US012390294B2

(12) **United States Patent**
Heiliger

(10) **Patent No.: US 12,390,294 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **ROBOTIC SURGICAL ASSEMBLIES INCLUDING SURGICAL INSTRUMENTS HAVING ARTICULATABLE WRIST ASSEMBLIES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 415 days.

(21) Appl. No.: **17/979,105**

(22) Filed: **Nov. 2, 2022**

(65) **Prior Publication Data**

US 2023/0181274 A1 Jun. 15, 2023

Related U.S. Application Data

(60) Provisional application No. 63/289,361, filed on Dec. 14, 2021.

(51) **Int. Cl.**
A61B 34/30 (2016.01)
A61B 34/00 (2016.01)

(52) **U.S. Cl.**
CPC ***A61B 34/71*** (2016.02); ***A61B 34/70*** (2016.02); *A61B 34/30* (2016.02)

(58) **Field of Classification Search**
CPC A61B 34/71; A61B 34/70; A61B 34/30; A61B 2034/302; A61B 2034/303; A61B 2034/305; A61B 17/068; A61B 17/28; A61B 17/2804; A61B 17/29; A61B 17/00234; A61B 2017/0046; A61B 2017/00464; A61B 2017/00473; A61B 2017/00367; A61B 2017/00477
See application file for complete search history.

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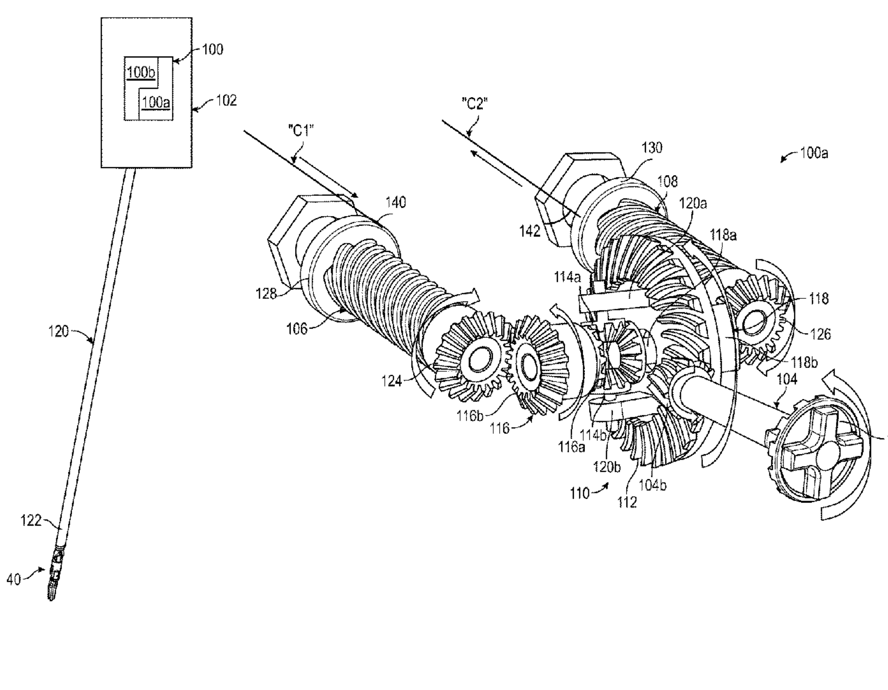
(57) **ABSTRACT**

A surgical instrument for use in a robotic surgical system includes an end effector, a housing configured to be operably coupled to an instrument drive unit, a shaft extending distally from the housing, a wrist assembly coupled to a distal end portion of the shaft, articulation cables that adjust the pitch and yaw of the end effector relative to the shaft, and a differential gear mechanism that transfers an input rotation to the articulation cables.

20 Claims, 6 Drawing Sheets



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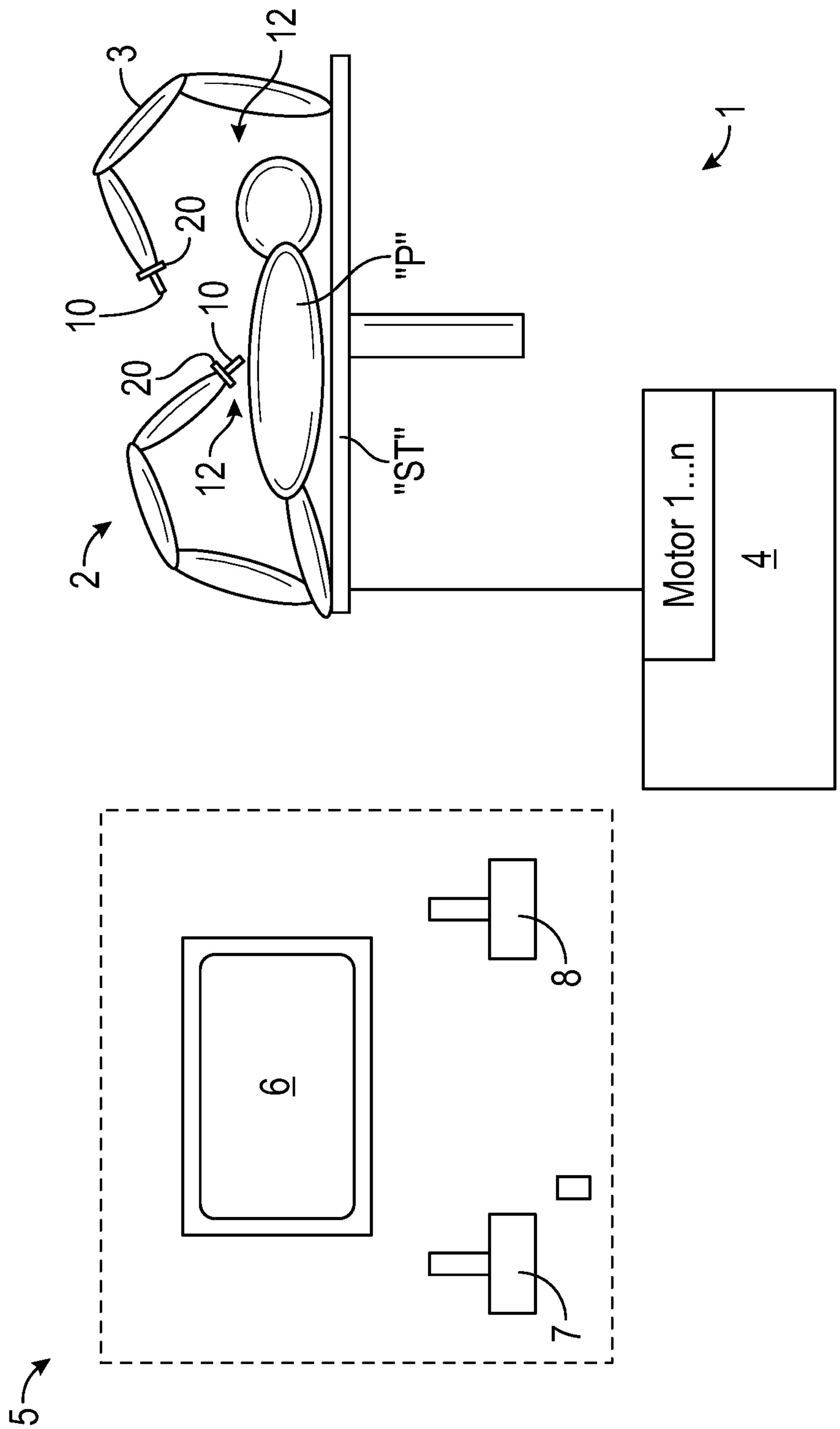

FIG. 1

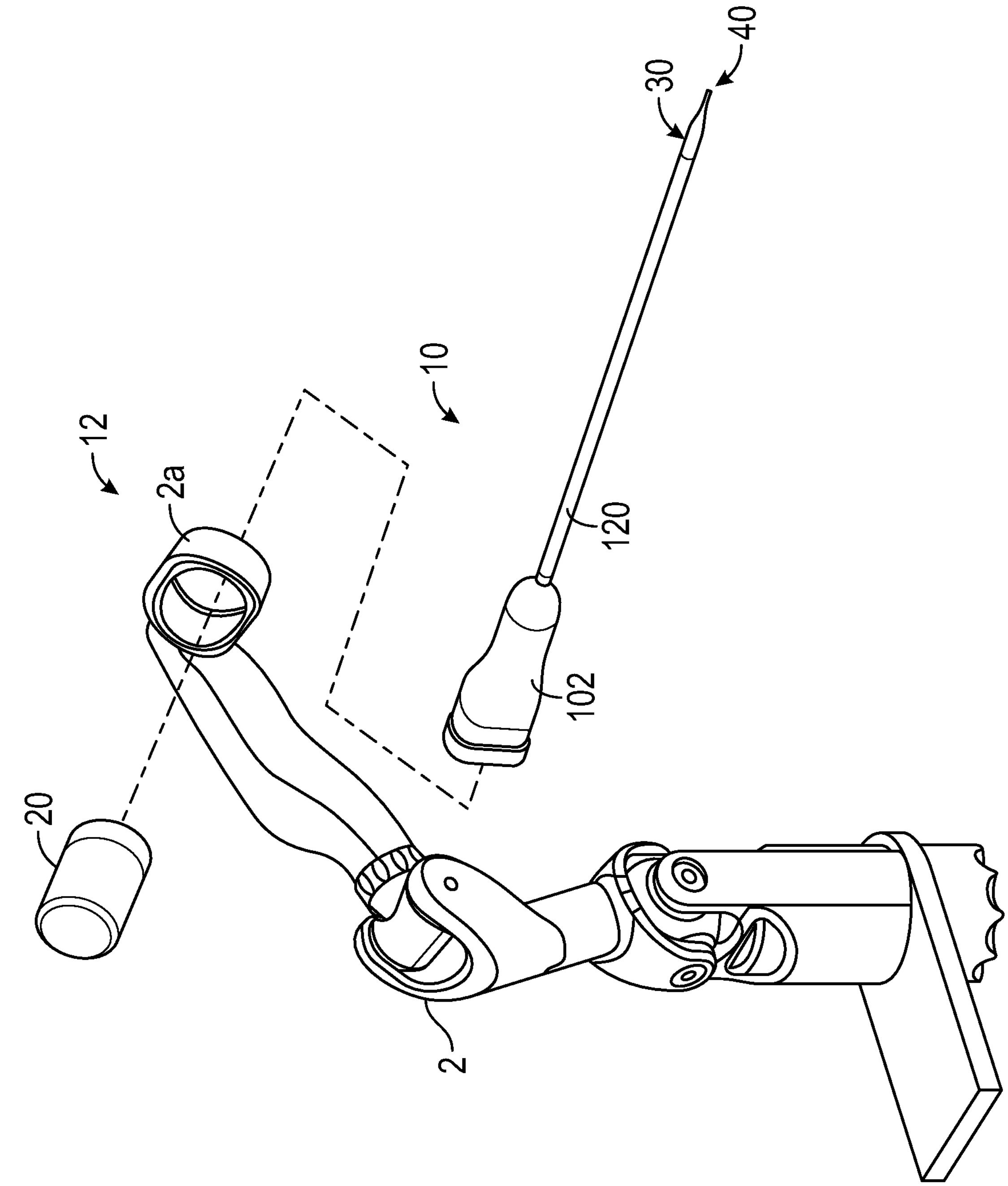

FIG. 2

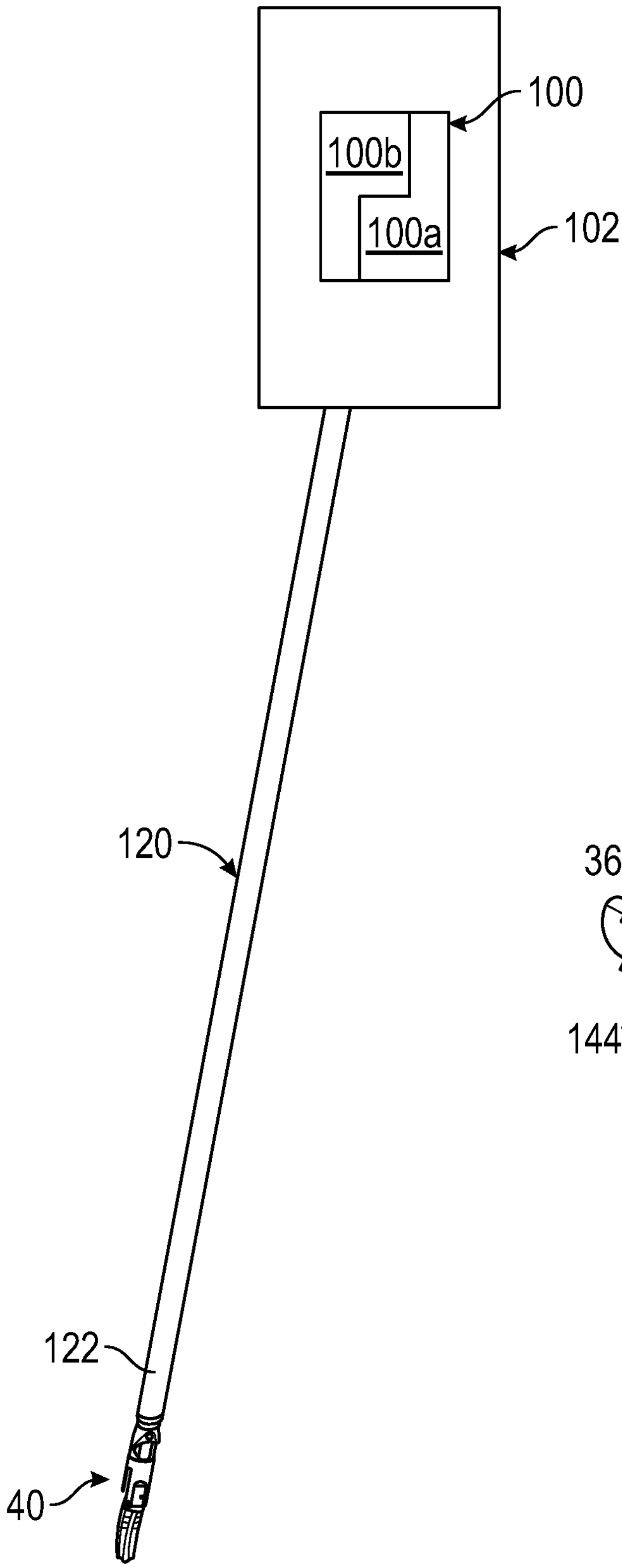

FIG. 3

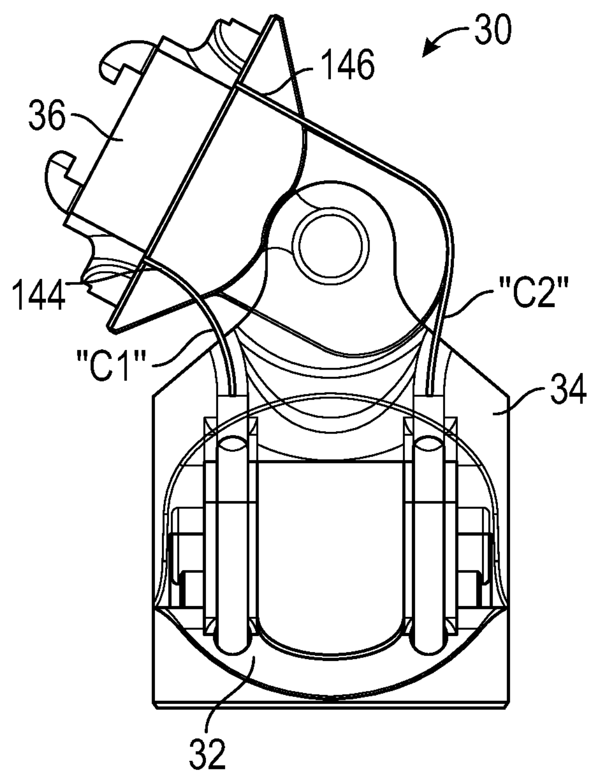

FIG. 4

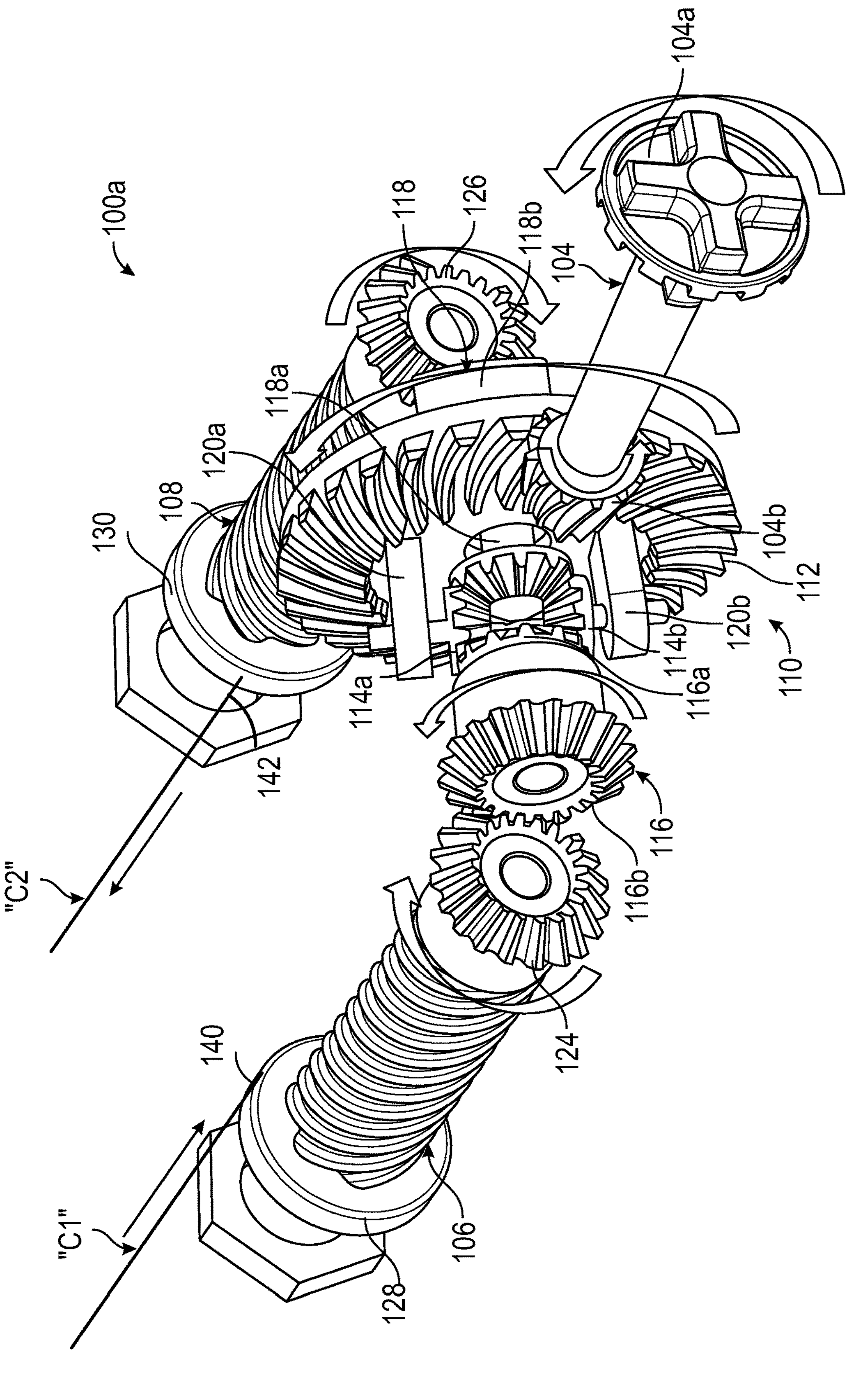
100a
104a
104
126
118
118b
118a
120a
108
130
104b
112
120b
114b
110
116a
114a
142
116
116b
"C2"
124
140
106
128
"C1"

FIG. 5A

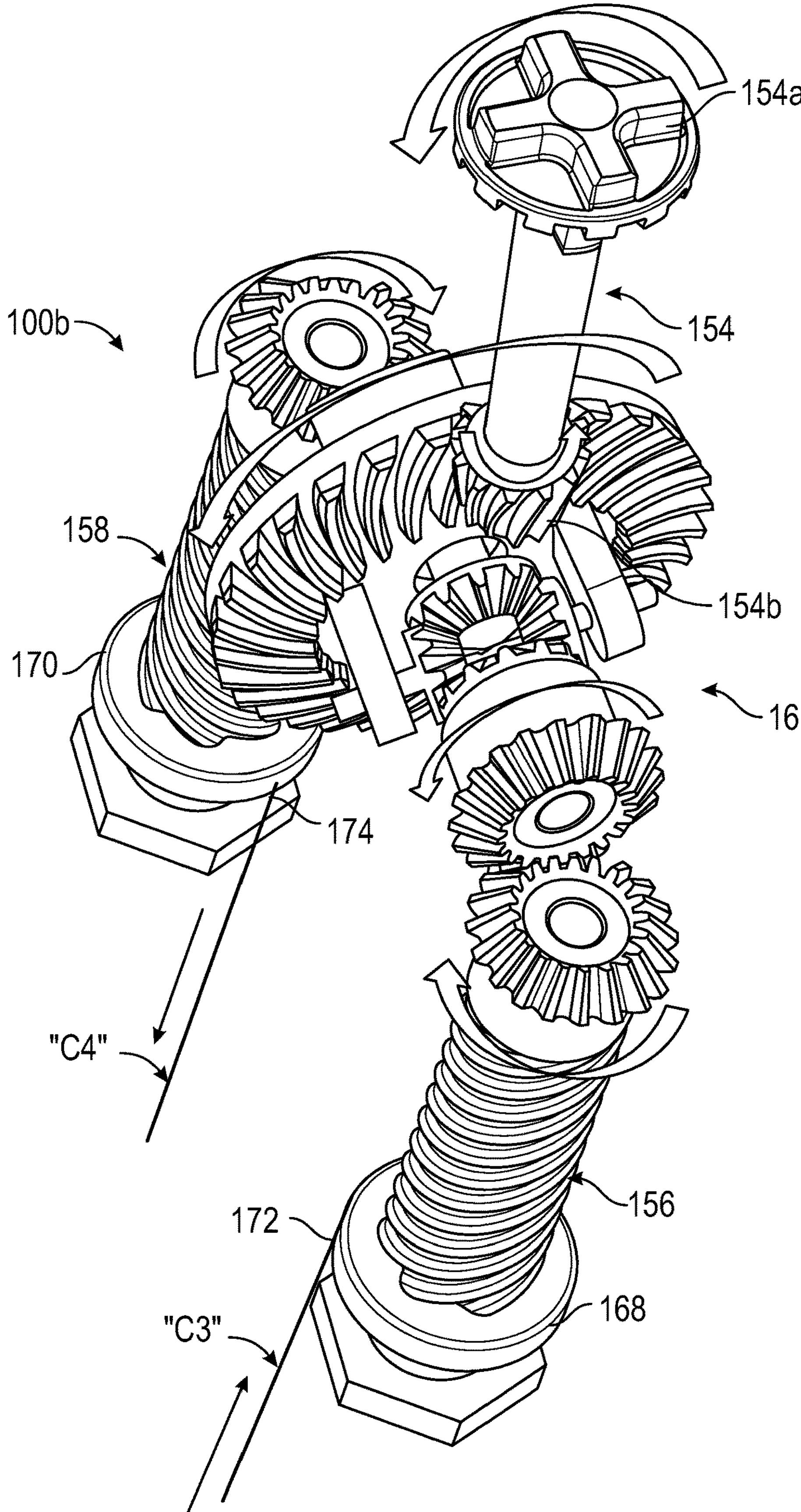

FIG. 5B

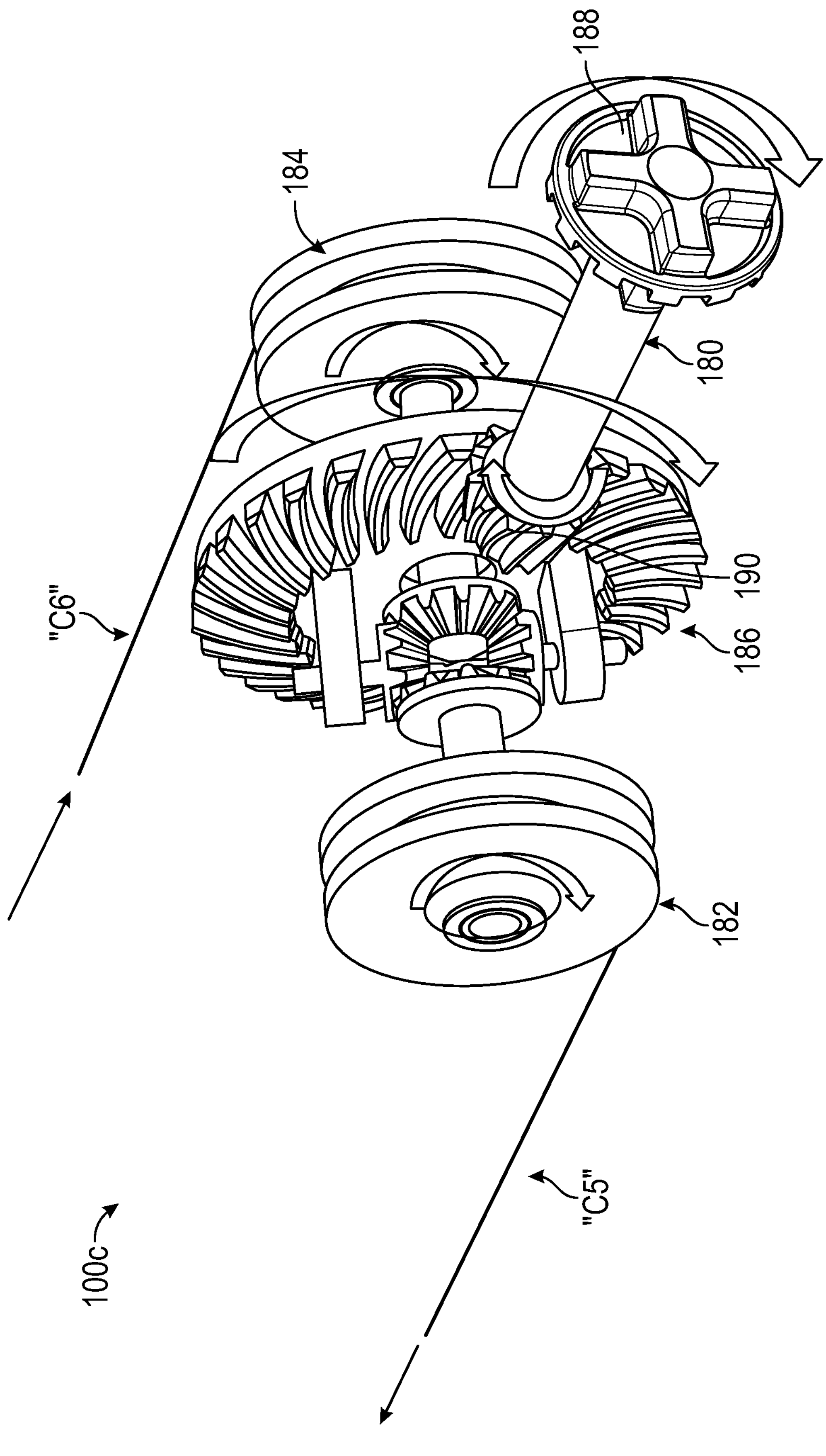

FIG. 6

ROBOTIC SURGICAL ASSEMBLIES INCLUDING SURGICAL INSTRUMENTS HAVING ARTICULATABLE WRIST ASSEMBLIES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/289,361, filed Dec. 14, 2021, the entire contents of which are incorporated by reference herein.

BACKGROUND

Some surgical robotic systems include a console supporting a surgical robotic arm and a surgical instrument or at least one end effector (e.g., forceps or a grasping tool) mounted to the robotic arm. The robotic arm provides mechanical power to the surgical instrument for its operation and movement. Each robotic arm may include an instrument drive unit operatively connected to the surgical instrument and coupled to the robotic arm via a rail. In operation, the robotic arm is moved to a position over a patient and then guides the surgical instrument into a small incision via a surgical trocar or a natural orifice of a patient to position the end effector at a work site within the patient's body. The instrument drive unit drives a rotation of each corresponding driven member of the attached surgical instrument to perform a surgical treatment. The instrument drive unit may be configured to articulate the end effector in a plurality of directions to adjust its pitch and/or yaw within a surgical site, to open/close jaw members, and/or to fire features thereof.

SUMMARY

In accordance with an aspect of the disclosure, a surgical instrument of a surgical robotic system is provided and includes a housing, a first transmission disposed within the housing, a shaft extending distally from the housing, an end effector pivotably coupled to a distal end portion of the shaft, and first and second articulation cables. The first transmission includes a rotatable first input shaft, first and second output shafts configured to rotate in response to a rotation of the first input shaft, and a first differential gear mechanism operably coupling the first input shaft to the first and second output shafts and the first and second output shafts to one another. Each of the first and second articulation cables has a proximal end portion operably coupled to the respective first and second output shafts, and a distal end portion secured to the end effector. The first and second articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the first input shaft.

In aspects, the first transmission may further include first and second articulation nuts operably coupled to the respective first and second output shafts. The articulation nuts mayb e configured to translate along the respective first and second output shafts in response to a rotation of the first and second output shafts. The articulation cables may be axially fixed to the respective first and second articulation nuts.

In aspects, the first differential gear mechanism may include a ring gear, first and second spider gears coupled to the ring gear, and first and second side axles. The ring gear may be operably coupled to the first input shaft such that the ring gear is configured to be rotated by the first input shaft.

The first and second spider gears may be configured to rotate about a respective axis thereof relative to the ring gear and with the ring gear around a rotation axis of the ring gear. The first side axle may be operably coupled to the first output shaft and the first and second spider gears, and the second side axle may be operably coupled to the second output shaft and the first and second spider gears.

In aspects, the first side axle may have opposing first and second gears. The first gear may be operably coupled to the first and second spider gears and the second gear may be operably coupled to the first output shaft.

In aspects, the second side axle may have opposing first and second gears. The first gear of the second side axle may be operably coupled to the first and second spider gears and the second gear of the second side axle may be operably coupled to the second output shaft.

In aspects, the first input shaft may have a pinion gear non-rotationally fixed to a distal end portion thereof. The pinion gear may be in meshing engagement with the ring gear.

In aspects, the ring gear may rotate about an axis that is perpendicular to a rotation axis of the first input shaft.

In aspects, the surgical instrument may further include a second transmission nested with or positioned adjacent the first transmission and supported in the housing. The second transmission may include a rotatable second input shaft, third and fourth output shafts configured to rotate in response to a rotation of the second input shaft, and a second differential gear mechanism operably coupling the second input shaft to the third and fourth output shafts and the third and fourth output shafts to one another.

In aspects, the surgical instrument may further include third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth output shafts, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

In aspects, the surgical instrument may further include a wrist assembly movably coupling the end effector to the distal end portion of the shaft. The wrist assembly may be configured to allow the end effector to articulate relative to the distal end portion of the shaft to adjust both a pitch and yaw of the end effector.

In aspects, the first transmission may be configured to change the pitch of the end effector, and the second transmission may be configured to change the yaw of the end effector.

In accordance with another aspect of the disclosure, a surgical robotic system is provided that includes a surgical robotic arm, an instrument drive unit configured to be supported on the surgical robotic arm, and a surgical instrument configured to be coupled to and driven by the instrument drive unit. The surgical instrument includes a housing configured to be attached to the instrument drive unit, a first transmission disposed within the housing, a shaft extending distally from the housing, an end effector pivotably coupled to a distal end portion of the shaft, and first and second articulation cables. The first transmission includes a rotatable first input shaft drivingly coupled to a corresponding drive shaft of the instrument drive unit, first and second output shafts configured to rotate in response to a rotation of the first input shaft, and a first differential gear mechanism operably coupling the first input shaft to the first and second output shafts and the first and second output shafts to one another. Each of the first and second articulation cables has a proximal end portion operably coupled to the respective first and second output shafts, and a distal end portion secured to the end effector, such that the first and second articulation cables move axially in opposing directions at a different rate from one another to adjust a pitch or a yaw of the end effector relative to the shaft in response to the rotation of the first input shaft.

In aspects, the surgical instrument may further include a second transmission nested with or positioned adjacent the first transmission and supported in the housing. The second transmission may further include a rotatable second input shaft, third and fourth output shafts configured to rotate in response to a rotation of the second input shaft, and a second differential gear mechanism operably coupling the second input shaft to the third and fourth output shafts and the third and fourth output shafts to one another. The surgical instrument may further include third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth output shafts, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

In aspects, the surgical instrument may further include a wrist assembly movably coupling the end effector to the distal end portion of the shaft. The wrist assembly may be configured to allow the end effector to articulate relative to the distal end portion of the shaft to adjust both the pitch and yaw of the end effector.

In aspects, the first transmission may be configured to change the pitch of the end effector, and the second transmission may be configured to change the yaw of the end effector.

In aspects, the first transmission may further include first and second articulation nuts operably coupled to the respective first and second output shafts and configured to translate therealong in response to a rotation of the respective first and second output shafts. The first and second articulation cables may be axially fixed to the respective first and second articulation nuts.

In accordance with further aspects of the disclosure, a surgical instrument of a surgical robotic system is provided that includes a housing, a first transmission disposed within the housing, a shaft extending distally from the housing, an end effector pivotably coupled to a distal end portion of the shaft, and first and second articulation cables. The first transmission includes a rotatable first input shaft, first and second outputs configured to rotate in response to a rotation of the first input shaft, and a first differential gear mechanism operably coupling the first input shaft to the first and second outputs and the first and second outputs to one another. The first and second articulation cables each have a proximal end portion operably coupled to the respective first and second outputs, and a distal end portion secured to the end effector. The first and second articulation cables move axially in opposing directions at a different rate from one another to change the pitch or yaw of the end effector relative to the shaft in response to the rotation of the first input shaft.

In aspects, each of the first and second outputs may include an articulation wheel configured to rotate via the first differential gear mechanism. The first and second articulation cables may be attached to the respective articulation wheels, such that the rotation of the articulation wheels axially moves the first and second articulation cables in the opposing directions.

In aspects, the first output may include a left-handed lead screw and the second output may include a right-handed lead screw.

In aspects, the first transmission may further include first and second articulation nuts operably coupled to the respective left-handed and right-handed lead screws. The articulation nuts may be configured to translate along the left-handed and right-handed lead screws in response to the rotation of the respective lead screws. The articulation cables may be axially fixed to the respective first and second articulation nuts.

In aspects, the surgical instrument may further include a second transmission nested with or positioned adjacent the first transmission and supported in the housing. The second transmission may include a rotatable second input shaft, third and fourth outputs configured to rotate in response to a rotation of the second input shaft, and a second differential gear mechanism operably coupling the second input shaft to the third and fourth outputs and the third and fourth outputs to one another. The surgical instrument may further include third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth output shafts, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

Further details and aspects of exemplary embodiments of the disclosure are described in more detail below with reference to the appended figures.

As used herein, the terms parallel and perpendicular are understood to include relative configurations that are substantially parallel and substantially perpendicular up to about + or −10 degrees from true parallel and true perpendicular.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the disclosure are described herein with reference to the accompanying drawings, wherein:

FIG. **1** is a schematic illustration of a robotic surgical system in accordance with the disclosure;

FIG. **2** is a perspective view of a surgical robotic arm of the robotic surgical system of FIG. **1** illustrating a surgical instrument and an instrument drive unit being coupled to the surgical robotic arm;

FIG. **3** is a perspective view, with parts shown schematically, of the surgical instrument of FIG. **2**;

FIG. **4** is an enlarged, perspective view of a wrist assembly of the surgical instrument shown in FIG. **3**;

FIG. **5**A is a perspective view illustrating a first transmission of the surgical instrument of FIG. **2**;

FIG. **5**B is a perspective view illustrating a second transmission of the surgical instrument of FIG. **2**; and

FIG. **6** is a perspective view illustrating a third transmission of the surgical instrument of the robotic surgical system of FIG. **2**.

DETAILED DESCRIPTION

Embodiments of the disclosed robotic surgical system and methods thereof are described in detail with reference to the drawings, in which like reference numerals designate identical or corresponding elements in each of the several views. As used herein the term “distal” refers to that portion of the robotic surgical system or component thereof that is further from the user, while the term "proximal" refers to that portion of the robotic surgical system or component thereof that is closer to the user.

Articulation in a wristed robotic instrument is not linear. Stated differently, the wrist imposes a non-linear curve into the system. Consequently, an inside articulation cable is pulled back further than an outside articulation cable, therefore covering a greater axial distance in the same amount of time. Thus, because the two articulation cables are not driven the same distance during the same amount of time, the disclosure provides a differential. The differential converts rotational motion of an input shaft to rotational motion of two output axles. An open differential system allows for torque to be applied regardless of rotational differences between the output axles, covering variable distances in the same amount of time.

Referring initially to FIGS. **1** and **2**, a robotic surgical system **1** is shown and generally includes a plurality of surgical robotic arms **2**, **3** each having a surgical instrument **10** (e.g., an electrosurgical instrument, a surgical stapling instrument, a surgical forceps, or the like) removably coupled thereto; a control device **4** (e.g., a computer); and an operating console **5** coupled with the control device **4**.

With continued reference to FIG. **1**, the operating console **5** includes a display device **6**, which is set up to display two-dimensional and three-dimensional images; and manual input devices **7**, **8** that serve to enable a user (e.g., a surgeon) to telemanipulate robotic arms **2**, **3**, as known in principle to a person skilled in the art. Each of the robotic arms **2**, **3** may include a plurality of members that are interconnected by joints. The robotic arms **2**, **3** may be driven by electric drives (not shown) that are connected to the control device **4**. The control device **4** is set up to execute a computer program to activate the electric drives in such a way that the robotic arms **2**, **3**, their instrument drive units **20**, and thus the surgical instrument **10** execute a movement in accordance with a movement of the manual input devices **7**, **8**. The control device **4** may also be set up in such a way that it regulates the movement of the robotic arms **2**, **3** and/or of the electric drives.

The robotic surgical system **1** is configured for minimally invasive treatment of a patient "P" lying on a surgical table "ST" using a surgical instrument (e.g., surgical instrument **10**) coupled to the robotic surgical system **1**. In some embodiments of the disclosure, the robotic surgical system **1** may include more than two robotic arms that are likewise coupled to the control device **4** and telemanipulatable by the operating console **5**. A surgical instrument (e.g., surgical instrument **10**) may also be attached to the additional robotic arm(s).

The surgical instrument **10** includes an end effector **40** (FIG. **2**) for grasping and, in aspects, treating tissue. The control device **4** may control a plurality of motors (Motor **1** . . . n) with each motor configured to drive a relative rotation of drive members of a transmission assembly **100** (FIG. **3**) of the surgical instrument **10** to effect operation and/or movement of the end effector **40** of the surgical instrument **10**. It is contemplated that the control device **4** coordinates the activation of the various motors (Motor **1** . . . n) to coordinate a clockwise or counter-clockwise rotation of drive members (not shown) of the instrument drive unit **20** in order to coordinate an operation and/or movement of the end effector **40**. In embodiments, each motor can be configured to actuate a drive rod or a lever arm to effect operation and/or movement of the end effector **40** of the surgical instrument **10**.

With specific reference to FIG. **2**, the robotic surgical system **1** includes a surgical assembly **12**, which includes the robotic arm **2**, the surgical instrument **10** coupled to the robotic arm **2**, and the instrument drive unit **20** configured to operably couple to the surgical instrument **10**. The instrument drive unit **20** is configured for powering the surgical instrument **10**. The instrument drive unit **20** transfers power and actuation forces from its motors (not shown) to the transmission assembly **100** (FIG. **3**) of the surgical instrument **10** to ultimately drive movement of components of the end effector **40**, for example, a movement of a knife blade (not explicitly shown) for cutting tissue and a closing and opening of jaw members of the end effector **40** for grasping tissue, and/or drive an articulation of the end effector **40**.

With reference to FIGS. **2** and **3**, the surgical instrument **10** generally includes a housing **102**, a shaft **120** extending distally from the housing **102**, and a wrist assembly **30** pivotably coupling the end effector **40** to the shaft **120**. The housing **102** is configured to hook, latch, or otherwise attach to a surface of the robotic arm **2**, e.g., the distal end **2**a of the robotic arm **2**, to secure the surgical instrument **10** to the robotic arm **2**. In embodiments, the housing **102** may be attached to the surgical robotic arm **2** via various fastening engagements, such as, for example, clips, latches, friction fit engagement, buttons, a variety of fasteners, and/or a bayonet-type connection. The housing **102** houses the transmission assembly **100** that interfaces with the instrument drive unit **20**. The transmission assembly **100** translates the motion and torques of the motors of the instrument drive unit **20** into the motion necessary to articulate the wrist assembly **30** of the surgical instrument **10**, open and close the jaw members of the end effector **40**, and deploy and retract a knife blade to cut tissue grasped between the jaw members of the end effector **40**.

With brief reference to FIG. **4**, the wrist assembly **30** of the surgical instrument **10** operably couples the end effector **40** to a distal end portion **122** (FIG. **3**) of the shaft **120**. More specifically, the wrist assembly **30** has a proximal body **32** immovably attached to the distal end portion **122** of the shaft **120**, a proximal pivot member **34** pivotably coupled to the proximal body **32**, and a distal pivot member **36** pivotably coupled to the proximal pivot member **34**. The proximal pivot member **34** is pivotable about a first articulation axis relative to the proximal body **32** to adjust a pitch of the end effector **40**, and the distal pivot member **36** is pivotable relative to the proximal pivot member **34** about a second articulation axis to adjust a yaw of the end effector **40**. The wrist assembly **30** is configured to affect the pivoting motion of the end effector **40** relative to the shaft **120** to adjust the yaw and/or pitch of the end effector **40** utilizing a series of translatable cables driven by the motors of the instrument drive unit **20**. One set of articulation cables "C1," "C2" for adjusting the yaw of the end effector **40** are routed through the wrist assembly **30** and fixed to the distal pivot member **36** of the wrist assembly **30** or a proximal end of the end effector **40**. Accordingly, translation of selected cables pivots the end effector **40** in one of a plurality of directions, as will be described further below. The cables "C3," "C4" for effecting the change in pitch of the end effector **40** are shown in FIG. **5**B.

Details about the transmission assembly **100** of the surgical instrument **10** will now be described with reference to FIGS. **3**-**5**B. The transmission assembly **100** includes a first transmission **100**a (FIG. **5**A) and a second transmission **100**b (FIG. **5**B) each disposed within the housing **102** and nested with one another, or located in axial alignment with one another (e.g., first transmission **100**a being located distal of second transmission **100***b* or first transmission **100***a* being located proximal of second transmission **100***b*).

The first transmission **100***a* includes a rotatable first input shaft **104**, first and second output shafts **106**, **108** each configured to rotate in response to a rotation of the first input shaft **104**, and a first differential gear mechanism **110** operably coupling the first input shaft **104** to the first and second output shafts **106**, **108** and the first and second output shafts **106**, **108** to one another. The first input shaft **104** has a proximal end portion **104***a* configured to be drivingly coupled to a corresponding drive member or shaft (not shown) of the instrument drive unit **20** (FIG. **2**), and a distal end portion having a pinion gear **104***b* non-rotationally fixed thereto. The pinion gear **104***b* is in meshing engagement with a ring gear **112** of the first differential gear mechanism **110** such that the ring gear **112** is rotatable by the pinion gear **104***b* of the first input shaft **104**. The ring gear **112** rotates about an axis that is perpendicular to a rotation axis of the first input shaft **104**. In aspects, the ring gear **112** may be a crown wheel.

In addition to the first differential gear mechanism **110** having the ring gear **112**, the first differential gear mechanism **110** further includes first and second spider gears **114***a*, **114***b* coupled to the ring gear **112**, and first and second side axles **116**, **118** coupled to the respective spider gears **114***a*, **114***b* and the respective output shafts **106**, **108**. The spider gears **114***a*, **114***b* are rotatably supported on respective posts **120***a*, **120***b* that are fixed to the ring gear **112** and rotatable therewith about the rotation axis of the ring gear **112**. As such, the first and second spider gears **114***a*, **114***b* are configured to rotate about their respective axes relative to the ring gear **112** and with the ring gear **112** around the rotation axis of the ring gear **112**.

The first and second side axles **116**, **118** of the first differential gear mechanism **110** each include opposing first and second gears **116***a*, **116***b*, **118***a*, **118***b*, such as, for example, bevel gears or crown gears. The first gear **116***a* of the first side axle **116** is in meshing engagement with both the first and second spider gears **114***a*, **114***b* and the second gear **116***b* of the first side axle **116** is in meshing engagement with a gear **124** (e.g., a bevel gear) of the first output shaft **106**. The second side axle **118** extends through a central opening of the ring gear **112**. The first gear **118***a* of the second side axle **118** is in meshing engagement with both the first and second spider gears **114***a*, **114***b* and the second gear **118***b* of the second side axle **118** is in meshing engagement with a gear **126** (e.g., a bevel gear) of the second output shaft **106**. Due to the function of the first differential gear mechanism **110**, the average of the rotational speed of the first and second output shafts **106**, **108** is equal to the input rotational speed of the input drive shaft **104** such that an increase in the speed of one of the output shafts **106** or **108** results in a proportional decrease in the speed of the other of the output shafts **106**, **108**, the benefit of which will be described in further detail below.

With continued reference to FIG. **5**A, the first transmission **100***a* further includes first and second articulation nuts **128**, **130** operably coupled to the respective first and second output shafts **106**, **108**. The first output shaft **106** may be a left-handed lead screw and the second output shaft **108** may be a right-handed lead screw such that rotation of the output shafts **106**, **108** in the same rotational direction is configured to translate the respective articulation nuts **128**, **130** therealong in opposing axial directions. For example, as the output shafts **106**, **108** rotate in a clockwise direction, the first articulation nut **128** may translate proximally whereas the second articulation nut **130** may translate distally. The first and second articulation cables "C **1**," "C2" each have a proximal end portion **140**, **142** operably coupled to the respective first and second output shafts **106**, **108**, and a distal end portion **144**, **146** (FIG. **4**) secured to the end effector **40**, such that the first and second articulation cables "C1," "C2" move axially in opposing directions at a different rate from one another to articulate the end effector **40** relative to the shaft **120** to adjust a yaw of the end effector **40**.

As illustrated in Table 1 below, it has been discovered that the degree of articulation of the end effector **40** is not linear to the degree of axial movement of the cables "C1-C4"; rather, articulation of the wrist assembly **30** imposes a non-linear curve into the system and to the degree of axial movement of the cables "C1-C4". Consequently, the inside articulation cable (e.g., articulation cable "C1") is translated proximally a greater distance than the outside articulation cable (e.g., articulation cable "C2") is translated distally. That is, the inside articulation cable "C1" traverses a greater axial distance in the same amount of time than does the outside articulation cable "C2". The differential gear mechanism **110** compensates for this difference to allow for the inside articulation cable "C1" to traverse the greater axial distance in the same amount of time thereby reducing stress and strain on the inside articulation cable "C2". Therefore, use of the transmission assembly **100** of this disclosure will result in the articulation cables having a longer lifespan, and articulation of the end effector **40** will be more precise.

TABLE 1

Joint Angle (deg)	Inside Cable (mm)	Outside Cable (mm)	Average Length (mm)	% Change
0	7.21313	7.21313	7.21313	0
15.5	6.52968	7.85589	7.192785	−0.282852887
31	5.74358	8.63665	7.190115	−0.320092238
46.5	4.88954	9.46854	7.17904	−0.474854577
62	4.05633	10.3072	7.181765	−0.436731082

With reference to FIG. **5**B, the second transmission **100***b* (FIG. **5**B) of the transmission assembly **100** is substantially similar or identical to the first transmission **100***a* but is configured to effect a change in pitch of the end effector **40** via translation of a second set of articulation cables "C3," "C4." The second transmission **100***b* is disposed within the housing **102** (FIG. **3**) and may be orientated generally perpendicular to and nested with the first transmission **100***a*. In aspects, instead of nesting or overlapping the first and second transmissions **100***a*, **100***b*, the first and second transmissions **100***a*, **100***b* may be positioned in side-by-side relation to one another, or, as mentioned above, may be positioned distal/proximal to one another.

The second transmission **100***b* includes a rotatable first input shaft **154**, first and second output shafts **156**, **158** each configured to rotate in response to a rotation of the first input shaft **154**, and a second differential gear mechanism **160** operably coupling the first input shaft **154** to the first and second output shafts **156**, **158** and the first and second output shafts **156**, **158** to one another. The first input shaft **154** has a proximal end portion **154***a* configured to be drivingly coupled to a corresponding drive member or shaft (not shown) of the instrument drive unit **20** (FIG. **2**), and a distal end portion **154***b* operably coupled to the second differential gear mechanism **160**. Since the second differential gear mechanism **160** is substantially similar or identical to the first differential gear mechanism **110**, details of the second differential gear mechanism **160** are not provided herein.

The second transmission **100***b* further includes third and fourth articulation nuts **168**, **170** operably coupled to the respective first and second output shafts **156**, **158**. The first output shaft **156** may be a left-handed lead screw and the second output shaft **158** may be a right-handed lead screw such that rotation of the output shafts **156**, **158** in the same rotational direction is configured to translate the respective articulation nuts **168**, **170** therealong in opposing axial directions. The articulation cables "C3," "C4" each have a proximal end portion **172**, **174** operably coupled to the respective first and second output shafts **156**, **158**, and a distal end portion (not explicitly shown) secured to the end effector **40**, such that the articulation cables "C3," "C4" move axially in opposing directions at a different rate from one another to articulate the end effector **40** relative to the shaft **120** to adjust a pitch of the end effector **40**.

With reference to FIG. **6**, another type of transmission **100***c* is illustrated that can be used in place of or in addition to one or both of the first and second transmissions **100***a*, **100***b*. Since the transmission **100***c* is substantially similar to transmissions **100***a*, **100***b*, only those details about the transmission **100***c* necessary to appreciate the differences from transmissions **100***a*, **100***b* will be provided.

The transmission **100***c* includes a rotatable first input shaft **180**, first and second outputs **182**, **184** each configured to rotate in response to a rotation of the first input shaft **180**, and a third differential gear mechanism **186** operably coupling the first input shaft **180** to the first and second outputs **182**, **184** and the first and second outputs **182**, **184** to one another. The first input shaft **180** has a proximal end portion **188** configured to be drivingly coupled to a corresponding drive member or shaft (not shown) of the instrument drive unit **20** (FIG. **2**), and a distal end portion **190** operably coupled to the third differential gear mechanism **186**. Since the third differential gear mechanism **186** is substantially similar or identical to the first and second differential gear mechanisms **110**, **160** described above, details of the third differential gear mechanism **180** are not provided herein.

The first and second outputs **182**, **184** of the third transmission **100***c* may be an articulation wheel rotatably supported in the housing **102** and configured to rotate via the third differential gear mechanism **186**. Articulation cables "C5," "C6" are fixed to the respective articulation wheels **182**, **184** such that the rotation of the articulation wheels **182**, **184** axially moves the first and second articulation cables "C5," "C6" in the opposing directions. For example, the articulation cables "C5," "C6" may be secured to the wheels **182**, **184** by being wrapped about the wheels **182**, **184** in opposing circumferential directions from one another such that rotation of the wheels **182**, **184** in the same rotational direction results in the translation of the cables "C5," "C6" in opposing axial directions. In aspects, the outputs **182**, **184** may be configured similarly to a capstan or a windlass.

It will be understood that various modifications may be made to the embodiments disclosed herein. Therefore, the above description should not be construed as limiting, but merely as exemplifications of various embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended thereto.

The invention claimed is:

1. A surgical instrument of a surgical robotic system, the surgical instrument comprising:

a housing;

a first transmission disposed within the housing and including:

a rotatable first input shaft;

first and second output shafts configured to rotate in response to a rotation of the first input shaft; and

a first differential gear mechanism operably coupling the first input shaft to the first and second output shafts and the first and second output shafts to one another;

a shaft extending distally from the housing;

an end effector pivotably coupled to a distal end portion of the shaft; and

first and second articulation cables each having a proximal end portion operably coupled to the respective first and second output shafts, and a distal end portion secured to the end effector, such that the first and second articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the first input shaft.

2. The surgical instrument according to claim **1**, wherein the first transmission further includes first and second articulation nuts operably coupled to the respective first and second output shafts and configured to translate therealong in response to a rotation of the respective first and second output shafts, the first and second articulation cables being axially fixed to the respective first and second articulation nuts.

3. The surgical instrument according to claim **1**, wherein the first differential gear mechanism includes:

a ring gear operably coupled to the first input shaft such that the ring gear is configured to be rotated by the first input shaft;

first and second spider gears coupled to the ring gear such that the first and second spider gears are configured to rotate about a respective axis thereof relative to the ring gear and with the ring gear around a rotation axis of the ring gear; and

first and second side axles, the first side axle operably coupled to the first output shaft and the first and second spider gears, and the second side axle operably coupled to the second output shaft and the first and second spider gears.

4. The surgical instrument according to claim **3**, wherein the first side axle has opposing first and second gears, the first gear is operably coupled to the first and second spider gears and the second gear is operably coupled to the first output shaft.

5. The surgical instrument according to claim **4**, wherein the second side axle has opposing first and second gears, the first gear of the second side axle is operably coupled to the first and second spider gears and the second gear of the second side axle is operably coupled to the second output shaft.

6. The surgical instrument according to claim **3**, wherein the first input shaft has a pinion gear non-rotationally fixed to a distal end portion thereof, the pinion gear being in meshing engagement with the ring gear.

7. The surgical instrument according to claim **3**, wherein the ring gear rotates about an axis that is perpendicular to a rotation axis of the first input shaft.

8. The surgical instrument according to claim **1**, further comprising:

a second transmission nested with or positioned adjacent the first transmission and supported in the housing, wherein the second transmission includes:

a rotatable second input shaft;

third and fourth output shafts configured to rotate in response to a rotation of the second input shaft; and a second differential gear mechanism operably coupling the second input shaft to the third and fourth output shafts and the third and fourth output shafts to one another; and

third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth output shafts, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

9. The surgical instrument according to claim **8**, further comprising a wrist assembly movably coupling the end effector to the distal end portion of the shaft, wherein the wrist assembly is configured to allow the end effector to articulate relative to the distal end portion of the shaft to adjust both a pitch and yaw of the end effector.

10. The surgical instrument according to claim **9**, wherein the first transmission is configured to change the pitch of the end effector, and the second transmission is configured to change the yaw of the end effector.

11. A surgical robotic system, comprising:

a surgical robotic arm;

an instrument drive unit configured to be supported on the surgical robotic arm; and

a surgical instrument configured to be coupled to and driven by the instrument drive unit, the surgical instrument including;

a housing configured to be attached to the instrument drive unit;

a first transmission disposed within the housing and including:

a rotatable first input shaft drivingly coupled to a corresponding drive shaft of the instrument drive unit;

first and second output shafts configured to rotate in response to a rotation of the first input shaft; and

a first differential gear mechanism operably coupling the first input shaft to the first and second output shafts and the first and second output shafts to one another;

a shaft extending distally from the housing;

an end effector pivotably coupled to a distal end portion of the shaft; and

first and second articulation cables each having a proximal end portion operably coupled to the respective first and second output shafts, and a distal end portion secured to the end effector, such that the first and second articulation cables move axially in opposing directions at a different rate from one another to adjust a pitch or a yaw of the end effector relative to the shaft in response to the rotation of the first input shaft.

12. The surgical robotic system according to claim **11**, wherein the surgical instrument further includes:

a second transmission nested with or positioned adjacent the first transmission and supported in the housing, wherein the second transmission includes:

a rotatable second input shaft;

third and fourth output shafts configured to rotate in response to a rotation of the second input shaft; and

a second differential gear mechanism operably coupling the second input shaft to the third and fourth output shafts and the third and fourth output shafts to one another; and

third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth output shafts, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

13. The surgical robotic system according to claim **12**, wherein the surgical instrument further includes a wrist assembly movably coupling the end effector to the distal end portion of the shaft, wherein the wrist assembly is configured to allow the end effector to articulate relative to the distal end portion of the shaft to adjust both the pitch and yaw of the end effector.

14. The surgical robotic system according to claim **12**, wherein the first transmission is configured to change the pitch of the end effector, and the second transmission is configured to change the yaw of the end effector.

15. The surgical robotic system according to claim **11**, wherein the first transmission further includes first and second articulation nuts operably coupled to the respective first and second output shafts and configured to translate therealong in response to a rotation of the respective first and second output shafts, the first and second articulation cables being axially fixed to the respective first and second articulation nuts.

16. A surgical instrument of a surgical robotic system, the surgical instrument comprising:

a housing;

a first transmission disposed within the housing and including:

a rotatable first input shaft;

first and second outputs configured to rotate in response to a rotation of the first input shaft; and

a first differential gear mechanism operably coupling the first input shaft to the first and second outputs and the first and second outputs to one another;

a shaft extending distally from the housing;

an end effector pivotably coupled to a distal end portion of the shaft; and

first and second articulation cables each having a proximal end portion operably coupled to the respective first and second outputs, and a distal end portion secured to the end effector, such that the first and second articulation cables move axially in opposing directions at a different rate from one another to change the pitch or yaw of the end effector relative to the shaft in response to the rotation of the first input shaft.

17. The surgical instrument according to claim **16**, wherein each of the first and second outputs includes an articulation wheel configured to rotate via the first differential gear mechanism, the first and second articulation cables being attached to the respective articulation wheels, such that the rotation of the articulation wheels axially moves the first and second articulation cables in the opposing directions.

18. The surgical instrument according to claim **16**, wherein the first output includes a left-handed lead screw and the second output includes a right-handed lead screw.

19. The surgical instrument according to claim **18**, wherein the first transmission further includes first and second articulation nuts operably coupled to the respective left-handed and right-handed lead screws and configured to translate therealong in response to the rotation of the respective left-handed and right-handed lead screws, the first and second articulation cables being axially fixed to the respective first and second articulation nuts.

20. The surgical instrument according to claim **16**, further comprising:

a second transmission nested with or positioned adjacent the first transmission and supported in the housing, wherein the second transmission includes:

a rotatable second input shaft;

third and fourth outputs configured to rotate in response to a rotation of the second input shaft; and

a second differential gear mechanism operably coupling the second input shaft to the third and fourth outputs and the third and fourth outputs to one another; and

third and fourth articulation cables each having a proximal end portion operably coupled to the respective third and fourth outputs, and a distal end portion secured to the end effector, such that the third and fourth articulation cables move axially in opposing directions at a different rate from one another to articulate the end effector relative to the shaft in response to the rotation of the second input shaft.

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