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(71) Applicant: THE RESEARCH FOUNDATION FOR  
THE STATE UNIVERSITY OF NEW YORK [US/US];  
University at Buffalo, Office of Science, Technology  
Transfer and, Economic Outreach, Baird Research Park,  
Suite 111, 1576 Sweet Home Road, Amherst, NY 14228-  
2567 (US).

(72) Inventors: KESAVADAS, Thenkurussi; 9030 Michael  
Douglas Drive, Clarence Center, NY 14032 (US).  
ASHAMMAGARI, Aditya, Reddy; 112 Niagara Falls  
Blvd, Buffalo, NY 14214 (US).

(74) Agents: LUCEK, Nathaniel, W. et al.; Hodgson Russ  
LLP, The Guaranty Building, 140 Pearl Street, Suite 100,  
Buffalo, NY 14202-4040 (US).

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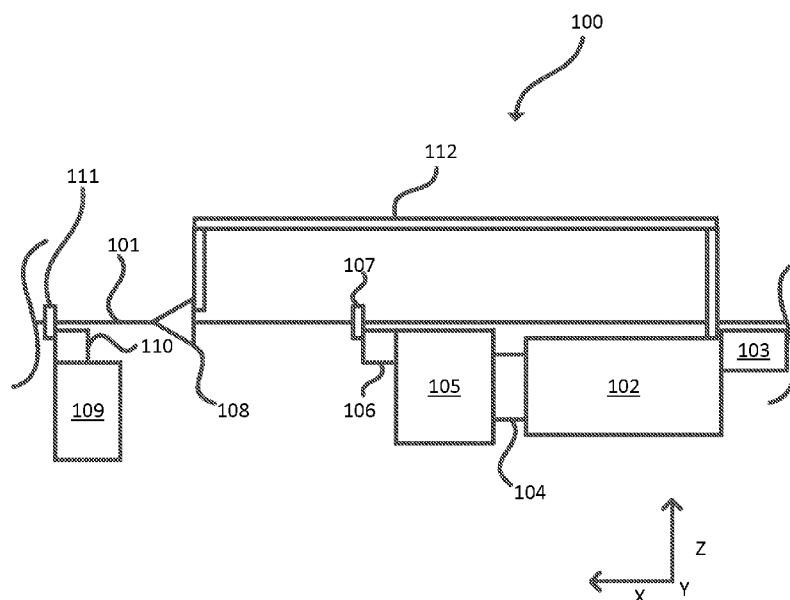


FIG. 1

(57) Abstract: A robotic system that may be used with a wire such as, for example, a stent, needle, guidewire, catheter, or another device is disclosed. This robotic system has a first pinch mechanism coupled to a first servo and a second pinch mechanism coupled to a second servo. An end effector is connected to the first servo and a frame is connected to the second servo. Each of the first and second pinch mechanisms can pinch and lock the wire in a fixed position relative to the respective first or second pinch mechanism. The wire may be translated into or out of a patient using the first pinch mechanism and second pinch mechanism.





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**END EFFECTOR FOR SURGICAL SYSTEM AND METHOD OF USE THEREOF****Cross-Reference to Related Applications**

[0001] This application claims priority to U.S. Patent Application No. 61/766,027, filed February 18, 2013, the disclosure of which is hereby incorporated by reference.

**5 Field of the Invention**

[0002] This invention relates to robotic systems and, more particularly, to a robotic system for translating a flexible device.

**Background of the Invention**

[0003] Stroke is the third most common cause of death in North America with  
10 approximately 600,000 new cases of stroke reported annually, of which 150,000 are fatal. Besides mortality, morbidity in 4,000,000 or more surviving stroke victims is substantial, making stroke the leading cause of disability in the United States. For most stroke patients, interventional treatment falls into three categories: i) medicinal (i.e., blood-thinning drugs) to improve the blood flow to impacted parts of the brain; ii) highly invasive surgery; or iii)  
15 minimally invasive endovascular techniques. Endovascular intervention is a minimally invasive surgery used to access regions of vasculature deep inside the skull and surrounding the brain using a process called catheterization. It involves insertion of elongated and highly flexible surgical instruments, such as guidewires, catheters, and stents, into the vasculature through a small incision near the patient's groin by pushing and twisting these flexible wires to reach the  
20 destination using visual feedback from fluoroscopic or x-ray images.

[0004] A new type of robot which can share the surgical space with the human user, such as a doctor or surgeon, is needed. Such a robot may need to be able to understand the physical phenomenon behind the device placement, understand the strategy the surgeon is proposing, and reduce tedium. It should also be able to perform the procedure with greater accuracy or  
25 precision, overcoming physical limitations of a human user. Complex vessel geometry increases the tedium of navigation and decision making for a surgeon. This happens because the navigation of a catheter, both in fluoroscope-based and current tele-robotic systems, require dexterous manual input from the surgeon. This takes away valuable time that could be otherwise spent in treatment planning and other cognitive tasks.

[0005] Previous robot-assisted wire insertion devices suffer from multiple drawbacks. First, wire slippage occurs, which should be avoided during surgery and could potentially be dangerous to a patient. Second, there may be a lag between readings taken for the steering mechanism. Thus, information that a user may need may be delayed. Third, previous devices lack force feedback to the user. This limits the user's ability to sense during a procedure and may prevent the user from fully comprehending potential dangers. Therefore, what is needed is an improved robotic system for translating a flexible device such as a stent, needle, or other component.

### **Brief Summary of the Invention**

[0006] In one embodiment, a robotic system is disclosed. This robotic system has a first pinch mechanism coupled to a first servo and a second pinch mechanism coupled to a second servo. An end effector is connected to the first servo and a frame is connected to the second servo. Each of the first and second pinch mechanisms can pinch a wire and lock this wire in a fixed position relative to the respective first or second pinch mechanism. The wire that is pinched by the first or second pinch mechanism may be, for example, a stent, a needle, a guidewire, or a catheter.

[0007] Each of the first pinch mechanism and second pinch mechanism may have a wire holder and a cam. The wire holder may be a hollow tube that the wire is configured to pass through. There is an aperture on the outer surface of the wire holder's hollow tube. The cam can rotate and may press the wire against the wire holder through this aperture.

[0008] The robotic system also may include a force and torque sensor on the first servo.

[0009] A robotic arm may be connected to the end effector. This robotic arm may have at least two degrees of freedom. In one example, the robotic arm may have six degrees of freedom. The end effector may be connected to the frame using this robotic arm.

[0010] A cap on a flexible beam may be located on the end effector. This cap may define an aperture that the wire projects through.

[0011] A haptic device may be connected to, for example, the first servo, the second servo, and a force and torque sensor.

[0012] In another embodiment, a method of operating a robotic system is disclosed. A wire is released by a second pinch mechanism while being pinched with a first pinch mechanism to lock the wire in a fixed position relative to the first pinch mechanism. The wire is translated into a patient by moving the first pinch mechanism toward the second pinch mechanism while the wire is pinched by the first pinch mechanism and released by the second pinch mechanism. After translating the wire into the patient, the wire is released by the first pinch mechanism while being pinched by the second pinch mechanism to lock the wire in a fixed position relative to the second pinch mechanism. The first pinch mechanism is moved away from the second pinch mechanism while the wire is released by the first pinch mechanism and pinched by the second pinch mechanism. The wire translated into the patient may be, for example, a stent, a needle, a guidewire, or a catheter. Translating the wire may advance the wire through the second pinch mechanism.

[0013] Pinching with the first pinch mechanism may use a first servo and may press the wire against a first wire holder with a first cam. Pinching with the second pinch mechanism may use a second servo and may press the wire against a second wire holder with a second cam. Both the first cam and second cam may be configured to rotate.

[0014] A haptic device may be used during the translation of the wire into the patient. Translating the haptic device a distance may correspond to a distance that the wire is translated into the patient.

[0015] The wire may be pinched by the first pinch mechanism to lock the wire in a fixed position relative to the first pinch mechanism while the wire is released by the second pinch mechanism. The wire may be translated out of the patient by moving the first pinch mechanism away from the second pinch mechanism while the wire is released by the second pinch mechanism and the wire is pinched by the first pinch mechanism. After translating the wire out of the patient, the wire is released by the first pinch mechanism and the wire is pinched by the second pinch mechanism to lock the wire in a fixed position relative to the second pinch mechanism. The first pinch mechanism moves toward the second pinch mechanism while the wire is released by first pinch mechanism and the wire is pinched by the second pinch mechanism.

[0016] The wire may be rotated with an end effector while first pinch mechanism pinches the wire. The wire also may be jiggled with an end effector while the first pinch mechanism pinches the wire.

[0017] Haptic feedback may be used to generate resistance corresponding to the  
5 resistance of the wire as this wire translates into the patient.

### Description of the Drawings

[0018] For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawings, in which:

- 10 FIG. 1 is a side elevation view of an end effector for a robotic system;  
FIG. 2 is a perspective view of part of the end effector illustrated in FIG. 1;  
FIG. 3 is a perspective view of a pinch mechanism for the end effector illustrated in FIG. 1;  
FIG. 4 is a perspective view of a flexible beam and cap used with the end effector illustrated in FIG. 1;
- 15 FIG. 5 is a side elevation view of a robotic system using the end effector of FIG. 1;  
FIG. 6 is an example of a visual interface used with the end effector of FIG. 1; and  
FIGs. 7 and 8 are flowcharts illustrating translating a wire into and out of a patient.

### Detailed Description of the Invention

- [0019] Although claimed subject matter will be described in terms of certain  
20 embodiments, other embodiments, including embodiments that do not provide all of the benefits and features set forth herein, are also within the scope of this invention. Various structural, logical, process step, and electronic changes may be made without departing from the spirit or scope of the invention. Accordingly, the scope of the invention is defined only by reference to the appended claims.

- 25 [0020] FIG. 1 is a side elevation view of an end effector for a robotic system. The wire 101 extends through the end effector 100. The end effector 100 advances, withdraws, positions, torques, or jiggles the wire 101. This wire 101 may be, for example, a stent, a needle, a guidewire, a catheter, a balloon, a coil, or another device that is inserted into a patient. In one particular example, the wire 101 is a 0.35" guidewire.

[0021] The wire 101 passes through an aperture of the first pinch mechanism 107, the second pinch mechanism 111, and the cap 109 in the x-direction. The first pinch mechanism 107 and second pinch mechanism 111 prevent slip of the wire 101 when activated. Thus, the first pinch mechanism 107 and second pinch mechanism 111 can grip the wire 101 or lock the wire 101 in a fixed position relative to either the first pinch mechanism 107 or second pinch mechanism 111. In one particular example, approximately 0.1 N to 4.5 N of force is used to pinch the wire 101 with either the first pinch mechanism 107 or second pinch mechanism 111.

[0022] A robotic arm 103 is connected to an end effector base 102. The end effector base 102 is connected to a holding frame 104. The holding frame is connected to a force and torque sensor 105. The force and torque sensor 105 is connected to a first servo 106, which is connected or coupled to the first pinch mechanism 107. In one example, the force and torque sensor 105 is an ATI force/torque sensor, though other sensors may be used. The force and torque sensor 105 may be able to measure between approximately 0.1 N and at least 10 N of force. A second servo 110 is connected to a frame 109. This second servo 110 is also connected or coupled to the second pinch mechanism 111. The robotic arm 103 also may be connected to the frame 109 (illustrated in FIG. 5).

[0023] The cap 108 is connected to the flexible beam 112, which is connected to the robotic arm 103, end effector base 102, or another part of the end effector 100. The flexible beam 112 may be bendable or may flex in the x-direction, y-direction, or z-direction. The second pinch mechanism 111 may be positioned relative to the cap 108 in a manner that the apertures of each are aligned. This may prevent stress or torque from being unintentionally induced in the wire 101. The apertures of the second pinch mechanism 111 and cap 109 may still be aligned even if the end effector 100 is angled in or relative to, for example, the y-direction or z-direction. Of course, the cap 108 may need to move relative to the second pinch mechanism 111 such that these apertures are not always aligned.

[0024] The first pinch mechanism 107 and second pinch mechanism 111 or first servo 106 and second servo 110 may be connected to one or more processors or microcontrollers (not illustrated). In one example, the first servo 106 and second servo 110 may be controlled using a Aurdino Mega ADK micro-controller chip, though other devices may be used.

[0025] FIG. 2 is a perspective view of part of the end effector illustrated in FIG. 1. The wire 101 passes through the first wire holder 201 that is disposed on the first servo 106. A first

cam 200, connected to and activated by the first servo 106, is used to pinch the wire 101. The first cam 200 and first wire holder 201 are part of the first pinch mechanism 107. The first servo 106 is connected to the end effector base 102 using the force and torque sensor 105 and holding frame 104.

5    **[0026]**       FIG. 3 is a perspective view of a pinch mechanism for the end effector illustrated in FIG. 1. The wire 101 passes through an aperture 300 extending along the length of the first wire holder 201. Thus, the first wire holder 201 may be a hollow tube having a diameter large enough to accommodate the wire 101. The first wire holder 201 also defines an aperture 301 on the surface of the hollow tube, such that the wire 101 is exposed through the aperture 301. This  
10   aperture 301 may be larger than the portion of the first cam 200 that contacts the wire 101. The first cam 200, positioned on an axis 303, rotates in the direction illustrated by arrow 302. Thus, the first cam 200 can press or otherwise lock the wire 101 against the wall of the first wire holder 201 through the aperture 301. This movement of the first cam 200 can result in the wire 101 being held in place without slippage. When the first cam 200 is not activated, the wire 101 can  
15   pass through the first wire holder 201 because the wire 101 is not pinched by the first cam 200.

**[0027]**       While the first cam 200 is illustrated as having four arms, more or fewer arms may be used. Thus, the first cam 200 is not limited solely to four arms.

**[0028]**       The second pinch mechanism 111 may contain a second cam similar to the first cam 200 and a second wire holder similar to the first wire holder 201. This second cam may be  
20   connected to and activated by the second servo 110. Thus, the second pinch mechanism 111 may operate similar to the first pinch mechanism 107.

**[0029]**       FIG. 4 is a perspective view of a flexible beam and cap used with the end effector illustrated in FIG. 1. The flexible beam 112 is connected to the cap 108 and the end effector 100. This cap 108, which may be fabricated of plastic, may be conical, pyramidal, or other  
25   shapes and defines an aperture 400 along its length that the wire 101 passes through. In one example, this aperture 400 is through the center of the cone in cap 108. The flexible beam 112 in one instance is fabricated of metal, such as aluminum, and may act as a leaf spring.

**[0030]**       The cap 108 protects the robotic system and the first pinch mechanism 107 when used with the flexible beam 112. The cap 108 also may ensure the wire 101 is inserted properly  
30   when used with the flexible beam 112. The cap 108 also carries the wire 101 to the second pinch

mechanism 111 and, with the flexible beam 112, can act as a safety mechanism if the end effector 100 applies more than a desired amount of pressure to the wire 101. Thus, the flexible beam 112 protects the first pinch mechanism 107 from shock due to any failure. For example, if the robotic system fails and is not held in a desired position or the robotic system moves suddenly beyond the limit, this flexible beam 112 absorbs the shock and limits the movement to protect the end effector 100 of the robotic system or the wire 101. The cap 108 and flexible beam 112 can act as a compliant mechanism and deflect to absorb the excess force or failure of the end effector 100 or robotic arm 103, thereby protecting the robotic system. The flexible beam 112 also protects the first pinch mechanism 107 if the wire 101 does not move or translate as expected because the flexible beam 112 can compress in the x-direction (as seen in FIG. 1). The flexible beam 112 and cap 108 also may prevent coiling of the wire 101 during insertion because the shape of the cap 108 may hold the wire 101 in place during the feed or correct any misalignment of the wire 101 during insertion.

**[0031]** FIG. 5 is a side elevation view of a robotic system using the end effector of FIG.

1. For ease of illustration, not all the components of the end effector 100 from FIG. 1 are labelled. The wire 101 is translated into, out of, or inside of the patient 500. The robotic arm 103 connects the end effector 100 to the frame 109. The number of segments, joints, or the degrees of freedom of the robotic arm 103 can vary. In one example, the robotic arm 103 has two degrees of freedom. In another example, the robotic arm 103 has six degrees of freedom. This robotic arm 103 may facilitate stroke lengths or simulate movement similar to a surgeon's hand, wrist, or arm.

**[0032]** In one specific example, the robotic arm 103 is based on the Robai Cyton Veta, which has 350 g of payload and 480 mm of reach. In another specific example, the robotic arm 103 is a KUKA youBot, which has brushless DC motors with a planetary gear box. Of course, other robotic arms 105 are possible and the design may vary from that illustrated in FIG. 5.

**[0033]** In an alternate design, the robotic arm 103 does not connect to the frame 109. Instead, the robotic arm 103 connects to a stand or some other unit. For example, the robotic arm 103 may be connected to a pedestal. The frame 109 with the second pinch mechanism 111 also may be connected to this pedestal in one particular example.

**[0034]** The end effector 100 is connected to a haptic device 501. In one specific example, the haptic device is an Omni-Phantom device, though other haptic tools or mechanisms

may be used. The haptic device 501 may be connected to the force and torque sensor 105, the first servo 106, or second servo 109. Of course, the haptic device 501 may be connected elsewhere in the end effector 100 or robotic arm 103. Force may be scaled and transmitted from the force and torque sensor 105 to the haptic device 501 and a visual interface (not illustrated) can show the motion, linear force, and torque in real-time. The force in the haptic device 501 may represent a curve in the patient's vessels, plaque in the patient's vessels, or a patient's vessels that are bunched or labyrinthine. A pedal (not illustrated) may be used activate and clutch at least one of the first pinch mechanism 107 or second pinch mechanism 111.

**[0035]** During operation, a suitable size of wire 101 and, optionally, a matching holder are chosen. The wire 101 is placed in the end effector 100. The first servo 106 is activated by a button actuated by a user, such as on the haptic device 501.

**[0036]** When a first button on the haptic device 501 is pressed by the user, it activates the first servo 106 to pinch the wire 101 using the first pinch mechanism 107 and the second servo 110 to release the wire 101 with the second pinch mechanism 111. When the first button is not pressed, the first servo 106 releases the wire 101 with the first pinch mechanism 107 and the second servo 110 pinches the wire 101 with the second pinch mechanism 111. This simultaneous or consecutive pinching and releasing of the wire 101 by the first pinch mechanism 107 and second pinch mechanism 111 may allow the robotic arm 103 to insert the wire 101 or extract the wire.

**[0037]** Pressing the first button on the haptic device 501 and moving the haptic device 501 joystick or pen, for example, forward moves the robotic arm 103 forward. Thus, the wire 101 can be urged into the patient because the wire 101 is pinched by the first pinch mechanism 107 while the end effector 101 is moved forward (such as in the x-direction). Releasing the first button on the haptic device 501 results in holding the inserted wire 101 in place with the second pinch mechanism 111 and allows the robotic arm 103 and end effector 100 to move back (such as in the x-direction) to get hold of more wire 101 for insertion without the wire 101 slipping or being withdrawn from the patient 500. This process of inserting parts of wire 101 may be performed until the required amount of wire 101 is inserted into a patient. Similarly, extraction of the wire 101 is done by opposite actions.

**[0038]** The second pinch mechanism 111 may be actuated to keep the wire 101, which has already been inserted, in-place. The second pinch mechanism 111 may protect the built up

force and torque of the wire 101 that has been inserted. The second servo 110 is used when the robotic arm 103 attempts to get hold of the next segment of the wire 101 to be inserted or withdrawn.

[0039] During operation, the force and torque sensor 105 also provides continuous force feedback to the user in real-time. Every action of the robotic system, including the proximal and distal forces, may be communicated to the haptic device 501 as graduated or resultant forces. The reaction to the force may be the supervisory layer on the system to execute the planned feed of the mechanism.

[0040] If the user pushes back to maintain the nominal position of the device handle in the haptic device 501, the device will work normally. However if the nominal position is negative, the haptic device 501 will slow down and vice versa. Thus, a positive position will increase the speed of the feed mechanism of the robotic system. This may not be tele-control because the actual rotation and translation and the path plan to reach the goal is being shared by robot and not by the implicit command from a user. In the same way, if the system applies negative force (pull back) the user must counter it to allow the robotic system to withdraw the wire 101.

[0041] In one particular example, if the wire 101 is moving at an expected rate into or in the patient, then no resistance may be felt by the user through the haptic device 501. The user may feel resistance through the haptic device 501 if the wire 101 is moving slower than expected in the patient. The user may feel the haptic device 501 pulling if the wire 101 is moving faster than expected in a patient. The robotic system may have a predictive range of resistance or range of expected speeds for certain regions of the patient, certain wires 101 or devices on the wire 101, or certain procedures to determine whether the user should feel no resistance, a degree of resistance, or pulling.

[0042] As one illustrative example, velocity of the wire 101 during insertion may average around 84 mm/s with a peak at approximately 562 mm/s. The average stroke may be around 54 mm with a peak at approximately 235 mm. In another example using a catheter insertion, the maximum axial force may be 4.5 N and the maximum torque may be 8 N mm. In yet another example, the range for patient safety during a procedure may be set with a permissible force between approximately 0.1 N and 4.5 N and permissible torque between approximately 0.5 N mm to 8 N mm. However, these are based on three distinct procedures and these numbers may

vary considerably depending on the patient, procedure, or type of wire 101 (i.e., a stent versus a needle). Thus, the exact range set for patient safety or predicted based on a patient may deviate from these numbers.

[0043] The wire 101 may be torqued or twisted. To torque or twist the wire 101, the first servo 106 may be activated to pinch the wire 101 with the first pinch mechanism 107. The end effector 100 may then rotate (such as around the x-direction). In one example, torquing of the wire 101 is done by pressing the first button on the haptic device 501 to pinch the wire 101 with the first pinch mechanism 107 and rotating the haptic pen or joystick in a direction to torque the wire 101 in that direction. The wrist of the robotic arm 103 may enable twisting or torquing motion.

[0044] The wire 101 also can be vibrated or jiggled. This may release wire 101 bunching or tension when the force encountered by the wire 101 is deemed as too high. This jiggling or vibrating also may free a wire 101 that is stuck. In one specific example, the wire 101 is harmonically jiggled. For example, the wire 101 may be jiggled harmonically with a frequency of 10 to 60 Hz and with an amplitude ranging from 1 mm to 10 mm. To jiggle the wire 101, the first pinch mechanism 107 may be activated to pinch the wire 101 while the second pinch mechanism 111 is not pinching the wire 101. The end effector 100 may then move in a manner to vibrate or jiggle the wire 101 (such as in the x-direction, y-direction, and/or z-direction).

[0045] The angle of entry of the wire 101 may be adjusted prior to or during insertion into a patient. The robotic arm 103 and end effector 100 may adjust the angle, such as in the y-direction or z-direction relative to the x-direction, based on user input or patient information. This may be used, for example, if the wire 101 is or contains a needle. Thus, the wire 101 can approach the patient's body at any angle.

[0046] Both the first pinch mechanism 107 and second pinch mechanism 111 can be commanded to release the wire 101 if, for example, both a first and second button are pressed on the haptic device 501. This allows for manual action on the wire 101 by the user. Manual action by a user may be used to thread a catheter over the wire or for inserting another device. Manual action by a user also may be used to take control for safety of the patient or for other reasons during the procedure.

[0047] While a first button and a second button on the haptic device 501 are disclosed, other control mechanisms known to those skilled in the art may be used. For example, the first and second button may be located elsewhere besides the haptic device 501. A pedal, voice command, or other control mechanism may be used instead of or supplementary to the disclosed first button and second button.

[0048] A visual interface may be included with the haptic device. FIG. 6 is an example of a visual interface used with the end effector of FIG. 1. Key locations and orientations may be displayed. Information about the patient and properties of the robotic system may be displayed to enable a user to make treatment planning decisions. Predicted intersections and potential obstacles that may need to be avoided to reduce the risk of vessel dissection or perforation may be marked or highlighted on the display. This may be helpful as treatment proceeds to more distal regions of the vascular tree. Changes in color and quantitative data may be presented at intersections. The location of the wire 101 in the patient also may be displayed.

[0049] The robotic arm 103 may be attached to a computer (not illustrated). A patient end computer may be connected through the internet to a user end computer. The haptic device 501 may be connected to the user end computer. The haptic device 501 and the robotic arm 103 may be mapped to move using a master/slave map. The communication between the devices is done using a TCP/IP protocol. One embodiment reduces data losses, given that the procedure is already learned by the robotic system. If any data losses occur in this embodiment, the robotic arm 103, while tele-controlled, does not make any unapproved actuations. It may use a predictive model to guess what it should do in case of data loss in between a communication sequence. One example of a TCP/IP includes performing a procedure several times offline by connecting the robotic system to the user control, such as the haptic device 501. Force profiles of the wire 101 can be captured for all procedures performed offline. A force versus wire position model can be generated from the data collected. The model is programmed as a reference instruction to the robotic system at the patient's end. In case of data losses during communication, the robotic system refers to the instructions and predicts its approach to overcome that data loss.

[0050] In one specific example, the robotic system can take a motion path from a 3D reconstruction of the patient's vessels and predict forces as the wire 101 moves through the

vessels. This allows the robotic system to react if the actual forces are higher than predicted forces.

[0051] FIGs. 7 and 8 are flowcharts illustrating translating a wire into and out of a patient. As illustrated in 700 of FIG. 7, to translate the wire 101 into the patient, the wire 101 is pinched with the first pinch mechanism 107 and released by the second pinch mechanism 111. In 701, the wire 101 is translated into the patient by moving the first pinch mechanism 107 toward the second pinch mechanism 111 while the wire 101 is pinched by first pinch mechanism 107 and released by second pinch mechanism 111. In 702, the wire 101 is released by the first pinch mechanism 107 while the wire 101 is pinched with the second pinch mechanism 111. In 703, the first pinch mechanism 107 is moved away from the second pinch mechanism 111 while the wire 101 is released by the first pinch mechanism 107 and pinched by the second pinch mechanism 111. This process may be repeated as needed until a desired length of the wire 101 is translated into the patient, as seen in 704.

[0052] As illustrated in 800 of FIG. 8, to translate the wire 101 out of the patient, the wire 101 is pinched with the first pinch mechanism 107 and released by the second pinch mechanism 111. In 801, the wire 101 is translated out of the patient by moving the first pinch mechanism 107 away from the second pinch mechanism 111 while the wire 101 is pinched by first pinch mechanism 107 and released by second pinch mechanism 111. In 802, the wire 101 is released by the first pinch mechanism 107 while the wire 101 is pinched with second pinch mechanism 111. In 803, the first pinch mechanism 107 is moved toward the second pinch mechanism 111 while the wire 101 is released by the first pinch mechanism 107 and pinched by the second pinch mechanism 111. This process may be repeated as needed until a desired length of the wire 101 is translated out of the patient, as seen in 804.

[0053] Both the embodiments of FIGs. 7 and 8 may use the haptic device 501 to translate the wire 101 into or out of the patient. For example, the haptic device 501 may move a distance that corresponds to a particular distance that the wire 101 is translated into or out of the patient. These distances may or may not be exactly one-to-one. Thus, the haptic device 501 may move a distance more than or less than the distance that the wire 101 is correspondingly translated into or out of the patient.

[0054] The robotic system can adjust the speed of the wire 101 to prevent harm to the patient. For example, if a user attempts to insert the wire 101 at a speed above a safety

threshold, the robotic system may automatically reduce the speed of insertion of the wire 101 or not perform the requested action.

[0055] Automatic shutdown may lock the wire 101 with the first pinching mechanism 107 and/or the second pinching mechanism 111 if the resistance or movement of the wire 101 exceeds a particular threshold sensed by force and torque sensor 105. This threshold may vary by procedure, by wire 101 or device on the wire 101, by region of the patient's body, or by another factor. This automatic shutdown may prevent the wire 101 from advancing, but the first pinching mechanism 107 and/or the second pinching mechanism 111 may enable the wire 101 to be withdrawn from the patient 101 after automatic shutdown.

[0056] Tele-control may be used. There may be instances where a user is not satisfied with the path the wire is taking or a complication occurs. In this case, the user's actions will be directly mapped to motions of the robotic system and the robotic system will navigate under full user control.

[0057] In another example, two robotic systems are used in conjunction to feed multiple wires or devices inside one another. Thus, two end effectors 100 may be used together.

[0058] The robotic systems herein may be used for placement of, for example, catheters, stents, or needles in a patient. Thus, this robotic system may be used for any cardiac or neuro-endovascular procedure where catheterization may be required for placement. Other minimally-invasive surgeries or endovascular surgeries also may use this robotic system. This robotic system also may be used for placement of needles for various procedures such as biopsies or brachytherapy.

[0059] The robotic system disclosed herein may imitate a human wrist and hand, which enables it to overcome many of the previous drawbacks in robotic systems. The dual pinch mechanism may enable quick changes to the wires 101. Thus, wires 101, catheters, or other devices of different sizes can be easily changed. The pinching applied by the first pinch mechanism 107 and second pinch mechanism 111 prevents slippage of the wire 101. A force and torque sensor 105 enable automatic shutdown, which improves patient safety. Force feedback is provided to the user through the haptic device 501, which improves patient safety and may enable a user to perform more complex procedures.

**[0060]** Although the present invention has been described with respect to one or more particular embodiments, it will be understood that other embodiments of the present invention may be made without departing from the spirit and scope of the present invention. Hence, the present invention is deemed limited only by the appended claims and the reasonable

5 interpretation thereof.

[0061] What is claimed is:

1. A robotic system comprising:

a first pinch mechanism coupled to a first servo, wherein said first pinch mechanism is configured to pinch a wire and lock said wire in a fixed position relative to said first pinch  
5 mechanism;

an end effector connected to said first servo;

a second pinch mechanism coupled to a second servo, wherein said second pinch mechanism is configured to pinch said wire and lock said wire in a fixed position relative to said second pinch mechanism; and

10 a frame disposed on said second servo.

2. The robotic system of claim 1, wherein said wire comprises a stent, a needle, a guidewire, or a catheter.

3. The robotic system of claim 1, wherein said first pinch mechanism and said second pinch mechanism each comprises:

15 a wire holder, said wire holder comprising a hollow tube that said wire is configured to pass through, said wire holder defining an aperture on an outer surface of said hollow tube; and

a cam configured to rotate and press said wire against said wire holder through said aperture.

4. The robotic system of claim 1, further comprising a force and torque sensor disposed on said  
20 first servo.

5. The robotic system of claim 1, further comprising a robotic arm connected to said end effector.

6. The robotic system of claim 5, wherein said robotic arm has at least two degrees of freedom.

7. The robotic system of claim 5, wherein said robotic arm has six degrees of freedom.

8. The robotic system of claim 1, further comprising a cap disposed on a flexible beam that is disposed on said end effector, said cap defining an aperture through which said wire projects.

9. The robotic system of claim 1, wherein said end effector is connected to said frame using a robotic arm.

5 10. The robotic system of claim 1, further comprising a haptic device connected to said first servo, said second servo, and a force and torque sensor.

11. A method of operating a robotic system comprising:

pinching a wire with a first pinch mechanism to lock said wire in a fixed position relative to said first pinch mechanism while releasing said wire with a second pinch mechanism;

10 translating said wire into a patient while said wire is pinched by said first pinch mechanism and said wire is released by said second pinch mechanism by moving said first pinch mechanism toward said second pinch mechanism;

pinching a wire with said second pinch mechanism to lock said wire in a fixed position relative to said second pinch mechanism and releasing said wire with said first pinch mechanism

15 after said translating said wire into said patient; and

moving said first pinch mechanism away from said second pinch mechanism while said wire is released by said first pinch mechanism and said wire is pinched by said second pinch mechanism.

20 12. The method of claim 11, wherein said wire comprises a stent, a needle, a guidewire, or a catheter.

13. The method of claim 11, wherein said translating said wire advances said wire through said second pinch mechanism.

25 14. The method of claim 11, wherein said pinching with said first pinch mechanism comprises using a first servo and said pinching with said second pinch mechanism comprises using a second servo.

15. The method of claim 11, wherein said pinching with said first pinch mechanism comprises pressing said wire against a first wire holder with a first cam that is configured to rotate and wherein said pinching with said second pinch mechanism comprises pressing said wire against a second wire holder with a second cam that is configured to rotate.

5 16. The method of claim 11, further comprising translating a haptic device a distance that corresponds to a distance of said translating said wire into said patient.

17. The method of claim 11, further comprising:

10 pinching a wire with said first pinch mechanism to lock said wire in a fixed position relative to said first pinch mechanism while releasing said wire with said second pinch mechanism;

translating said wire out of said patient while said wire is pinched by said first pinch mechanism and said wire is released by said second pinch mechanism by moving said first pinch mechanism away from said second pinch mechanism;

15 pinching a wire with said second pinch mechanism to lock said wire in a fixed position relative to said second pinch mechanism and releasing said wire with said first pinch mechanism after said translating said wire out of said patient; and

moving said first pinch mechanism toward said second pinch mechanism while said wire is released by said first pinch mechanism and said wire is pinched by said second pinch mechanism.

20 18. The method of claim 11, further comprising rotating said wire with an end effector while said first pinch mechanism pinches said wire.

19. The method of claim 11, jiggling said wire with an end effector while said first pinch mechanism pinches said wire.

25 20. The method of claim 11, further comprising using haptic feedback to generate resistance corresponding to resistance of said wire as said wire translates into said patient.

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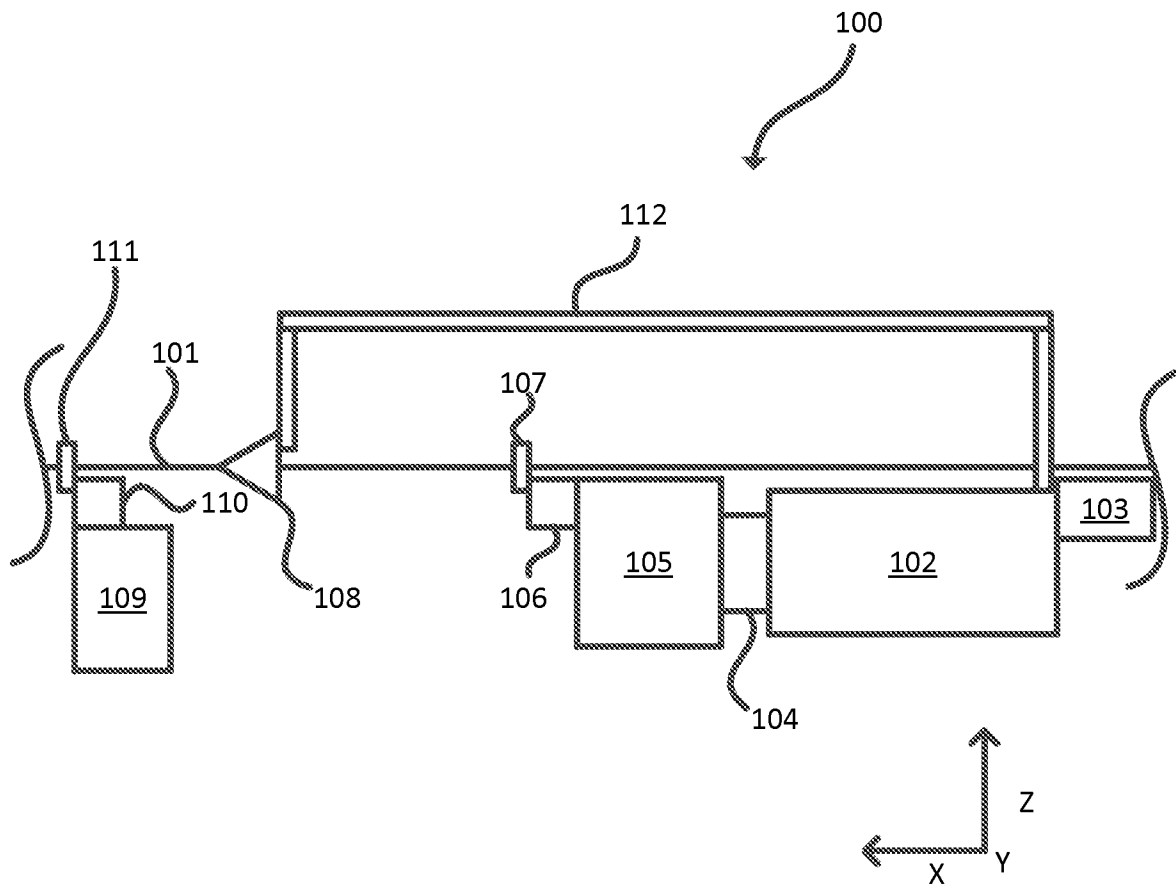


FIG. 1

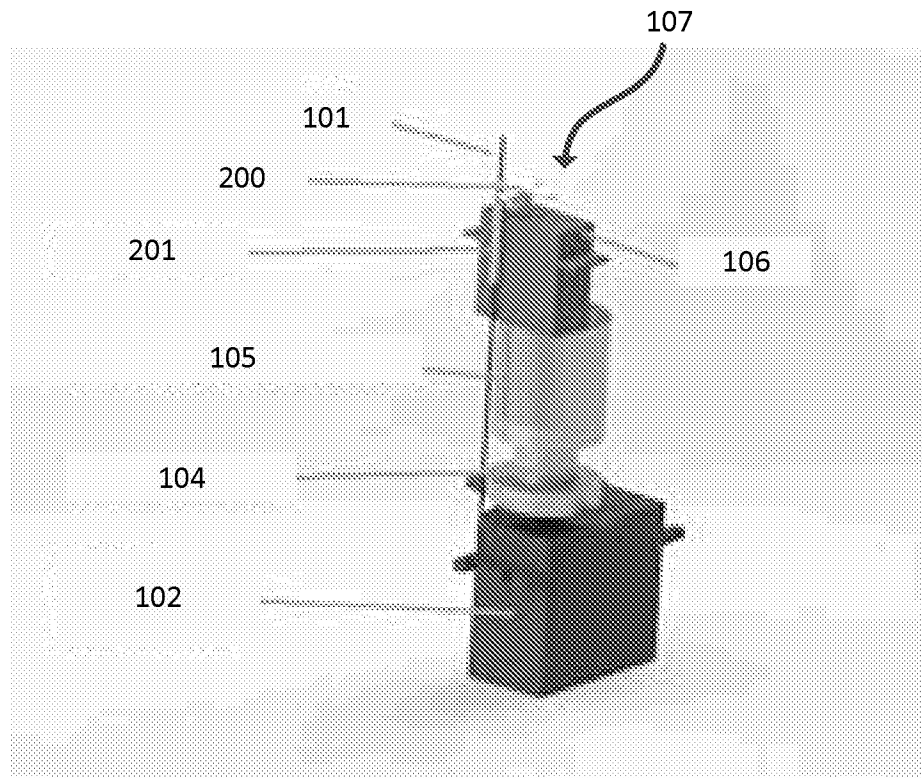


FIG. 2

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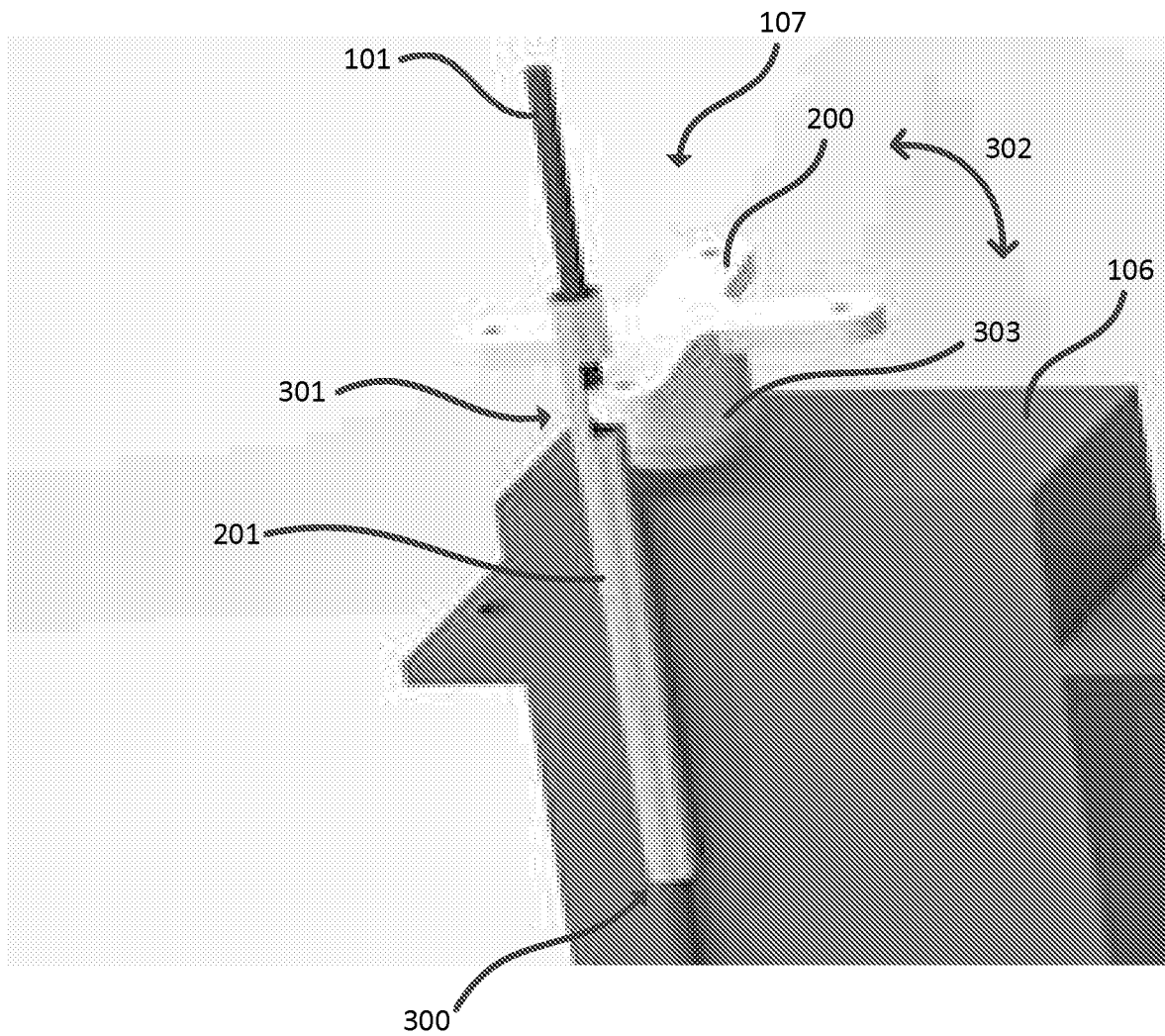


FIG. 3

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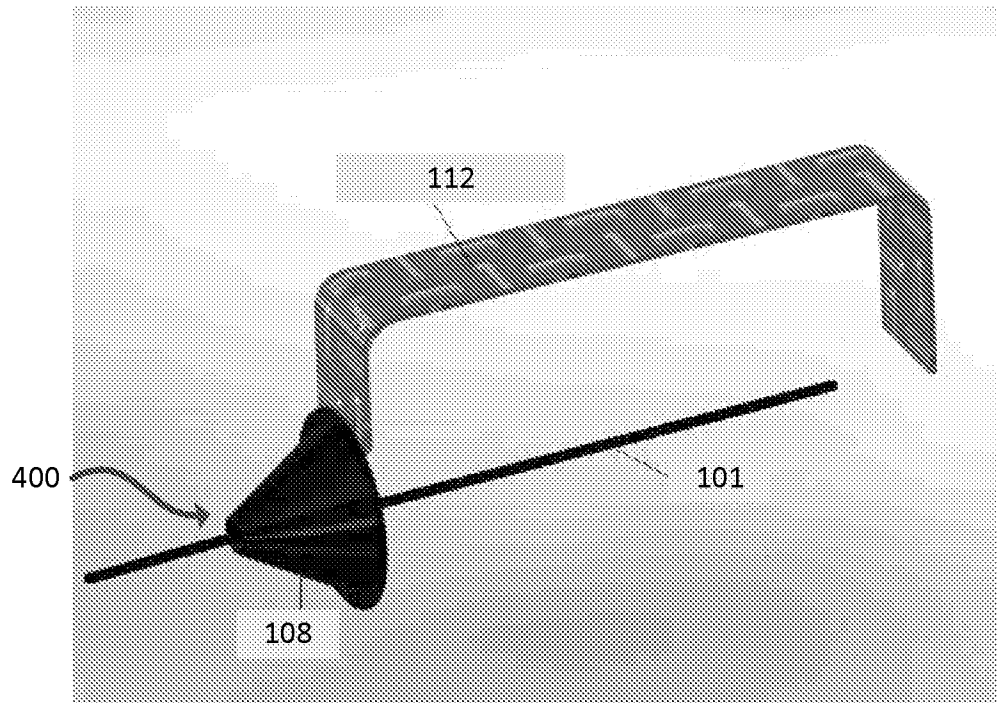


FIG. 4

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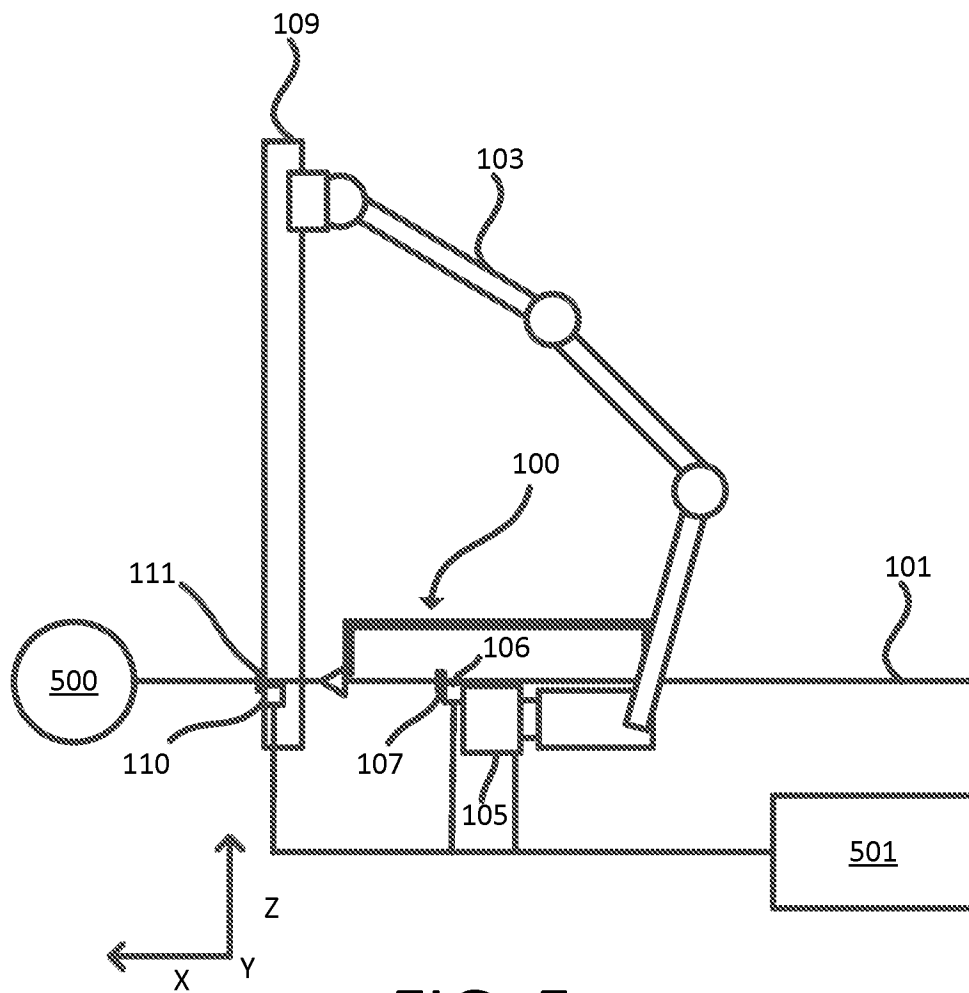


FIG. 5

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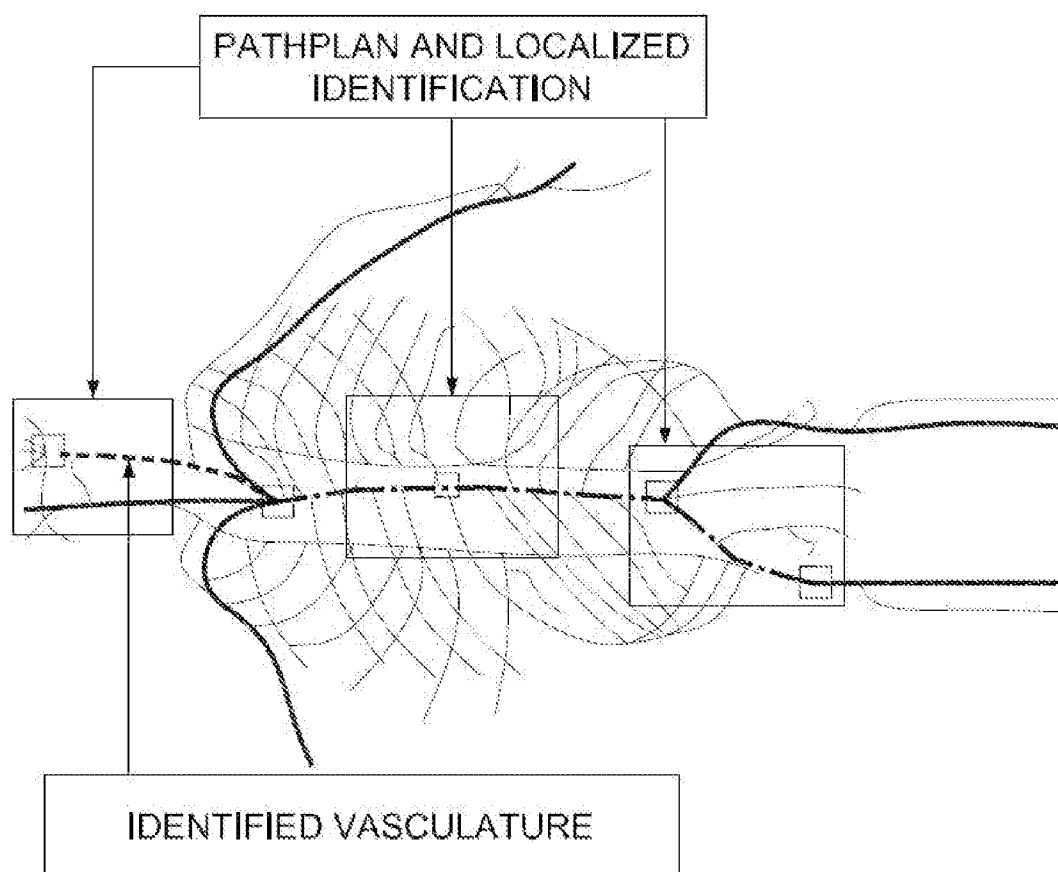


FIG. 6

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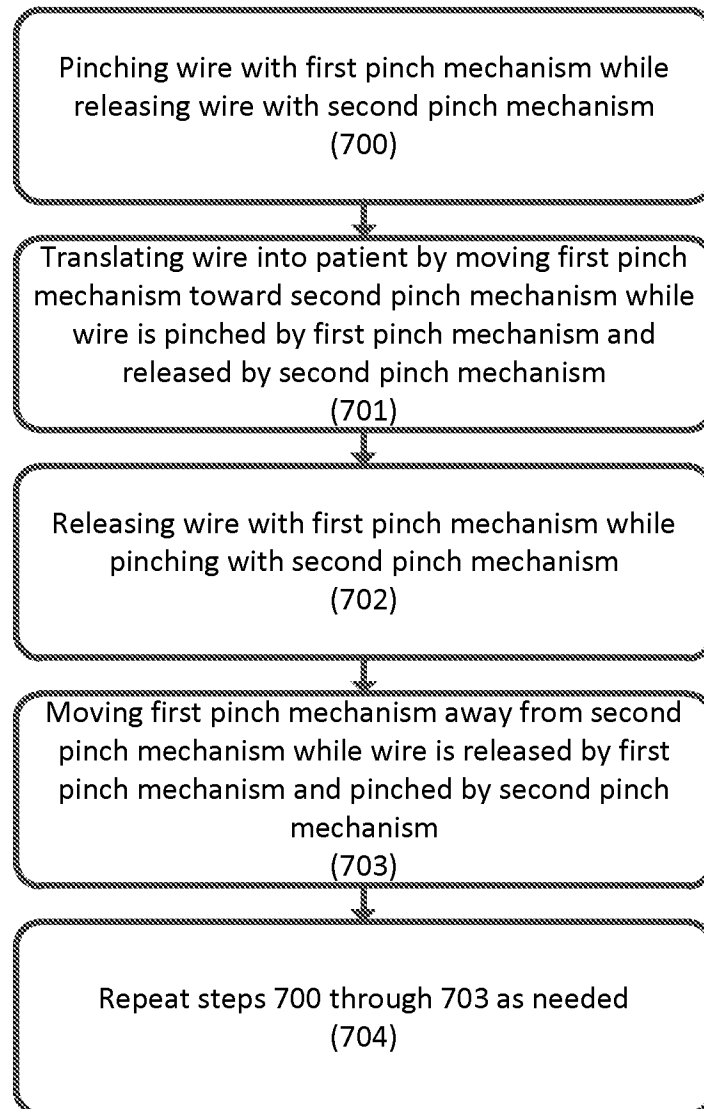


FIG. 7

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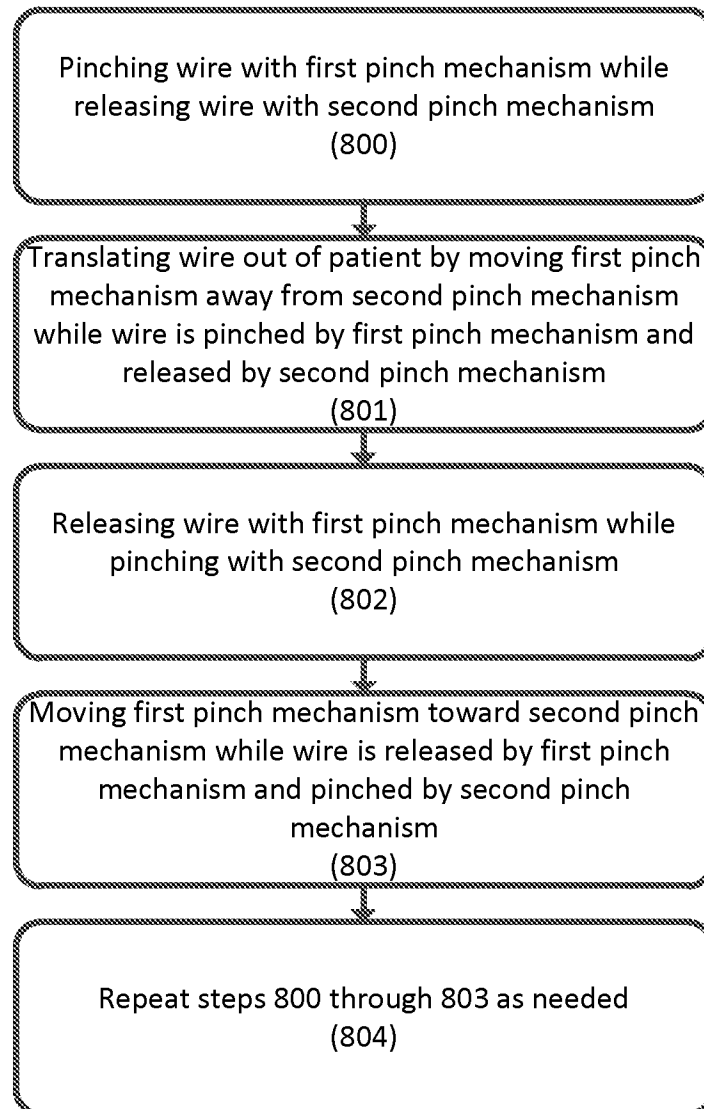


FIG. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US14/16889

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 19/00 (2014.01)

USPC - 606/130

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)

IPC(8) - A61B 17/00, 17/56, 19/00 (2014.01)

USPC - 600/1; 606/130

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

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

MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); Google Scholar; ProQuest Dialog;  
 Medline/PubMed: actuator\*, cable, clamp\*, effector, effector, end, fix\*, grasp\*, grip\*, held, hold\*, lock\*, motor\*, pinch\*, place, position,  
 robot\*, servo\*, tendon, wire

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                        | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------|-----------------------|
| A         | US 2012/0071895 A1 (STAHLER, GJ, et al.) March 22, 2012; figures 20-23; paragraphs [0296], [0316], [0616] | 1-20                  |
| A         | US 2010/0198230 A1 (SHOHAM, M) August 5, 2010; figures 7, 8; paragraphs [0022]-[0023], [0031]             | 1-20                  |
| A         | US 2009/0012533 A1 (BARBAGLI, F, et al.) January 8, 2009; paragraphs [0049], [0108]                       | 1-20                  |
| A         | US 2007/0250074 A1 (BROCK, DL, et al.) October 25, 2007; paragraph [0076], [0141], [0195], [0210]         | 1-20                  |
| A         | US 2012/0199632 A1 (SPIVEY, JT, et al.) August 9, 2012; paragraphs [0014], [0207], [0313]                 | 1-20                  |
| P, Y      | WO 2013/084221 A1 (BAR, Y, et al.) June 13, 2013; entire document                                         | 1-20                  |

☐ Further documents are listed in the continuation of Box C.


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"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

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"&amp;" document member of the same patent family

Date of the actual completion of the international search

25 April 2014 (25.04.2014)

Date of mailing of the international search report

08 MAY 2014

Name and mailing address of the ISA/US

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Shane Thomas

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