator 860 to the end effector so as to controllably actuate the end effector.

[0061] FIG. 9 illustrates, as an example, a flow diagram of a method implemented in controller 102 of the medical robotic system 100 for providing a computer generated auxiliary view including articulatable instruments, such as the articulatable camera 211 and/or one or more of the articulatable surgical tools 231, 241, extending out of the distal end of the entry guide 200. For the purposes of this example, it is assumed that the articulatable camera 211 and surgical tools 231, 241 extend out of the distal end of the entry guide 200 and are included in the auxiliary view. However, it is to be appreciated that the method is applicable to any combination of articulatable instruments, including those without an articulatable camera and/or those with an alternative type of image capturing device such as an ultrasound probe.

[0062] In 901, the method determines whether or not an auxiliary view is to be generated. If the determination in 901 is NO, then the method loops back to periodically check to see whether the situation has changed. On the other hand, if the determination in 901 is YES, then the method proceeds to 902. The indication that an auxiliary view is to be generated may be

programmed into the controller 102, created automatically or created by operator command.

[0063] In 902, the method receives state information, such as positions and orientations, for each of the instruments 211, 231, 241 and the entry guide 200. This information may be provided by encoders coupled to the actuators in their respective manipulators 212, 232, 242, 202. Alternatively, the information may be provided by sensors coupled to joints and/or links of the instruments 211, 231, 241 and the entry guide manipulator 202, or the coupling mechanisms, gears and drive trains of the interface between corresponding manipulators and instruments, so as to measure their movement. In this second case, the sensors may be included in the instruments 211, 231, 241 and entry guide manipulator 202 such as rotation sensors that sense rotational movement of rotary joints and linear sensors that sense linear movement of prismatic joints in the instruments 211, 231, 241 and entry guide manipulator 202. Other sensors may also be used for providing information of the positions and orientations of the instruments 211, 231, 241 and entry guide 200 such as external sensors that sense and track trackable elements, which may be active elements (e.g., radio frequency, electromagnetic, etc.) or passive elements (e.g., magnetic, etc.), placed at strategic points on the instruments 211, 231, 241, the entry guide 200 and/or the entry guide manipulator 202 (such as on their joints, links and/or tips).

[0064] In 903, the method generates a three-dimensional computer model of the articulatable camera 211 and articulatable surgical tools 231, 241 extending out of the distal end of the entry guide 200 using the information received in 902 and the forward kinematics and known constructions of the instruments 211, 231, 241, entry guide 200, and entry guide manipulator 202. The generated computer model in this example may be referenced to the remote center reference frame (X, Y, Z axes) depicted in

FIG. 5. Alternatively, the generated computer model may be referenced to a reference frame defined at the distal end of the entry guide **200**. In this latter case, if the orientation and extension of the entry guide **200** from the remote center does not have to be accounted for in the auxiliary view that is being generated by the method, then the position and orientation information for the entry guide **200** may be omitted in **902**.

[0065] For example, referring to **FIG. 10**, if the state information received in **902** is the instruments' joint positions **1001**, then this information may be applied to the instruments' forward kinematics **1002** using the instruments' kinematic models **1003** to generate the instruments' link positions and orientations **1005** relative to reference frame **1004**. The same process may also be generally applied if the state information received in **902** is sensed states of the joggle coupling and gear mechanisms in the manipulator/instrument interfaces.

[0066] On the other hand, referring to **FIG. 11**, if the state information received in **902** is the instruments' tip positions **1101** (in the reference frame **1004**), then this information may be applied to the instruments' inverse kinematics **1102** using the instruments' kinematic models **1003** and the sensor reference frame to generate the instruments' joint positions **1001**. The instruments' joint positions **1001** may then be applied as described in reference to **FIG. 10** to generate the instruments' link positions and orientations **1005** relative to reference frame **1004**.

[0067] Alternatively, also referring to **FIG. 11**, if the state information provided in **902** is limited to only the camera's tip position, then the positions of the tips of the surgical tools **231**, **241** may be determined relative to the camera reference frame by identifying the tips in the image captured by the camera **211** using conventional image processing techniques and

then translating their positions to the reference frame 1004, so that the positions of the camera and tool tips may be applied as described in reference to FIGS. 10, 11 to generate the instruments' link positions and orientations 1005 relative to the reference frame 1004.

[0068] In 904, the method adjusts the view of the computer model of the articulatable camera 211 and articulatable surgical tools 231, 241 extending out of the distal end of the entry guide 200 in the three-dimensional space of the reference frame to a specified viewing point (wherein the term "viewing point" is to be understood herein to include position and orientation). For example, FIG. 12 illustrates a top view of the articulatable camera 211 and articulatable surgical tools 231, 241 extending out of the distal end of the entry guide 200 which corresponds to a viewing point above and slightly behind the distal end of the entry guide 200. As another example, FIG. 13 illustrates a side view of the articulatable camera 211 and articulatable surgical tools 231, 241 extending out of the distal end of the entry guide 200 which corresponds to a viewing point to the right and slightly in front of the distal end of the entry guide 200. Note that although the auxiliary views depicted in FIGS. 12-13 are two-dimensional, they may also be three-dimensional views since three-dimensional information is available from the generated computer model. In this latter case, the auxiliary display screen 140 that they are being displayed on would have to be a three-dimensional display screen like the monitor 104.

[0069] The viewing point may be set at a fixed point such as one providing an isometric (three-dimensional) view from the perspective shown in FIG. 12. This perspective provides a clear view to the surgeon of the articulatable camera 211 and the articulatable surgical tools 231, 241 when the tools 231, 241 are bent "elbows out" as shown (which is a typical configuration for performing a medical procedure using the surgical tools 231,

241). On the other hand, when a third surgical tool is being used (e.g., inserted in the passage 351 shown in FIG. 6), a side view from the perspective of FIG. 13 may additionally be useful since the third surgical tool may be beneath the articulatable camera 211 and therefore obscured by it in the perspective shown in FIG. 12.

[0070] Rather than setting the viewing point to a fixed point at all times, the viewing point may also be automatically changed depending upon the control mode (i.e., one of the modes described in reference to FIG. 2) that is operative at the time. As an example, FIG. 18 illustrates a method for automatically changing the auxiliary viewing mode depending upon the control mode currently operative in the medical robotic system 100. In particular, using this method, a first auxiliary viewing mode is performed in 1802 when the medical robotic system 100 is determined in 1801 to be in a tool following mode, a second auxiliary viewing mode is performed in 1804 when the medical robotic system 100 is determined in 1803 to be in an entry guide positioning mode, and a third auxiliary viewing mode is performed in 1806 when the medical robotic system 100 is determined in 1805 to be in a camera positioning mode. The viewing modes for each control mode are selected so as to be most beneficial to the surgeon for performing actions during that mode. For example, in the tool following and camera positioning modes, either or both the surgical tools 231, 241 and camera 211 is being moved at the time and therefore, an auxiliary view of the articulatable camera 211 and articulatable surgical tools 231, 241 extending out of the distal end of the entry guide 200, such as depicted in FIGS. 12 and 13, is useful to avoid collisions between links that are out of the field of view of the camera 211. On the other hand, in the entry guide positioning mode, the articulatable camera 211 and the articulatable surgical tools 231, 241 are locked in position relative to the entry guide 200 and therefore, an auxiliary view

providing information on other things such as depicted in **FIGS. 16** and **17** may be useful.

[0071] Alternatively, operator selectable means for changing the viewing point during the performance of a medical procedure may be provided. For example, the GUI **170** or voice recognition system **160** may be adapted to provide an interactive means for the Surgeon to select the viewing mode and/or change the viewing point of an auxiliary view of the articulatable camera **211** and/or articulatable surgical tools **231**, **241** as they extend out of the distal end of the entry guide **200**. Buttons on the input devices **108**, **109** or the foot pedal **105** may also be used for Surgeon selection of viewing modes. For the Assistant(s), the input device **180** may be used along with a GUI associated with the display screen **140'** for selection of viewing modes. Thus, the viewing modes that the Surgeon and Assistant(s) see at the time may be optimized for their particular tasks at the time. Examples of such operator selectable viewing modes and viewing angles are depicted in **FIGS. 12-17**.

[0072] In **905**, the method renders the computer model. Rendering in this case includes adding three-dimensional qualities such as known construction features of the instruments **211**, **231**, **241** and the distal end of the entry guide **200** to the model, filling-in any gaps to make solid models, and providing natural coloring and shading. In addition, rendering may include altering the color or intensity of one or more of the instruments **211**, **231**, **241** (or one or more of their joints or links or portions thereof) so that the instrument (or joint or link or portion thereof) stands out for identification purposes.

[0073] Alternatively, the altering of the color, intensity, or frequency of blinking on and off (e.g., flashing) of one or more of the instruments **211**, **231**, **241** (or their joints, links, or portions thereof) may serve as a warning that the instrument

(or joint or link or portion thereof) is approaching an undesirable event or condition such as nearing a limit of its range of motion or getting too close to or colliding with another one of the instruments. When color is used as a warning, the color may go from a first color (e.g., green) to a second color (e.g., yellow) when a warning threshold of an event to be avoided (e.g., range of motion limitation or collision) is reached, and from the second color to a third color (e.g., red) when the event to be avoided is reached. When intensity is used as a warning, the intensity of the color changes as the instrument (or portion thereof) moves past the warning threshold towards the event to be avoided with a maximum intensity provided when the event is reached. When blinking of the color is used as a warning, the frequency of blinking changes as the instrument (or portion thereof) moves past the warning threshold towards the event to be avoided with a maximum frequency provided when the event is reached. The warning threshold may be based upon a range of motion of the instrument (or portion thereof, such as its joints) or upon a distance between the instrument (or portion thereof) and another instrument (or portion thereof) that it may collide with. Velocity of the instrument's movement may also be a factor in determining the warning threshold. The warning threshold may be programmed by the operator, using the GUI **170**, for example, or determined automatically by a programmed algorithm in the processor **102** that takes into account other factors such as the velocity of the instruments' movements.

[0074] Alternatively, the altering of the color, intensity, or frequency of blinking on and off (e.g., flashing) of one or more of the instruments **211**, **231**, **241** (or their joints, links, or portions thereof) may serve as an alert that the instrument (or joint or link or portion thereof) is approaching a desirable event or condition such as an optimal position or configuration for performing or viewing a medical procedure. In this case, an

alert threshold may be defined so that the color, intensity, and/or blinking of the one or more of the instruments **211**, **231**, **241** (or their joints, links, or portions thereof) may change in a similar manner as described previously with respect to warning thresholds and undesirable events or conditions, except that in this case, the change starts when the alert threshold is reached and maximizes or otherwise ends when the desirable event or condition is reached or otherwise achieved. The alert threshold may also be programmed by the operator or determined automatically by a programmed algorithm in a conceptually similar manner as the warning threshold.

[0075] As an example of such highlighting of an instrument for identification, warning or alerting purposes, **FIG. 15** shows an auxiliary view of the camera **211** and surgical tools **231**, **241** in a window **1502**, where the camera **211** has been highlighted. As an example of such highlighting of joints of instruments for identification, warning or alerting purposes, **FIG. 12** shows joints of the surgical tools **231**, **241** that have been highlighted. As an example of highlighting portions of instruments for warning purposes, **FIG. 14** shows a portion **1402** of the surgical tool **241** and a portion **1403** of the camera **211** highlighted to indicate that these portions are dangerously close to colliding.

[0076] Rendering may also include overlaying the image captured by the camera **211** over the auxiliary view when the viewing point of the auxiliary image is the same as or directly behind that of the camera **211**. As an example, **FIG. 17** illustrates a captured image **1700** of the camera **211** rendered as an overlay to an auxiliary view of surgical tools **231**, **241** which has been generated from a viewing point of (or right behind) the camera **211**. In this example, the auxiliary view of the surgical tools **231**, **241** being displayed on the auxiliary display screen **140** (and/or the auxiliary display screen **140'**) includes portions

(e.g., 1731, 1741) in the overlaying captured image 1700 and portions (e.g., 1732, 1742) outside of the overlaying captured image 1700. Thus, the portions of the surgical tools 231, 241 outside of the captured image 1700 provide the Surgeon with additional information about their respective links or articulating arms that are out of the field of view of the camera 211. Highlighting of the instrument portions (e.g., 1732, 1742) outside of the captured image 1700 may also be done for identification purposes or to indicate a warning or alerting condition as described above. Overlaying the captured image 1700 onto the auxiliary view also has the advantage in this case of showing an anatomic structure 360 which is in front of the surgical tools 231, 241 that would not otherwise normally be in the auxiliary view. Although this example shows the captured image 1700 overlaying the auxiliary view on the auxiliary display screen 140, in another rendering scheme, the auxiliary view may overlay the captured image that is being displayed on the monitor 104.

[0077] Rather than overlaying the captured image, rendering may also include using the auxiliary view to augment the image captured by the camera 211 by displaying only the portions of the instruments 231, 241 that are not seen in the captured image (i.e., the dotted line portion of the instruments 231, 241 in FIG. 17) in proper alignment and adjacent the captured image in a mosaic fashion.

[0078] In addition to, or in lieu of, overlaying the captured image over the auxiliary view or augmenting the captured image with the auxiliary view, rendering may also include providing other useful information in the auxiliary view. As an example, FIG. 16 illustrates an auxiliary side view of an articulatable camera 211 with a frustum 1601 rendered on the auxiliary view so as to be displayed on the auxiliary display 140 as emanating from, and moving with, the camera tip 311. Note that although

the frustum 1601 is shown in the figure as a truncated cone, it may also appear as a truncated pyramid to correspond to the captured image that is shown on the monitor 104. The sides of the frustum 1601 indicate a viewing range of the camera 211 and the base 1602 of the frustum 1601 displays an image 1650 that was captured by the camera 211. Note that for simplification purposes, the surgical tools 231, 241 normally in the auxiliary view have been removed for this example. As another example, FIG. 14 shows a semi-translucent sphere or bubble 1401 (preferably colored red) which is displayed by the method as part of the rendering process when a warning threshold is reached so as to indicate to the operator that the highlighted portions 1402, 1403 of the surgical tool 241 and camera 211 are dangerously close to colliding. In this case, the highlighted portions 1402, 1403 are preferably centered within the sphere. As yet another example, FIG. 14 also shows a marker or other indicator 1410 indicating an optimal position for the camera tip 311 for viewing the end effectors of the surgical tools 231, 241 as they are being used to perform a medical procedure. The optimal position may be determined, for example, by finding a location where the tips of the end effectors are equidistant from a center of the captured image.

[0079] In 906, the method causes the rendered computer model (i.e., the auxiliary view) to be displayed on one or more displayed screens (e.g., 140 and 140') from the perspective of the selected viewing point. As shown in FIGS. 12-14 and 16-17, the auxiliary view is displayed on the auxiliary display screen 140. As shown in FIG. 14, more than one auxiliary view may be displayed at one time (e.g., top and side perspectives may be provided at the same time respectively in windows 1421 and 1422). As shown in FIG. 15, the auxiliary view may also be displayed on the primary monitor 104 in a window 1502 that is adjacent to an image captured by the articulatable camera 211 which is being shown in another window 1501. Although the

windows 1501 and 1502 appear in this example to be the same size, it is to be appreciated that the position and size of the auxiliary view window 1502 may vary and still be within the scope of the present invention. Also, as previously mentioned, the auxiliary view may be overlaid the captured image in the window 1501 instead of in its own separate window 1502. In such case, the overlaid auxiliary view may be switched on and off by the Surgeon so as not to clutter the captured image during the performance of a medical procedure. The switching on and off in this case may be performed by depressing a button on one of the input devices 108, 109 or depressing the foot pedal 105. Alternatively, it may be done by voice activation using the voice recognition system 160 or through Surgeon interaction with the GUI 170 or using any other conventional function switching means.

[0080] After completing 906, the method then loops back to 901 to repeat 901-906 for the next processing cycle of the controller 102.

[0081] Although the various aspects of the present invention have been described with respect to a preferred embodiment, it will be understood that the invention is entitled to full protection within the full scope of the appended claims.

We claim:

1. A method for providing a computer generated view, comprising:

receiving information of states of one or more articulatable instruments extending out of a distal end of an entry guide;

generating a view using the received information and forward kinematics of the one or more articulatable instruments; and

displaying the generated view on a display screen.

2. The method according to claim 1, wherein the displayed view serves to supplement an image captured by a camera viewing at least one distal tip of the one or more articulatable instruments.

3. The method according to claim 1, wherein the one or more articulatable instruments includes an articulatable camera and the displayed view serves to supplement an image captured by the articulatable camera.

4. The method according to claim 1, wherein the received information is provided by sensors that sense activity of actuators for articulating the articulatable instruments.

5. The method according to claim 1, wherein the received information is provided by sensors that sense the states of the one or more articulatable instruments.

6. The method according to claim 5, wherein the sensors include rotation sensors that sense rotational states of joints of the one or more articulatable instruments.

7. The method according to claim 5, wherein the sensors include displacement sensors that sense linear states of prismatic joints of the one or more articulatable instruments.

8. The method according to claim 5, wherein the sensors are included in the one or more articulatable instruments.

9. The method according to claim 5, wherein the sensors are external of the one or more articulatable instruments so as to sense positions of trackable elements placed at strategic points on the one or more articulatable instruments.

10. The method according to claim 9, wherein the trackable elements are active elements.

11. The method according to claim 10, wherein the trackable elements are placed on the tips of the one or more articulatable instruments, and the generation of the view comprises:

determining joint positions of the one or more articulatable instruments by applying the sensed positions of the trackable elements to inverse kinematics of the one or more articulatable instruments; and

determining link positions and orientations of the one or more articulatable instruments by applying the determined joint positions to the forward kinematics of the one or more articulatable instruments.

12. The method according to claim 9, wherein the trackable elements are passive elements.

13. The method according to claim 1, wherein the generation of the view comprises:

generating a computer model of the one or more articulatable instruments using the received information;
translating the computer model to a perspective of a selectable viewing point; and
rendering the translated model.

14. The method according to claim 13, wherein the generation of the computer model includes using forward kinematics of the one or more articulatable instruments with respect to a fixed reference point.

15. The method according to claim 14, wherein the fixed reference point is a remote center about which the entry guide is pivotable.

16. The method according to claim 14, wherein the translation of the computer model to the perspective of the selectable viewing point comprises:

computing a distance from the fixed reference point to the selectable viewing point; and

using the computed distance to translate and orient the computer model to the perspective of the selectable viewing point.

17. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera and one or more articulatable surgical tools and the rendering of the translated computer model comprises rendering the articulatable camera in a different color than the one or more articulatable surgical tools so that the articulatable camera may be readily distinguished in the view being displayed on the display screen.

18. The method according to claim 13, wherein the rendering of the translated computer model comprises changing a color of at least a portion of at least one of the one or more articulatable instruments as the at least one of the articulatable instruments reaches a threshold of an event.

19. The method according to claim 18, wherein the threshold is a warning threshold and the event is a condition to be avoided.

20. The method according to claim 19, wherein the warning threshold is based upon a range of motion of the portion of the at least one of the one or more articulatable instruments.

21. The method according to claim 20, wherein the condition to be avoided is a limitation of the range of motion of the portion of the at least one of the one or more articulatable instruments.

22. The method according to claim 19, wherein the warning threshold is based upon a distance between the portion of the at least one of the one or more articulatable instruments and a portion of another of the one or more articulatable instruments.

23. The method according to claim 22, wherein the condition to be avoided is a collision between the portion of the at least one of the one or more articulatable instruments and the portion of the another of the one or more articulatable instruments.

24. The method according to claim 23, wherein the portion of the another of the one or more articulatable instruments changes color as the portion of the at least one of the one or more articulatable instruments reaches the warning threshold.

25. The method according to claim 23, wherein a sphere is displayed around the portion of the at least one of the one or more articulatable instruments and the portion of the another of the one or more articulatable instruments as the portion of the at least one of the one or more articulatable instruments reaches the warning threshold.

26. The method according to claim 19, wherein an intensity of the color changes as the portion of the at least one of the one or more articulatable instruments moves beyond the warning threshold towards the event to be avoided.

27. The method according to claim 19, wherein the color turns on and off at a frequency that increases as the portion of the at least one of the one or more articulatable instruments moves beyond the warning threshold towards the event to be avoided.

28. The method according to claim 19, wherein the color changes from a first color to a second color when the portion of the at least one of the one or more articulatable instruments reaches the warning threshold and from the second color to a third color as the portion of the at least one of the one or more articulatable instruments reaches the event to be avoided.

29. The method according to claim 18, wherein the threshold is an alert threshold and the event is a desirable

position for the at least one of the one or more articulatable instruments.

30. The method according to claim 18, wherein the threshold is an alert threshold and the event is a desirable configuration for the at least one of the one or more articulatable instruments.

31. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera and the generation of the computer model includes generating a frustum so as to extend out from a tip of the articulatable camera and indicate the viewing range of the articulatable camera.

32. The method according to claim 31, wherein the rendering of the translated computer model includes rendering an image captured by the articulatable camera on a base of the frustum.

33. The method according to claim 13, further comprising: calculating a centroid for the one or more articulatable instruments, and the displaying of the view on the display screen which includes displaying the centroid on the display screen so as to provide an indication of whether the entry guide needs to be repositioned.

34. The method according to claim 13, further comprising: receiving an indication of the selectable viewing point from an operator controlled input mechanism.

35. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera and one or more articulatable surgical tools, the

selectable viewing point coincides with a viewing point of the articulatable camera, and the displaying of the generated view on the display screen includes displaying an image captured by the articulatable camera on the display screen so that the one or more articulatable surgical tools captured in the image coincides with and overlays the one or more articulatable surgical tools in the view.

36. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera, the selectable viewing point coincides with a viewing point of the articulatable camera, and the displaying of the generated view on the display screen includes displaying an image captured by the articulatable camera on the display screen and augmenting the image by mosaicing, adjacent the image, aligned portions of the rendered and translated model that are not shown in the image.

37. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera and one or more articulatable surgical tools, the articulatable camera includes a stereoscopic camera and an image captured by the articulatable camera is displayed as a three-dimensional image on the display screen adjacent the displayed view of the articulatable camera and the one or more articulatable surgical tools extending out of the distal end of the entry guide.

38. The method according to claim 37, wherein the displayed view of the articulatable camera and the one or more articulatable surgical tools extending out of the distal end of the entry guide is a three-dimensional view.

39. The method according to claim 13, wherein the one or more articulatable instruments include an articulatable camera and one or more articulatable surgical tools, the selectable view is from a first position and orientation when one or more input devices are associated with the entry guide for repositioning of the entry guide, the selectable view is from a second position and orientation when the one or more input devices are associated with the one or more articulatable surgical tools for performing a procedure using the tools, and the selectable view is from a third position and orientation when the one or more input devices are associated with the articulatable camera for moving the articulatable camera so as to capture an image from a different perspective.

40. A medical robotic system comprising:
an entry guide;
a plurality of instruments extending through and out of a distal end of the entry guide;
a plurality of sensors adapted to sense states of articulating elements of the plurality of instruments;
a display screen; and
a controller configured to receive information including the sensed states of the articulating elements from the plurality of sensors, generate a view using the received information, and display the generated view on the display screen.

41. The medical robotic system according to claim 40, wherein the articulating elements include actuators for articulating the plurality of instruments.

42. The medical robotic system according to claim 40, wherein the articulating elements include joints and the

plurality of sensors include rotation sensors that sense rotational movement of the joints.

43. The medical robotic system according to claim 40, wherein the articulating elements include links and the plurality of sensors include translation sensors that sense linear movement of the links.

44. The medical robotic system according to claim 40, wherein the plurality of sensors are disposed within the plurality of instruments.

45. The medical robotic system according to claim 40, wherein the plurality of sensors are external of the plurality of instruments so as to sense states of trackable elements placed at strategic points on the plurality of instruments.

46. The medical robotic system according to claim 40, wherein the controller generates the view by generating a computer model of the plurality of instruments using the received information, translating the computer model to a perspective of a selectable viewing point, and rendering the translated model.

47. The medical robotic system according to claim 46, wherein the controller generates the computer model by computing forward kinematics of the plurality of instruments with respect to a fixed reference point.

48. The medical robotic system according to claim 47, wherein the fixed reference point is a remote center about which the entry guide is pivotable.

49. The medical robotic system according to claim 46, wherein the controller translates the computer model to the perspective of the selectable viewing point by computing a distance from the fixed reference point to the selectable viewing point and translating and orienting the computer model to the perspective of the selectable viewing point using the computed distance.

50. The medical robotic system according to claim 46, wherein plurality of instruments includes an articulatable camera, and the controller renders the translated computer model by rendering the articulatable camera in a different color than others of the plurality of instruments so that the articulatable camera may be readily distinguished in the view being displayed on the display screen.

51. The medical robotic system according to claim 46, wherein the controller renders the translated computer model by changing a color of at least a portion of at least one of the plurality of instruments as the at least one of the plurality of instruments reaches a threshold of an event.

52. The medical robotic system according to claim 51, wherein the threshold is a warning threshold and the event is a condition to be avoided.

53. The medical robotic system according to claim 52, wherein the warning threshold is based upon a range of motion of the portion of the at least one of the plurality of instruments.

54. The medical robotic system according to claim 53, wherein the condition to be avoided is a limitation of the range

of motion of the portion of the at least one of the plurality of instruments.

55. The medical robotic system according to claim 52, wherein the warning threshold is based upon a distance between the portion of the at least one of the plurality of instruments and a portion of another of the plurality of instruments.

56. The medical robotic system according to claim 55, wherein the condition to be avoided is a collision between the portion of the at least one of the plurality of instruments and the portion of the another of the plurality of instruments.

57. The medical robotic system according to claim 56, wherein the portion of the another of the plurality of instruments changes color as the portion of the at least one of the plurality of instruments reaches the warning threshold.

58. The medical robotic system according to claim 57, wherein a sphere is displayed around the portion of the at least one of the plurality of instruments and the portion of the another of the plurality of instruments as the portion of the at least one of the plurality of instruments reaches the warning threshold.

59. The medical robotic system according to claim 52, wherein an intensity of the color changes as the portion of the at least one of the plurality of instruments moves beyond the warning threshold towards the event to be avoided.

60. The medical robotic system according to claim 52, wherein the color turns on and off at a frequency that increases as the portion of the at least one of the plurality of

instruments moves beyond the warning threshold towards the event to be avoided.

61. The medical robotic system according to claim 52, wherein the color changes from a first color to a second color when the portion of the at least one of the plurality of instruments reaches the warning threshold and from the second color to third color as the portion of the at least one of the plurality of instruments reaches the event to be avoided.

62. The medical robotic system according to claim 51, wherein the threshold is an alert threshold and the event is a desirable position for the at least one of the one or more articulatable instruments.

63. The medical robotic system according to claim 51, wherein the threshold is an alert threshold and the event is a desirable configuration for the at least one of the one or more articulatable instruments.

64. The medical robotic system according to claim 46, wherein the plurality of instruments includes an articulatable camera and the controller generates the computer model by generating a frustum so as to extend out from a tip of the articulatable camera and indicate the viewing range of the articulatable camera.

65. The medical robotic system according to claim 64, wherein the controller renders the translated computer model by rendering an image captured by the articulatable camera on a base of the frustum.

66. The medical robotic system according to claim 46, wherein the controller is configured to calculate a centroid for

the plurality of instruments and display the view on the display screen by displaying the centroid on the display screen so as to provide an indication of whether the entry guide needs to be repositioned.

67. The medical robotic system according to claim 46, further comprising:

an input mechanism;

wherein the controller is configured to receive an indication of the selectable viewing point from the input mechanism.

68. The medical robotic system according to claim 46, wherein the plurality of instruments includes an articulatable camera and one or more articulatable surgical tools, the selectable viewing point coincides with a viewing point of the articulatable camera, and the controller displays the generated view on the display screen by displaying an image captured by the articulatable camera on the display screen so that the one or more articulatable surgical tools captured in the image coincides with and overlays the one or more articulatable surgical tools in the view.

69. The medical robotic system according to claim 46, wherein the plurality of instruments includes an articulatable camera and one or more articulatable surgical tools, the selectable viewing point coincides with a viewing point of the articulatable camera, and the controller displays the generated view on the display screen by displaying an image captured by the articulatable camera on the display screen and augmenting the image by mosaicing, adjacent the image, aligned portions of the rendered and translated model that are not shown in the image.

70. The medical robotic system according to claim 46, wherein the plurality of instruments includes an articulatable camera and one or more articulatable surgical tools, the articulatable camera includes a stereoscopic camera and an image captured by the articulatable camera is displayed as a three-dimensional image on the display screen adjacent the displayed view of the one or more surgical tools extending out of the distal end of the entry guide.

71. The medical robotic system according to claim 70, wherein the displayed view of the one or more surgical tools extending out of the distal end of the entry guide is a three-dimensional view.

72. The medical robotic system according to claim 46, further comprising: one or more input devices; wherein the selectable view is from a first position and orientation when the one or more input devices are associated with the entry guide for repositioning of the entry guide, the selectable view is from a second position and orientation when the one or more input devices are associated with the one or more articulatable surgical tools for performing a procedure using the tools, and the selectable view is from a third position and orientation when the one or more input devices are associated with the articulatable camera for moving the articulatable camera so as to capture an image from a different perspective.

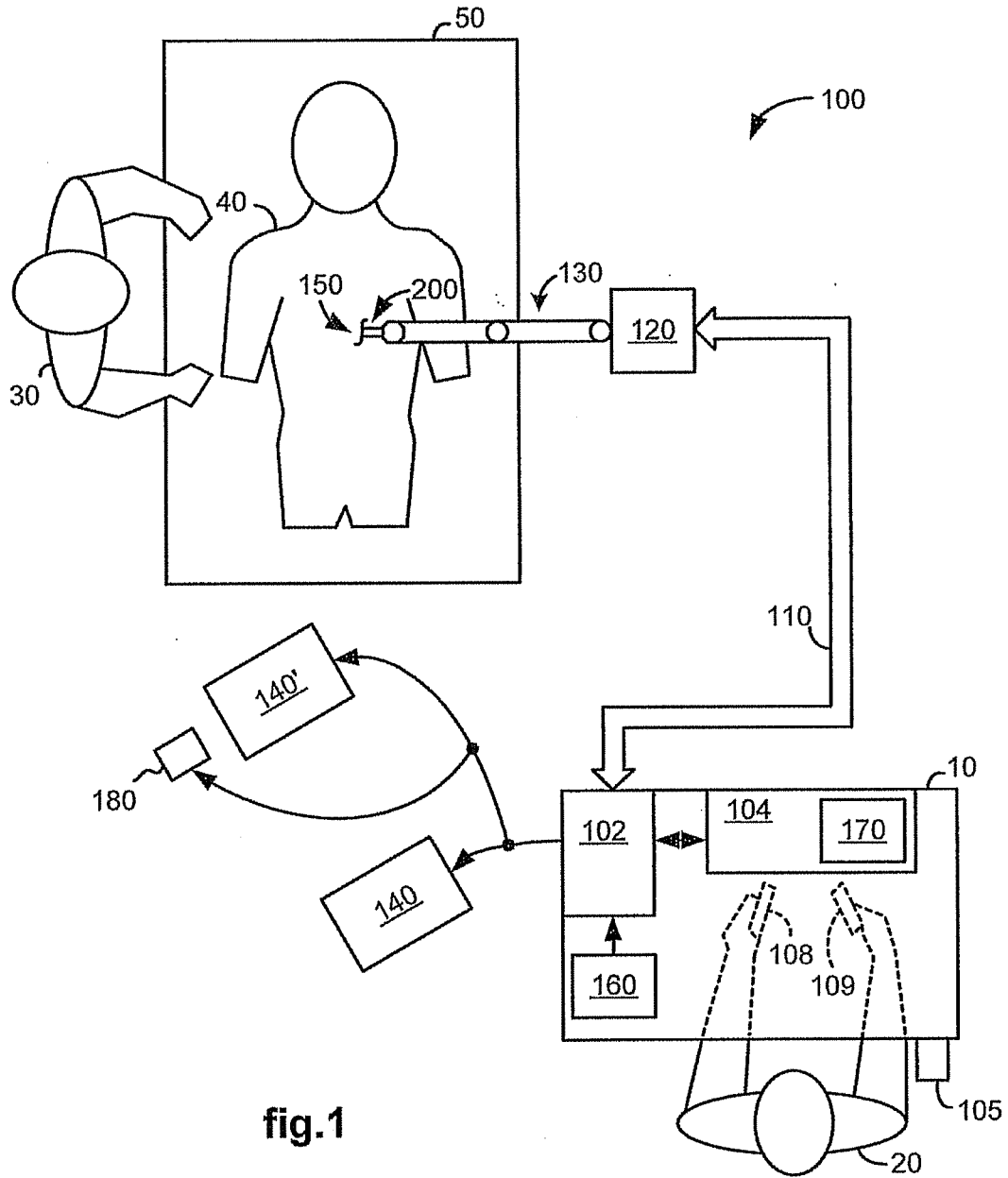


fig.1

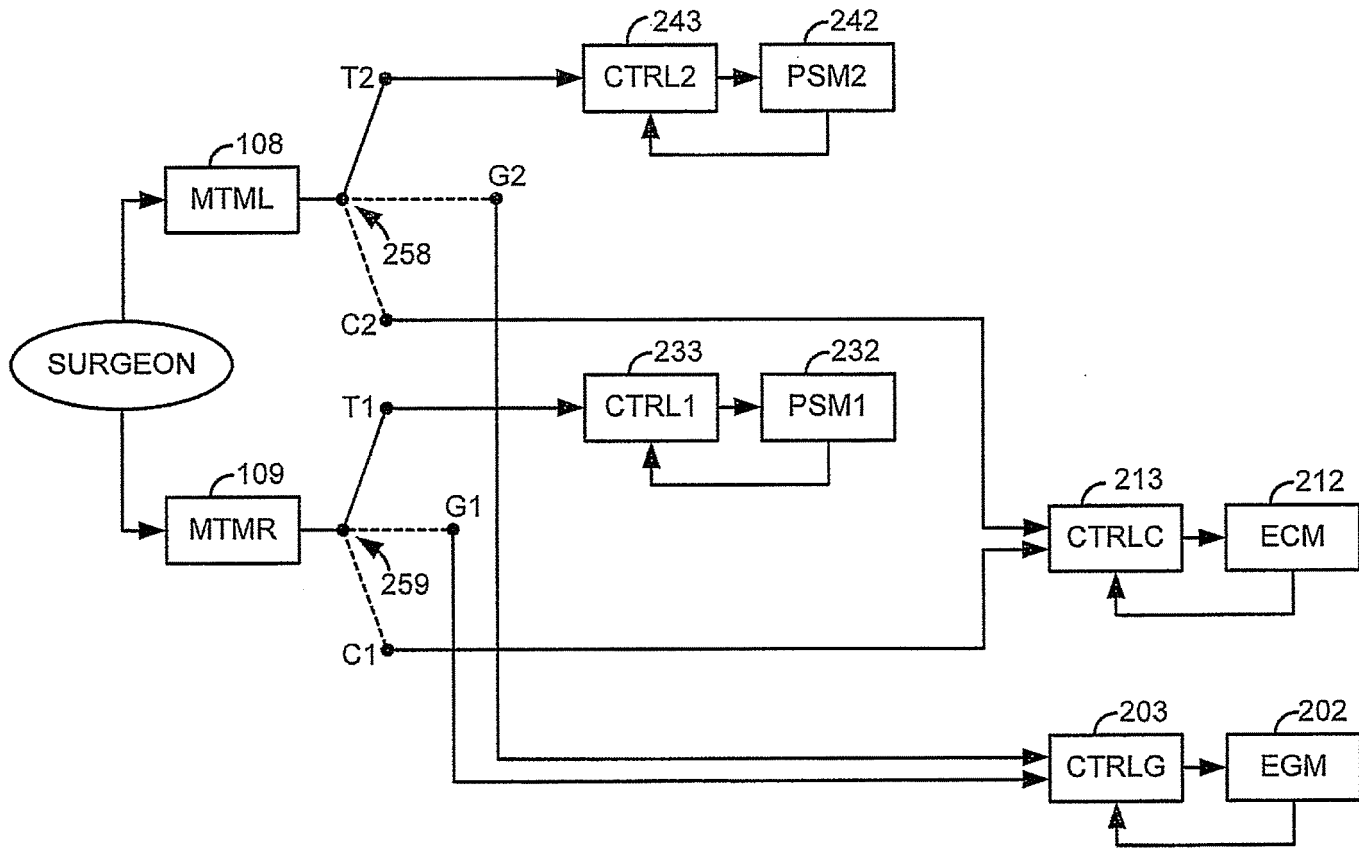


fig.2

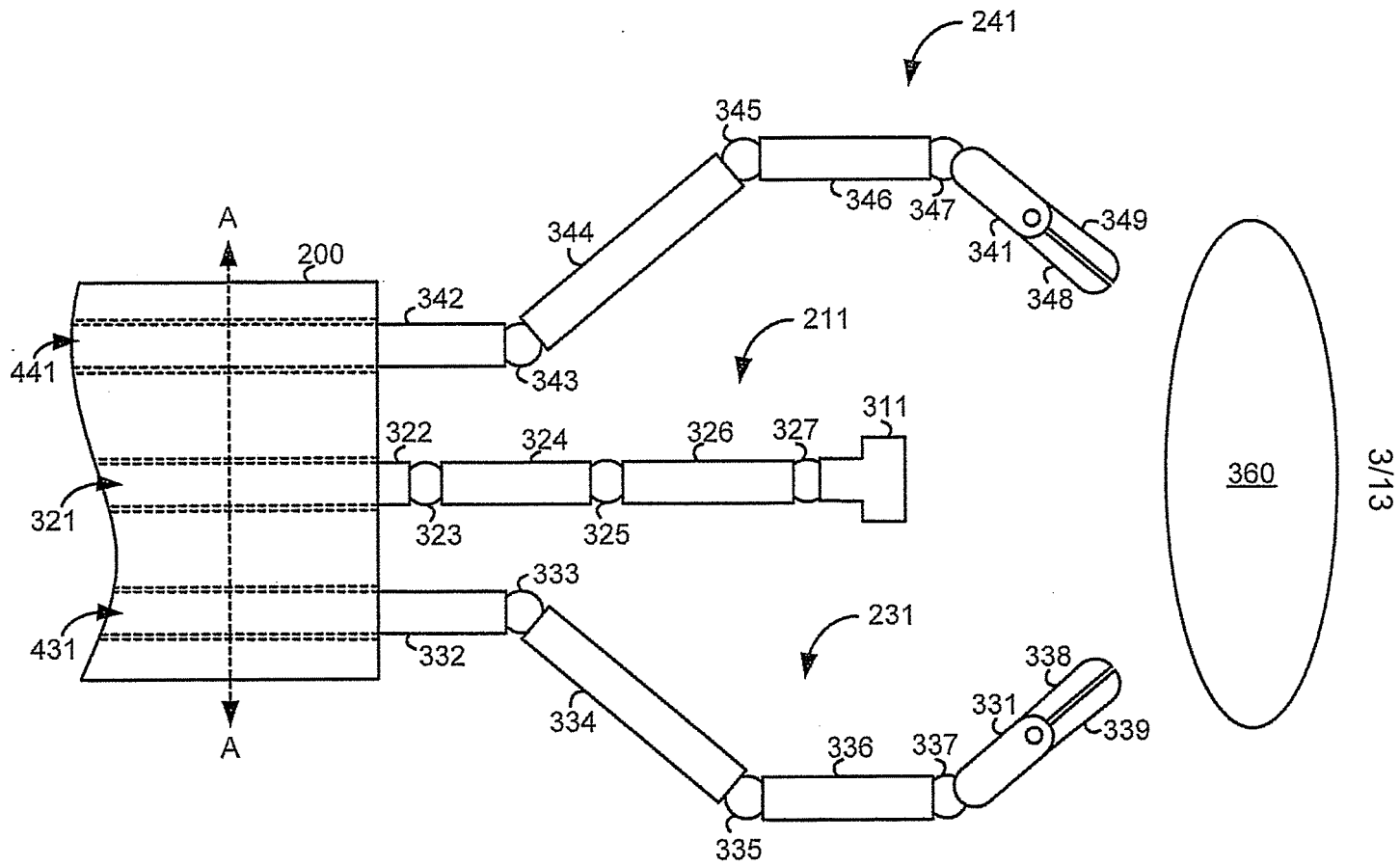


fig.3

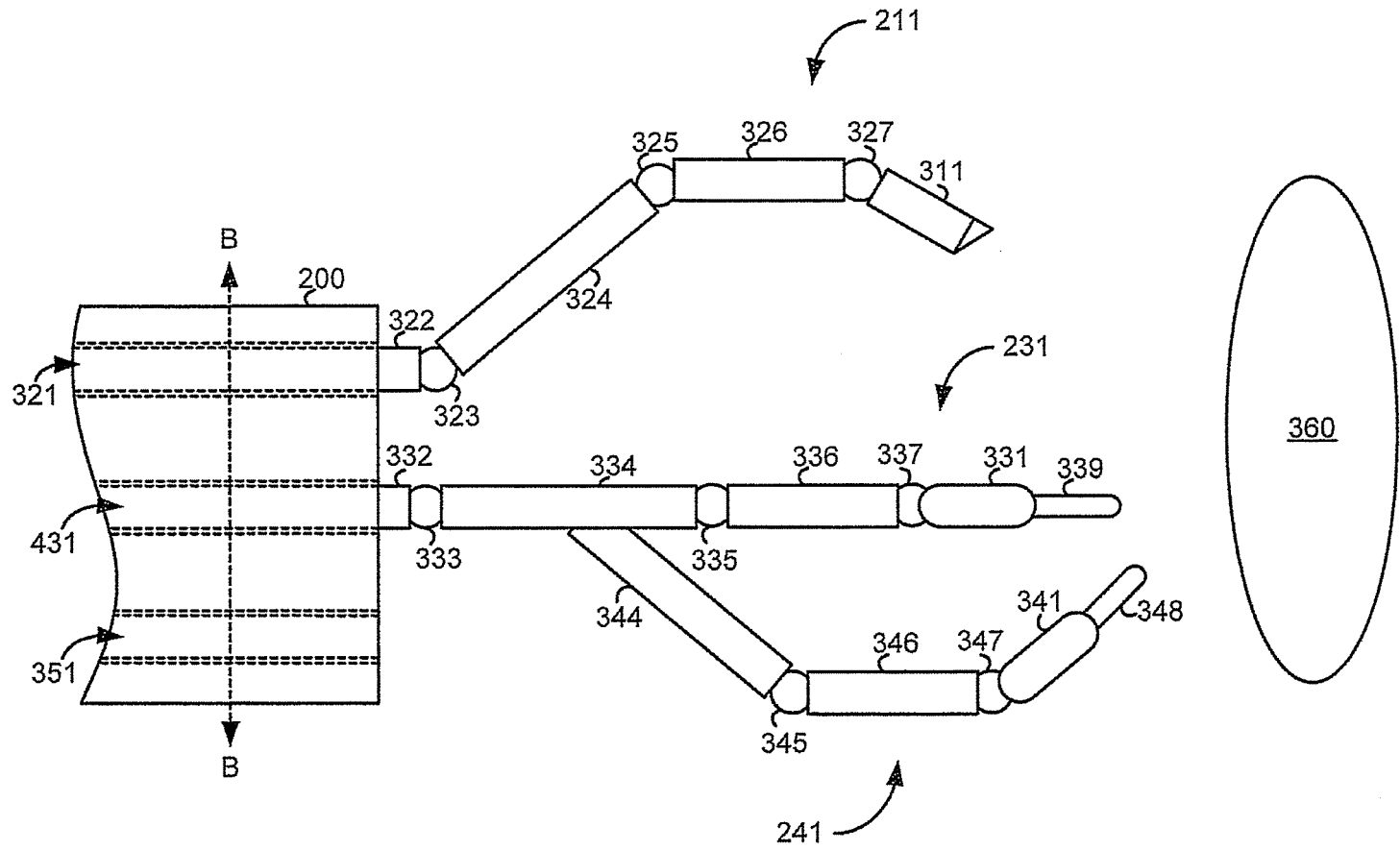


fig.4

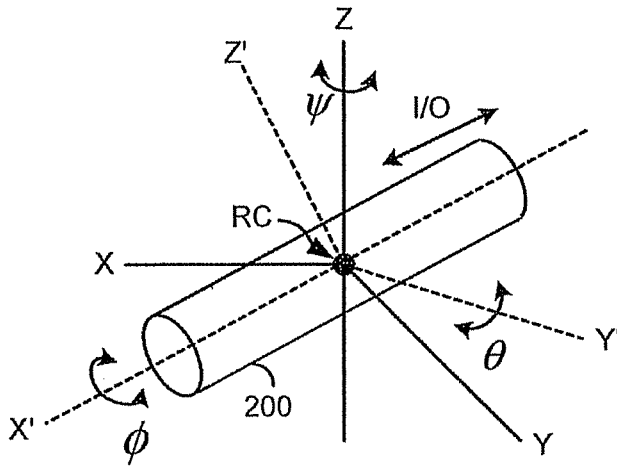


fig.5

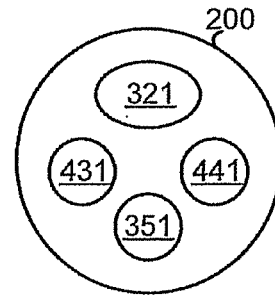


fig.6

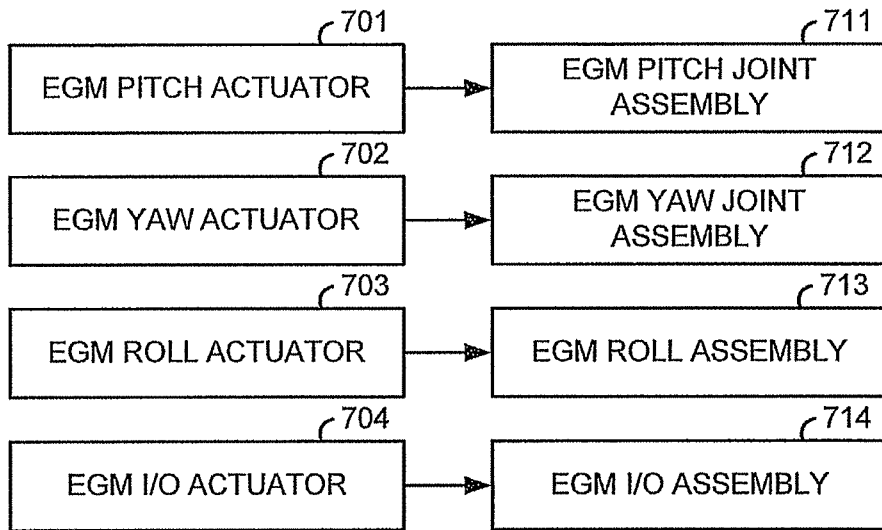


fig.7

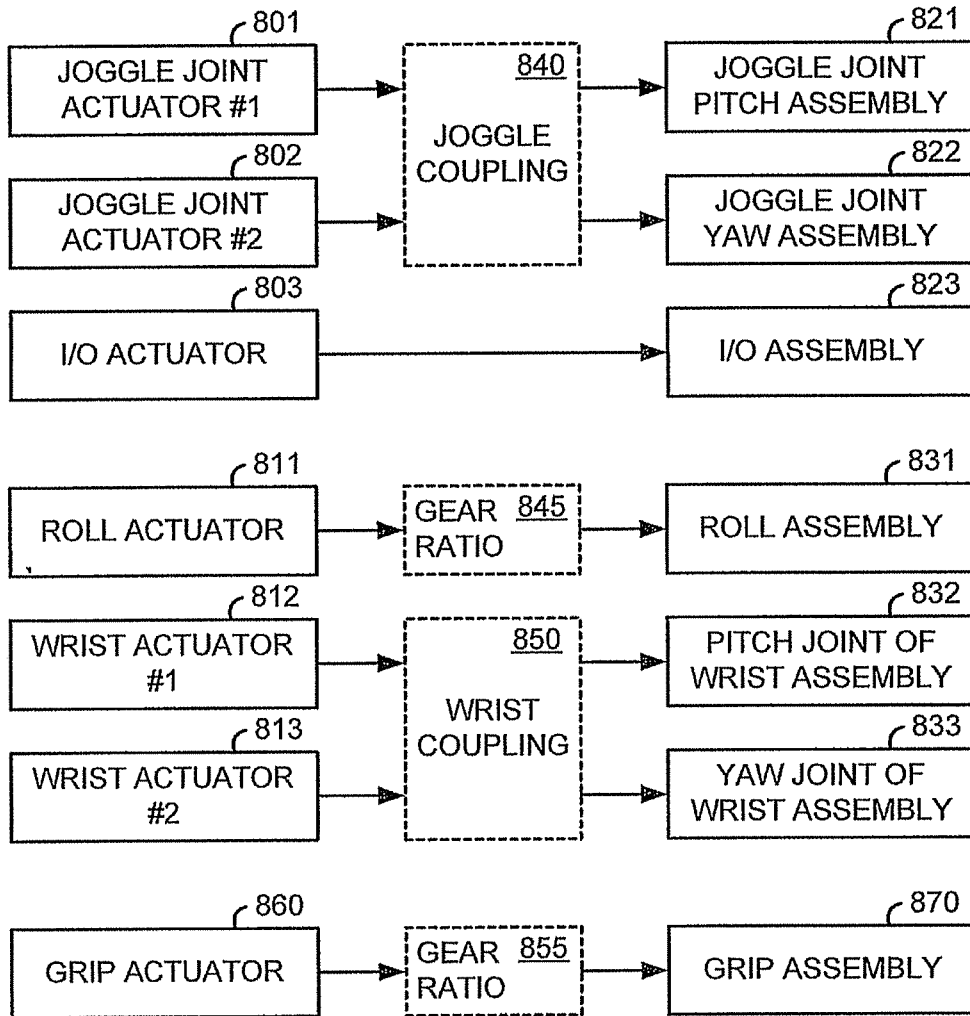


fig.8

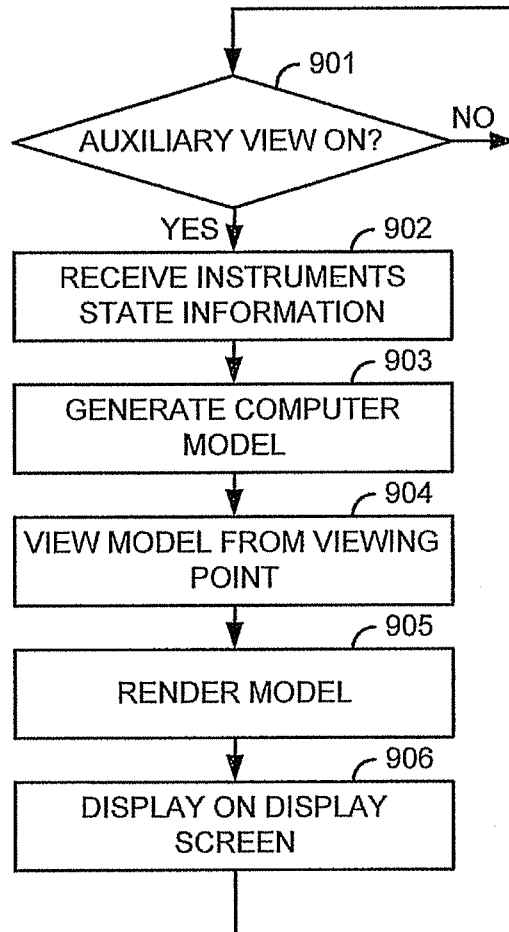


fig.9

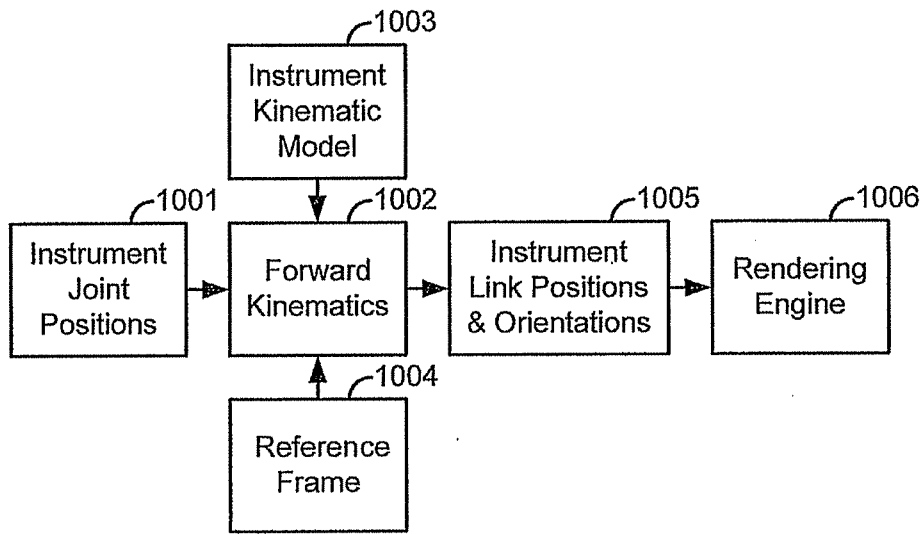


fig.10

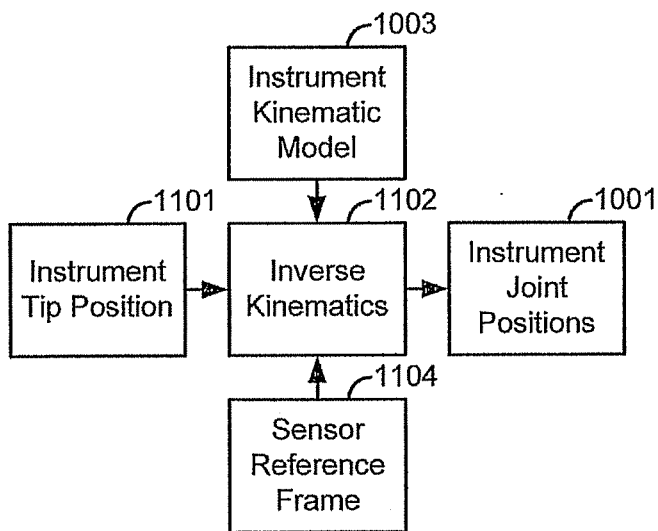


fig.11

9/13

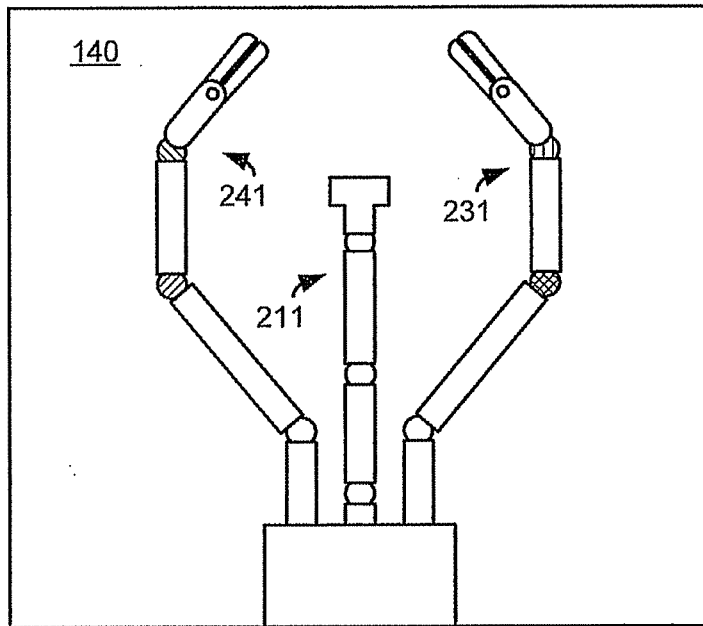


fig.12

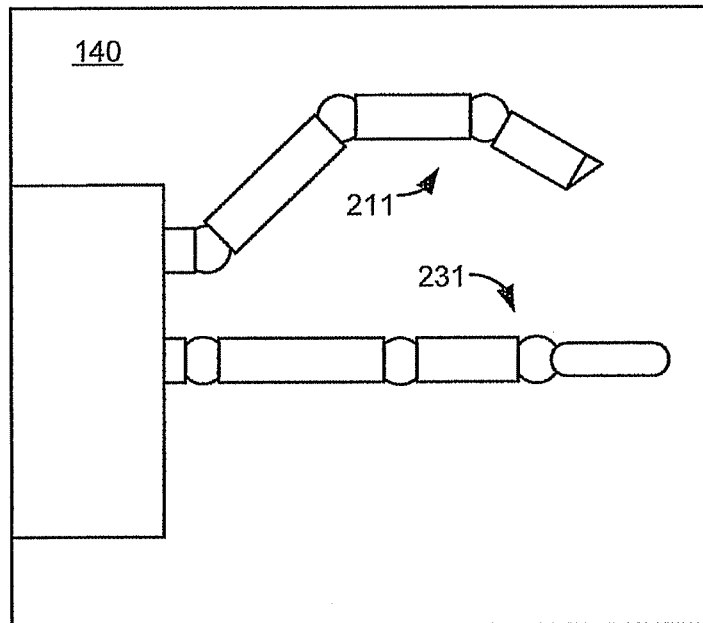


fig.13

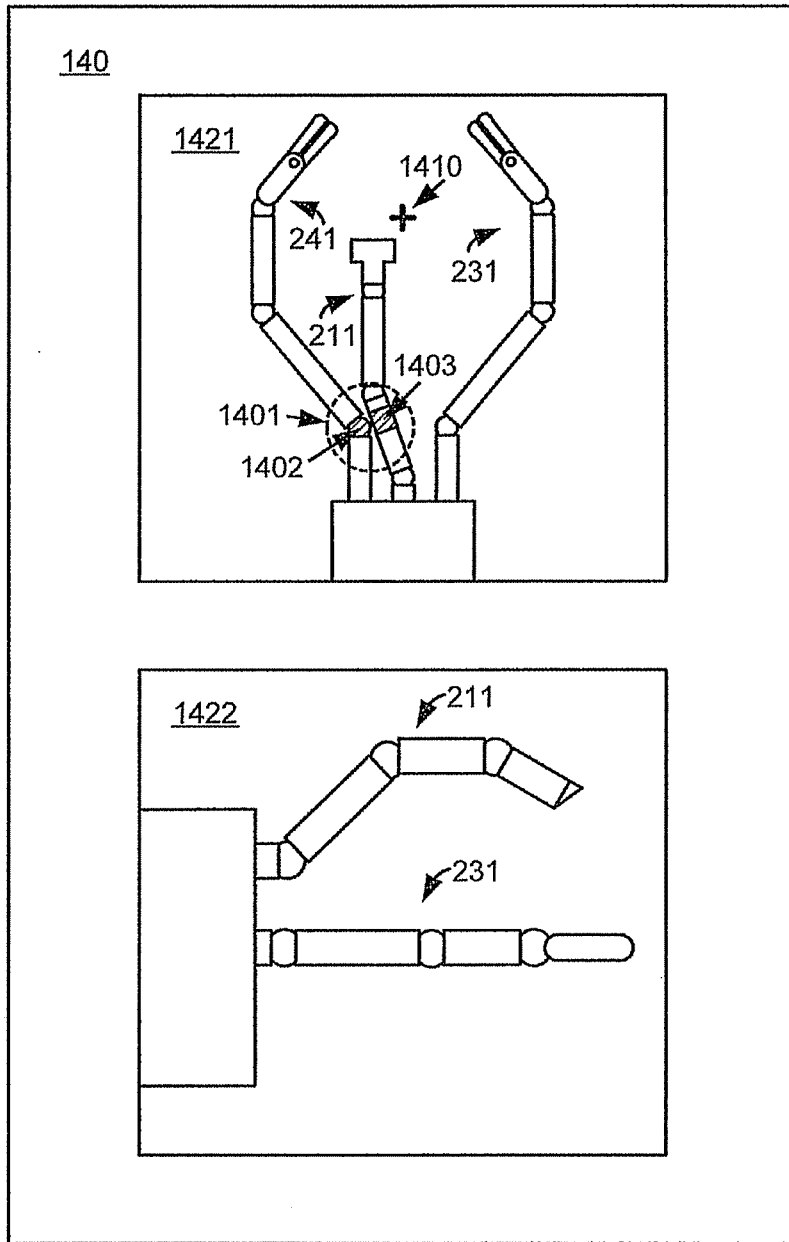


fig.14

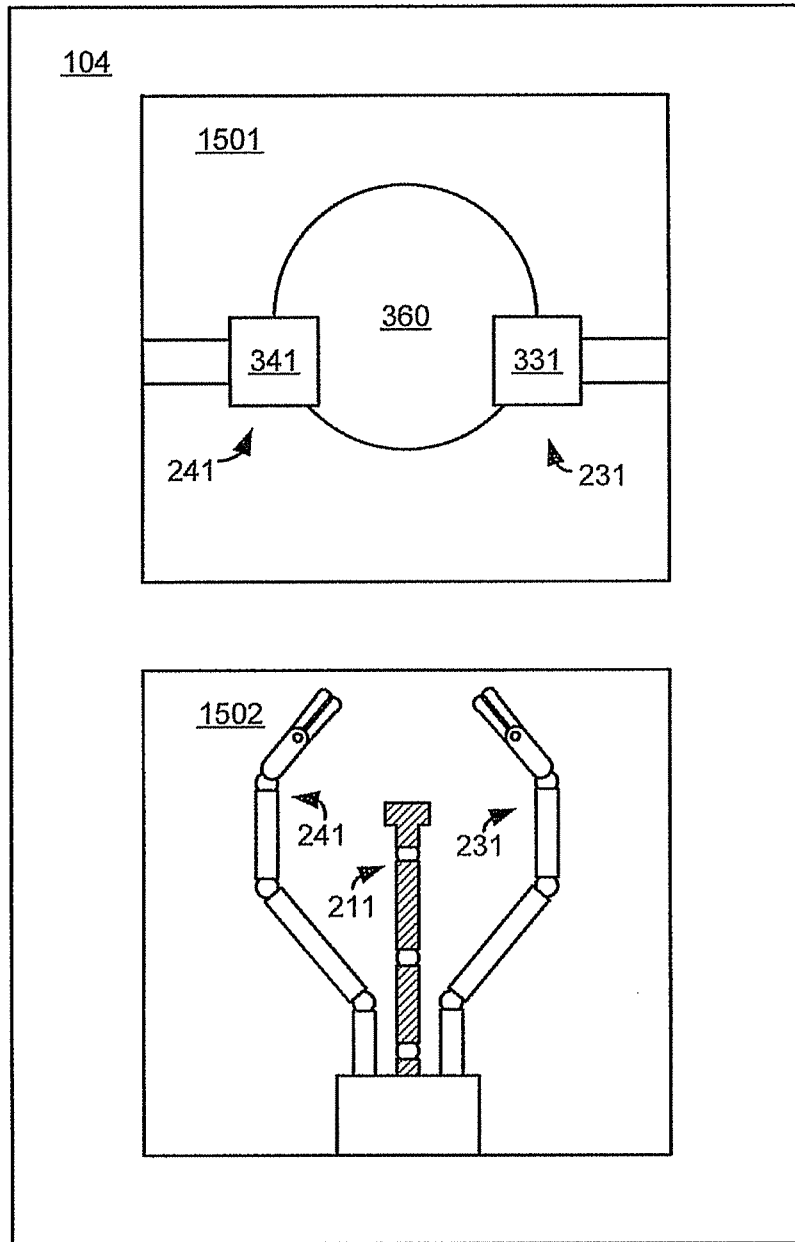


fig.15

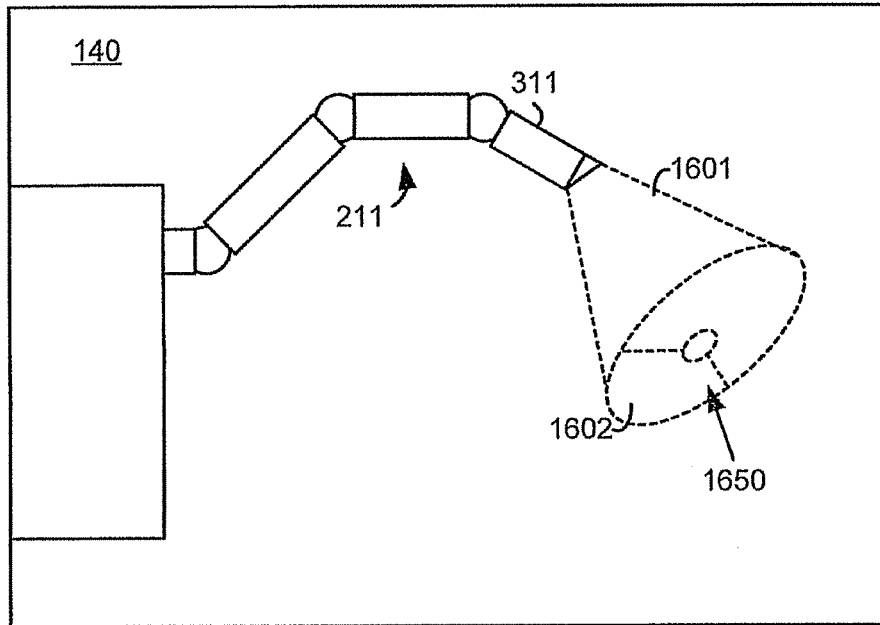


fig.16

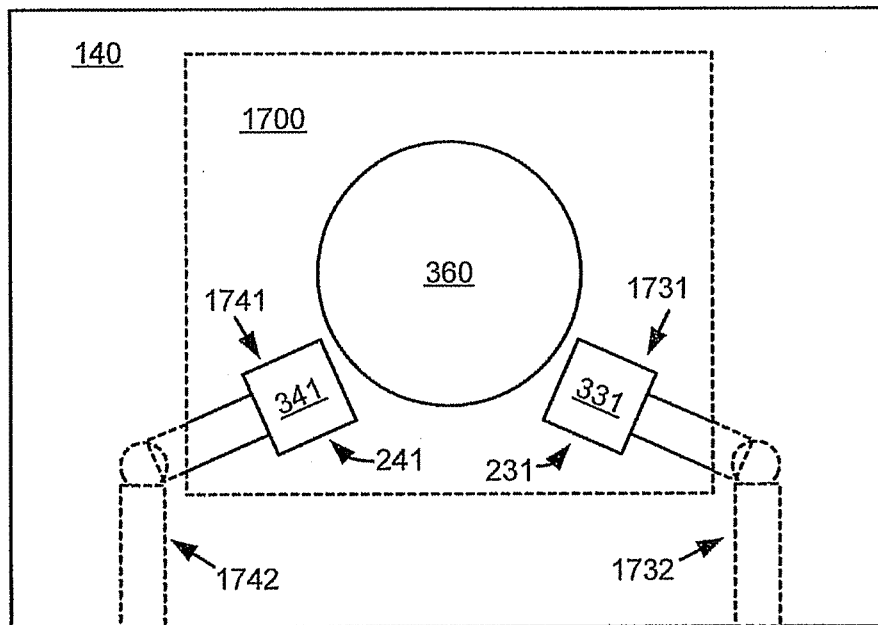


fig.17

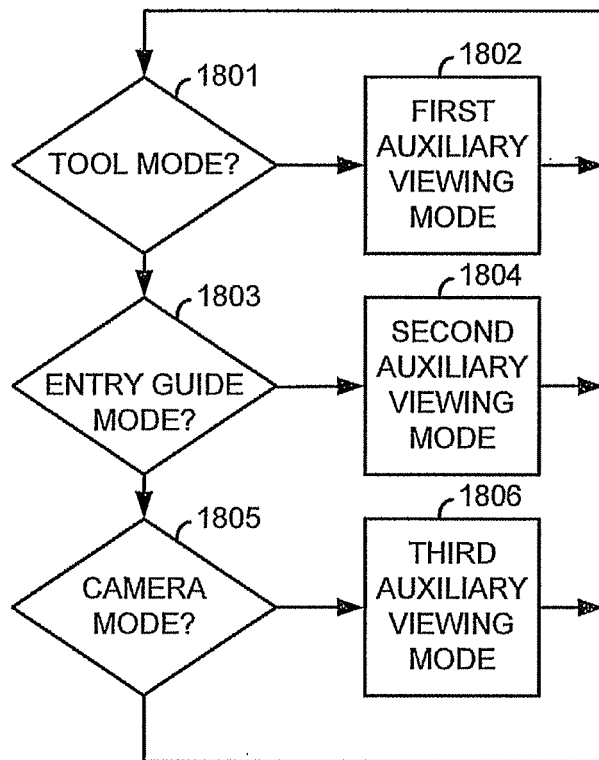


fig.18

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/046234

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/146987 A (INTUITIVE SURGICAL INC [US]) 21 December 2007 (2007-12-21)	40-49, 64,65, 67-72
Y	page 2, lines 12-19 page 5, line 33 - page 6, line 2 page 7, lines 17-39 page 22, lines 7-20 page 28, line 42 - page 35, line 20 figures 12A,17B,18C page 29, lines 4-6	50-63,66
Y	US 2006/258938 A1 (HOFFMAN BRIAN D [US] ET AL) 16 November 2006 (2006-11-16) paragraphs [0008] - [0036] paragraphs [0050] - [0065] paragraph [0141]	50-63,66
	----- -/-- -----	

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document 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

31 August 2009

Date of mailing of the international search report

09/09/2009

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040;
Fax: (+31-70) 340-3016

Authorized officer

Grieb, Christian

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/046234

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 125 557 A (HITACHI LTD [JP]) 22 August 2001 (2001-08-22) paragraphs [0040] - [0061]	51-63
Y	US 2006/142657 A1 (QUAID ARTHUR [US] ET AL) 29 June 2006 (2006-06-29) paragraphs [0157], [0158], [0203]	58
Y	WO 2008/002830 A (INTUITIVE SURGICAL INC [US]) 3 January 2008 (2008-01-03) paragraphs [0029] - [0031], [0038] - [0043], [0050] - [0052]	60

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/046234

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: 1-39
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery
2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2009/046234

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
WO 2007146987	A	21-12-2007	EP 2037794 A2	25-03-2009
			KR 20090019908 A	25-02-2009
			US 2008065097 A1	13-03-2008
			US 2008064931 A1	13-03-2008
			US 2008065098 A1	13-03-2008
			US 2008071288 A1	20-03-2008
			US 2008064927 A1	13-03-2008
			US 2008064921 A1	13-03-2008
			US 2008065099 A1	13-03-2008
			US 2008071289 A1	20-03-2008
			US 2008065100 A1	13-03-2008
			US 2008065101 A1	13-03-2008
			US 2008065102 A1	13-03-2008
			US 2008065103 A1	13-03-2008
			US 2008065104 A1	13-03-2008
			US 2008065105 A1	13-03-2008
			US 2008065106 A1	13-03-2008
			US 2008071290 A1	20-03-2008
			US 2008065107 A1	13-03-2008
			US 2008071291 A1	20-03-2008
			US 2008065108 A1	13-03-2008
US 2008065109 A1	13-03-2008			
US 2008065110 A1	13-03-2008			
US 2006258938	A1	16-11-2006	CN 101222882 A	16-07-2008
			EP 1893118 A1	05-03-2008
			KR 20080027256 A	26-03-2008
			WO 2006124388 A1	23-11-2006
EP 1125557	A	22-08-2001	NONE	
US 2006142657	A1	29-06-2006	US 2009000626 A1	01-01-2009
			WO 2006091494 A1	31-08-2006
WO 2008002830	A	03-01-2008	EP 2046538 A2	15-04-2009
			KR 20090034813 A	08-04-2009
			US 2008004603 A1	03-01-2008