

ROBOTIC SURGICAL SYSTEM CONTROL ARM INCLUDING DUAL ENCODERS

BACKGROUND

[0001] Robotic surgical systems have been used in minimally invasive medical procedures. During such medical procedures, the robotic surgical system is controlled by a surgeon or clinician interfacing with a user interface of the robotic surgical system. The user interface or console allows the clinician to manipulate and end effector associated with the surgical system acting on the patient.

[0002] The user console includes one or more control arms which support an input handle or gimbal that is movable by the clinician to control the robotic surgical system. The control arms transmit signals to a controller which correspond to the position or pose of the control arms in a workspace during the medical procedure. The controller may transmit force feedback to the input handles via one or more motors that are operably coupled to the input handles by a transmission. The transmission can required additional forces be applied by a clinician to overcome frictional forces within the transmission. Where additional forces are required, the input handle may be perceived as “heavy” by the clinician during a surgical procedure.

SUMMARY

[0003] This disclosure relates generally to systems and methods that compensate for frictional forces within the transmission associated with the control arm of a robotic surgical system.

[0004] In accordance with an aspect of the present disclosure, a control arm of a robotic surgical system includes a member, a drive motor, a first joint encoder, and a controller. The member is supported about a first joint. The drive motor is operably coupled to the member and is configured to rotate the member about the first joint. The first joint encoder is disposed about the first joint and is configured to transmit position signals indicative of a pose of the member about the first joint. The controller is configured to transmit control signals in response to receiving position signals from the first joint encoder.

[0005] In aspects, the control arm further includes a transmission component. The transmission component may be disposed between the drive motor and the first joint to couple the member to the drive motor. The controller may be configured to transmit control signals to overcome a friction associated with the transmission component for moving the member about the first joint.

[0006] According to aspects, the control arm includes a motor encoder configured to transmit motor position signals to the controller. The drive motor may be coupled to the transmission component at a second joint. The motor encoder may be coupled to the drive motor at the second joint.

[0007] According to aspects, the controller is configured to calculate a direction of the member moving about the first joint. The controller may be configured to generate control signals to overcome transmission friction in response to calculating the direction of the member moving about the first joint. The controller may also be configured to calculate a velocity of the member moving about the first joint. The controller may be configured to generate control signals to

overcome transmission friction in response to calculating the direction and the velocity of the member about the first joint.

[0008] According to aspects of the present disclosure, a method of compensating for friction in a transmission component includes receiving first position information of a member moving about a first joint from a joint encoder disposed about the first joint, calculating a first direction and a first velocity of the member in response to receiving the first position information, and transmitting control signals to a drive motor to overcome transmission friction associated with the transmission component cooperating with movement of the member. The member is coupled to the drive motor at the first joint by a transmission component.

[0009] In aspects, the method includes receiving second position information from the joint encoder in response to the member moving about the first joint, calculating a second direction and a second velocity of the member moving about the first joint, and comparing the first direction to the second direction.

[0010] In certain aspects, the method includes transmitting control signals to move the drive motor a predetermined distance in the second direction when the first direction is different from the second direction.

[0011] According to aspects of the present disclosure, a method of compensating for positional offsets between a member and a drive motor includes receiving first position information from a first joint encoder disposed about a first joint, calculating a first direction of movement of the member about the first joint, receiving second position information from the first joint encoder, calculating a second direction of movement of the member about the first joint, comparing the first direction of movement to the second direction of movement, and transmitting

control signals to move the drive motor a predetermined distance in the first direction of movement when the first direction of movement is different from the second direction of movement. The first joint operably couples the member to the drive motor at the first joint. In aspects, the drive motor is coupled to a transmission component at a second joint. The predetermined distance may be equal to an offset distance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic view of a robotic surgical system having a user console and a surgical robot provided in accordance with an embodiment of the present disclosure;

[0013] FIG. 2 is a perspective view of a tower of the surgical robot of FIG. 1;

[0014] FIG. 3 is a functional block diagram of a system architecture for controlling the robotic surgical system of FIG. 1;

[0015] FIG. 4 is a perspective view of a control arm of the user console of FIG. 1 with covers removed;

[0016] FIG. 5 is a lower perspective view of a control arm base of the control arm of FIG. 4;

[0017] FIG. 6 is a position diagram of the position of the control arm of FIG. 4 and the position of one of the motors of the control arm of FIG. 5 over time;

[0018] FIG. 7 is a flow chart illustrating a method of compensating for friction in a transmission component; and

[0019] FIG. 8 is a flow chart illustrating a method of compensating for positional offsets.

DETAILED DESCRIPTION

[0020] Embodiments of the present robotic surgical control systems are described in detail with reference to the drawings, in which like reference numerals designate identical or corresponding elements in each of the several views.

[0021] As used herein, the term “clinician” refers to a doctor, nurse, healthcare provider, support personnel, or other operators of the robotic surgical system described herein.

[0022] As used herein, the term “surgical field” refers to the space in which the surgical robot operates. Such space may include, but is not limited to, an operating room, surgical robot storage and/or maintenance facility, or other such spaces.

[0023] As used herein, the term “pose” refers to a position and orientation of a component within space or a workspace.

[0024] The present disclosure relates generally to the positioning of position sensors or encoders in a control arm of a robotic surgical system, and use thereof. The encoders are positioned between a transmission component associated with a drive motor of the control arm and an input handle supported by the control arm. The encoders communicate positional or encoder signals to a controller, which are indicative of the pose of a joint of the control arm. In response to the encoder signals, the controller determines a direction and velocity in which a clinician is moving the input handle. In response to the direction and velocity of movement of the input handle, the controller sends control signals to move a motor associated with the joint of the control arm, the motor applying a force to overcome the forces associated with the transmission

components. The application of force by the motor may reduce or eliminate the resistance the clinician would otherwise encounter while moving the input handle.

[0025] Referring initially to FIG. 1, a robotic surgical system in accordance with the present disclosure is shown generally as robotic surgical system 1 and includes a surgical robot 100, a controller 200, and a user interface or console 300.

[0026] The surgical robot 100 generally includes a robotic cart or tower 116 which has linkages 112. The linkages 112 moveably support an end effector or tool 108 that is configured to act on tissue. The linkages 112 may form robotic arms 102 which are configured to act on tissue. Each robotic arm 102 may have an end 104 that supports the tool 108. In addition, the ends 104 of the robotic arms 102 may include an imaging device 106 to image a surgical site "S". Further, the ends 104 of the robotic arms 102 may include one or more motors 122 that apply force about joints "J" (FIG. 2) of the robotic arm to move and/or actuate the tools 108.

[0027] The console 300 communicates with the tower 116 via the controller 200. The console 300 includes a display 306 that is configured to display three-dimensional images which may include data captured by imaging devices 106, 114 positioned about the surgical field, e.g., an imaging device positioned within the surgical site "S", an imaging device positioned adjacent to the patient "P", and/or an imaging device 114 supported by an end 104 of a robotic arm 102. The imaging devices, e.g., imaging devices 106, 114, may capture visual images, infra-red images, ultrasound images, X-ray images, thermal images, and/or any other known real-time images of the surgical site "S". The imaging devices 106, 114 transmit captured imaging data to the controller 200 which generates three-dimensional images of the surgical site "S" in real-time from the imaging data and transmits the three-dimensional images to the display 306 for display.

[0028] The console 300 includes control arms 304 which moveably support input handles 302 in a workspace “W”. The control arms 304 allow a clinician to manipulate the surgical robot 100, e.g., move the robotic arms 102, the ends 104 of the robotic arms 102, and/or the tools 108. Each of the input handles 302 is in communication with the controller 200 to transmit input signals thereto and receive output or feedback signals therefrom. Additionally or alternatively, each of the input handles 302 may allow the surgeon to manipulate, e.g., clamp, grasp, fire, open, close, rotate, thrust, slice, etc., the tools 108 supported at the ends 104 of the robotic arms 102.

[0029] With continued reference to FIG. 1, motion of each of the input handles 302 through the workspace “W” moves the ends 104 of the robotic arms 102 and/or tools 108 within a surgical site “S”. The three-dimensional images on the display 306 are oriented such that movement of the input handles 302 moves the ends 104 of the robotic arms 102 as viewed on the display 306. The three-dimensional images may remain stationary while movement of the input handles 302 is scaled to movement of the ends 104 of the robotic arms 102 within the three-dimensional images. To maintain an orientation of the three-dimensional images, kinematic mapping of the input handles 302 is based on a camera orientation relative to an orientation of the ends 104 of the robotic arm 102. The orientation of the three-dimensional images on the display 306 may be mirrored or rotated relative to a view from above the patient “P”. In addition, the size of the three-dimensional images on the display 306 may be scaled to be larger or smaller than the actual structures of the surgical site “S” permitting the clinician to have a better view of structures therein. As the input handles 302 are moved, the tools 108 are moved within the surgical site “S” as detailed below. Movement of the tools 108 may also include movement of the ends 104 of the robotic arms 102 which support the tools 108.

[0030] For a detailed discussion of the construction and operation of a robotic surgical system 1, reference may be made to U.S. Patent No. 8,828,023, the entire disclosure of which is hereby incorporated by reference.

[0031] The movement of the input handles 302 may be scaled relative to the movement of the tools 108. When the input handles 302 are moved within the workspace “W”, the control arm 304 transmits encoder signals to the controller 200, which analyzes the encoder signals and generates control signals to move the tools 108 in response to the encoder signals. The controller 200 transmits control signals to the tower 116 to move the tools 108 in response to the movement of the input handles 302. Prior to transmission of the control signals, the controller 200 scales the encoder signals by dividing an $\text{Input}_{\text{distance}}$, e.g., the distance moved by one of the input handles 302 within the workspace “W”, by a scaling factor S_F to arrive at a scaled $\text{Output}_{\text{distance}}$, e.g., the distance that one of the ends 104 is moved. The scaling factor S_F may be in a range between about 1 and about 10, in embodiments, about 3. This scaling is represented by the following equation:

$$\text{Output}_{\text{distance}} = \text{Input}_{\text{distance}} / S_F$$

After the encoder signal is scaled, the controller 200 transmits control signals corresponding to the scaled encoder signal to the tower 116 to move the tools 108 accordingly. It will be appreciated that the larger the scaling factor S_F the smaller the movement of the tools 108 relative to the movement of the input handles 302.

[0032] For a detailed description of scaling movement of the input handles 302 along the X, Y, and Z coordinate axis to movement of the tool 108, reference may be made to commonly owned International Patent Application Serial No. PCT/US2015/051130, filed on September 21, 2015 (now International Patent Publication No. WO 2016/053657), and International Patent

Application No. PCT/US2016/14031, filed January 20, 2016, the entire disclosures of which are hereby incorporated by reference.

[0033] Referring to FIG. 2, the surgical robot 100 includes the robotic cart or tower 116 supporting the linkages 112 which support the tool 108. The linkages 112 include one or more motors 122 that are each associated with a respective joint “J” of the linkage 112, to manipulate the linkage 112 and/or the tool 108 supported by the linkage 112.

[0034] In use, the controller 200 (FIG. 1) transmits control signals to the surgical robot 100. The surgical robot 100 activates a motor 122 to apply a force about or to a respective joint “J” in response to the control signals. Specifically, in response to a control signal, the surgical robot 100 delivers a power current to the motor 122 which applies a force to the joint “J” to move the linkage 112 and/or the tool 108 during a surgical procedure. Additionally, a sensor 120 is coupled to the joint “J” and measures a torque about the joint “J” in response to application of the force to the joint “J”. The sensor 120 transmits the measured force to the controller 200 (FIG. 1).

[0035] With reference to FIG. 3, communication between the surgical robot 100, the console 300, and the controller 200 is described in accordance with the present disclosure. The controller 200 is in communication with the tower 116 of the surgical robot 100 to provide instructions for operation of the surgical robot 100 in response to encoder signals received from the console 300.

[0036] The controller 200 generally includes a processing unit 206, a memory 208, a tower interface 204, and a console interface 202. The processing unit 206 executes instructions or a computer program stored in the memory 208 which functions to cause components of the tower 116, e.g., linkages 112, to execute desired movements according to movement defined by the input

handle 302 of the console 300. In this regard, the processing unit 206 includes any suitable logic control circuit adapted to perform calculations and/or operate according to a set of instructions. The processing unit 206 may include one or more processing devices (not shown) such as a microprocessor or other physical device capable of executing instructions stored in the memory 208 and/or processing data. The memory 208 may include transitory type memory, e.g., RAM, and/or non-transitory type memory, e.g., flash media or disk media. The tower interface 204 and console interface 202 communicate with the tower 116 and console 300, respectively, via either wireless configurations, e.g., radio frequency, optical, WIFI, Bluetooth[®] (an open wireless protocol for exchanging data over short distances, using short length radio waves, from fixed and mobile devices, creating personal area networks (PANs), ZigBee[®] (a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4-2003 standard for wireless personal area networks (WPANs)), etc., and/or wired configurations. Although depicted as a separate module, the console interface 202 and tower interface 204 may be a single component.

[0037] With continued reference to FIGS. 2-3, the tower 116 includes a communications interface 118 that receives communications and/or data from the tower interface 204. The communications interface 118 transmits signals which manipulate the motor 122 to move the linkages 112 associated with the tower 116. The motor 122 may be located in the robotic arm 102 and/or the linkages 112. In embodiments, the motor 122 mechanically manipulates the robotic arm 102, the linkages 112, and/or the tool 108 (FIG. 1) in response to power supplied to the motor 122. Mechanical manipulation of the robotic arm 102, linkages 112, and/or the tool 108 may include application of force from the motor 122 to move the robotic arm 102 and/or the tool 108 coupled to the robotic arm 102, in response to instructions from the processing unit 206. For

example, the motor 122 may be operably coupled to a joint “J” via cables (not shown) to manipulate the robotic arm 102.

[0038] The console 300 includes a computer 308 to receive encoder signals from position sensors or encoders E₁, E₂, E₃, transmit the encoder signals to the controller 200, and receive control signals from the controller 200 to move members, e.g. the of the control arm 304, about joints J₁, J₂, J₃ (FIG. 4-5). Each input handle 302 is coupled to the control arm 304. The control arm 304 includes a first, second, and third drives motors 324, 326, 328 that are in either wired or wireless communication with the computer 308. The encoders E₁, E₂, E₃ are disposed in the drive motors 324, 326, 328, respectively, and are configured to generate encoder signals representative of the pose of the members of the control arm 304 (FIG. 4-5) associated with joints J₁, J₂, J₃. The encoder signals representing the pose of the members of the control arm 304 about joints J₁, J₂, J₃ are transmitted by the encoders E₁, E₂, E₃ to the computer 308 which transmits the encoder signals to the controller 200. In response to the encoder signals, the controller 200 transmits control signals to the tower 116 to affect motion of the robotic arm 102 and/or the tools 108 as detailed above.

[0039] The input handle 302 may be a handle, a pedal, or a computer accessory (e.g., a keyboard, joystick, mouse, button, touch screen, switch, trackball, etc.). The display 306 displays images or other data received from the controller 200 to communicate data to the clinician. The computer 308 includes a processing unit and memory (not shown) which includes data, instructions, and/or information related to the various components, algorithms, and/or operations of the tower 116 and can operate using any suitable electronic service, database, platform, cloud, or the like. The computer 308 may include processing units (not shown) which include any

suitable logic control circuit adapted to perform calculations and/or operate according to a set of instructions located in memory (not shown) as described similarly with reference to the controller 200.

[0040] For a detailed description of a surgical robot 100, reference may be made to U.S. Provisional Patent Application No. 62/345,032, filed June 3, 2016, and entitled “Multi-Input Robotic Surgical System Control Scheme,” the entire disclosure of which is hereby incorporated by reference.

[0041] Referring to FIG. 4-5, a control arm 304 of the console 300 includes a base 310, a swivel member 312, a vertical member 314, a support arm 316, a horizontal member 318, and a support member 320 (collectively referred to as “members of control arm 304”). The base 310 rotatably supports the swivel member 312 about a first joint J_1 defining a first axis of rotation A_1 . The swivel member 312 pivotally supports the vertical member 314 and the support arm 316 about a second joint J_2 defining a second axis of rotation A_2 . The support arm 316 supports a lower end of the support member 320 which may be in substantial parallel relationship with the vertical member 314. It is contemplated that the support member 320 may be askew from the vertical member 314. The vertical member 314 pivotally supports the horizontal member 318 about a third joint J_3 defining a third axis of rotation A_3 . The horizontal member 318 rotatably supports the input handle 302 (FIG. 1) about a joint J_4 defining a fourth axis of rotation G-G.

[0042] The base 310 includes a drive mechanism 322 for manipulating the control arm 304 about each of the first, second, and third axes of rotation A_1 , A_2 , A_3 . The drive mechanism 322 may manipulate the control arm 304 to provide force feedback to the clinician manipulating the

control arm 304 via the input handle 302 (FIG. 1). The drive mechanism 322 may also manipulate the control arm 304 to reposition components of the control arm 304 during a surgical procedure.

[0043] The drive mechanism 322 includes a first drive motor 324, a second drive motor 326, and a third drive motor 328. The first drive motor 324 manipulates the control arm 304 about the first axis of rotation A_1 and includes a first drive shaft 330 that extends through the base 310. The first drive shaft 330 rotates a first spindle 332 that is coupled to a first cable 334 and a second cable 336 that rotate a rotation flange 338 about the first axis of rotation A_1 . The rotation flange 338 includes a cylindrical member 340 that couples to the swivel member 312 such that the swivel member 312 rotates in concert with the cylindrical member 340.

[0044] The second drive motor 326 manipulates the vertical member 314 of the control arm 304 about the second axis A_2 and includes a second drive shaft 342 that extends through the base 310. The second drive shaft 342 rotates a second spindle 344 that is coupled to a third cable 346 and a fourth cable 350 to rotate a lower pulley 348A of the pulley assembly 348. The lower pulley 348A is operably coupled to the vertical member 314 to pivot the vertical member 314 about the second axis of rotation A_2 in response to rotation of the lower pulley 348A.

[0045] The third drive motor 328 manipulates the support arm 316 to pivot the horizontal member 318 about the third axis A_3 and includes a third drive shaft 352 that extends through the base 310. The third drive shaft 352 rotates a third spindle 354 that is coupled to a fifth cable 356 and a sixth cable 358 to rotate an upper pulley 348B of the pulley assembly 348. The upper pulley 348B is operably coupled to the horizontal member 318 to pivot the horizontal member 318 about the third axis A_3 in response to rotation of the upper pulley 348B.

[0046] For a detailed description of control arm 304, reference may be made to U.S. Provisional Patent Application No. 62/345,537, filed June 3, 2016, and entitled “Control Arm for Robotic Surgical Systems,” the entire disclosure of which is hereby incorporated by reference.

[0047] With continuing reference to FIG. 5, the base 310 includes motor encoders E_1 , E_2 , E_3 that are each associated with a respective drive motor 324, 326, 328. The first, second, and/or third encoder E_1 , E_2 , E_3 may be disposed within or external to the first drive motor 324, the second drive motor 326, or third drive motor 328, respectively. The first motor encoder E_1 transmits encoder signals to the computer 308 which measures the pose and/or velocity of the first drive shaft 330. The second motor encoder E_2 transmits encoder signals to the computer 308 which measures the pose and/or velocity of the second drive shaft 342. The third motor encoder E_3 transmits encoder signals to the computer 308 which measures the pose and/or velocity of the third drive shaft 352. Additionally or alternatively the first, second, and third motor encoders E_1 , E_2 , E_3 may be in direct communication with the controller 200 to transmit encoder signals measured by the respective encoders E_1 , E_2 , E_3 to the controller 200 (FIG. 1). In response to receiving the positional signals, the controller 200 may determine the corresponding pose, velocity, or direction of rotation of the respective drive shaft 330, 342, 352.

[0048] To accurately determine the pose of components or members of the control arm 304, e.g., the swivel member 312, the vertical member 314, and/or the horizontal member 318, the control arm 304 includes joint encoders E_4 , E_5 , E_6 (collectively referred to as joint encoders) are each coupled to a respective one of the first, second, and third joints J_1 , J_2 , J_3 of the control arm 304. Specifically, the first joint encoder E_4 is configured to determine the pose and/or the velocity of the base 310 and the swivel member 312 about the first joint J_1 , the second joint encoder E_5 is

configured to determine the pose and/or the velocity of the vertical member 314 and the support arm 316 about the second joint J_2 , and the third joint encoder E_6 is configured to determine the pose and/or the velocity of the vertical member 314 and the horizontal member 318 rotating about the third joint J_3 . As the clinician manipulates the input handle 302, the swivel member 312, vertical member 314, and/or horizontal member 318 may rotate about the first, second, and third joints J_1 , J_2 , J_3 , respectively.

[0049] For purposes of brevity, only motion of the swivel member 312 and the base 310 about the first axis A_1 will be described in detail herein. Specifically, with reference to FIGS. 4 and 5, the rotation of the swivel member 312 about the first axis A_1 is described in accordance with the present disclosure. As the swivel member 312 rotates about the first joint J_1 , the first joint encoder E_4 transmits encoder signals to the controller 200. In response to the encoder signals, the controller 200 determines the pose, direction, and/or velocity of the swivel member 312.

[0050] As the clinician manipulates the input handle 302, the swivel member 312 can be rotated about the first axis A_1 such that corresponding transmission components associated with the swivel member, e.g., the cylindrical member 340, the rotation flange 338, the second cable 336, the first cable 334, the first spindle 332, and the first drive shaft 330, may rotate in response to rotation of the swivel member 312 to backdrive the first drive motor 324. As the transmission components are rotated, compliance in the transmission, e.g., elastic deformation of the transmission components such as binding, lashing, and/or compression, may delay backdriving of the first drive motor 324 in response to input from the input handle 302. The delay in the backdriving of the first drive motor 324 may result in a positional error between the first drive

motor 324 and the joint J_1 . The positional error may be measured by calculating the difference between encoder signals sent from the first motor encoder E_1 and the joint encoder E_4 .

[0051] Referring to FIG. 6, as the clinician manipulates the pose of the input handle 302 supported by the control arm 304, the swivel member 312 is rotated relative to the base 310 about the first axis A_1 . The pose of the swivel member 312 and the base 310 about the first joint J_1 is measured by the first joint encoder E_4 which transmits encoder signals to the computer 308. As shown, rotation of the first drive motor 324 in response to movement of the input handle 302 is delayed due to compliance in the transmission components. The delay occurs between time T_0 and time T_1 , resulting in an offset distance defined as the distance which the swivel member 312 moves about the first joint J_1 before the first drive motor 324 moves in response to the movement of the swivel member 312.

[0052] The offset distance may be a predetermined distance which is measurable during initial or periodic calibration of the control arm 304. For example, the display 306 may prompt the clinician to move the control arm 304 to one or more poses, the controller 200 measuring position data from the first joint encoder E_4 and the first motor encoder E_1 . In response to receiving the encoder signals from the first joint encoder E_4 and the first motor encoder E_1 , the controller 200 calculates an offset distance associated with motion of input handle 302 about the first axis A_1 to a desired pose. Additionally or alternatively, the controller 200 may send control signals to the first drive motor 324 to move the input handle 302 about the first axis A_1 to a pose. In response to moving the input handle 302 to a desired pose, the controller 200 calculates the offset distance associated with the motion of the swivel member 312 and the base 310 about the first joint J_1 relative to the first drive motor 324.

[0053] Specifically, in response to manipulation of the input handle 302 by the clinician, the controller 200 may more accurately determine the position of the first drive motor 324 relative to the swivel member 312 and the base 310, and transmit control signals as the clinician moves the input handle 302 about the workspace “W” to adjust the position of the first drive motor 324. This adjustment of the position of the motor relative to the swivel member 312 and the base 310 corrects for any compliance in the transmission components.

[0054] Referring to FIG. 7, a method 400 of compensating for friction in a transmission component is described in accordance with the present disclosure. The transmission friction is defined as the friction associated with rotation of the transmission components. Initially, the controller 200 receives first position information from the joint encoder E₄ (Step 402) and calculates a first direction and a first velocity of the swivel member 312 about the base 310 at the first joint J₁ (Step 404). After calculating the first direction and the first velocity of the swivel member 312 relative to the base 310 at the joint J₁, the controller 200 transmits control signals to rotate the first drive motor 324 to compensate for friction of a transmission component. Specifically, in response to the control signals, the first drive motor 324 applies a force in the direction which the swivel member 312 is moving relative to the base 310 at the first joint J₁ to overcome an estimated friction or transmission friction of the transmission components (Step 406).

[0055] Specifically, method 400 helps minimize a friction felt by a surgeon when changing a direction of movement of the input handle 302 and the control arm 304. If the first motor encoder E₁ were used only, then the surgeon would feel the full level of friction in the input handle 302 and in the control arm 304 when changing a direction of movement of the input handle 302 and/or the control arm 304, whereby the joint and the drive train must all be moving in order for a friction

thereof to go from positive-to-negative to negative-to-positive. However, in accordance with the present disclosure, and in accordance with method 400, the time and friction observed and/or measured is reduced by measuring and monitoring a change in direction of the joint encoder E_4 , as compared to that of the first motor encoder E_1 .

[0056] After the controller 200 transmits control signals to overcome the estimated friction, the controller 200 receives second position information from the joint encoder E_4 (Step 408). In response to receiving the second position information, the controller 200 calculates a second direction and a second velocity of the swivel member 312 relative to the base 310 at the first joint J_1 (Step 410). When the controller 200 determines the second direction is the same as the first direction (Step 412), the controller 200 transmits control signals to the first drive motor 324 to overcome an estimated friction associated with rotation of the transmission components operably coupling the first drive motor 324 to the input handles 302 at the second velocity (Step 416). It will be appreciated that when the first velocity and/or the second velocity are equal to zero, the control signals transmitted by the controller 200 to overcome the estimated friction will not cause the first drive motor 324 to rotate.

[0057] With continued reference to FIG. 7, when the controller 200 determines that the first direction and the second direction are different (Step 412), the controller 200 transmits control signals to rotate the first drive motor 324 a predetermined distance in the second direction (Step 414). The predetermined distance may be a distance equal to the offset distance measured during initial or periodic calibration of the control arm 304 (FIG. 6). Rotation of the first drive motor 324 in the second direction reduces or eliminates positional errors between the first drive motor 324, the swivel member 312 and the base 310 which may otherwise exist as a result of compliance in

the transmission components. By reducing or eliminating positional errors due to compliance, the control signals sent by the controller 200 allow for more accurate application of force by the first drive motor 324 to overcome transmission friction. As a result, the clinician may feel as if the input handle 302 is more responsive than would otherwise be due to transmission friction.

[0058] Referring to FIG. 8, a method of compensating for positional offsets is described in accordance with the present disclosure. Initially, the controller 200 receives first position information from the joint encoder E₄ (Step 502). In response the controller 200 calculates a first direction of the swivel member 312 relative to the base 310 about the first joint J₁. The controller 200 subsequently receives second position information from the joint encoder E₄ (Step 506) and calculates a second direction of the members of the control arm 304 associated with the first joint J₁. If the controller 200 determines that the first direction and the second direction are different (Step 510), the controller 200 transmits control signals to rotate the first drive motor 324 a predetermined distance in the first direction (Step 512). The predetermined distance may be a distance equal to the offset distance (FIG. 6). By rotating the first drive motor 324 the predetermined distance in the first direction, as the clinician subsequently manipulates the input handles 302 and backdrives the first drive motor 324, the application of force feedback by the first drive motor 324 is applied almost instantaneously, thereby allowing for more accurate application of force feedback. Specifically, the application of force feedback to the input handle 302 is not delayed due to any compliance in the transmission components.

[0059] While method 400 of compensating for friction in a transmission component and method 500 of compensating for positional offsets have been described in relation to motion of the swivel member 312 about the base 310 along the first axis of rotation A₁, the present disclosure

should not be seen as limited to the identified components. It will be appreciated that methods 400, 500 may also be applied to motion of the vertical member 314 and the support arm 316 relative to the swivel member 312 about the second axis of rotation A_2 . Additionally, it will be appreciated that methods 400, 500 may be applied to motion of the horizontal member 318 relative to the vertical member 314 about the third axis of rotation A_3 .

[0060] While the disclosed embodiments contemplate location of a controller 200 external to a surgical robot 100, it is contemplated that the controller 200 may be located within the control arm 304, or alternatively that elements of the robotic surgical system 1 may include circuitry which executes the described encoder measurements and calculations independent of the controller 200.

[0061] As detailed above, the console 300 is in operable communication with the surgical robot 100 to perform a surgical procedure on a patient; however, it is envisioned that the console 300 may be in operable communication with a surgical simulator (not shown) to virtually actuate a surgical robot and/or tool in a simulated environment. For example, the robotic surgical system 1 may have a first mode in which the console 300 is coupled to actuate the surgical robot 100 and a second mode in which the display 306 is coupled to the surgical simulator to virtually actuate a robotic surgical system. The surgical simulator may be a standalone unit or be integrated into the controller 200. The surgical simulator virtually responds to a clinician interfacing with the console 300 by providing visual, audible, force, and/or haptic feedback to a clinician through the console 300. For example, as a clinician interfaces with the input handles 302, the surgical simulator moves representative tools that are virtually acting on tissue. It is envisioned that the surgical simulator may allow a clinician to practice a surgical procedure before performing the surgical procedure on a patient. In addition, the surgical simulator may be used to train a clinician on a

surgical procedure. Further, the surgical simulator may simulate “complications” during a proposed surgical procedure to permit a clinician to plan a surgical procedure.

[0062] Additionally, while the application refers to members of the control arm as receiving and propagating forces received by the input handle through transmission components generally, the identified members of the control arm have been identified for illustrative purposes only and are not intended to limit the disclosure. As such, members of the control arm should be understood generally to be components of the control arm 304 which may receive forces exerted by a clinician thereon. Likewise, the identified transmission components are identified for illustrative purposes only and are not intended to limit the disclosure. As such, transmission components should be understood generally to be components which propagate forces received by members of the input components to the first, second, and/or third drive motors 324, 326, 328.

[0063] It is contemplated that the systems and methods described in the present disclosure may be implemented in robotic surgical systems which implement telemanipulation techniques. “Telemanipulation” refers generally to the operation of a surgical system from a remote console by a clinician. By way of example, a telemanipulation may be a remote adjustment of the position of a robotic surgical instrument relative to a patient. Alternatively, telemanipulation may include an individual causing a robotic surgical instrument to perform one or more functions which the instrument is capable of doing.

[0064] While several embodiments of the disclosure have been shown in the drawings, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Any combination of the above embodiments is also envisioned and is within the scope of the appended claims. Therefore,

the above description should not be construed as limiting, but merely as exemplifications of particular embodiments. Those skilled in the art will envision other modifications within the scope of the claims appended hereto.

WHAT IS CLAIMED IS:

1. A control arm of a robotic surgical system, comprising:

a member supported about a first joint;

a drive motor operably coupled to the member and configured to rotate the member about the first joint;

a first joint encoder disposed about the first joint, the first joint encoder configured to transmit position signals indicative of a pose of the member about the first joint; and

a controller configured to transmit control signals in response to receiving position signals from the first joint encoder.
2. The control arm of claim 1, further comprising a transmission component disposed between the drive motor and the first joint to couple the member to the drive motor.
3. The control arm of claim 2, wherein the controller is configured to transmit control signals to overcome a friction associated with the transmission component for moving the member about the first joint.
4. The control arm of claim 3, further comprising a motor encoder configured to transmit motor position signals to the controller.
5. The control arm of claim 4, wherein the drive motor is coupled to the transmission component at a second joint.

6. The control arm of claim 5, wherein the motor encoder is coupled to the drive motor at the second joint.

7. The control arm of claim 1, wherein the controller is configured to calculate a direction of the member moving about the first joint.

8. The control arm of claim 7, wherein the controller is configured to generate control signals to overcome transmission friction in response to calculating the direction of the member moving about the first joint.

9. The control arm of claim 7, wherein the controller is configured to calculate a velocity of the member moving about the first joint.

10. The control arm of claim 9, wherein the controller is configured to generate control signals to overcome transmission friction in response to calculating the direction and the velocity of the member about the first joint.

11. A method of compensating for friction in a transmission component, the method comprising:

receiving first position information of a member moving about a first joint from a joint encoder disposed about the first joint, the member coupled to a drive motor at the first joint by a transmission component;

calculating a first direction and a first velocity of the member in response to receiving the first position information; and

transmitting control signals to the drive motor to overcome transmission friction associated with the transmission component cooperating with movement of the member.

12. The method according to claim 11, further comprising:

receiving second position information from the joint encoder in response to the member moving about the first joint;

calculating a second direction and a second velocity of the member moving about the first joint; and

comparing the first direction to the second direction.

13. The method according to claim 12, further comprising transmitting control signals to move the drive motor a predetermined distance in the second direction when the first direction is different from the second direction.

14. A method of compensating for positional offsets between a member and a drive motor, the method comprising:

receiving first position information from a first joint encoder disposed about a first joint, the first joint operably coupling a member to a drive motor;

calculating a first direction of movement of the member about the first joint;

receiving second position information from the first joint encoder;

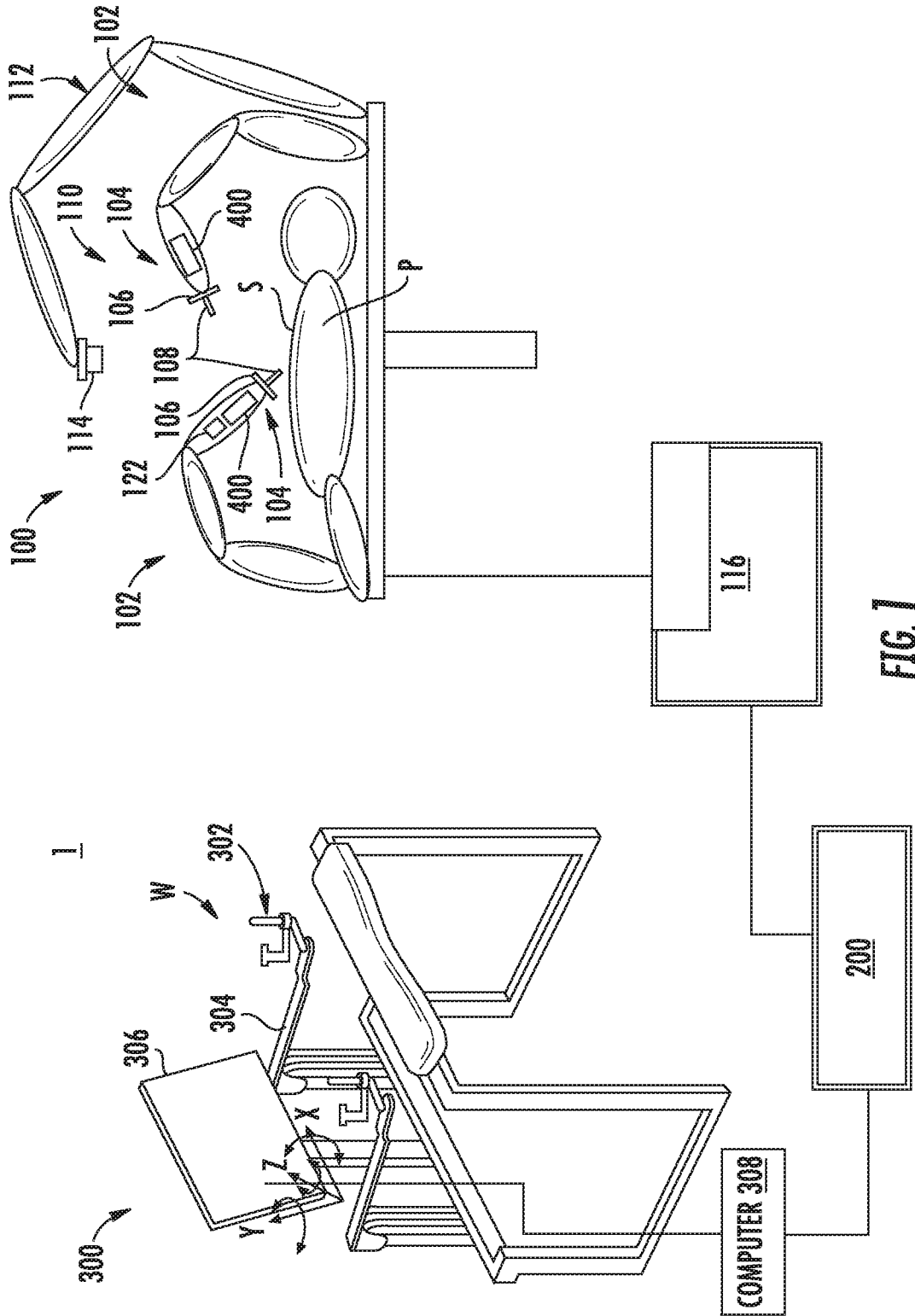
calculating a second direction of movement of the member about the first joint;

comparing the first direction of movement to the second direction of movement; and

transmitting control signals to move the drive motor a predetermined distance in the first direction of movement when the first direction of movement is different from the second direction of movement.

15. The method according to claim 14, wherein transmitting control signals includes rotating the drive motor the predetermined distance in the first direction of movement, the drive motor coupled to a transmission component at a second joint.

16. The method according to claim 14, wherein transmitting control signals includes rotating the drive motor the predetermined distance, where the predetermined distance is equal to an offset distance.



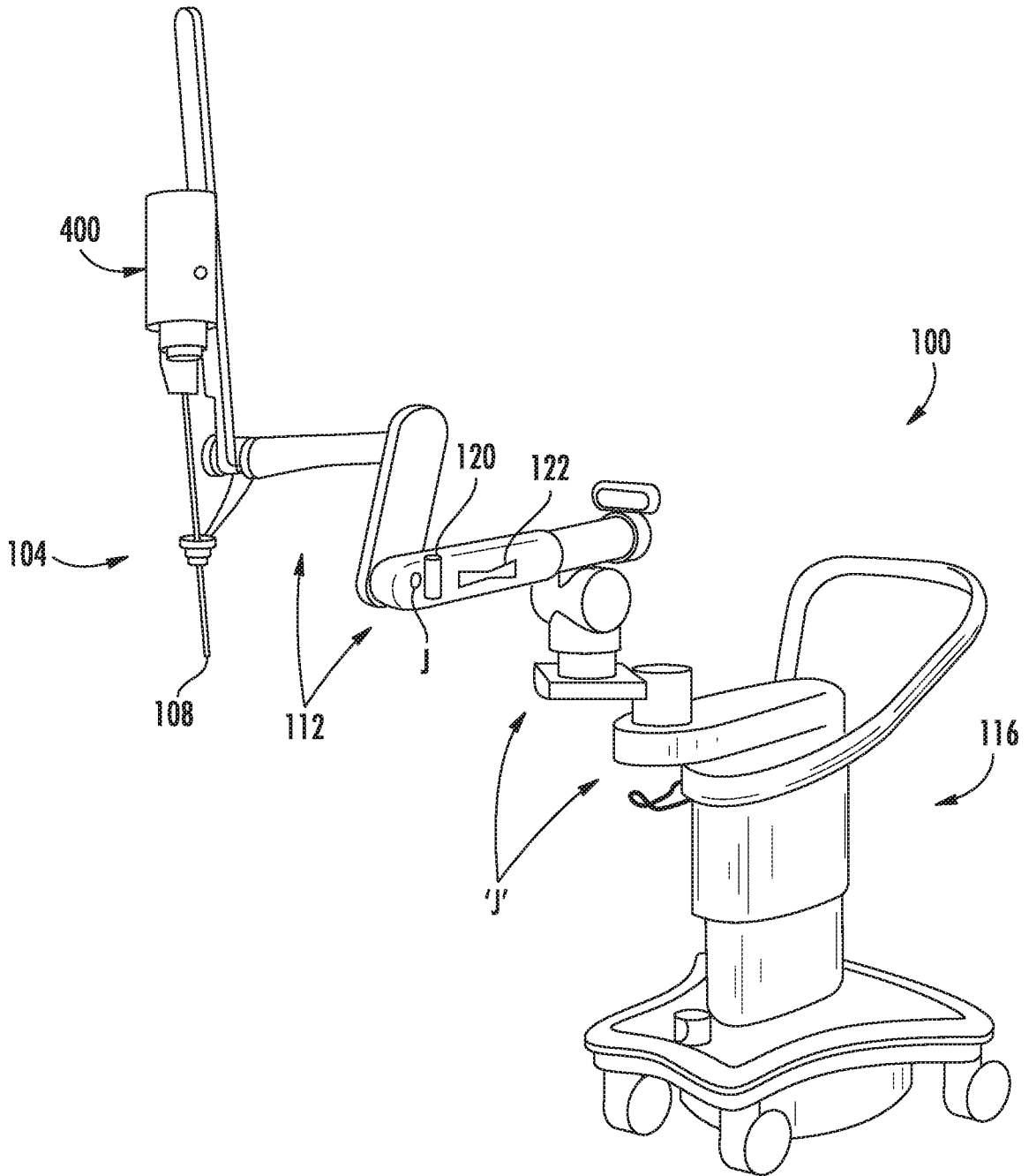


FIG. 2

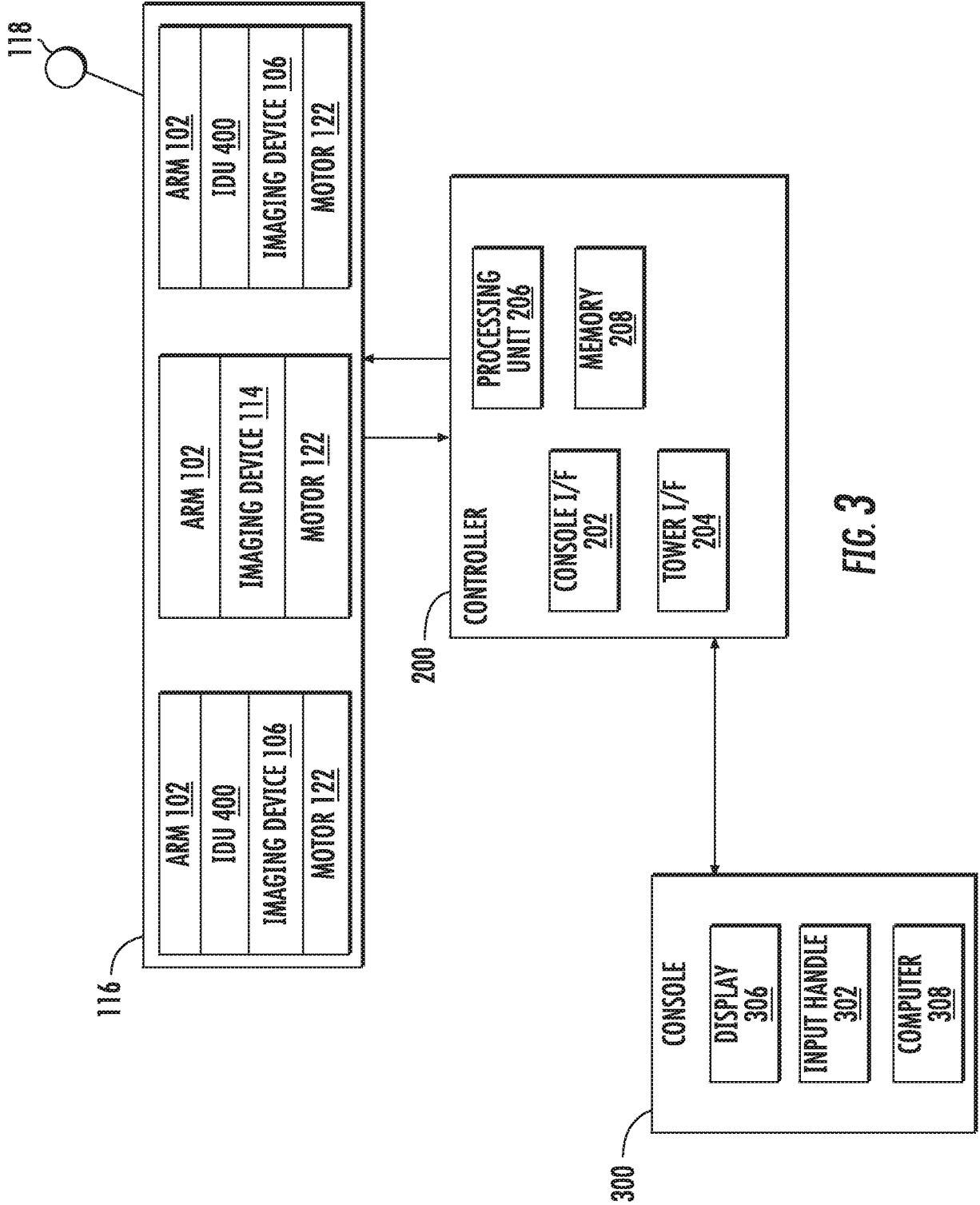


FIG. 3

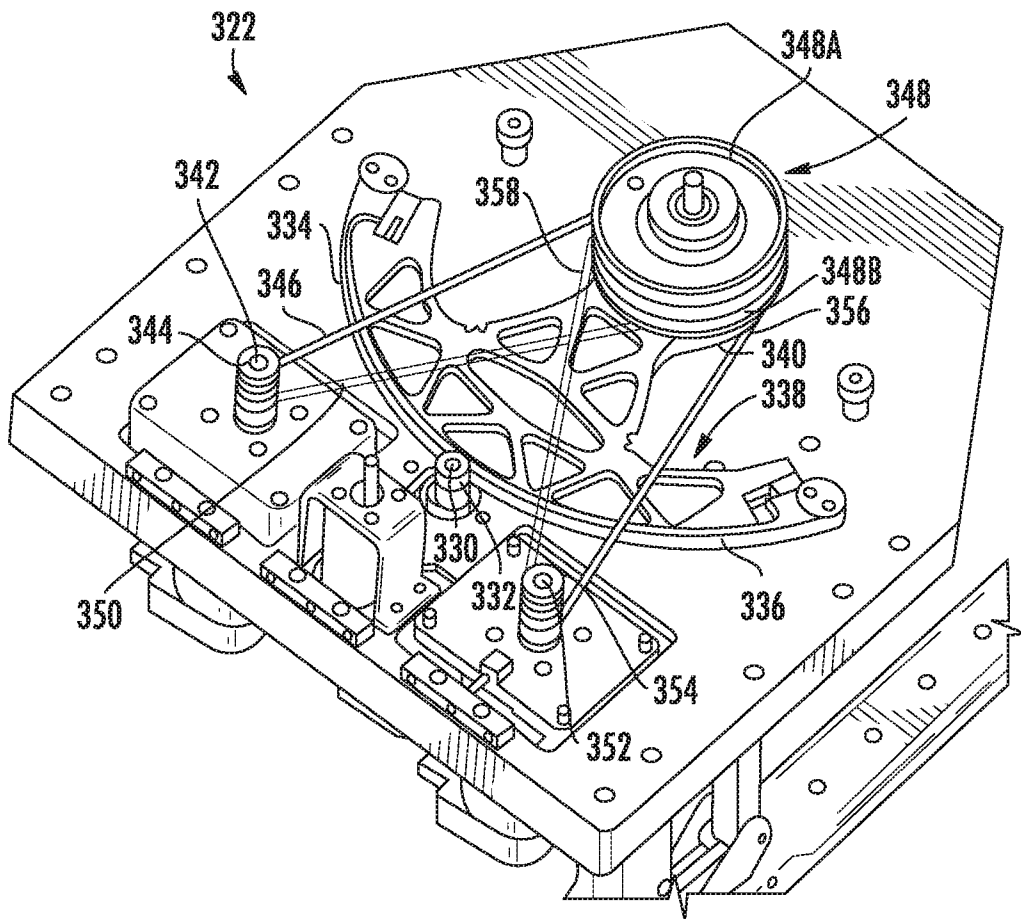


FIG. 5

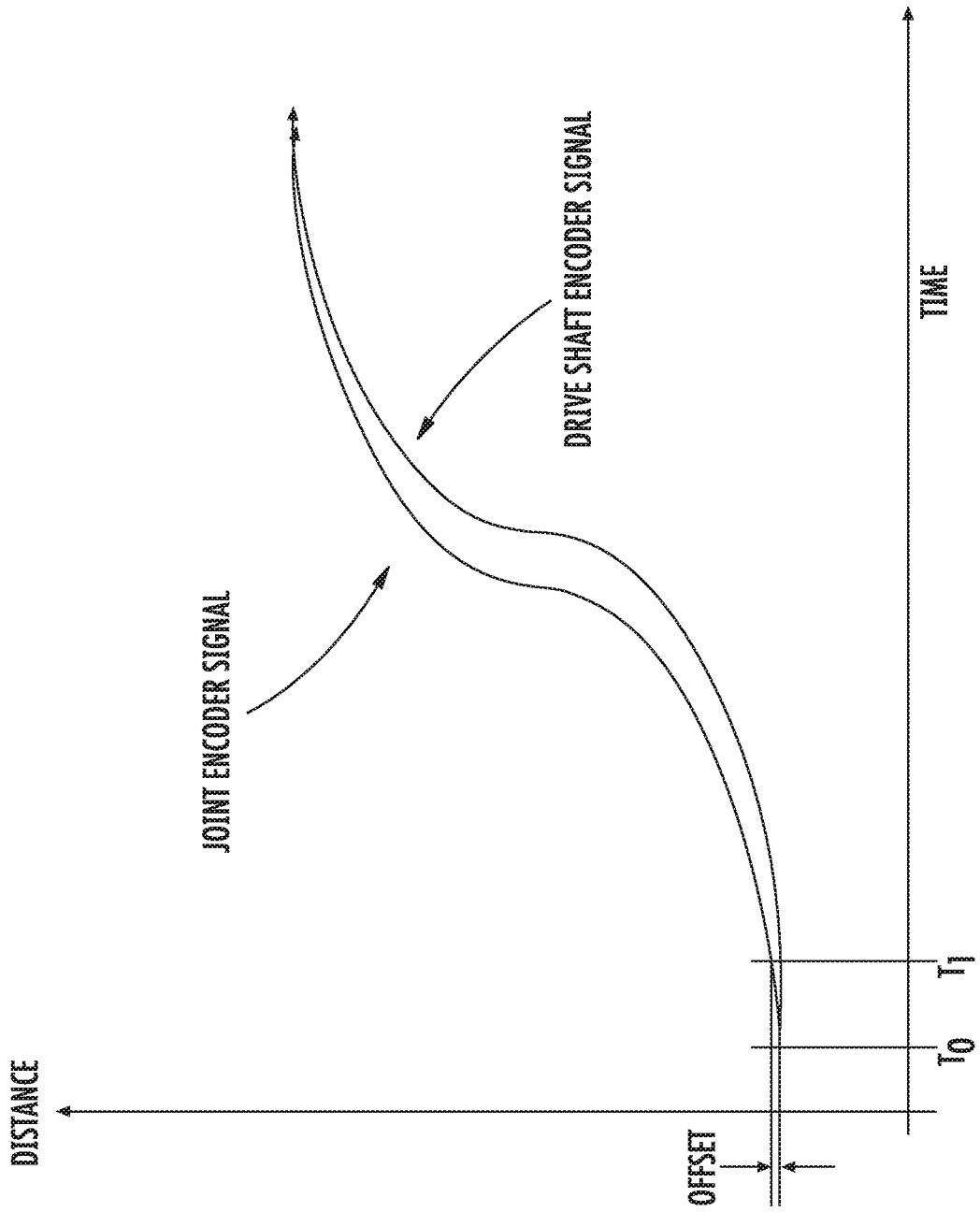


FIG. 6

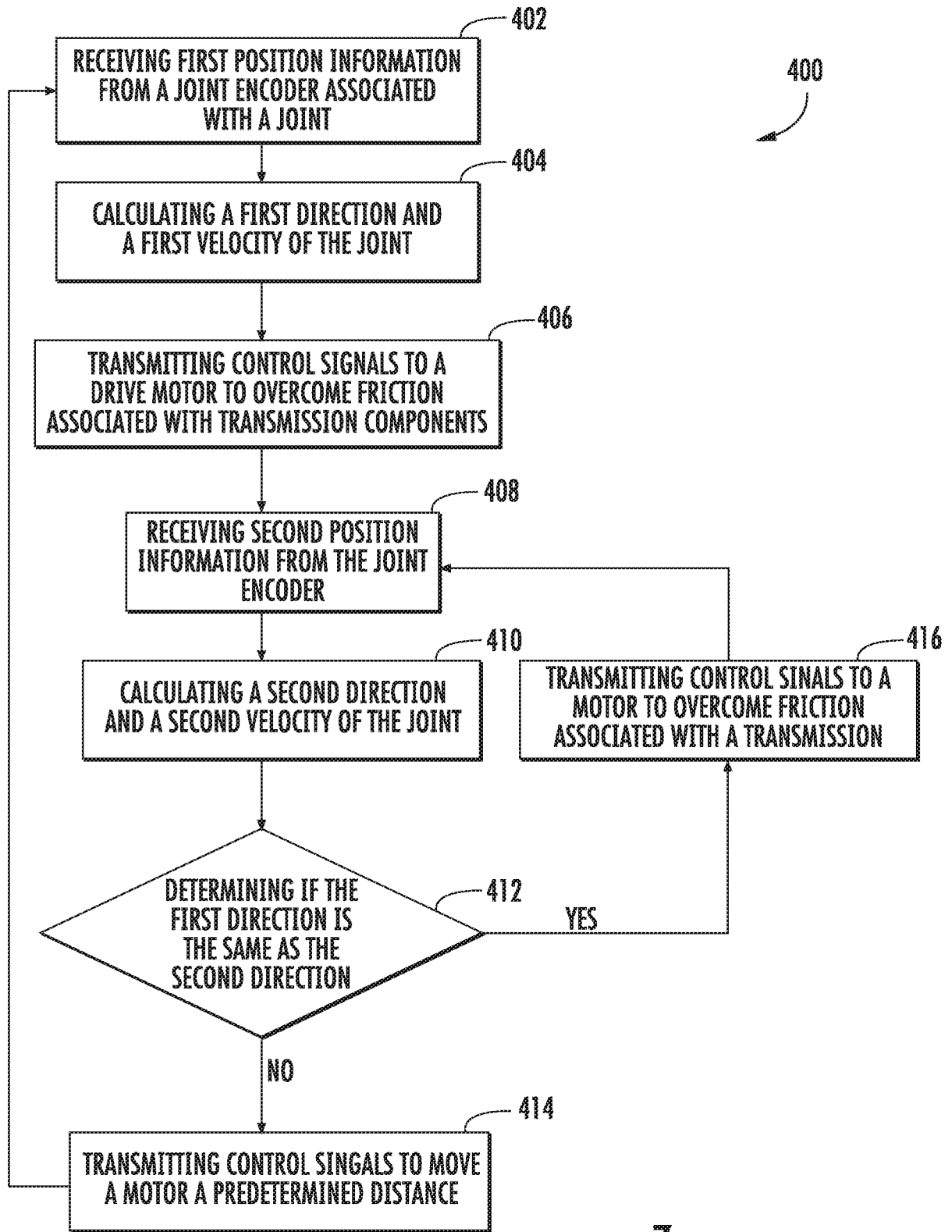


FIG. 7

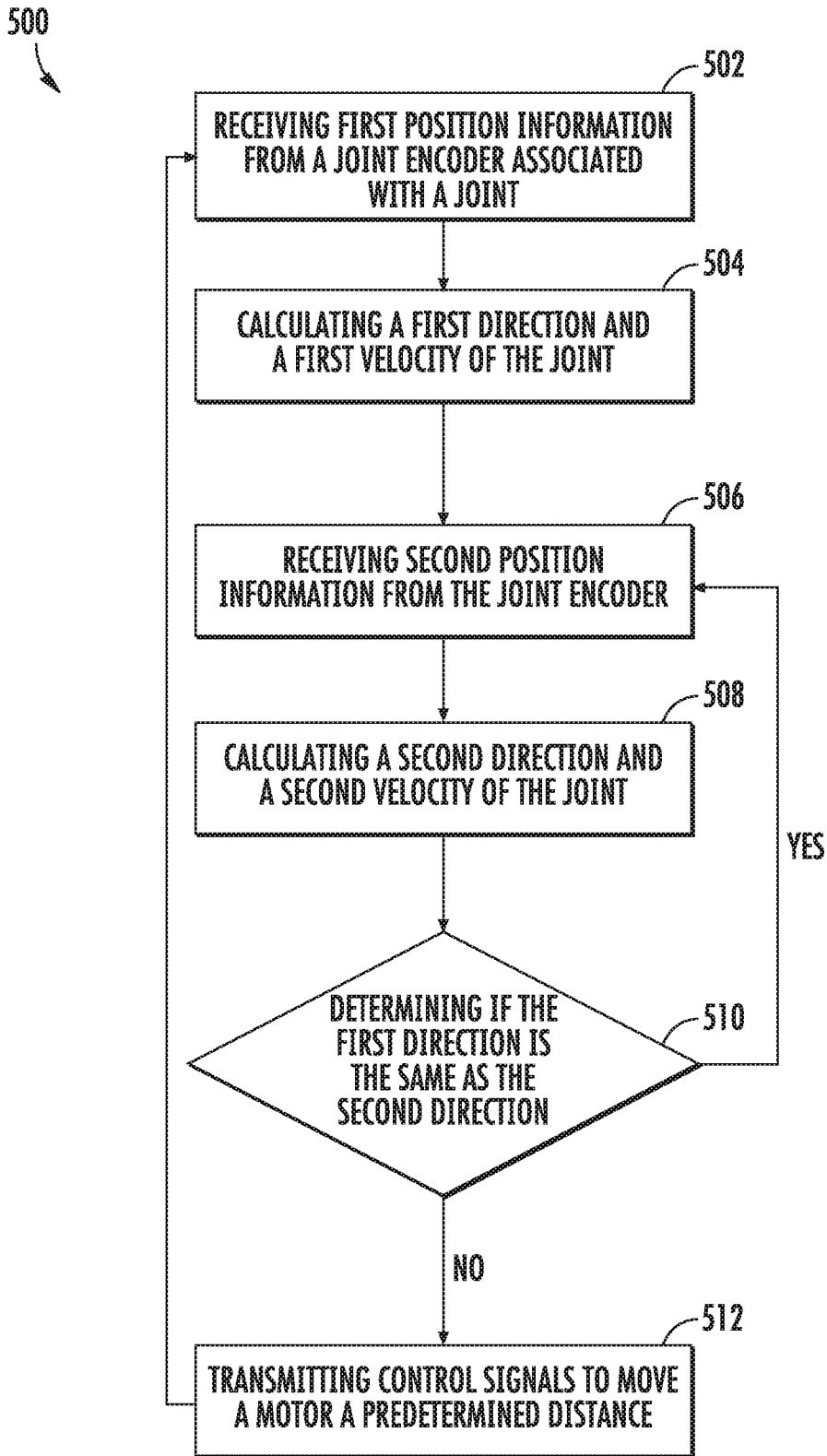


FIG. 8

A. CLASSIFICATION OF SUBJECT MATTER**A61B 34/00(2016.01)i, A61B 34/35(2016.01)i, A61B 34/30(2016.01)i, A61B 17/00(2006.01)i**

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 34/00; A61B 19/00; A61M 37/00; B25J 13/06; B25J 15/02; B25J 18/00; B25J 3/04; B25J 9/16; G09G 5/08; A61B 34/35; A61B 34/30; A61B 17/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: robotic surgical system, control arm, input interface, joint encoder, controller, compensating friction, transmission

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016-0375577 A1 (HAPTION) 29 December 2016 See claims 1-17; paragraphs [0154]-[0171].	1, 2, 7
Y		3-6, 8-16
Y	KR 10-1369286 B1 (KOREA INST SCI & TECH) 06 March 2014 See claims 1-3 and 5; paragraphs [0027]-[0047].	3-6, 8-16
A	US 2009-0248042 A1 (KIRSCHENMAN, M. B.) 01 October 2009 See the whole document.	1-16
A	US 2012-0245595 A1 (KESAVADAS, T. et al.) 27 September 2012 See the whole document.	1-16
A	US 5954692 A (SMITH, K. W. et al.) 21 September 1999 See the whole document.	1-16
A	US 6437771 B1 (ROSENBERG, L. B. et al.) 20 August 2002 See the whole document.	1-16

 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

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"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

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Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/049319

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016-0375577 A1	29/12/2016	EP 3109014 A1 EP 3109014 B1 US 0118289 B2	28/12/2016 20/09/2017 06/11/2018
KR 10-1369286 B1	06/03/2014	None	
US 2009-0248042 A1	01/10/2009	CN 102046081 A CN 102046081 B CN 102046235 A CN 102046235 B EP 2187806 A2 EP 2187806 B1 EP 2195064 A1 EP 2195064 B1 EP 2249736 A2 EP 2249736 B1 EP 2254643 A2 EP 2254643 B1 EP 2542292 A1 EP 2542296 A1 JP 2011-517421 A JP 2011-519286 A JP 2012-513845 A JP 2014-158942 A JP 5773884 B2 JP 6025328 B2 JP 6055434 B2 US 2009-0247942 A1 US 2009-0247943 A1 US 2009-0247944 A1 US 2009-0247993 A1 US 2010-0073150 A1 US 2010-0256558 A1 US 2011-0015569 A1 US 2011-0021984 A1 US 2011-0144806 A1 US 2011-0178532 A1 US 2011-0238010 A1 US 2013-0041243 A1 US 2013-0096575 A1 US 2013-0123803 A1 US 2013-0172906 A1 US 2013-0178794 A1 US 2014-0194897 A1 US 2014-0194898 A1 US 2014-0276942 A1 US 2016-0106957 A1 US 2016-0310220 A1 US 2016-0320930 A1	04/05/2011 09/10/2013 04/05/2011 11/06/2014 26/05/2010 28/02/2018 16/06/2010 26/09/2018 17/11/2010 15/08/2018 01/12/2010 21/02/2018 09/01/2013 09/01/2013 09/06/2011 07/07/2011 21/06/2012 04/09/2014 02/09/2015 16/11/2016 27/12/2016 01/10/2009 01/10/2009 01/10/2009 01/10/2009 25/03/2010 07/10/2010 20/01/2011 27/01/2011 16/06/2011 21/07/2011 29/09/2011 14/02/2013 18/04/2013 16/05/2013 04/07/2013 11/07/2013 10/07/2014 10/07/2014 18/09/2014 21/04/2016 27/10/2016 03/11/2016

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/049319

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 2017-0049524 A1	23/02/2017
		US 2018-0132950 A1	17/05/2018
		US 8317744 B2	27/11/2012
		US 8317745 B2	27/11/2012
		US 8343096 B2	01/01/2013
		US 8390438 B2	05/03/2013
		US 8641663 B2	04/02/2014
		US 8641664 B2	04/02/2014
		US 8684962 B2	01/04/2014
		US 8690821 B2	08/04/2014
		US 9161817 B2	20/10/2015
		US 9241768 B2	26/01/2016
		US 9295527 B2	29/03/2016
		US 9301810 B2	05/04/2016
		US 9314310 B2	19/04/2016
		US 9314594 B2	19/04/2016
		US 9330497 B2	03/05/2016
		US 9439736 B2	13/09/2016
		US 9795447 B2	24/10/2017
		US 9888973 B2	13/02/2018
		WO 2009-120940 A2	01/10/2009
		WO 2009-120940 A3	30/12/2009
		WO 2009-120944 A2	01/10/2009
		WO 2009-120944 A3	30/12/2009
		WO 2009-120945 A1	01/10/2009
		WO 2009-120946 A2	01/10/2009
		WO 2009-120946 A3	07/01/2010
		WO 2009-120948 A2	01/10/2009
		WO 2009-120948 A3	07/01/2010
		WO 2009-120982 A2	01/10/2009
		WO 2009-120982 A3	30/12/2009
		WO 2009-120992 A2	01/10/2009
		WO 2009-120992 A3	30/12/2009
		WO 2009-120992 A8	01/10/2009
		WO 2010-036746 A1	01/04/2010
		WO 2010-078344 A1	08/07/2010
		WO 2011-123595 A1	06/10/2011
		WO 2011-123669 A1	06/10/2011
		WO 2013-025257 A1	21/02/2013
US 2012-0245595 A1	27/09/2012	EP 2470105 A2	04/07/2012
		WO 2011-028627 A2	10/03/2011
		WO 2011-028627 A3	14/07/2011
US 5954692 A	21/09/1999	CA 2244163 A1	14/08/1997
		EP 0880337 A1	02/05/2003
		EP 0880337 B1	10/11/2004
		EP 1321106 A1	25/06/2003
		EP 1321106 B1	26/10/2005
		EP 1516577 A1	23/03/2005

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/049319

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		JP 2000-505318 A	09/05/2000
		US 5624398 A	29/04/1997
		US 5833656 A	10/11/1998
		US 6296635 B1	02/10/2001
		WO 97-28734 A1	14/08/1997
US 6437771 B1	20/08/2002	CA 2167304 A1	26/01/1995
		CA 2167304 C	21/04/1998
		CA 2210725 A1	25/07/1996
		CA 2210725 C	08/05/2001
		CA 2223289 A1	27/12/1996
		CA 2223289 C	25/03/2003
		CA 2228587 A1	20/02/1997
		CA 2228587 C	01/11/2005
		CA 2233136 A1	03/04/1997
		CA 2233136 C	31/01/2012
		CA 2233206 A1	03/04/1997
		CA 2233206 C	03/04/2001
		CA 2237977 A1	29/05/1997
		CA 2237977 C	26/03/2002
		CA 2239125 A1	12/06/1997
		CA 2254854 A1	27/11/1997
		CA 2254854 C	09/01/2007
		CA 2261893 A1	12/02/1998
		CA 2261893 C	16/04/2002
		CA 2271129 A1	04/06/1998
		CA 2271129 C	12/08/2003
		CA 2272553 A1	04/06/1998
		CA 2272553 C	10/04/2012
		CA 2272627 A1	18/06/1998
		CA 2272627 C	04/10/2005
		CA 2278726 A1	30/07/1998
		CA 2278726 C	31/08/2004
		CA 2281923 A1	27/08/1998
		CA 2281923 C	21/08/2007
		CA 2287349 A1	05/11/1998
		CA 2287349 C	25/06/2002
		CA 2291226 A1	30/09/1999
		CA 2291226 C	22/10/2002
		CA 2294085 A1	23/12/1998
		CA 2294085 C	15/08/2006
		CA 2294128 A1	23/12/1998
		CA 2297514 A1	02/08/2000
		CA 2300899 A1	29/12/1999
		CA 2319586 A1	05/08/1999
		CA 2319586 C	31/01/2012
		CN 1496549 A	12/05/2004
		CN 1496549 C	12/07/2006
		CN 1571989 A	26/01/2005
		CN 1571989 B	04/04/2012

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/049319

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		CN 1571989 C	26/01/2005
		CN 1924775 A	07/03/2007
		CN 1924775 C	15/10/2008
		EP 0804786 A1	21/01/2004
		EP 0804786 B1	31/03/2004
		EP 0836735 A1	09/03/2005
		EP 0836735 B1	24/08/2005
		EP 0843808 A1	17/12/2003
		EP 0843808 B1	17/12/2003
		EP 0852770 A1	15/09/1999
		EP 0852770 B1	15/03/2000
		EP 0852789 A1	21/05/2003
		EP 0852789 B1	15/11/2006
		EP 0864144 A2	31/08/2005
		EP 0864144 B1	08/03/2006
		EP 0870296 A1	18/06/2003
		EP 0870296 B1	04/02/2004
		EP 0941578 A1	05/12/2001
		EP 0943179 A1	04/05/2005
		EP 0943179 B1	07/06/2006
		EP 0951714 A2	16/03/2005
		EP 0951714 B1	24/09/2014
		EP 0958536 A1	21/07/2004
		EP 0974889 A1	26/01/2000
		EP 0974889 B1	26/03/2003
		EP 0979444 A1	16/02/2000
		EP 0979444 B1	15/05/2013
		EP 0979500 A1	16/02/2000
		EP 0995152 A1	26/04/2000
		EP 0995152 B1	10/08/2011
		EP 0995186 A2	26/04/2000
		EP 1005690 A1	07/06/2000
		EP 1005690 B1	05/04/2017
		EP 1012697 A1	28/06/2000
		EP 1012697 B1	05/08/2015
		EP 1036390 A1	20/09/2000
		EP 1036390 B1	03/11/2004
		EP 1046151 A1	25/10/2000
		EP 1046151 B1	14/06/2017
		EP 1066616 A2	10/01/2001
		EP 1066616 B1	22/09/2010
		EP 1157339 A2	28/11/2001
		EP 1157339 B1	02/07/2014
		EP 1374217 A1	02/01/2004
		EP 1374217 B1	05/03/2014
		EP 1424538 A1	02/06/2004
		EP 1424538 B1	07/07/2010
		EP 1440429 A1	28/07/2004
		EP 1440429 B1	12/12/2012
		EP 1640851 A2	29/03/2006

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/049319

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		EP 1988446 A1	05/11/2008
		EP 2246770 A2	03/11/2010
		EP 2246770 A3	14/09/2011
		EP 2246770 B1	05/12/2012
		EP 2273346 A1	12/01/2011
		EP 2273346 B1	03/10/2018
		EP 2309365 A2	13/04/2011
		EP 2309365 A3	20/04/2011
		JP 10-512983 A	08/12/1998
		JP 11-514469 A	07/12/1999
		JP 2000-515285 A	14/11/2000
		JP 2001-109558 A	20/04/2001
		JP 2004-530200 A	30/09/2004
		JP 2005-514681 A	19/05/2005
		JP 2006-286016 A	19/10/2006
		JP 2010-061667 A	18/03/2010
		JP 2011-065678 A	31/03/2011
		JP 3753744 B2	08/03/2006
		JP 3847782 B2	22/11/2006
		JP 4394664 B2	06/01/2010
		JP 4689747 B2	25/05/2011
		JP 4929394 B2	09/05/2012
		KR 10-0887778 B1	09/03/2009
		KR 10-0950822 B1	02/04/2010
		KR 10-1035450 B1	18/05/2011
		KR 10-1136307 B1	25/04/2012
		KR 10-2001-0108361 A	07/12/2001
		KR 10-2004-0045908 A	02/06/2004
		KR 10-2008-0096854 A	03/11/2008
		KR 10-2009-0082519 A	30/07/2009
		KR 10-2010-0057903 A	01/06/2010
		US 5576727 A	19/11/1996
		US 5691898 A	25/11/1997
		US 5701140 A	23/12/1997
		US 5721566 A	24/02/1998
		US 5724264 A	03/03/1998
		US 5731804 A	24/03/1998
		US 5734373 A	31/03/1998
		US 5739811 A	14/04/1998
		US 5767839 A	16/06/1998
		US 5805140 A	08/09/1998
		US 5825308 A	20/10/1998
		US 5880714 A	09/03/1999
		US 5903456 A	11/05/1999
		US 5907487 A	25/05/1999
		US 5929607 A	27/07/1999
		US 5929846 A	27/07/1999
		US 5956484 A	21/09/1999