

# US Patent & Trademark Office

## Patent Public Search | Text View

---

United States Patent	12392396
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Fenech; Carolyn M. et al.

---

### Systems and methods for a compact remote center manipulator

---

#### Abstract

A surgical manipulator linkage assembly may comprise a linkage arm that includes a first pulley and a second pulley. Each of the first pulley and the second pulley comprise a first drive track and a second drive track. The first drive track and the second drive track are substantially co-planar, and the first drive track extends at least partially around the second drive track. The linkage arm also includes a first drive member section extending between the first drive tracks of the first pulley and the second pulley. The linkage arm also includes a second drive member section extending between the second drive tracks of the first pulley and the second pulley. The first drive member section is wound around the first pulley in a first tensile direction and the second drive member section is wound around the first pulley in a opposite second tensile direction.

---

**Inventors:** Fenech; Carolyn M. (San Jose, CA), Gomez; Daniel H. (Los Gatos, CA), Stamatelaky; Jason N. (Tracy, CA)

**Applicant:** INTUITIVE SURGICAL OPERATIONS, INC. (Sunnyvale, CA)

**Family ID:** 1000008763372

**Assignee:** INTUITIVE SURGICAL OPERATIONS, INC. (Sunnyvale, CA)

**Appl. No.:** 18/605516

**Filed:** March 14, 2024

#### Prior Publication Data

Document Identifier	Publication Date
US 20240216095 A1	Jul. 04, 2024

#### Related U.S. Application Data

continuation parent-doc US 17330672 20210526 US 11957427 child-doc US 18605516  
us-provisional-application US 63034733 20200604

---

## Publication Classification

**Int. Cl.:** F16H7/08 (20060101); A61B34/00 (20160101); B25J9/10 (20060101)

**U.S. Cl.:**

**CPC** F16H7/08 (20130101); A61B34/71 (20160201); B25J9/104 (20130101); B25J9/106 (20130101); F16H2007/0865 (20130101)

## Field of Classification Search

**CPC:** A61B (34/71); A61B (34/35); B25J (9/104); B25J (9/106)

---

## References Cited

### U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
5794487	12/1997	Solomon	474/271	B25J 9/106
6634851	12/2002	Bonora	414/744.3	H01L 21/68707
7736254	12/2009	Schena	N/A	N/A
9068628	12/2014	Solomon et al.	N/A	N/A
9295524	12/2015	Schena et al.	N/A	N/A
10143525	12/2017	Schena et al.	N/A	N/A
11957427	12/2023	Fenech et al.	N/A	N/A
2017/0020615	12/2016	Koenig et al.	N/A	N/A
2018/0079074	12/2017	Devengenzo et al.	N/A	N/A
2018/0079090	12/2017	Koenig et al.	N/A	N/A
2021/0378771	12/2020	Fenech et al.	N/A	N/A

### OTHER PUBLICATIONS

Vertut, J., and Coiffet, P., "Robot Technology: Teleoperation and Robotics Evolution and Development," English translation, Prentice-Hall, Inc., Englewood Cliffs, NJ, USA 1986, vol. 3A, 332 pages. cited by applicant

---

*Primary Examiner:* Rushing, Jr.; Bobby

*Attorney, Agent or Firm:* Haynes & Boone, LLP.

---

## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/330,672 filed May 26, 2021 which claims priority to and the benefit of U.S. Provisional Application 63/034,733 filed Jun. 4, 2020, each of which is incorporated by reference herein in its entirety.

### FIELD

(1) The present disclosure is directed to systems and methods for robotically-assisted manipulation of an instrument about a remote center of manipulation using a compact manipulator.

## BACKGROUND

(2) Minimally invasive medical techniques are intended to reduce the amount of tissue that is damaged during diagnostic or surgical procedures, thereby reducing patient recovery time, discomfort, and harmful side effects. Such minimally invasive techniques may be performed through one or more surgical incisions or through natural orifices in a patient anatomy. Through these incisions or natural orifices, clinicians may insert minimally invasive medical instruments (including surgical, diagnostic, therapeutic, or biopsy instruments) to reach a target tissue location. Minimally invasive robotically-assisted and computer-assisted medical systems have been developed to increase a surgeon's dexterity and avoid some of the limitations on traditional minimally invasive techniques. Robotically-assisted medical systems allow a user to control medical instruments via a manipulator. The manipulator may include two or more links coupled together by one or more joints. The joints may include actively controlled joints. The joints may also include passive joints, which are not actively controlled, but comply with movement of actively controlled joints. Such active and passive joints may be revolute or prismatic joints.

(3) Minimally invasive telesurgical systems allow a surgeon to operate on a patient from a remote location. Telesurgery is a general term for surgical systems where the surgeon uses some form of remote control, e.g., a servomechanism, or the like, to manipulate surgical instrument movements rather than directly holding and moving the instruments by hand. In such a telesurgery system, the surgeon is provided with an image of the surgical site at the remote location. While viewing typically a three-dimensional image of the surgical site on a suitable viewer or display, the surgeon performs the surgical procedures on the patient by manipulating master control input devices, which in turn control the motion of robotic instruments.

(4) In some robotically-assisted medical systems, multiple manipulators may be mounted to a common platform which may be unwieldy or make some aspects of patient access difficult. For some medical procedures, more compact, more portable, and lighter weight manipulators may be suitable to improve patient access and procedure efficiency.

## SUMMARY

(5) Examples of the invention are summarized by the claims that follow the description.

(6) Consistent with some examples, a manipulator for a surgical instrument may comprise an instrument holder coupled with the surgical instrument and rotatable in a plane that passes through a remote center. The manipulator may also comprise a linkage assembly coupled to the instrument holder to limit motion of the instrument holder to rotation about an axis that intersects the remote center. The linkage assembly may comprise a first linkage arm comprising first and second pulleys. Each pulley may comprise first and second drive tracks which are substantially co-planar. The first linkage arm may also comprise a first drive member section extending between the first drive tracks of the pulleys and a second drive member section extending between the second drive tracks of the pulleys. The first drive member section may be wound around the first pulley in a first direction and the second drive member section may be wound around the first pulley in an opposite direction. The first drive member section and the second drive member section may each comprise at least one selected from the group consisting of belts, cables, and chains.

(7) In another example, a manipulator for articulating a surgical instrument may comprise an instrument holder configured to couple with the surgical instrument and to rotate in a plane that passes through a remote center of manipulation. The manipulator may also comprise a linkage assembly coupled to the instrument holder and configured to produce motion of the instrument holder that is limited to rotation about a first axis that intersects the remote center of manipulation. The linkage assembly may comprise a first linkage arm comprising a first pulley and a second pulley. Each of the first pulley and the second pulley may include an outer drive track and an inner drive track nested within the outer drive track. The first linkage arm may also comprise a first drive member section extending between the inner drive tracks of the first pulley and the second pulley and a second drive member section extending between the outer drive tracks of the first pulley and

the second pulley. Rotation of the first pulley in a first direction causes a rotation of the second pulley in the first direction, and rotation of the first pulley in a second direction causes a rotation of the second pulley in the second direction. The first drive member section and the second drive member section may each comprise at least one selected from the group consisting of belts, cables, and chains.

(8) In another example a method may comprise rotating a first linkage arm in a first direction. The first linkage arm may house a first pulley and a second pulley. The first pulley may be coupled to the second pulley by a first drive member section and a second drive member section. Each of the first pulley and the second pulley may comprise a first drive track and a second drive track. The first drive track and the second drive track may be substantially co-planar. The first drive member section may extend between the first drive tracks of the first pulley and the second pulley and the second drive member section may extend between the second drive tracks of the first pulley and the second pulley. The method may further comprise winding the first drive member section on the first drive track of the first pulley as the first linkage arm is rotated in the first direction and unwinding the second drive member section from the second drive track of the first pulley as the first linkage arm is rotated in the first direction. The method may also comprise operating a linkage assembly comprising the first linkage arm to produce motion of an instrument holder that is limited to rotation about a first axis that intersects a remote center of manipulation.

(9) It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory in nature and are intended to provide an understanding of the present disclosure without limiting the scope of the present disclosure. In that regard, additional aspects, features, and advantages of the present disclosure will be apparent to one skilled in the art from the following detailed description.

---

## Description

### BRIEF DESCRIPTIONS OF THE DRAWINGS

- (1) FIG. 1 is a simplified diagram of a robotically-assisted medical system according to some embodiments.
- (2) FIG. 2 illustrates a manipulator assembly mounted to a surgical table according to some embodiments.
- (3) FIG. 3 is a side view of a manipulator assembly according to some embodiments.
- (4) FIG. 4. is a rear view of the manipulator assembly of FIG. 3.
- (5) FIG. 5A is a view of a portion of FIG. 4 according to some embodiments.
- (6) FIG. 5B is a view of a portion of FIG. 4 according to some embodiments.
- (7) FIG. 6 illustrates a manipulator transmission system according to some embodiments.
- (8) FIG. 7A illustrates a perspective view of a pulley component of the manipulator transmission system of FIG. 6, according to some embodiments.
- (9) FIG. 7B illustrates a perspective view of a pulley component of the manipulator transmission system according to some embodiments.
- (10) FIG. 8A is a perspective view of a manipulator assembly in a retracted configuration according to some embodiments.
- (11) FIG. 8B is a perspective view of the manipulator transmission system of the manipulator assembly of FIG. 8A in the retracted configuration according to some embodiments.
- (12) FIG. 9A is a perspective view of a manipulator assembly in a partially extended or mid-extension configuration according to some embodiments.
- (13) FIG. 9B is a perspective view of the manipulator transmission system of the manipulator assembly of FIG. 9A in the partially extended or mid-extension configuration according to some embodiments.

(14) FIG. **10A** is a perspective view of a manipulator assembly in an extended configuration according to some embodiments.

(15) FIG. **10B** is a perspective view of the manipulator transmission system of the manipulator assembly of FIG. **10A** in the extended configuration according to some embodiments.

(16) FIG. **11** illustrates a cross-sectional view of the joint between two linkage arms according to some embodiments.

(17) FIG. **12** illustrates a manipulator transmission system according to some embodiments.

(18) FIG. **13** illustrates a method for operating a manipulator transmission system according to some embodiments.

(19) Embodiments of the present disclosure and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures for purposes of illustrating but not limiting embodiments of the present disclosure.

#### DETAILED DESCRIPTION

(20) FIG. **1** is a simplified diagram of a robotically-assisted medical system **100** according to some embodiments. In some embodiments, system **100** may be suitable for use in therapeutic and diagnostic procedures. While some embodiments are provided herein with respect to such procedures, any reference to medical or surgical instruments and medical or surgical methods is non-limiting. The systems, instruments, and methods described herein may be used for animals, human cadavers, animal cadavers, portions of human or animal anatomy, non-surgical diagnosis, as well as for industrial systems and general robotic, general teleoperational, or robotic medical systems. For example, the systems, instruments, and methods described herein may be used for non-medical purposes including industrial uses, general robotic uses, and manipulating non-tissue work pieces.

(21) As shown in FIG. **1**, system **100** generally includes a plurality of manipulator assemblies **102**. Although three manipulator assemblies **102** are illustrated in the embodiment of FIG. **1**, in other embodiments, more or fewer manipulator assemblies may be used. The exact number of manipulator assemblies will depend on the medical procedure and the space constraints within the operating room, among other factors.

(22) The manipulator assembly **102** is used to operate a medical instrument **104** (e.g., a surgical instrument or an image capturing device) in performing various procedures on a patient P. The manipulator assembly **102** may be teleoperated, non-teleoperated, or a hybrid teleoperated and non-teleoperated assembly with select degrees of freedom of motion that may be motorized and/or teleoperated and select degrees of freedom of motion that may be non-motorized and/or non-teleoperated. Manipulator assembly **102** is mounted to or located near an operating or surgical table T. In embodiments in which a plurality of manipulator assemblies **102** are employed, one or more of the manipulator assemblies **102** may support surgical instruments, and another of the manipulator assemblies **102** may support an image capturing device, such as a monoscopic or stereoscopic endoscope.

(23) A user control system **106** allows an operator (e.g., a surgeon or other clinician as illustrated in FIG. **1**) to view the interventional site and to control manipulator assembly **102**. In some examples, the user control system **106** is a surgeon console, which is usually located in the same room as the operating or surgical table T, such as at the side of a table on which patient P is located. It is to be understood, however, that operator O can be located in a different room or a completely different building from patient P. That is, one or more user control systems **106** may be collocated with the manipulator assemblies **102**, or the user control systems may be positioned in separate locations. Multiple user control systems allow more than one operator to control one or more robotically-assisted manipulator assemblies in various combinations.

(24) User control system **106** generally includes one or more input devices for controlling manipulator assembly **102**. The input devices may include any number of a variety of devices, such

as joysticks, trackballs, data gloves, trigger-guns, hand-operated controllers, voice recognition devices, body motion or presence sensors, and/or the like. To provide operator O a strong sense of directly controlling medical instrument **104**, the input devices may be provided with the same degrees of freedom as the associated medical instrument **104**. In this manner, the input devices provide operator O with telepresence and the perception that the input devices are integral with medical instrument **104**.

(25) Manipulator assembly **102** supports medical instrument **104** and may include a kinematic manipulator support structure of one or more non-servo controlled linkages (e.g., one or more links that may be manually positioned and locked in place), and/or one or more servo controlled linkages (e.g., one or more links that may be controlled in response to commands from a control system), and an instrument holder. Manipulator assembly **102** may optionally include a plurality of actuators or motors that drive inputs on medical instrument **104** in response to commands from the control system (e.g., a control system **110**). The actuators may optionally include drive systems that when coupled to medical instrument **104** may advance medical instrument **104** into a naturally or surgically created anatomic orifice. Other drive systems may move the distal end of medical instrument **104** in multiple degrees of freedom, which may include three degrees of linear motion (e.g., linear motion along the X, Y, Z Cartesian axes) and three degrees of rotational motion (e.g., rotation about the X, Y, Z Cartesian axes). Additionally, the actuators can be used to actuate an articulable end effector of medical instrument **104** for grasping tissue in the jaws of a biopsy device and/or the like. Actuator position sensors such as resolvers, encoders, potentiometers, and other mechanisms may provide sensor data to system **100** describing the rotation and orientation of the motor shafts. This position sensor data may be used to determine motion of the objects manipulated by the actuators. The manipulator assembly **102** may position its held instrument **104** so that a pivot point occurs at the instrument's entry aperture into the patient. The pivot point may be referred to as a remote center of manipulation. The manipulator assembly **102** may then manipulate its held instrument so that the instrument may be pivoted about the remote center of manipulation, inserted into and retracted out of the entry aperture, and rotated about its shaft axis.

(26) System **100** also includes a display system **108** for displaying an image or representation of the surgical site and medical instrument **104**. Display system **108** and user control system **106** may be oriented so operator O can control medical instrument **104** and user control system **106** with the perception of telepresence. In some examples, the display system **108** may present images of a surgical site recorded pre-operatively or intra-operatively using image data from imaging technology such as, computed tomography (CT), magnetic resonance imaging (MRI), fluoroscopy, thermography, ultrasound, optical coherence tomography (OCT), thermal imaging, impedance imaging, laser imaging, nanotube X-ray imaging, and/or the like.

(27) System **100** also includes control system **110**. Control system **110** includes at least one memory **114** and at least one computer processor **112** for effecting control between medical instrument **104**, user control system **106**, and display system **108**. Control system **110** also includes programmed instructions (e.g., a non-transitory machine-readable medium storing the instructions) to implement some or all of the methods described in accordance with aspects disclosed herein, including instructions for providing information to display system **108**. While control system **110** is shown as a single block in the simplified schematic of FIG. 1, the system may include two or more data processing circuits with one portion of the processing optionally being performed on or adjacent to manipulator assembly **102**, another portion of the processing being performed at user control system **106**, and/or the like. The processors of control system **110** may execute instructions corresponding to processes disclosed herein and described in more detail below. Any of a wide variety of centralized or distributed data processing architectures may be employed. Similarly, the programmed instructions may be implemented as a number of separate programs or subroutines, or they may be integrated into a number of other aspects of the robotic medical systems described herein. In one embodiment, control system **110** supports wireless communication protocols such as

Bluetooth, IrDA, HomeRF, IEEE 802.11, DECT, and Wireless Telemetry.

(28) Movement of a manipulator assembly **102** may be controlled by the control system **110** so that a shaft or intermediate portion of instruments mounted to the manipulator assemblies **102** are constrained to safe motions through minimally invasive surgical access sites or other apertures. Such motion may include, for example, axial insertion of a shaft through an aperture site, rotation of the shaft about its axis, and pivotal motion of the shaft about a pivot point adjacent the access site. In some cases, excessive lateral motion of the shaft that might otherwise tear the tissues adjacent the aperture or enlarge the access site inadvertently is inhibited. Some or all of such constraint on the motions of the manipulator assemblies **102** at the access sites may be imposed using mechanical manipulator joint linkages that inhibit improper motions, or may in part or in full be imposed using data processing and control techniques. In some embodiments, control system **110** may receive force and/or torque feedback from medical instrument **104**. Responsive to the feedback, control system **110** may transmit signals to user control system **106**. In some examples, control system **110** may transmit signals instructing one or more actuators of manipulator assembly **102** to move medical instrument **104**.

(29) FIG. 2 illustrates a manipulator assembly **202** mounted to a side rail **203** of the surgical table T according to some embodiments. In this embodiment, the manipulator assembly **202** includes a base linkage arm **204** rotatably coupled to a linkage arm **206**. The linkage arm **206** is rotatably coupled to a linkage arm **208** which is rotatably coupled to an instrument holder **210**. A medical instrument **212** is mounted to the instrument holder and is manipulatable by the manipulator assembly **202** to perform a procedure on the patient P.

(30) FIGS. 3 and 4 illustrate a hardware-constrained remote center manipulator assembly **300** (e.g., **102**, **202**) in accordance with many embodiments. The manipulator assembly **300** includes a linkage assembly **302** including a support link **303**, a base linkage arm **304**, a linkage arm **306**, and a linkage arm **308**. The manipulator assembly **300** also includes an instrument holder **310** configured to support a detachable surgical instrument **312**. A cannula **314** is removably mounted to the instrument holder **310** such that the cannula **314** is rigidly mounted to a lower portion of the instrument holder **310** when attached. An opening in the cannula **314** is sized for passage of a shaft of the instrument **312** through the opening for insertion of a distal (toward the patient) portion of the instrument **312** into a patient P. In many embodiments, the support link **303** may be held in a fixed position relative to a patient P being operated on with the manipulator assembly **300**. For example, the support link **303** may be rigidly mounted to the table T, to a cart placed near the table T, or to a floor stand, and in some embodiments, the support link **303** may be supported by movable set-up arms/joints. A joint **316** between the support link **303** and the base linkage arm **304** allows rotation of the base linkage arm **304** around an axis A1 that intersects a remote center of motion RC. The remote center of motion RC may be located coincident with a portion of the cannula **314** through which the instrument **312** passes, and in some embodiments, may be coincident with a longitudinal axis of the cannula **314**.

(31) The linkages of the manipulator assembly **300** distal of the link **303** are configured to provide selective movement of the instrument holder **310** that is limited to two-dimensional rotation of the instrument holder **310** about the remote center RC. With respect to a direction of rotation of the instrument holder **310** about the remote center RC, referred to herein as pitch, the instrument holder **310** and the linkage arms **306**, **308** are coupled so as to form a parallelogram linkage that provides movement of the instrument holder **310** that is limited to rotation about the remote center RC around an axis A2 (see FIG. 9A) that is substantially perpendicular to the axis A1 and to a plane extending along an extension direction of base linkage arm **304** (see axis A2 in the perspective view of FIG. 9A). In the orientation depicted in FIG. 3, the pitch direction about the remote center is substantially perpendicular to the depicted Z axis and to the XY plane. The linkage arm **306** has a proximal end that is rotationally coupled with a distal end of the base linkage arm **304** via a joint **318**. The linkage arm **308** has a proximal end that is rotationally coupled with a distal end of the

linkage arm **306** via a joint **320**. The instrument holder **310** is coupled with a distal end of the linkage arm **308** via a joint **322**. The joints **320**, **322** are rotationally driven by rotation of the first joint **318** so that the linkage arm **306**, the linkage arm **308**, and the instrument holder **310** form the parallelogram linkage. In the position shown, the linkage arm **306** defines a first parallelogram side **330** extending between the first and second parallelogram joints **318**, **320**; the linkage arm **308** defines a second parallelogram side **332** extending between the joints **320**, **322**; and the instrument holder **310** defines a third parallelogram side **334** extending between the joint **322** and the remote center RC. Rotation of the linkage arm **306** relative to the base linkage arm **304** serves to move the instrument holder **310** so that the distal end of the third parallelogram side **334** remains coincident with the remote center of manipulation RC, thereby pitching the instrument holder **310** about the axis A2 (See axis A2 in the perspective view of FIG. 9A) substantially perpendicular to the axis A1.

(32) Any suitable approach can be used to rotationally couple the joint **318**, the joint **320**, and the joint **322**. For example, linkage arm **306** may include a pulley or pulley assembly **340** coupled to joint **318** that is rotationally fixed to base linkage arm **304** and rotatable relative to linkage arm **306**. The linkage arm **306** may also include a pulley or pulley assembly **342** coupled to joint **320** that is rotationally fixed to linkage arm **308** and rotatable relative to linkage **306**. The rotation of the pulley assembly **340** may be tied to rotation of the pulley assembly **342**, for example by one or more drive member sections (e.g., cable sections, belt sections, or any other suitable drive member). By tying the rotation of pulley assemblies **340** and **342**, the rotation of the linkage arm **308** about the joint **320** may be coupled and driven by the rotation of linkage arm **306** relative to the base linkage arm **304**, such that the relative angular orientation between the linkage arm **308** and the linkage arm **306** will be tied to the relative angular orientation between the linkage arm **306** and the base linkage arm **304**. In another example, the linkage arm **308** may include a pulley or pulley assembly **344** (coaxial with the pulley assembly **342**, which is substantially along the axis Z in the orientation in FIG. 3) coupled to joint **320** that is rotationally fixed to linkage arm **306** and rotatable relative to linkage arm **308**. The linkage arm **308** may also include a pulley or pulley assembly **346** coupled to joint **322** that is rotationally fixed to the instrument holder **310** and rotatable relative to linkage arm **308**. The rotation of the pulley assembly **344** may be tied to rotation of the pulley assembly **346**, for example by one or more drive member sections (e.g., cable sections, belt sections, or any other suitable drive member). By tying the rotation of pulley assemblies **344** and **346**, the rotation of the instrument holder **310** about the joint **322** may be coupled and driven by the rotation of linkage arm **308** relative to the linkage arm **306**, such that the relative angular orientation between the instrument holder **310** and the linkage arm **308** will be tied to the relative angular orientation between the linkage arm **308** and the linkage arm **306**. Motion of the linkage **306** may be driven by an actuator **343**, such as a motor, to drive the parallelogram linkage about the remote center RC.

(33) FIG. 5A illustrates one embodiment of the pulley assemblies **342** and **344**. In the embodiment of FIG. 5A, pulley assembly **342A** includes a pulley **356A** to which a drive belt section **358A** is attached (e.g., in a first tensile direction) and a pulley **360A** to which a drive belt section **362A** is attached (e.g., in a second tensile direction that is opposite to the first tensile direction). Pulley assembly **344A** includes a pulley **364A** to which a drive belt section **366A** is attached (e.g., in the first tensile direction) and a pulley **368A** to which a drive belt section **370A** is attached (e.g., in the second tensile direction). In this embodiment, each linkage arm includes a pair of side-by-side pulleys. In this embodiment the width W1 of the linkage arm **308** and the width W2 of the linkage arm **306** must be wide enough to accommodate the side-by-side pulleys. With wide linkage arms, the joint **322** may be located farther away from the remote center of manipulation RC to provide clearance for neighboring manipulator assemblies and user access to manipulator assemblies and the patient. Consequently, the wide linkage arms may result in longer (and thus heavier) linkage arms that may require heavier and stronger motors for actuation.

(34) For some surgical approaches or when the manipulator assembly is desired to be positioned



close to the patient, a compact manipulator assembly may be suitable. For example, when the manipulator assembly **300** is configured for coupling to a rail of an operating table T, the assembly may have shorter linkage arms and have a lighter weight than manipulator assemblies that are coupled to a common chassis that is positioned further from the table. The manipulator assembly **300** may have a compact design by configuring the joint **322** to be close to the remote center of manipulation RC. In this embodiment, the linkage arm **308** may be coupled to a portion (e.g., side) of the instrument holder **310** near the cannula **314** to locate the joint **322** close to the remote center of manipulation RC. As a distance D3 between the joint **322** and the remote center of manipulation RC is minimized, the length D1 of the linkage arm **306** between the joints **318** and **320** becomes minimized. A distance D2 between the joints **320** and **322** may also be minimized to reduce the weight of the linkage arm **308**. Such compact and lighter weight assemblies may also be used for non-table mounted assemblies, such as cart-mounted assemblies.

(35) With the joint **322** moved closer to the remote center of manipulation RC and the linkage arm **308** coupled to the side of the instrument holder **310**, reducing the width W1 of the linkage arm **308** and the width W2 of the linkage arm **306** would provide greater clearance for neighboring manipulator assemblies and user access to the manipulator assemblies and the patient. FIG. 5B illustrates another embodiment of the pulley assemblies **342** and **344**. In this embodiment, a nested track pulley configuration allows for a narrower profile linkage arm, as compared to the side-by-side pulley configuration of FIG. 5A. In the embodiment of FIG. 5B, pulley assembly **342B** includes a pulley **356B** to which a drive belt section **358B** is attached. In this embodiment, a nested drive belt section (not shown in this view) may attach to an inner pulley track of pulley **356B** as will be described in greater detail below. Pulley assembly **344B** includes a pulley **364B** to which a drive belt section **366B** is attached. In this embodiment, a nested drive belt section may attach to an inner pulley track of pulley **364B** as will be described in detail below. In this embodiment, each linkage arm includes a pair of nested pulley tracks. In this embodiment the width W1 of the linkage arm **308** and the width W2 of the linkage arm **306** may be just wide enough to accommodate the width of a single drive belt section. In this embodiment, the width W1 and W2 may be, for example, approximately 0.810 inches. In other embodiments, a linkage arm accommodating the width of a single drive belt section may be less than 1.0 inches or less than 0.50 inches. In some embodiments, the linkage arm may be wider or narrower, depending on the width of the single drive belt section. With narrower linkage arms, the joint **322** may be located closer to the remote center of manipulation RC while still providing clearance for neighboring manipulator assemblies and user access to manipulator assemblies and the patient. Consequently, the narrower linkage arms may result in shorter (and thus lighter) linkage arms that may accommodate smaller, more lightweight motors for actuation. In some embodiments, the distance D1 between the joints **318**, **320** may be approximately 5.9 inches, but in other embodiments may be longer or shorter. In some embodiments, the distance D2 between the joints **320**, **322** may be approximately 10.0 inches, but in other embodiments may be longer or shorter. The belt sections described herein are examples of drive member sections that may be used to effectuate movement of the parallelogram linkage arms. In alternative examples, the drive member sections may include mechanical cables, chains, and/or other suitable drive members. For example, in some embodiments, pulley assemblies **342** and **344** may include nested drive cable sections instead of nested drive belt sections. Further, the various embodiments of FIGS. 6-13 are described below using belt sections and/or belt tracks as examples. However, such embodiments may use alternative drive member sections and associated drive tracks. For example, the embodiments described herein may use cable sections and cable tracks. Further, in various embodiments, the drive member sections may include more than one type of drive member, for example, using a cable section for one drive member section and a belt section for another drive member section.

(36) FIG. 6 illustrates a manipulator transmission system **400** that may be used, for example, within the linkage arm **306**. The manipulator transmission system **400** includes the pulley **342** (e.g., a first

pulley), the pulley **340** (e.g., a second pulley), a drive belt section **402** (e.g., a first drive member section) having a distal end **401** and a proximal end **403**, and a drive belt section **404** (e.g., a second drive member section) having a distal end **405** and a proximal end **407**. The drive belt section **402** is attached at its distal end **401** to pulley **342** and wraps around an outer belt track **406** (e.g., a first drive track) of the pulley **342**. The drive belt section **402** is also attached at its proximal end **403** to pulley **340** and wraps around an outer belt track **408** (e.g., a first drive track) of the pulley **340**. The drive belt section **404** is attached at its distal end **405** to pulley **342** and wraps around an inner belt track **410** (e.g., a second drive track). The drive belt section **404** is also attached at its proximal end **407** to pulley **340** and wraps around an inner belt track **412** (e.g., a second drive track). The drive belt section **402** is wound around pulley **340** in a first tensile direction **T1**, and a drive belt section **404** is wound around pulley **340** in a second tensile direction **T2**, with the first tensile direction **T1** being opposite to the second tensile direction **T2**. In the example orientation depicted in FIG. 6, drive belt section **402** is subject to an increased tensile force in the tensile direction **T1** when the linkage arm **306** is rotated counter-clockwise about the joint **318**, and drive belt section **404** is subject to an increased tensile force in the tensile direction **T2** when the linkage arm **306** is rotated clockwise about the joint **318**. It should be appreciated that tensile directions **T1** and **T2** are provided by way of example and that the pulleys **340** and **342** may be alternatively configured, for example, such that an outer drive belt section is subject to an increased tensile force when the linkage arm **306** rotates clockwise about the joint **318** and that an inner drive belt section is subject to an increased tensile force when the linkage arm **306** rotates counter-clockwise about the joint **318**. In various embodiments, the drive belt sections may be subject to intrinsic tensions when in a static, motionless state. The intrinsic tensions may be due to, for example, component weight, gravitational effects, and/or pre-tensions applied during an assembly process.

(37) FIG. 7A provides a perspective view of the pulley **342** of the manipulator transmission system **400**. In this embodiment, the pulley **342** includes a pulley body **418** including a pulley component **420** and a pulley component **422** extending from the pulley body. The pulley component **420** and the pulley component **422** may be concentric and may be arranged around an inner opening of the pulley **342**, with pulley component **420** arranged outside of pulley component **422**. For example, pulley component **420** may circumferentially surround at least a portion of the circumference of pulley component **422**. The outer belt track **406** extends along an outer surface (e.g., circumference) of the pulley component **420**, and the inner belt track **410** extends along an outer surface (e.g., circumference) of the pulley component **422**. Optionally, in some embodiments, the outer belt track **406** and the inner belt track **410** are substantially co-planar with a plane **P1**. In some embodiments, the outer belt track **406** and the inner belt track **410** are offset from one another and are not coplanar. The distal end **401** of the drive belt section **402** may be attached to pulley component **420** in any of a variety of ways. In this embodiment, the drive belt section **402** may include a belt anchor **424** that lodges within a groove **421** in the pulley component **420** to couple the drive belt section **402** to the pulley **342**. The distal end **405** of the drive belt section **404** may be attached to pulley component **422** in any of a variety of ways. In this embodiment, the drive belt section **404** may include a belt anchor **426** that lodges within a groove **423** to couple the drive belt section **404** to the pulley **342**. In alternative embodiments, the drive belt sections may be coupled to the pulleys by welded connections, chemical adhesives, screws, snaps, clamps, rivets, tabs, tapes, elastomeric bands, or other suitable connection systems. The drive belt section **404** extends from the groove **423** and around the inner belt track **410** and nests between the pulley components **420**, **422**. In this embodiment, the outer belt track **406** and the inner belt track **410** may be separated by an abutment surface **430** with a curved profile. When the drive belt section **404** is fully wound around the inner belt track **410**, the abutment surface **430** may abut or be proximate to the drive belt section **404**. In this embodiment, the outer belt track **406** may terminate at an abutment surface **432**. When the drive belt section **402** is fully wound around the outer belt track **406**, the abutment surface **432** may abut or be proximate to the drive belt section **404**. In the embodiment of FIG. 7A,

a radius  $r1$  of the pulley component **422** and a radius  $r2$  of the pulley component **420** may be uniform. In alternative embodiments, the radii of the pulley components and/or the radii of the belt or drive track profiles may be variable to maintain proportional motion of the instrument holder or to modify an acceleration of manipulator components. Pulley **340** of the manipulator transmission system **400** may be substantially similar to pulley **342** with similar attachment for drive belt sections **402**, **404**

(38) FIG. 7B provides a perspective view of an alternative pulley **450** of the manipulator transmission system that may be substantially the same as the pulley **342** with the differences as provided. In this embodiment, the pulley **450** includes a pulley body **468** including a pulley component **470** and a pulley component **472** extending from the pulley body. The pulley component **470** and the pulley component **472** may be concentric and may be arranged around an inner opening of the pulley **450**, with pulley component **470** arranged outside of pulley component **472**. For example, pulley component **470** may circumferentially surround at least a portion of the circumference of pulley component **472**. An outer belt track **456** extends along an outer surface (e.g., circumference) of the pulley component **470**, and an inner belt track **460** extends along an outer surface (e.g., circumference) of the pulley component **472**. The outer belt track **456** and the inner belt track **460** are substantially co-planar with a plane **P1**. The distal end **401** of the drive belt section **402** may be attached to pulley component **420** in any of a variety of ways. In this embodiment, the belt anchor **424** lodges within a groove **471** in the pulley component **470** to couple the drive belt section **402** to the pulley **450**. The distal end **405** of the drive belt section **404** may be attached to pulley component **472** in any of a variety of ways. In this embodiment, the belt anchor **426** lodges within a groove **473** to couple the drive belt section **404** to the pulley **450**. The drive belt section **404** extends from the groove **473** and around the inner belt track **460** and nests between the pulley components **470**, **472**. In this embodiment, the inner belt track **460** may be substantially continuous (e.g., in the shape of a cylinder) except for the opening to the groove **423** and may be non-continuous with the outer belt track **456**. In this embodiment, the outer belt track **456** may be partially continuous (e.g. a partial cylinder) with abutment surfaces **480**, **482**. When the drive belt section **404** is fully wound around the inner belt track **460**, the abutment surface **480** may abut or be proximate to the drive belt section **404**. When the drive belt section **402** is fully wound around the outer belt track **456**, the abutment surface **482** may abut or be proximate to the drive belt section **404**. In the embodiment of FIG. 7B, a radius  $r3$  of the pulley component **472** and a radius  $r4$  of the pulley component **470** may be uniform. In alternative embodiments, the radii of the pulley components may be variable to maintain proportional motion of the instrument holder or to modify an acceleration of manipulator components. A pulley substantially similar to pulley **450** may be paired with the pulley **450** in the manipulator transmission system **400**, in the same way that pulley **342** is paired with pulley **340**. In some embodiments, the pulley **342** and the pulley **450** may be paired in the manipulator transmission system **400**.

(39) In alternative embodiments, the outer belt track (e.g, belt track **406**) and the outermost drive belt section (e.g. drive belt section **402**) may be located within grooves, similar to belt track **410** and drive belt section **404**. In other words, a component wall may extend from the pulley body (e.g. pulley body **418**) to provide a circumferential cover for all or a portion of the outer belt track and the outermost drive belt section.

(40) FIG. 8A is a perspective view of the manipulator assembly **300** in a retracted configuration according to some embodiments. FIG. 8B is a perspective view of the manipulator transmission system **400** of the manipulator assembly **300** in the retracted configuration according to some embodiments. In some embodiments of the retracted configuration, the drive belt section **404** may be circumferentially fully wound or at an otherwise maximum winding around the inner belt track **410** of pulley **342**, with the abutment surface **430** being in abutment with or proximate to a portion **435** of the drive belt section **404** tangential to the inner belt track **410**. In the retracted configuration, the drive belt section **402** may be circumferentially fully wound or at an otherwise

maximum winding around the outer belt track **408** of pulley **340**, with the abutment surface **436** being in abutment with or proximate to a portion **437** of the drive belt section **404** tangential to the inner belt track **412**.

(41) FIG. **9A** is a perspective view of the manipulator assembly **300** in a partially extended configuration according to some embodiments. FIG. **9B** is a perspective view of the manipulator transmission system **400** of the manipulator assembly **300** in the partially extended configuration according to some embodiments. To move from the retracted configuration of FIG. **8A** to the partially extended configuration of FIG. **9A**, the actuator **343** coupled to the linkage arm **306** may rotate the linkage arm **306** in the clockwise direction **R3** about the joint **318**, increasing tension (as compared to a motionless state) in the drive belt section **404** in the tensile direction **T2**. As compared to the retracted configuration, in the partially extended configuration, the drive belt section **404** may have a lesser amount of winding around the inner belt track **410** of pulley **342**, with the abutment surface **430** being farther away from the portion **435** of the inner drive belt section **404** tangential to the inner belt track **410**. The drive belt section **402** may also have a lesser amount of winding around the outer belt track **408** of pulley **340**, with the abutment surface **436** being farther away from the portion **437** of the drive belt section **404** tangential to the inner belt track **412**. As the linkage arm **306** extends to the partially extended configuration by rotating clockwise from the fully retracted configuration, the drive belt section **402** wraps on to the outer belt track **406** of the pulley **342** and unwraps from the outer belt track **408** of the pulley **340**. Also, as the linkage arm **306** extends, the drive belt section **404** unwraps from the inner belt track **410** of the pulley **342** and wraps on to the inner belt track **412** of the pulley **340**.

(42) FIG. **10A** is a perspective view of the manipulator assembly **300** in an extended configuration according to some embodiments. FIG. **10B** is a perspective view of the manipulator transmission system **400** of the manipulator assembly **300** in the extended configuration according to some embodiments. To move from the partially extended configuration of FIG. **9A** to the extended configuration of FIG. **10A**, the actuator **343** coupled to the linkage arm **306** may continue rotation of the linkage arm **306** in the clockwise direction **R3**, increasing tension (as compared to a motionless state) in the drive belt section **404** in the tensile direction **T2**. In some embodiments of the extended configuration, the drive belt section **404** may be fully wound or at an otherwise maximum winding around the inner belt track **412** of pulley **340**, such that an abutment surface **434** is in abutment with or proximate to the portion **437** of the drive belt section **404** tangential to the inner belt track **412**. The outer drive belt section **402** may be fully wound or at an otherwise maximum winding around the outer belt track **406** of pulley **342**, such that the abutment surface **432** is in abutment with or proximate to the portion **435** of the drive belt section **404** tangential to the inner belt track **410**. As the manipulator assembly **300** moves to the extended configuration from the partially extended configuration, the drive belt section **402** wraps further on to the outer belt track **406** of the pulley **342** and unwraps further from the outer belt track **408** of the pulley **340**. Also, the drive belt section **404** unwraps further from the inner belt track **410** of the pulley **342** and wraps further on to the inner belt track **412** of the pulley **340**.

(43) As shown in the schematic cross-sectional view of FIG. **11**, pulley **342** is fixed both rotationally and translationally with respect to linkage arm **308**. Pulley **344** is fixed rotationally and translationally with respect to linkage arm **306**. More specifically, a coupling extension **350** of the linkage arm **306** extends into the linkage arm **308** to fixedly couple the pulley **344** to the linkage arm **306** such that the pulley **344** moves with the linkage arm **306**. A coupling extension **352** of the linkage arm **308** extends into the linkage arm **306** to fixedly couple the pulley **342** to the linkage arm **308** such that the pulley **342** moves with the linkage arm **308**.

(44) As the linkage arms **306**, **308** are pitched forward or backward, the instrument holder **310** and cannula **314** rotate about the axis **A2** through the remote center of manipulation **RC**. To return the linkage arms **306**, **308** to the retracted configuration from the partially extended configuration, the actuator **343** may rotate the linkage arm **306** in a counter-clockwise direction, thus causing a

reverse rotation of the pulleys and linkage arms described above.

(45) The drive belt section **402** and the drive belt section **404** may be a discrete belt sections such that the distal end **401** is not continuous with or directly coupled to the distal end **405**. Similarly, the proximal end **403** is not continuous with or directly coupled to the proximal end **407**. FIG. **12** illustrates an alternative embodiment of a manipulator transmission system **500** in which an outer drive belt section **502** is continuous with an inner drive belt section **504**. In this embodiment, the outer drive belt section **502** and the inner drive belt section **504** are portions of a single continuous drive belt **506**. The drive belt **506** may include an end **508** terminating on an outer belt track of pulley **520** (e.g. pulley **342**) and an end **510** terminating on an inner belt track of pulley **520**. At a redirection guide **524** (e.g., a pin), the drive belt **506** is routed off of the outer belt track of pulley **522** and onto an inner belt track. At a redirection guide **526** (e.g., a pin), the drive belt **506** wraps again around the inner belt track and extends out of the pulley **522**. With a single drive belt, two belt anchors may be eliminated in the pulley **522**. Since welding at the belt anchors is a potential point of failure, eliminating at least some belt anchors may improve the reliability of the manipulator transmission system. However, with a single drive belt, the belt follows a tight-radius serpentine path which may generate stresses in the belt and limit belt life. In an alternative embodiment, the outer drive belt section **502** and the inner drive belt section **504** may be two separate drive belt sections that are coupled at a common point such as the redirection guide **526** or at within a groove (e.g., groove **473**).

(46) FIG. **13** illustrates a method **600** for operating a manipulator transmission system (e.g., manipulator transmission system **400**) according to some embodiments. The method **600** is illustrated as a set of operations or processes **602** through **608** and is described with continuing reference to FIGS. **1-11**. Not all of the illustrated processes may be performed in all embodiments of method **600**. Additionally, one or more processes that are not expressly illustrated in FIG. **12** may be included before, after, in between, or as part of the processes **602** through **608**. In some embodiments, one or more of the processes may be implemented, at least in part, in the form of executable code stored on non-transitory, tangible, machine-readable media that when run by one or more processors (e.g., the processors of a control system) may cause the one or more processors to perform one or more of the processes. In one or more embodiments, the processes may be performed by the control system **110**.

(47) At a process **602**, a first linkage arm (e.g. linkage arm **306**) may be rotated by rotating an actuator coupled to the first linkage arm (e.g., actuator **343**). At a process **604**, a first belt section is wound on to a first belt track of the first pulley. For example, rotation of the linkage arm **306** causes the drive belt section **404** to become wound on the inner belt track **412** of pulley **340**. At a process **606**, a second belt section is unwound from a second belt track of the first pulley. For example, as the drive belt section **404** is becoming wound on the inner belt track **412**, the drive belt section **402** becomes unwound from the outer belt track **408** of the pulley **340**. At a process **608**, a linkage assembly comprising the first linkage arm is operated to rotate an instrument holder about an axis that intersects a remote center of manipulation. For example, the linkage assembly **302** which includes the linkage arms **306**, **308**, rotates the instrument holder **310** with cannula **314** about the axis **A2** through the remote center of manipulation **RC**, as a result of the actuator **343** rotating the pulley **340**.

(48) One or more elements in embodiments of this disclosure may be implemented in software to execute on a processor of a computer system such as a control processing system. When implemented in software, the elements of the embodiments of the invention are essentially the code segments to perform the necessary tasks. The program or code segments can be stored in a processor readable storage medium or device that may have been downloaded by way of a computer data signal embodied in a carrier wave over a transmission medium or a communication link. The processor readable storage device may include any medium that can store information including an optical medium, semiconductor medium, and magnetic medium. Processor readable

storage device examples include an electronic circuit; a semiconductor device, a semiconductor memory device, a read only memory (ROM), a flash memory, an erasable programmable read only memory (EPROM); a floppy diskette, a CD-ROM, an optical disk, a hard disk, or other storage device. The code segments may be downloaded via computer networks such as the Internet, Intranet, etc.

(49) Note that the processes and displays presented may not inherently be related to any particular computer or other apparatus, and various systems may be used with programs in accordance with the teachings herein. The required structure for a variety of the systems discussed above will appear as elements in the claims. In addition, the embodiments of the invention are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

(50) In the above description, specific details describe some embodiments consistent with the present disclosure. Numerous specific details are set forth in order to provide a thorough understanding of the embodiments. It will be apparent to one skilled in the art, however, that some embodiments may be practiced without some or all of these specific details. The specific embodiments disclosed herein are meant to be illustrative but not limiting. One skilled in the art may realize other elements that, although not specifically described, are within the scope and the spirit of this disclosure. In addition, to avoid unnecessary repetition, one or more features shown and described in association with one embodiment may be incorporated into other embodiments unless specifically described otherwise or if the one or more features would make an embodiment non-functional. In some instances, well known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

(51) In the above description, the singular forms “a”, “an”, and “the” are intended to include the plural forms as well, unless the context indicates otherwise. And the terms “comprises,” “comprising,” “includes,” “has,” and the like specify the presence of stated features, steps, operations, elements, and/or components but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups. Components described as coupled may be electrically or mechanically directly coupled, or they may be indirectly coupled via one or more intermediate components. The auxiliary verb “may” likewise implies that a feature, step, operation, element, or component is optional.

(52) Although some of the examples described herein refer to surgical procedures or instruments, or medical procedures and medical instruments, the techniques disclosed optionally apply to non-medical procedures and non-medical instruments. For example, the instruments, systems, and methods described herein may be used for non-medical purposes including industrial uses, general robotic uses, and sensing or manipulating non-tissue work pieces. Other example applications involve cosmetic improvements, imaging of human or animal anatomy, gathering data from human or animal anatomy, and training medical or non-medical personnel. Additional example applications include use for procedures on tissue removed from human or animal anatomies (without return to a human or animal anatomy), and performing procedures on human or animal cadavers. Further, these techniques can also be used for surgical and nonsurgical medical treatment or diagnosis procedures.

(53) Further, although some of the examples presented in this disclosure discuss teleoperational robotic systems or remotely operable systems, the techniques disclosed are also applicable to computer-assisted systems that are directly and manually moved by operators, in part or in whole.

(54) Elements described in detail with reference to one embodiment, implementation, or application optionally may be included, whenever practical, in other embodiments, implementations, or applications in which they are not specifically shown or described. For example, if an element is described in detail with reference to one embodiment and is not described with reference to a second embodiment, the element may nevertheless be claimed as included in the

second embodiment. Thus, to avoid unnecessary repetition in the following description, one or more elements shown and described in association with one embodiment, implementation, or application may be incorporated into other embodiments, implementations, or aspects unless specifically described otherwise, unless the one or more elements would make an embodiment or implementation non-functional, or unless two or more of the elements provide conflicting functions.

## Claims

1. A surgical manipulator linkage assembly comprising: a linkage arm comprising: a first pulley and a second pulley, wherein each of the first pulley and the second pulley comprise a first drive track and a second drive track, wherein the first drive track and the second drive track are substantially co-planar, with the first drive track extending at least partially around the second drive track; a first drive member section extending between the first drive tracks of the first pulley and the second pulley; and a second drive member section extending between the second drive tracks of the first pulley and the second pulley, wherein the first drive member section is wound around the first pulley in a first tensile direction and the second drive member section is wound around the first pulley in a second tensile direction opposite to the first tensile direction.
2. The surgical manipulator linkage assembly of claim 1, wherein the first drive track of the first pulley is concentric with the second drive track of the first pulley.
3. The surgical manipulator linkage assembly of claim 1, wherein the first drive member section comprises a first belt section and the second drive member section comprises a second belt section, and wherein the first pulley includes a first belt anchor configured to retain an end portion of the first belt section in the first pulley.
4. The surgical manipulator linkage assembly of claim 1, wherein the first drive member section is directly coupled to the second drive member section.
5. The surgical manipulator linkage assembly of claim 1, wherein the first drive member section and the second drive member section each comprise at least one selected from the group consisting of belts, cables, and chains.
6. The surgical manipulator linkage assembly of claim 1, further comprising a joint coupled to the linkage arm and configured to rotate an instrument holder.
7. The surgical manipulator linkage assembly of claim 1, further comprising a linkage assembly including the linkage arm, which is a first linkage arm, and a second linkage arm coupled to the first linkage arm.
8. The surgical manipulator linkage assembly of claim 7, wherein the second linkage arm comprises: a third pulley and a fourth pulley, wherein each of the third pulley and the fourth pulley comprise a third drive track and a fourth drive track, wherein the third drive track and the fourth drive track are substantially co-planar; a third drive member section extending between the third drive tracks of the third pulley and the fourth pulley; and a fourth drive member section extending between the fourth drive tracks of the first pulley and the fourth pulley, wherein the third drive member section is wound around the third pulley in a third tensile direction and the fourth drive member section is wound around the third pulley in a fourth tensile direction opposite to the third tensile direction.
9. The surgical manipulator linkage assembly of claim 8, wherein the second and third pulleys are rotatable about a common axis.
10. The surgical manipulator linkage assembly of claim 8, wherein the third drive track of the third pulley is concentric with the fourth drive track of the third pulley.
11. A surgical manipulator linkage assembly comprising: a linkage arm comprising: a first pulley and a second pulley, wherein each of the first pulley and the second pulley includes an outer drive track and an inner drive track nested within the outer drive track; a first drive member section

extending between the inner drive tracks of the first pulley and the second pulley; and a second drive member section extending between the outer drive tracks of the first pulley and the second pulley, wherein rotation of the first pulley in a first direction causes a rotation of the second pulley in the first direction, and wherein rotation of the first pulley in a second direction causes a rotation of the second pulley in the second direction.

12. The surgical manipulator linkage assembly of claim 11, wherein the inner drive track and the outer drive track are substantially co-planar.

13. The surgical manipulator linkage assembly of claim 11, wherein the first drive member section comprises a first belt section and the second drive member section comprises a second belt section, and wherein the first pulley includes a first belt anchor configured to retain an end portion of the first belt section.

14. The surgical manipulator linkage assembly of claim 11, wherein the first drive member section is directly coupled to the second drive member section.

15. The surgical manipulator linkage assembly of claim 11, wherein the first drive member section and the second drive member section each comprise at least one selected from the group consisting of belts, cables, and chains.

16. The surgical manipulator linkage assembly of claim 11, further comprising a joint coupled to the linkage arm and configured to rotate an instrument holder.

17. The surgical manipulator linkage assembly of claim 11, further comprising a linkage assembly including the linkage arm, which is a first linkage arm, and a second linkage arm coupled to the first linkage arm.

18. The surgical manipulator linkage assembly of claim 17, wherein the second linkage arm comprises: a third pulley and a fourth pulley, wherein each of the third pulley and the fourth pulley includes an outer drive track and an inner drive track nested within the outer drive track; a third drive member section extending between the inner drive tracks of the third pulley and the fourth pulley; and a fourth drive member section extending between the outer drive tracks of the third pulley and the fourth pulley, wherein rotation of the third pulley in a third direction causes a rotation of the fourth pulley in the third direction, and wherein rotation of the third pulley in a fourth direction causes a rotation of the fourth pulley in the fourth direction.

19. The surgical manipulator linkage assembly of claim 18, wherein the second and third pulleys are rotatable about a common axis.

20. The surgical manipulator linkage assembly of claim 18, wherein the inner drive track and the outer drive track of the third pulley are substantially co-planar.

---