(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 April 2026 (16.04.2026)

WIPO | PCT

(10) International Publication Number
WO 2026/080687 A1

(51) International Patent Classification:
A61F 2/58 (2006.01) *A61F 2/70* (2006.01)

(21) International Application Number:
PCT/US2025/050210

(22) International Filing Date:
09 October 2025 (09.10.2025)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/706,007 10 October 2024 (10.10.2024) US

(71) Applicant: TESLA, INC. [US/US]; 1 Tesla Road, Austin, Texas 78725 (US).

(72) Inventors: GIACOBETTI, Megan; 1 Tesla Road, Austin, Texas 78725 (US). JAFARI, Rod; 1 Tesla Road, Austin, Texas 78725 (US). LEDDY, Michael; 1 Tesla Road, Austin, Texas 78725 (US). OLIVE, Harry Edward; 1 Tesla Road, Austin, Texas 78725 (US). PANG, Shitong; 1 Tesla Road, Austin, Texas 78725 (US).

(74) Agent: SOPHIR, Eric et al.; Foley & Lardner LLP, 3000 K Street N.W., Washington, District of Columbia 20007 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UY, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MU, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: MECHANICALLY ACTUATED ROBOTIC HAND

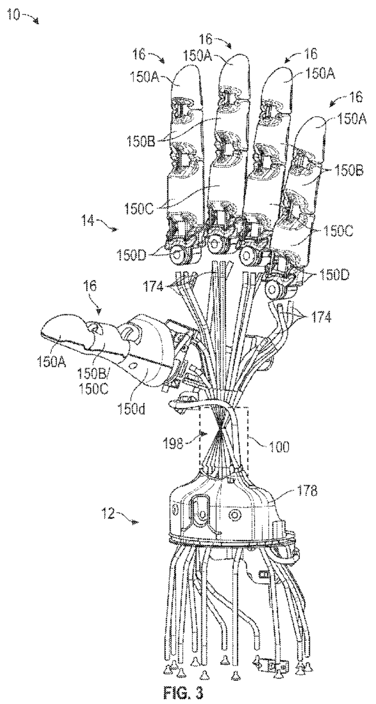


FIG. 3

(57) Abstract: A robotic lower arm assembly includes a forearm member, a hand member including a plurality of appendage members, a plurality of control cables coupled with the forearm member at first ends thereof and coupled with the plurality of appendage members at second ends thereof, a control cable of the plurality of control cables configured to apply a force to an appendage member of the plurality of appendage members to actuate the appendage member, and a wrist joint pivotably coupled with the forearm member and the hand member. The plurality of control cables is arranged in a first configuration at a forearm side of the wrist joint and is arranged in a second configuration different from the first configuration at a hand side of the wrist joint opposite the forearm side.

WO 2026/080687 A1

MECHANICALLY ACTUATED ROBOTIC HAND

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Application No. 63/706,007, filed October 10, 2024, the entire disclosure of which is incorporated by reference herein.

TECHNICAL FIELD

[0002] The present disclosure relates generally to robotics. More specifically, the present disclosure relates to cable routing and management for moving robotic appendages.

BACKGROUND

[0003] Robotic appendages are used by robots to interact with objects in the surrounding environment. By way of example, an appendage may be used to push or grasp an object or to propel the robot. To accomplish this, some appendages utilize joints that permit relative motion between different components. It may be desirable for such a joint to movably connect two components while also permitting communication between those components.

SUMMARY

[0004] In at least one embodiment, a robotic lower arm assembly includes a forearm member, a hand member including a plurality of appendage members, a plurality of control cables coupled with the forearm member at first ends thereof and coupled with the plurality of appendage members at second ends thereof, a control cable of the plurality of control cables configured to apply a force to an appendage member of the plurality of appendage members to actuate the appendage member, and a wrist joint pivotably coupled with the forearm member and the hand member. The plurality of control cables is arranged in a first configuration at a forearm side of the wrist joint and is arranged in a second configuration different from the first configuration at a hand side of the wrist joint opposite the forearm side.

[0005] In some embodiments, in the first configuration, the plurality of control cables is arranged in a lateral stack, and in the second configuration, the plurality of control cables is arranged in a vertical stack.

[0006] In some embodiments, the wrist joint includes a first control cable support member configured to support the plurality of control cables in the first configuration and a second control cable support member configured to support the plurality of control cables in the second configuration.

[0007] In some embodiments, the first control cable support member is coupled with the forearm member and the second control cable support member is coupled with the hand member.

[0008] In some embodiments, the plurality of control cables defines a transition region at the wrist joint where the plurality of control cables transitions from the first configuration to the second configuration.

[0009] In some embodiments, the wrist joint is pivotably coupled with the forearm member about a yaw axis and pivotably coupled with the hand member about a pitch axis, the yaw axis and the pitch axis being perpendicular with each other, the first configuration of the plurality of control cables limits a first moment arm on the plurality of control cables across the pitch axis, and the second configuration of the plurality of control cables limits a second moment arm on the plurality of control cables across the yaw axis.

[0010] In some embodiments, the appendage member includes a control cable channel configured to receive at least a portion of the control cable.

[0011] In some embodiments, the control cable channel is positioned to laterally align the control cable along a length of the appendage member with the second end of the control cable.

[0012] In some embodiments, the control cable channel opens to a pivot joint between adjacent structures of the appendage member.

[0013] In some embodiments, the second end of the control cable terminates at a termination structure integrally formed with the appendage member.

[0014] In some embodiments, the appendage member includes at least two joints, and the control cable is routed behind a first joint of the at least two joints and forward a second joint of the at least two joints.

[0015] In some embodiments, the appendage member includes a first structure, a second structure, a third structure, and a fourth structure, the third structure is pivotable relative to the fourth structure at the first joint, the second structure is pivotable relative to the third structure at the second joint, and the first structure is pivotable relative to the second structure at a third joint, and the control cable is routed behind the first joint and forward the second joint and the third joint.

[0016] In some embodiments, the control cable is coupled with the first structure at the second end.

[0017] In some embodiments, the control cable is a first control cable, and a second control cable and a third control cable of the plurality of control cables are coupled with the third structure at second ends thereof.

[0018] In some embodiments, the first joint is positioned closer to a proximal end of the appendage member relative to the second joint.

[0019] In at least one embodiment, a joint assembly includes a plurality of structures including a first structure, a second structure, a third structure, and a fourth structure, and a plurality of control cables including a first control cable, a second control cable, and a third control cable. The third structure is pivotable relative to the fourth structure at a first joint, the second structure is pivotable relative to the third structure at a second joint, and the first structure is pivotable relative to the second structure at a third joint. The first control cable is coupled with the first structure and is routed behind the first joint and forward the second joint and the third joint. The second control cable and the third control cable are coupled with the third structure and are routed forward the first joint.

[0020] In some embodiments, the first joint is positioned closer to a proximal end of the joint assembly relative to the second joint and the third joint.

[0021] In at least one embodiment, a joint assembly includes a plurality of structures and a control cable. The plurality of structures includes a first structure, a second structure, and a third structure, the first structure including a first control cable channel, the second structure including a second control cable channel and a third control cable channel, and the third structure including a fourth control cable channel. The second structure is pivotable relative to the third structure at a first joint, and the first structure is pivotable relative to the second structure at a second joint. The first control cable channel and the second control cable channel open to the first joint. The third control cable channel and the fourth control cable channel open to the second joint. The first control cable channel, the second control cable channel, the third control cable channel, and the fourth control cable channel are configured to receive at least a portion of the control cable.

[0022] In some embodiments, the control cable is coupled with the first structure at a termination structure, and the first control cable channel, the second control cable channel, the third control cable channel, and the fourth control cable channel are laterally aligned with the termination structure.

[0023] In some embodiments, the plurality of structures include a fourth structure pivotable relative to the third structure at a third joint, the control cable is a first control cable, and the joint assembly further comprises a second control cable and a third control cable, the third structure includes a fifth control cable channel and a sixth control cable channel laterally spaced from the fifth control cable channel, the fourth structure includes a seventh control cable channel and an eighth control cable channel laterally spaced from the seventh control cable channel, the fifth control cable channel, the sixth control cable channel, the seventh control cable channel, and the eighth control cable channel open to the third joint, the fifth control cable channel and the seventh control cable channel are configured to receive at least a portion of the second control cable, and the sixth control cable channel and the eighth control cable channel are configured to receive at least a portion of the third control cable.

[0024] This summary is illustrative only and is not intended to be in any way limiting. Other aspects, inventive features, and advantages of the devices or processes described herein will become apparent in the detailed description set forth herein, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements.

BRIEF DESCRIPTION OF THE FIGURES

[0025] FIG. 1 is a side view of a robotic arm assembly, according to an embodiment.

[0026] FIG. 2 is a top view of the robotic arm assembly of FIG. 1, according to an embodiment.

[0027] FIG. 3 is a perspective view of a robotic arm assembly, according to an embodiment.

[0028] FIG. 4 is a perspective view of a control cable arrangement, according to an embodiment.

[0029] FIG. 5 is a perspective view of a wrist joint supporting the control cable arrangement of FIG. 4, according to an embodiment.

[0030] FIG. 6 is a perspective view of an appendage member, according to an embodiment.

[0031] FIG. 7 is a perspective view of the appendage member of FIG. 6 with portions of finger members removed, according to an embodiment.

[0032] FIG. 8 is a side view of the appendage member of FIG. 6, according to an embodiment.

DETAILED DESCRIPTION

[0033] Before turning to the figures, which illustrate certain exemplary embodiments in detail, it should be understood that the present disclosure is not limited to the details or methodology set forth in the description or illustrated in the figures. It should also be understood that the terminology used herein is for the purpose of description only and should not be regarded as limiting.

[0034] Referring generally to the figures, a robotic lower arm assembly includes a forearm member, a hand member having a plurality of appendage members, and a wrist joint pivotably coupling the forearm member and the hand member. A plurality of control cables extends between the forearm member and the plurality of appendage members and are coupled at first ends thereof to the forearm member and at second ends thereof to the respective appendage members. Each control cable is configured to apply a force to the corresponding appendage member to actuate the appendage member. The control cables are arranged in a first configuration at a forearm side of the wrist joint and in a second configuration, different from the first configuration, at a hand side of the wrist joint opposite the forearm side. The first configuration positions the control cables to limit a first moment arm relative to the pitch axis of the wrist joint, and the second configuration positions the control cables to limit a second moment arm relative to the yaw axis of the wrist joint. In other words, the control cable routing is selected to position the cables proximate to the respective rotational centers of the pitch and yaw axes, thereby reducing cable length change as the hand member moves relative to the forearm member. This arrangement further reduces crosstalk between the control cables such that wrist movement does not cause unintended movement of the appendage members and movement of the appendage members does not cause unintended movement of the wrist joint. In some embodiments, the appendage members include a plurality of pivotably connected structures coupled by joints, with control cables routed behind or forward respective joints to selectively control bending directions or other degrees of freedom. Control cable channels formed in the structures of the appendage members are configured to maintain the lateral alignment of the control cables with their respective termination structures to limit bending or misalignment and to reduce the number of crossovers between cables. This routing and channel arrangement also limits the number of bends each cable passes through, which reduces friction along the cable path and maintains consistent force transmission to the appendage members.

Overview

[0035] Referring to FIGS. 1–3, a robotic lower arm assembly (e.g., humanoid appendage, robotic appendage, limb, jointed assembly, posable assembly, etc.), is shown as robotic arm assembly 100. The robotic arm assembly 10 includes a first member (e.g., forearm member, upper member, etc.), shown as forearm 12, a second member (e.g., hand member, hand assembly, lower member, articulatable member, etc.), shown as hand 14, and a plurality of third members (e.g., humanoid appendages, robotic appendages, jointed assemblies, posable assemblies, digits, etc.), shown as fingers 16. The fingers 16 are movably coupled with the hand 14 such that the fingers 16 can pivot, rotate, or otherwise actuate relative to the hand 14 and the forearm 12. The hand 14 is coupled with the forearm 12 via a wrist joint (e.g., linkage, wrist assembly, joint, etc.), shown as joint assembly 100. The joint assembly 100 allows rotation of the hand 14 relative to the forearm 12 about a first axis, shown as yaw axis 102, and about a second axis, shown as pitch axis 104.

[0036] The joint assembly 100 includes a bracket 112 (e.g., a fixed member, a forearm frame, etc.), a hand structure 120 (e.g., a structure, a hand frame member, a hand frame, etc.), and a universal joint 118. The bracket 112 is contained within or forms a part of the forearm 12. In some embodiments, the bracket 112 is fixed to (e.g., anchored to) the forearm 12. In some embodiments the bracket 112 is fixed to a forearm frame member 110. The hand structure 120 (e.g., a frame, a palm member, a hand frame, a hand member, etc.) is similarly disposed within the hand 14. The hand structure 120 can be fixed to the hand 14 and may be contained within or form part of the hand 14.

[0037] The universal joint 118 rotatably couples with both the bracket 112 and the hand structure 120. In particular, the universal joint 118 pivotally couples with the bracket 112 about the yaw axis 102 and pivotally couples with the hand structure 120 about the pitch axis 104. The universal joint 118 can define both the yaw axis 102 and the pitch axis 104. The yaw axis 102 and the pitch axis 104 are perpendicular to each other and are defined by corresponding portions of the universal joint 118. The universal joint 118 can be rotatably coupled to the bracket 112 about the yaw axis 102 and the hand structure 120 about the pitch axis 104 via bearings (e.g., ball bearings, roller bearings, etc.). In particular, the universal joint 118 can be coupled to an end of the bracket 112. The joint assembly 100 facilitates radial and ulnar deviation of the hand 14 about the yaw axis 102, and flexion and extension of the hand 14 about the pitch axis 104. The bracket 112 includes an upper member 113a and a lower member 113b that are offset from each other to define a space. The universal joint 118 is positioned between the upper member 113a and the lower member 113b. As shown in FIG. 2, the pitch axis 104 is offset a distance 136 from the yaw axis 102 along the centerline 18 or in a direction parallel with the centerline 18 (e.g., a longitudinal direction).

[0038] The joint assembly 100 also includes a plurality of actuators 116 including a first actuator 116a and a second actuator 116b, and a plurality of links 114 including a first link 114a (e.g., a connecting member, a bar, a rod, etc.) and a second link 114b (e.g., a connecting member, a bar, a rod, etc.). The first actuator 116a and the second actuator 116b can be linear actuators that extend and retract. The first actuator 116a and the second actuator 116b are coupled to the forearm frame member 110. In particular, the first actuator 116a and the second actuator 116b are constrained such that the first actuator 116a and the second actuator 116b do not pivot or move laterally while extending and retracting. In this way, the first actuator 116a and the second actuator 116b are configured to only provide linear motion without themselves rotating or otherwise moving. The first actuator 116a and the second actuator 116b are disposed on opposite sides of the bracket 112. In particular, the first actuator 116a and the second actuator 116b can be offset from the yaw axis 102 such that a moment arm is defined and the first actuator 116a and the second actuator 116b can provide torque in either direction to drive rotation of the universal joint 118 about the yaw axis 102 (e.g., to independently control position of the hand 14 relative to the forearm 12. As shown in FIG. 2, the first link 114a and the second link 114b are disposed on opposite sides of a centerline 18 of the forearm 12. The first actuator 116a is configured to exert a first force on a first side 140 of the hand structure 120 via the first link 114a, and the second actuator 116b is configured to exert a second force on a second side 142 of the hand structure 120 via the second link 114b.

[0039] As shown in FIGS. 1 and 2, the joint assembly 100 also includes a pair of links, shown as first link 114a and second link 114b. The first link 114a is coupled at its proximate end 126 (e.g., a first end) with an end of the first actuator 116a and is coupled at its distal end 128 (e.g., a second end) with the hand structure 120. Likewise, the second link 114b is coupled at its proximate end 126 (e.g., a first end) with an end of the second actuator 116b and is coupled at its distal end 128 (e.g., a second end) with the hand structure 120. The first link 114a and the second link 114b are disposed on opposite sides of the centerline 18 of the forearm 12. The distal ends 128 of the links 114 can be provided as yoked ends, clevises, U-shape protrusions, etc.

[0040] As shown in FIG. 2, the first link 114a and the second link 114b each have a curved shape or angled shape. In particular, the first link 114a and the second link 114b each have a first portion that is angled outwards from their proximate ends 126 relative to the centerline 18, and a second portion that is angled inwards towards the distal ends 128 relative to the centerline 18. For example, as shown in FIG. 2, the first link 114a and the second link 114b protrude outwards from the actuators 116 and then protrude inwards to opposite sides of the hand structure 120. The angled shapes of the first link 114a and the second link 114b facilitate improved rotational range of the universal joint 118 about the yaw axis 102 and the pitch axis 104 by providing additional space or clearance between the bracket 112 and the links 114.

[0041] As shown in FIGS. 1 and 2, the links 114 are coupled with the hand structure 120 via secondary universal joints, shown as coupling universal joints 122. In some embodiments, the universal joint 118 is a central universal joint. The coupling universal joints 122 are disposed on opposite sides of the hand structure 120 such that the links 114 are configured to exert a torque to rotate the hand structure 120 and the universal joint 118 about the yaw axis 102 in either direction. The coupling universal joints 122 pivotally couple with the distal ends 128 of the links 114 on opposite sides (e.g., fore and aft sides or left and right sides) of the hand structure 120 about first axes 106, shown as first axis 106a and first axis 106b. The first axes 106 are generally perpendicular to the pitch axis 104. The first axes 106, as viewed from the side of the robotic arm assembly 10, are angularly offset relative to the yaw axis 102. In particular, the first axes 106 are non-parallel with the yaw axis 102. For example, as shown in FIG. 1, the yaw axis 102 is perpendicular to both the pitch axis 104 and the centerline 18 and extends in a vertical or upwards direction. However, as shown in FIG. 1, the first axes 106 are angled such that, when the hand 14 is in the neutral position as shown in FIG. 1, the first axes 106 extend upwards and also forwards towards the hand 14. As shown in FIG. 2, the first axes 106 extend inwards towards the centerline 18. In this way, the first axes 106 are angled both towards the hand 14 and also inwards towards the centerline 18. The coupling universal joints 122 can include bores or openings that define the first axes 106 and are aligned with corresponding openings of the distal ends 128. In some embodiments, pins or cylindrical members are received within the openings of the distal ends 128 (e.g., formed in opposing portions of the yoked ends) and the bore of the coupling universal joints 122 that define the first axes 106.

[0042] In certain embodiments, the orientation and offset of the yaw axis 102, pitch axis 104, and first axes 106 of the coupling universal joints 122 are selected to enable independent and simultaneous control of both yaw and pitch rotation of the hand 14 relative to the forearm 12 using only two actuators 116. Specifically, the first axes 106 of the coupling universal joints 122 are radially offset from and non-parallel to the yaw axis 102, while the second axes 108 of the coupling universal joints 122 are substantially parallel to the pitch axis 104 of the central universal joint. This geometric relationship allows differential actuation between the first and second actuators 116 to effect rotation about the yaw axis 102, while uniform actuation of the first and second actuators 116 effects rotation about the pitch axis 104. As a result, the wrist assembly (i.e., the joint assembly 100) achieves full two-degree-of-freedom control without requiring separate dedicated actuators for each axis, reducing part count, mechanical complexity, and weight while maintaining precise and responsive motion in both yaw and pitch directions.

[0043] The coupling universal joints 122 also define second axes 108, shown as second axis 108a and second axis 108b. The second axes 108 are parallel with the pitch axis 104. The second axes 108 are positioned above (e.g., higher than, offset in a direction parallel with the yaw axis 102) the pitch axis 104. The second axes 108 are co-axial with each other. The coupling universal joints 122 are pivotally coupled with the hand structure 120 about the second axes 108. The coupling universal joints 122 facilitate coupling the first link 114a and the second link 114b with the hand structure 120 such that the first link 114a and the second link 114b can move the universal joint 118 and the hand structure 120 to rotate about the yaw axis 102 and the pitch axis 104. The coupling universal joints 122 can be coupled with the first side 140 and the second side 142 of the hand structure 120 similarly to the coupling between the distal ends 128 of the links 114 and the coupling universal joints at the first axes 106.

[0044] As shown in FIGS. 3 and 6–8, the fingers 16 may be robotic appendages (e.g., robotic fingers, etc.) and/or may be a portion of a larger robotic appendage (e.g., a robotic hand, a robotic humanoid, etc.). The fingers 16 may be utilized to press, grasp, grab, grapple, pull, push, twist, or otherwise interact with other objects. By way of example, a group of the fingers 16 may be used together to grab and lift an object, such as a tool, part, container, or other object.

[0045] As shown in FIGS. 3 and 6–8, a finger 16 includes a series of jointed members (e.g., pivoting members, bodies, structures, elements, phalanges, etc.), shown as finger members 150. The finger members 150 may form a structure of the finger 16. The finger members 150 include a distal body, distal structure, or finger member, shown as distal finger member 150A, a first intermediate or middle body (e.g., middle structure, finger member, etc.), shown as middle finger member 150B, a second intermediate or middle body (e.g., middle structure, finger member, etc.), shown as middle finger member 150C, and a proximal or base body (e.g., base structure, finger member), shown as base finger member 150D. In some embodiments, one or more of the fingers 16 of the hand 14 may include more or fewer finger members 150 than the distal finger member 150A, the middle finger member 150B, the middle finger member 150C, and the base finger member 150D. By way of example, as shown in FIG. 3, the hand 14 includes a first finger 16 (e.g., index finger, pointer finger, etc.), a second finger 16 (e.g., middle finger), a fourth finger 16 (e.g., ring finger), and a fourth finger 16 (e.g., pinky finger) each including the distal finger member 150A, the middle finger member 150B, the middle finger member 150C, and the base finger member 150D. Further, the hand 14 may include a fifth finger 16 (e.g., thumb) that does not include (e.g., omits) one of the middle finger member 150B or the middle finger member 150C.

[0046] As shown, the finger members 150 are generally arranged in line with one another, such that the finger members 150 are longitudinally offset from one another. The distal finger member 150A, the middle finger member 150B, the middle finger member 150C, and the base finger member 150D arranged in sequence along the longitudinal direction. The base finger member 150D may include one or more mounting features (e.g., fasteners, bosses, etc.) that facilitate coupling the finger 16 to the hand 14. As shown in FIGS. 6 and 7, the base finger member 150D is configured to pivotably couple the finger 16 with the hand 14 such that the finger 16 is pivotable relative to the hand 14 about an axis of rotation, shown as axis 152. The finger 16 may be pivotable about the axis 152 in a first direction to adductively move the finger 16 (e.g., to adduct the finger 16), and may be pivotable in a second direction opposite the first direction to abductively move the finger 16 (e.g., to abduct the finger 16). In some embodiments, the axis 152 is substantially parallel with the yaw axis 102.

[0047] Each of the finger members 150 includes a first surface, shown as top surface 154, and a second surface, bottom surface, engagement surface, or grasping surface, shown as bottom surface 158. As shown in FIG. 8, the top surface 154 faces upward, and the bottom surface 158 faces downward. Accordingly, the top surface 154 and the bottom surface 158 generally face in opposing directions.

[0048] Each adjacent pair of the finger members 150 are pivotably coupled to one another, such that the adjacent finger members 150 are pivotable about a lateral axis (e.g., an axis perpendicular to the pitch axis 104). By way of example, the distal finger member 150A may be pivotable relative to the middle finger member 150B about a lateral axis. The collective pivoting of each pair of finger members 150 may permit the finger 16 to bend in a pivoting direction, rotation direction, or bending direction, shown as grasping direction 162. The finger 16 may bend in the grasping direction 162 from a fully extended configuration (e.g., as shown in FIGS. 3 and 6–8) to a bent configuration in which the finger 16 curves downward. Moving the finger 16 to the bent configuration may cause the bottom surfaces 158 to engage an object, permitting the finger 16 to grasp and manipulate the object.

[0049] Each of the finger members 150 includes at least one exterior surface, contact surface, rolling surface, or engagement surface, shown as contact surface 166. The contact surfaces 166 are curved and positioned to engage one another (e.g., arranged facing toward one another). As shown in FIG. 8, the distal finger member 150A includes a contact surface 166 positioned to engage a corresponding contact surface 166 of the middle finger member 150B. The middle finger member 150B includes a pair of contact surfaces 166 positioned to engage corresponding contact surfaces 166 of the distal finger member 150A and the middle finger member 150C, respectively. The middle finger member 150C includes a pair of contact surfaces 166 positioned to engage corresponding contact surfaces 166 of the middle finger member 150B and the base finger member 150D, respectively. The base finger member 150D includes a contact surface 166 positioned to engage a corresponding contact surface 166 of the middle finger member 150C.

[0050] As two finger members 150 pivot relative to one another, the contact surfaces 166 of those finger members 150 engage one another in rolling contact. The contact surfaces 166 may engage one another directly or indirectly through one or more intervening members. The lateral axis about which the finger members 150 pivot relative to one another may be positioned at the point of contact between the two contact surfaces 166. As the finger members 150 pivot, different portions of the contact surfaces 166 come into engagement with one another. Accordingly, the lateral axis may move along the contact surfaces 166 as the finger 16 moves through a range of motion between the fully extended configuration and the bent configuration. This relative motion of the finger members 150 may be referred to as rolling contact motion.

[0051] Referring to FIGS. 6–8, the finger 16 includes a series of couplers (e.g., pivot joints, rolling joints, connections, bending assemblies, etc.), shown as joints 170. Front and rear portions of each joint 170 may be received within adjacent finger members 150, and a middle portion of each joint 170 may be exposed between the adjacent finger members 150. Each joint 170 is configured to pivotably couple an adjacent pair of the finger members 150. As shown in FIGS. 6 and 8, a first joint 170 couples the base finger member 150D and the middle finger member 150C, a second joint 170 couples the middle finger member 150C and the middle finger member 150B, and a third joint 170 couples the middle finger member 150B and the distal finger member 150A. The joints 170 may permit rolling contact between the finger members 150 (e.g., along the contact surfaces 166) while limiting movement other than rolling contact motion (e.g., vertical and lateral translation, rotation about a longitudinal axis, etc.). As shown in FIGS. 6 and 8, the first joint 170 is positioned closer to a proximal end of the finger 16 relative to the second joint 170, and the second joint 170 is positioned closer to the proximal end of the finger 16 relative to the third joint 170 (e.g., the third joint 170 is positioned closer to a distal end of the finger 16 than the second joint 170).

Control Cable Management

[0052] As shown in FIGS. 1–8, the robotic arm assembly 10 includes a plurality of cables (e.g., hand tendons, hand control lines, tensile members, actuator cables, etc.), shown as control cables 174. The control cables 174 extend throughout the robotic arm assembly 10 through the forearm 12, the hand 14, and the fingers 16. The control cables 174 are coupled to the forearm 12 at first ends thereof and are coupled to one or more of the finger members 150 at second ends thereof. When a tensile force is applied to the control cables 174, the control cables 174 may apply forces to one or more of the finger members 150, causing the finger members 150 to pivot and bend the fingers 16 in the grasping direction 162. In some embodiments, the control cables 174 are coupled to an actuator (e.g., an electric motor, an electric linear actuator, etc.) that applies a tensile force to one or more of the control cables 174 to actuate the fingers 16.

[0053] The control cables 174 may be made from a polymer or another suitable material configured to facilitate flexibility of the control cables 174, repeated use under bending and tension, inhibiting friction between adjacent control cables 174 and other components of the robotic arm assembly 10. In some embodiments, the control cables 174 are coated using a material (e.g., polymer) configured to reduce heat generation during operation of the robotic arm assembly 10. In some embodiments, the control cables 174 are braided to increase the bending resistance of the control cables 174 under tension. In some embodiments, the control cables 174 are made from another suitable material (e.g., metal, metal alloys, etc.). In some embodiments, the control cables 174 are received in linings (e.g., tubes, conduits, etc.). The linings may be made from an abrasion resistant material, a low friction material, or another suitable material configured to decrease force loss of the control cables 174 and decrease heat generation of the control cables 174 during operation of the robotic arm assembly 10. The linings and the control cables 174 therein may be lubricated to decrease force loss of the control cables 174 and decrease heat generation of the control cables 174. The lining may be lubricated from one or both sides thereof using capillary action or using a differential pressure (e.g., before or after the control cables 174 are terminated or coupled at the finger members 150). In other embodiments, the control cables 174 do not include linings.

[0054] In some embodiments, the finger 16 includes a series of biasing members (e.g., springs) coupled to the finger members 150 and configured to apply a biasing force onto the finger members 150. The biasing forces of the springs may oppose the tensile forces of the control cables 174, such that the biasing forces cause the finger 16 to bend opposite the grasping direction 162. When tension on the control cables 174 is released, the springs may automatically return the finger 16 to the fully extended position.

[0055] As shown in FIG. 3, the joint assembly 100 is positioned between the forearm 12 and the hand 14. The robotic arm assembly 10 includes a cable guide member (e.g., forearm cable guide), shown as cable guide structure 178, positioned within the forearm 12. The joint assembly 100 is positioned longitudinally between the cable guide structure 178 and the hand 14. The cable guide structure 178 may define an opening (e.g., cavity, space, etc.) configured to receive the control cables 174. The cable guide structure 178 may include a plurality of guides (e.g., slots, grooves, channels, etc.) each configured to receive a control cable 174 to guide the control cables 174 in a direction towards the joint assembly 100. By way of example, the cable guide structure 178 may be configured to align the control cables 174 prior to the control cables 174 being routed to and through the joint assembly 100. In some embodiments, the robotic arm assembly 10 does not include the cable guide structure 178.

[0056] As shown in FIGS. 4 and 5, the control cables 174 are arranged in a first configuration 182 (e.g., horizontal arrangement, lateral arrangement, etc.) at a first side 186 (e.g., forearm side, proximal side, etc.) of the joint assembly 100, and the control cables 174 are arranged in a second configuration 190 (e.g., vertical configuration) at a second side 194 (e.g., hand side, distal side, etc.) of the joint assembly 100. According to an example embodiment, in the first configuration 182, the control cables 174 are arranged in at least one lateral stack such that adjacent control cables 174 in a respective lateral stack are laterally adjacent to each other. In other words, in the first configuration 182, there are more control cables 174 arranged adjacent to one another in the lateral direction than there are control cables 174 arranged adjacent to one another in a vertical direction perpendicular to the lateral direction. The control cables 174 in the first configuration 182 extend in a longitudinal direction through or past the joint assembly 100 at the first side 186. In some embodiments, the first configuration 182 includes more than one lateral stack of control cables 174. By way of example, as shown in FIGS. 4 and 5, the control cables 174 arranged in the first configuration 182 include two lateral stacks of control cables 174 positioned on top of each other. According to an example embodiment, in the second configuration 190, the control cables 174 are arranged in at least one vertical stack such that adjacent control cables 174 in a respective vertical stack are vertically adjacent to each other. In other words, in the second configuration 190, there are more control cables 174 arranged adjacent to one another in the vertical direction than there are control cables 174 arranged adjacent to one another in the lateral direction perpendicular to the vertical direction. The control cables 174 in the second configuration 190 extend in a longitudinal direction through or past the joint assembly 100 at the second side 194. In some embodiments, the second configuration 190 includes more than one vertical stack of control cables 174. By way of example, as shown in FIG. 4, the control cables 174 arranged in the second configuration 190 include two vertical stacks of control cables 174 positioned laterally adjacent to each other. In some embodiments, the control cables 174 in the first configuration 182 or the second configuration 190 are otherwise suitably arranged (e.g., in a line, rectangle, or other close-packing arrangement) to minimize the lever arm of the control cables 174 across the joint assembly 100.

[0057] As shown in FIG. 4, the control cables 174 define a transition region 198 at the joint assembly 100 where the control cables 174 transition from the first configuration 182 to the second configuration 190. In some embodiments, the control cables 174 are configured to pass through the joint assembly 100. By way of example, the joint assembly 100 may include one or more components defining openings through which the control cables 174 are received and routed from the first side 186 of the joint assembly 100 to the second side 194 of the joint assembly 100. In such an example, the control cables 174 may transition from the first configuration 182 to the second configuration 190 at the transition region 198 within the joint assembly 100. In other embodiments, the control cables 174 are configured to pass around (e.g., over the top of, or underneath) the joint assembly 100. In such embodiments, the transition region 198 may be located above or below the joint assembly 100 as the control cables 174 are routed from the first side 186 of the joint assembly 100 to the second side 194 of the joint assembly 100.

[0058] As shown in FIG. 5, the joint assembly 100 includes a first cable guide, shown as first control cable support member 202, and a second cable guide, shown as second control cable support member 206. The first control cable support member 202 and the second control cable support member 206 may be coupled to the joint assembly 100 using one ore more fasteners. In some embodiments, the first control cable support member 202 and the second control cable support member 206 are integrally formed with one or more components off the joint assembly 100. By way of example, the first control cable support member 202 may be integrally formed with the universal joint 118 and the second control cable support member 206 may be integrally formed with the hand structure 120. By way of another example, the universal joint 118 may be the first control cable support member 202 and the hand structure 120 may be the second control cable support member 206. In some embodiments, the first control cable support member 202 is coupled with the forearm 12 and the second control cable support member 206 is coupled with the hand 14. In some embodiments, the first control cable support member 202 and the second control cable support member 206 are pivotable relative to the forearm 12 and/or the hand 14 about the yaw axis 102 and/or the pitch axis 104.

[0059] As shown in FIG. 5, the first control cable support member 202 defines a first opening 210 (e.g., first aperture, first through hole, first passthrough, first conduit, etc.) configured to receive the control cables 174 and support the control cables 174 in the first configuration 182 (e.g., to retain the control cables 174 in the first configuration 182 as the control cables 174 pass through the first opening 210). The second control cable support member 206 defines a second opening 214 (e.g., second aperture, second through hole, second passthrough, second conduit, etc.) configured to receive the control cables 174 and support the control cables 174 in the second configuration 190 (e.g., to retain the control cables 174 in the second configuration 190 as the control cables 174 pass through the second opening 214).

[0060] According to an example embodiment, when the control cables 174 are arranged in either the first configuration 182 or the second configuration 190, the control cables 174 are grouped or otherwise positioned within the stack according to the fingers 16 to which the control cables 174 are coupled with. As shown in FIG. 4, the control cables 174 in the first configuration 182 and the second configuration 190 are grouped in five groups 218 each corresponding with a respective one of the five fingers 16 of the hand 14. In particular, the five groups 218 include a first group 218A of control cables 174 that correspond with and are routed to a first finger 16, a second group 218B of control cables 174 that correspond with and are routed to a second finger 16, a third group 218C of control cables 174 that correspond with and are routed to a third finger 16, a fourth group 218D of control cables 174 that correspond with and are routed to a fourth finger 16, and a fifth group 218E of control cables 174 that correspond with and are routed to a fifth finger 16. In other words, the control cables 174 in a group 218 at a first lateral side of the stack (e.g., the lateral stack or the vertical stack) are routed to (e.g., dedicated to) the fingers 16 at the same respective lateral side of the hand 14, the control cables 174 in a group 218 at a lateral middle of the stack are routed to the fingers 16 at the middle of the hand 14, and the control cables 174 in a group 218 at a second lateral side of the stack are routed to the finger 16 at the same respective side of the hand 14. By way of example, for a left-hand robotic arm assembly 10, the control cables 174 in the first group 218A may be routed to the thumb finger 16. By way of another example, the control cables 174 in a group 218 along a right side of the stack in the first configuration 182 or the second configuration 190 may be routed to the fingers 16 at the right side of the hand 14. In this arrangement, the control cables 174 are positioned and grouped in the groups 218 within the first configuration 182 and the second configuration 190 to limit the bends in the control cables 174 and limit the number of cross overs (e.g., when one control cable 174 crosses over the top of or underneath another control cable 174) as the control cables 174 are routed to respective fingers 16. While the groups 218 are shown as having a particular number of control cables 174, it should be understood that the groups 218 may have more or fewer control cables 174 than shown. Further, while the groups 218 are shown in a particular arrangement, order, or sequence, it should be understood that the groups 218 may be otherwise suitably arranged based on the locations of the fingers 16 to which the control cables 174 in the groups 218 are being routed to, thereby limiting the bends and cross overs along the lengths of the control cables 174.

[0061] According to an example embodiment, the control cables 174 are arranged in the first configuration 182 at the first side 186 of the joint assembly 100 and in the second configuration 190 at the second side 194 of the joint assembly 100 to reduce a bending force on the control cables 174 and reduce crosstalk between the control cables 174. As discussed in greater detail above, the joint assembly 100 provides two degrees of freedom of the robotic arm assembly 10 including movement of the hand 14 about the yaw axis 102 and the pitch axis 104. On the first side 186 of the joint assembly 100, the control cables 174 are arranged in the first configuration 182 in which the control cables 174 are laterally stacked in a direction substantially parallel with the pitch axis 104. On the second side 194 of the joint assembly 100, the control cables 174 are arranged in the second configuration 190 in which the control cables 174 are vertically stacked in a direction substantially parallel with the yaw axis 102. Further, the transition region 198 is positioned such that the control cables 174 pass proximate to the yaw axis 102 and the pitch axis 104 to limit a moment arm on the control cables 174 as they pass through or around the joint assembly 100. In other words, the control cables 174 are positioned such that the first configuration 182 minimizes the moment arm of the control cables 174 across (e.g., relative to) the pitch axis 104, and the control cables 174 are positioned such that the second configuration 190 minimizes the moment arm of the control cables 174 across (e.g., relative to) the yaw axis 102. Stated differently, the first configuration 182 and the second configuration 190 are configured to position the control cables 174 proximate to the respective yaw and pitch centers of the hand 14, thereby limiting torque generation and control cable length change during movement of the hand 14. Further, the first configuration 182 and the second configuration 190 may be configured to arrange the control cables 174 to reduce crosstalk between the control cables 174 such that actuation of the hand 14 does not unintentionally actuate the fingers 16, and vice versa. This routing is configured to reduce total friction between the control cables 174 and the number of routing bends in each control cable 174, which in turn improves efficiency of force transmission to the fingers 16.

[0062] As shown in FIGS. 3 and 6–8, a plurality of control cables 174 are coupled to each finger 16 such that when a tensile force is applied to the control cables 174, the control cables 174 may apply forces to one or more of the finger members 150, causing the finger members 150 to pivot and bend the fingers 16 in the grasping direction 162. As shown in FIGS. 6–7, three control cables 174 are coupled with the finger 16 to selectively pivot one or more of the finger members 150 to bend the finger 16 in the grasping direction 162. In particular, a first control cable 174 is coupled with the distal finger member 150A at a second end of the first control cable 174 opposite the first end of the first control cable 174 where the first control cable 174 is coupled with the forearm 12, and second and third control cables 174 are coupled with the middle finger member 150C at second ends thereof. The finger 16 shown in FIGS. 6–

8 therefore defines four degrees of freedom including a first degree of freedom at the first joint 170, a second degree of freedom at the second joint 170, a third degree of freedom at the third joint 170, and a fourth degree of freedom about the axis 152. In some embodiments, more or fewer than three control cables 174 are coupled to a respective finger 16. By way of example, four control cables 174 may be coupled to a respective finger 16 such that the respective finger 16 defines four degrees of freedom including the first, second, third, and fourth degrees of freedom, and a fifth degree of freedom about an axis offset from and angled relative to the axis 152.

[0063] Referring to FIGS. 6–8, applying a tensile force to the first control cable 174 coupled with the distal finger member 150A causes the first control cable 174 to apply a force to pivot the distal finger member 150A and the middle finger member 150B to bend the finger 16 in the grasping direction 162. Further, applying a tensile force to the second control cable 174 coupled with the middle finger member 150C causes the second control cable 174 to apply a force to pivot the finger 16 about the axis 152 in a first direction to adductively move the finger 16, and applying a tensile force to the third control cable 174 coupled with the middle finger member 150C causes the second control cable 174 to apply a force to pivot the finger 16 about the axis 152 in a second direction opposite the first direction to abductively move the finger 16.

[0064] As shown in FIGS. 7 and 8, the first control cable 174 is routed behind (e.g., on top of) the first joint 170 between the middle finger member 150C and the base finger member 150D, and routed forward (e.g., in front of, underneath, etc.) (i) the second joint 170 between the middle finger member 150C and the middle finger member 150B and (ii) the third joint 170 between the middle finger member 150B and the distal finger member 150A. In other words, the first control cable 174 is routed along a back side of the first joint 170 proximate the top surface 154 of the base finger member 150D and the middle finger member 150C, and routed along (i) a front side of the second joint 170 proximate the bottom surfaces 158 the middle finger member 150C and the middle finger member 150B and (ii) a front side of the third joint 170 proximate the bottom surfaces 158 the middle finger member 150B and the distal finger member 150A. Because the first control cable 174 is routed forward the second joint 170 and the third joint 170, when a tensile force is applied to the first control cable 174, the first control cable 174 applies a force to pivot the distal finger member 150A and the middle finger member 150B to bend the finger 16 in the grasping direction 162. Further, because the first control cable 174 is routed behind the first joint 170, when a tensile force is applied to the first control cable 174, the first control cable 174 applies a force to pivot the middle finger member 150C to bend the finger 16 in an extension direction opposite the grasping direction 162. In some embodiments, when a tensile force is applied to the first control cable 174, the first control cable 174 applies a force to pivot the middle finger member 150C to bend the finger 16 in the grasping direction 162.

[0065] As shown in FIGS. 7 and 8, the second and third control cables 174 are routed in front of (e.g., beneath) the first joint 170 between the middle finger member 150C and the base finger member 150D, and terminate at (e.g., are coupled to) the middle finger member 150C. In other words, the second and third control cables 174 are routed along a front side of the first joint 170 proximate the bottom surfaces 158 of the base finger member 150D and the middle finger member 150C. Because the second and third control cables 174 are routed forward the first joint 170, when a tensile force is applied to the second and third control cables 174 (e.g., a substantially similar tensile force applied to both the second control cable 174 and the third control cable 174), the second and third control cables 174 collectively apply a force to pivot the middle finger member 150C to bend the finger 16 in the grasping direction 162.

[0066] As shown in FIG. 6, the finger members 150 include a plurality of slots (e.g., grooves, openings, cutouts, etc.), shown as control cable channels 222, each configured to receive at least a portion of a respective control cable 174. The control cables 174 are routed within the control cable channels 222 along the length of the finger 16 to a control cable termination (e.g., termination cavity), shown as termination structure 226, at which the second ends of the control cables 174 terminate. As shown in FIG. 6, the control cable channels 222 are positioned at the longitudinal ends of the finger members 150 and open to the joints 170 to facilitate passing the control cables 174 across the joints 170. As shown in FIG. 6, the distal finger member 150A includes a first control cable channel 222 at a proximal end thereof that opens to the third joint 170. The first control cable channel 222 may be laterally centered along the distal finger member 150A. As shown in FIG. 6, the middle finger member 150B includes (i) a second control cable channel 222 at a distal end thereof aligned (e.g., laterally aligned, laterally centered, etc.) with the first control cable channel 222 and opened to the third joint 170 and (ii) a third control cable channel 222 at a proximal end thereof that opens to the second joint 170. The third control cable channel 222 may be laterally aligned with the first control cable channel 222 and the second control cable channel 222. As shown in FIG. 6, the middle finger member 150C includes (i) a fourth control cable channel 222 at a distal end thereof aligned with the third control cable channel 222 and opened to the second joint 170 and (ii) fifth and sixth control cable channels 222 at a proximal end thereof that open to the first joint 170. The fifth and sixth control cable channels 222 are laterally spaced apart from each other and are positioned along the contact surface 166 of the middle finger member 150C. As shown in FIG. 6, the base finger member 150D includes seventh and eighth control cable channels 222 at a distal end thereof that open to the first joint 170. The seventh and eighth control cable channels 222 are laterally spaced apart from each other and are laterally aligned with the fifth and sixth control cable channels 222. The seventh and eighth control cable channels 222 are positioned along the contact surface 166 of the base finger member 150D.

[0067] According to an example embodiment, the control cable channels 222 are configured to receive the control cables 174 to maintain a lateral position of the control cables 174 as the control cables 174 are routed along the finger 16 (e.g., to laterally align a respective control cable 174 along a portion of the length of the finger 16). By way of example, the control cable channels 222 may engage with sides of the control cables 174 to prevent the control cables 174 from moving out of the control cable channels 222. The control cable channels 222 are positioned along the finger members 150 to laterally align the control cables 174 received therein with the respective termination structure 226 to which the control cables 174 are being routed. The control cable channels 222 may therefore inhibit unintentional bending of the finger 16 due to the control cables 174 being laterally misaligned with the termination structure 226 along the finger 16. As shown in FIG. 6, the first, second, third, and fourth control cable channels 222 are configured to receive the first control cable 174 to (i) guide the first control cable 174 to a respective termination structure 226 that couples the first control cable 174 with the distal finger member 150A and (ii) laterally align the first control cable 174 with the respective termination structure 226. The fifth and seventh control cable channels 222 are configured to receive the second control cable 174 to (i) guide the second control cable 174 to a respective termination structure 226 that couples the second control cable 174 with the middle finger member 150C and (ii) laterally align the second control cable 174 with the respective termination structure 226. Similarly, the sixth and eighth control cable channels 222 are configured to receive the third control cable 174 to (i) guide the third control cable 174 to a respective termination structure 226 that couples the third control cable 174 with the middle finger member 150C and (ii) laterally align the third control cable 174 with the respective termination structure 226.

[0068] As shown in FIGS. 7 and 8, the termination structures 226 are configured to couple the control cables 174 with the finger members 150 at the second ends thereof. In particular, a first termination structure 226 is configured to couple the first control cable 174 with the distal finger member 150A, a second termination structure 226 is configured to couple the second control cable 174 with the middle finger member 150C, and a third termination structure 226 is configured to couple the third control cable 174 with the middle finger member 150C. In some embodiments, the finger 16 includes more or fewer termination structures 226 depending on the number of control cables 174 coupled with the finger 16. In some embodiments, the respective termination structure 226 are configured to couple the first ends of the control cables 174 with the forearm 12.

[0069] Each termination structure 226 may include one or more mechanical features to secure the control cables 174 and facilitate transmitting the tensile force applied to the control cables 174 to the finger members 150 to bend the finger 16. In some embodiments, the termination structures 226 are disposed within or adjacent to a distal portion or a proximal portion of the finger members 150. The respective termination structure 226 may be embedded, fastened, or otherwise fixed to the finger members 150. In some embodiments, the termination structures 226 include a spelter socket-style termination (e.g., resin-filled cavity, cast metal socket, etc.) in which the control cable 174 is splayed and embedded within a resin or cast metal body. The splayed configuration of the control cables 174 may increase bonding surface area between the control cables 174 and the termination structures 226. In some embodiments, the termination structures 226 include a crimp-style termination (e.g., swaged sleeve, ferrule, etc.) in which a shell is compressed around the control cables 174. In some embodiments, the termination structures 226 include a shell-type termination (e.g., metal housing, polymer casing, etc.) in which the control cables 174 are enclosed within a rigid or semi-rigid shell. In some embodiments, the termination structures 226 include a self-tightening cam or wedge mechanism (e.g., friction lock, cam lock, wedge lock, etc.) in which the control cables 174 are secured by a structure defining a geometry that tightens (e.g., self-tightens) under a load. In some embodiments, the termination structures 226 include a knot or splice (e.g., overhand knot, eye splice, etc.) in which the control cables 174 are tied or woven to form a mechanical stop or loop. In some embodiments, the termination structures 226 include an interlocking termination (e.g., modular connector, split anchor, etc.) in which the control cables 174 are divided into multiple parts to facilitate ease of assembly and maintenance. In some embodiments, the termination structures 226 include a capstan or winding path (e.g., tension-reducing drum, routing groove, etc.) in which the control cables 174 are routed around a curved surface to reduce the tension applied to the termination point, which may reduce stress concentrations at the termination structures 226. In other embodiments, the robotic arm assembly 10 may include clamp-style terminations in which the control cables 174 are directly clamped to a pushrod, an actuator, or finger member 150 without a dedicated termination fitting. In such embodiments, the robotic arm assembly 10 may omit the termination structures 226, and the control cables 174 may be coupled directly to an integral component of the robotic arm assembly 10 without using a termination structure 226.

[0070] As utilized herein with respect to numerical ranges, the terms “approximately,” “about,” “substantially,” and similar terms generally mean +/- 10% of the disclosed values. When the terms “approximately,” “about,” “substantially,” and similar terms are applied to a structural feature (e.g., to describe its shape, size, orientation, direction, etc.), these terms are meant to cover minor variations in structure that may result from, for example, the manufacturing or assembly process and are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the disclosure as recited in the appended claims.

[0071] It should be noted that the term “exemplary” and variations thereof, as used herein to describe various embodiments, are intended to indicate that such embodiments are possible examples, representations, or illustrations of possible embodiments (and such terms are not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

[0072] The term “coupled” and variations thereof, as used herein, means the joining of two members directly or indirectly to one another. Such joining may be stationary (e.g., permanent or fixed) or moveable (e.g., removable or releasable). Such joining may be achieved with the two members coupled directly to each other, with the two members coupled to each other using a separate intervening member and any additional intermediate members coupled with one another, or with the two members coupled to each other using an intervening member that is integrally formed as a single unitary body with one of the two members. If “coupled” or variations thereof are modified by an additional term (e.g., directly coupled), the generic definition of “coupled” provided above is modified by the plain language meaning of the additional term (e.g., “directly coupled” means the joining of two members without any separate intervening member), resulting in a narrower definition than the generic definition of "coupled" provided above. Such coupling may be mechanical, electrical, or fluidic.

[0073] References herein to the positions of elements (e.g., "top," "bottom," "above," "below") are merely used to describe the orientation of various elements in the FIGURES. It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

[0074] Although the figures and description may illustrate a specific order of method steps, the order of such steps may differ from what is depicted and described, unless specified differently above. Also, two or more steps may be performed concurrently or with partial concurrence, unless specified differently above. Such variation may depend, for example, on the software and hardware systems chosen and on designer choice. All such variations are within the scope of the disclosure. Likewise, software implementations of the described methods could be accomplished with standard programming techniques with rule-based logic and other logic to accomplish the various connection steps, processing steps, comparison steps, and decision steps.

[0075] It is important to note that the construction and arrangement of the mounting system 100 as shown in the various exemplary embodiments is illustrative only. Additionally, any element disclosed in one embodiment may be incorporated or utilized with any other embodiment disclosed herein.

CLAIMS

What is claimed is:

1. A robotic lower arm assembly comprising:

a forearm member;

a hand member including a plurality of appendage members;

a plurality of control cables coupled with the forearm member at first ends thereof and coupled with the plurality of appendage members at second ends thereof, a control cable of the plurality of control cables configured to apply a force to an appendage member of the plurality of appendage members to actuate the appendage member; and

a wrist joint pivotably coupled with the forearm member and the hand member,

wherein the plurality of control cables is arranged in a first configuration at a forearm side of the wrist joint and is arranged in a second configuration different from the first configuration at a hand side of the wrist joint opposite the forearm side.

2. The robotic lower arm assembly of claim 1, wherein, in the first configuration, the plurality of control cables is arranged in a lateral stack, and wherein, in the second configuration, the plurality of control cables is arranged in a vertical stack.

3. The robotic lower arm assembly of claim 1, wherein the wrist joint includes a first control cable support member configured to support the plurality of control cables in the first configuration and a second control cable support member configured to support the plurality of control cables in the second configuration.

4. The robotic lower arm assembly of claim 3, wherein the first control cable support member is coupled with the forearm member and the second control cable support member is coupled with the hand member.

5. The robotic lower arm assembly of claim 1, wherein the plurality of control cables defines a transition region at the wrist joint where the plurality of control cables transitions from the first configuration to the second configuration.

6. The robotic lower arm assembly of claim 1, wherein the wrist joint is pivotably coupled with the forearm member about a yaw axis and pivotably coupled with the hand member about a pitch axis, the yaw axis and the pitch axis perpendicular with each other, and

wherein the first configuration of the plurality of control cables limits a first moment arm on the plurality of control cables across the pitch axis, and wherein the second configuration of the plurality of control cables limits a second moment arm on the plurality of control cables across the yaw axis.

7. The robotic lower arm assembly of claim 1, wherein the appendage member includes a control cable channel configured to receive at least a portion of the control cable.

8. The robotic lower arm assembly of claim 7, wherein the control cable channel is positioned to laterally align the control cable along a length of the appendage member with the second end of the control cable.

9. The robotic lower arm assembly of claim 7, wherein the control cable channel opens to a pivot joint between adjacent structures of the appendage member.

10. The robotic lower arm assembly of claim 1, wherein the second end of the control cable terminates at a termination structure integrally formed with the appendage member.

11. The robotic lower arm assembly of claim 1, wherein the appendage member includes at least two joints, and wherein the control cable is routed behind a first joint of the at least two joints and forward a second joint of the at least two joints.

12. The robotic lower arm assembly of claim 11, wherein the appendage member includes a first structure, a second structure, a third structure, and a fourth structure, wherein the third structure is pivotable relative to the fourth structure at the first joint, the second structure is pivotable relative to the third structure at the second joint, and the first structure is pivotable relative to the second structure at a third joint, and wherein the control cable is routed behind the first joint and forward the second joint and the third joint.

13. The robotic lower arm assembly of claim 12, wherein the control cable is coupled with the first structure at the second end.

14. The robotic lower arm assembly of claim 13, wherein the control cable is a first control cable, and wherein a second control cable and a third control cable of the plurality of control cables are coupled with the third structure at second ends thereof.

15. The robotic lower arm assembly of claim 11, wherein the first joint is positioned closer to a proximal end of the appendage member relative to the second joint.

16. A joint assembly comprising:

a plurality of structures including a first structure, a second structure, a third structure, and a fourth structure; and

a plurality of control cables including a first control cable, a second control cable, and a third control cable,

wherein the third structure is pivotable relative to the fourth structure at a first joint, the second structure is pivotable relative to the third structure at a second joint, and the first structure is pivotable relative to the second structure at a third joint,

wherein the first control cable is coupled with the first structure and is routed behind the first joint and forward the second joint and the third joint, and

wherein the second control cable and the third control cable are coupled with the third structure and are routed forward the first joint.

17. The joint assembly of claim 16, wherein the first joint is positioned closer to a proximal end of the joint assembly relative to the second joint and the third joint.

18. A joint assembly comprising:

a plurality of structures including a first structure, a second structure, and a third structure, the first structure including a first control cable channel, the second structure including a second control cable channel and a third control cable channel, and the third structure including a fourth control cable channel; and

a control cable,

wherein the second structure is pivotable relative to the third structure at a first joint, and the first structure is pivotable relative to the second structure at a second joint,

wherein the first control cable channel and the second control cable channel open to the first joint,

wherein the third control cable channel and the fourth control cable channel open to the second joint, and

wherein the first control cable channel, the second control cable channel, the third control cable channel, and the fourth control cable channel are configured to receive at least a portion of the control cable.

19. The joint assembly of claim 18, wherein the control cable is coupled with the first structure at a termination structure, and wherein the first control cable channel, the second control cable channel, the third control cable channel, and the fourth control cable channel are laterally aligned with the termination structure.

20. The joint assembly of claim 18, wherein the plurality of structures include a fourth structure pivotable relative to the third structure at a third joint, wherein the control cable is a first control cable, and the joint assembly further comprises a second control cable and a third control cable, wherein the third structure includes a fifth control cable channel and a sixth control cable channel laterally spaced from the fifth control cable channel, wherein the fourth structure includes a seventh control cable channel and an eighth control cable channel laterally spaced from the seventh control cable channel, wherein the fifth control cable channel, the sixth control cable channel, the seventh control cable channel, and the eighth control cable channel open to the third joint, wherein the fifth control cable channel and the seventh control cable channel are configured to receive at least a portion of the second control cable, and wherein the sixth control cable channel and the eighth control cable channel are configured to receive at least a portion of the third control cable.

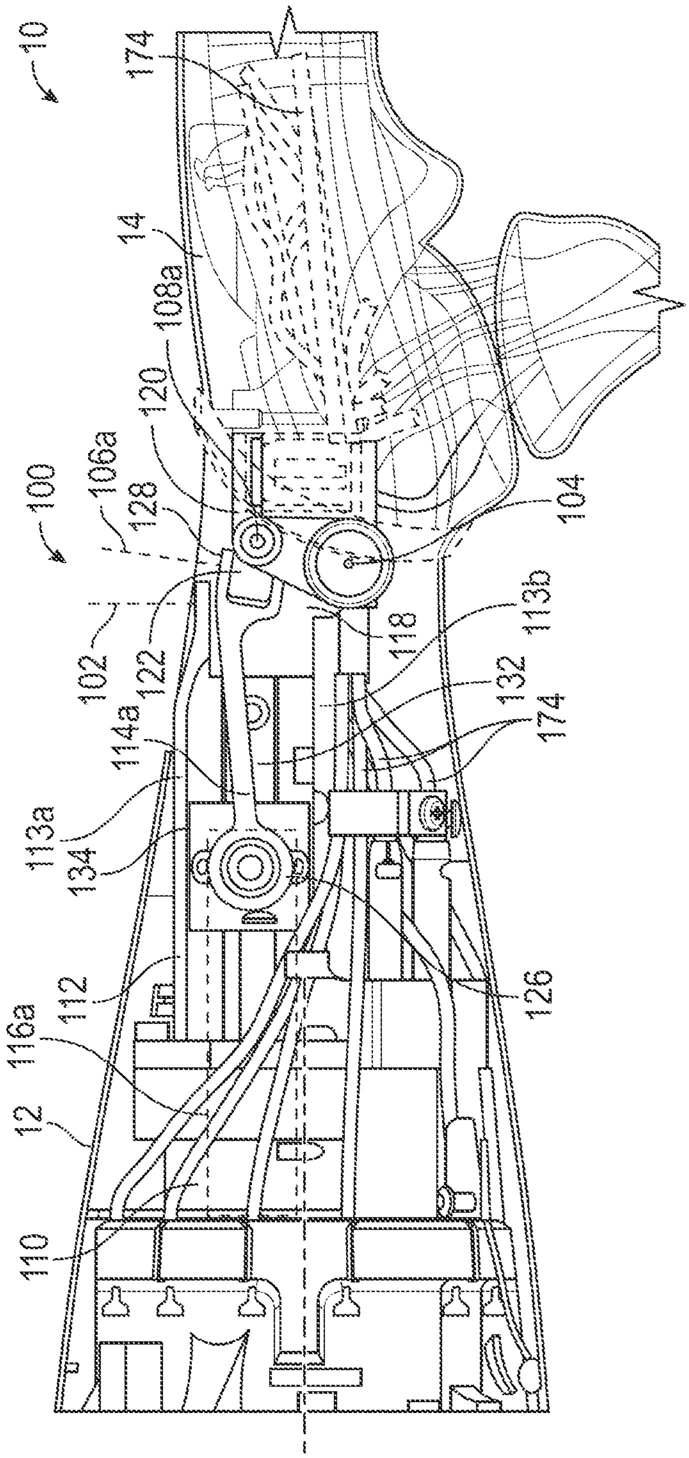

10
174
14
108a
120
106a
128
100
104
102
122
118
113b
132
174
114a
113a
134
112
126
116a
12
110
18

FIG. 1

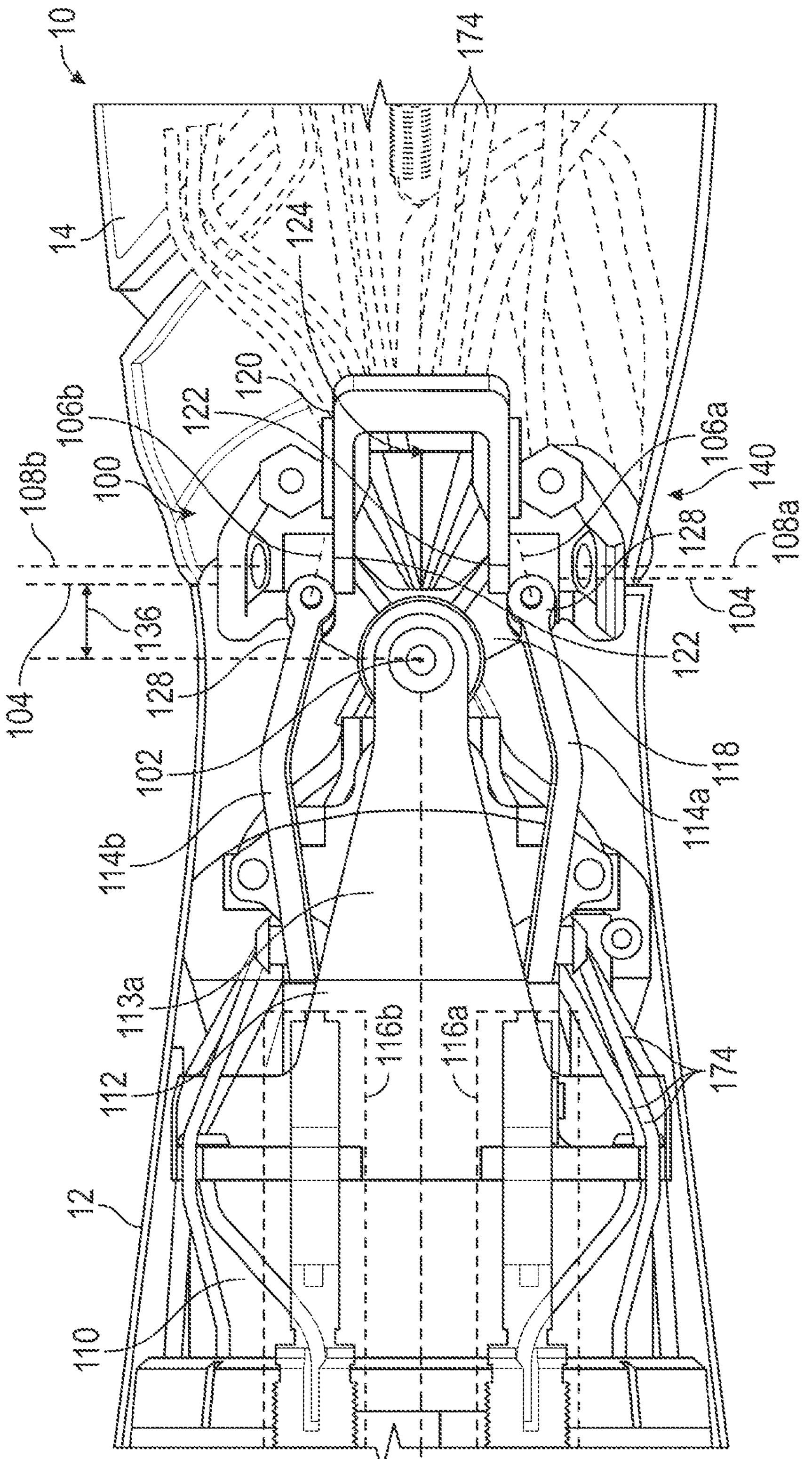
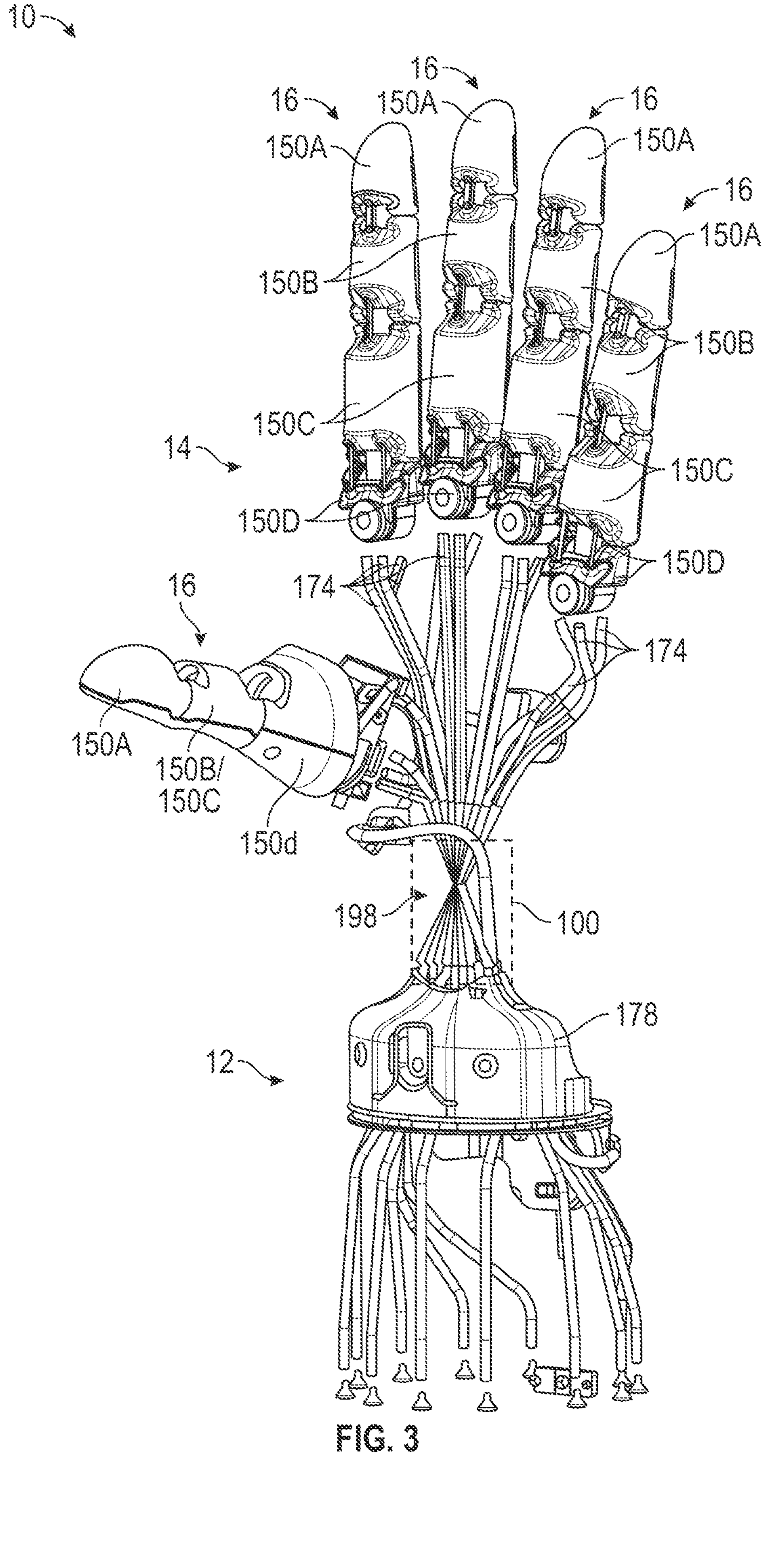

10
174
14
124
120
122
106b
142
108b
100
106a
140
128
108a
104
136
104
128
122
102
118
114a
114b
113a
116b
116a
112
174
12
110
18

FIG. 2



10
16
16
16
16
150A
150A
150A
150A
150B
150B
150C
150C
14
150D
150D
174
174
16
150A
150B/
150C
150d
198
100
178
12

FIG. 3

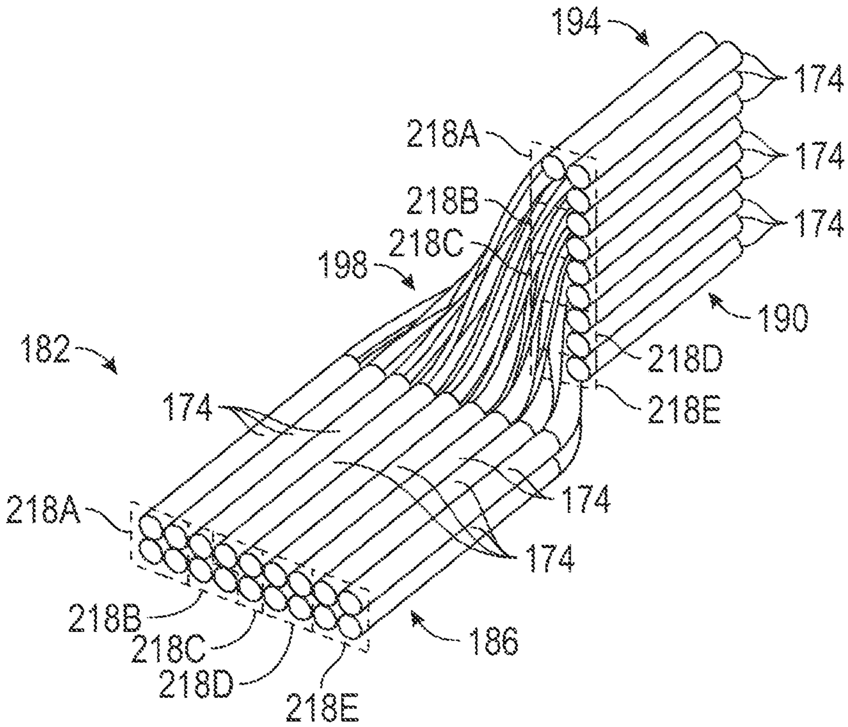

194
174
174
174
218A
218B
218C
198
190
182
218D
218E
174
218A
174
174
218B
218C
186
218D
218E

FIG. 4

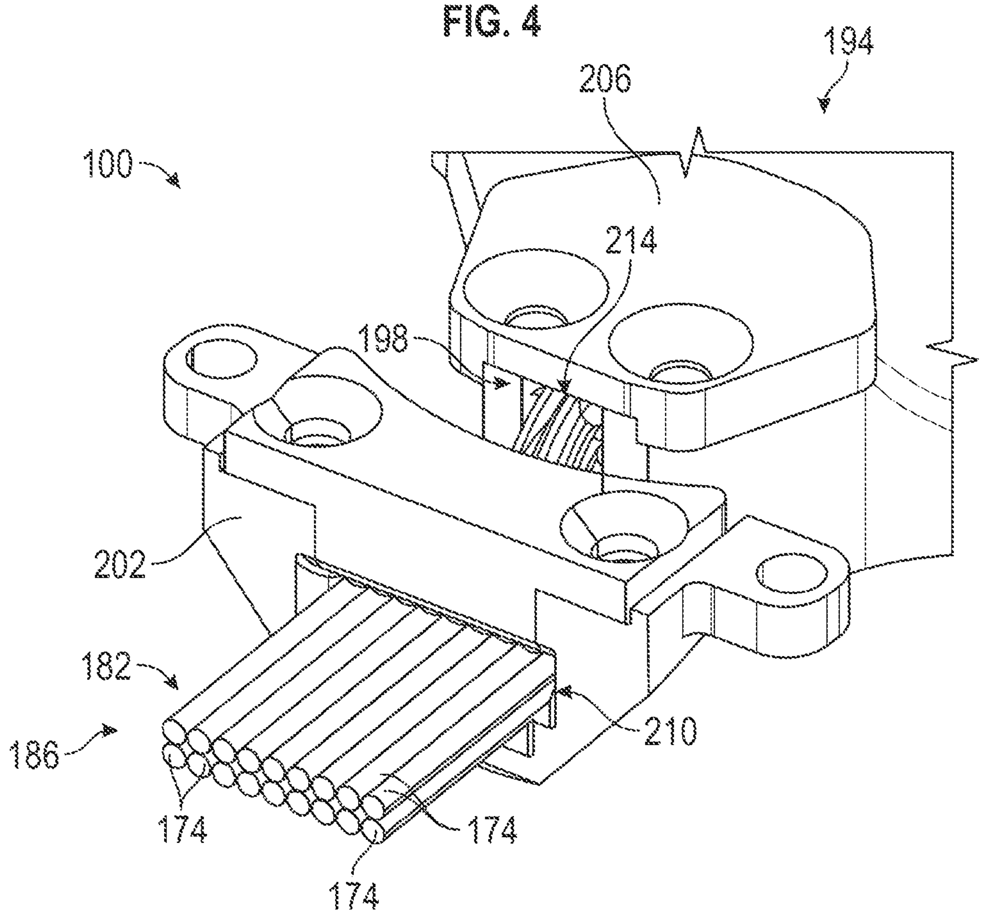

194
206
100
214
198
202
182
210
186
174
174
174

FIG. 5

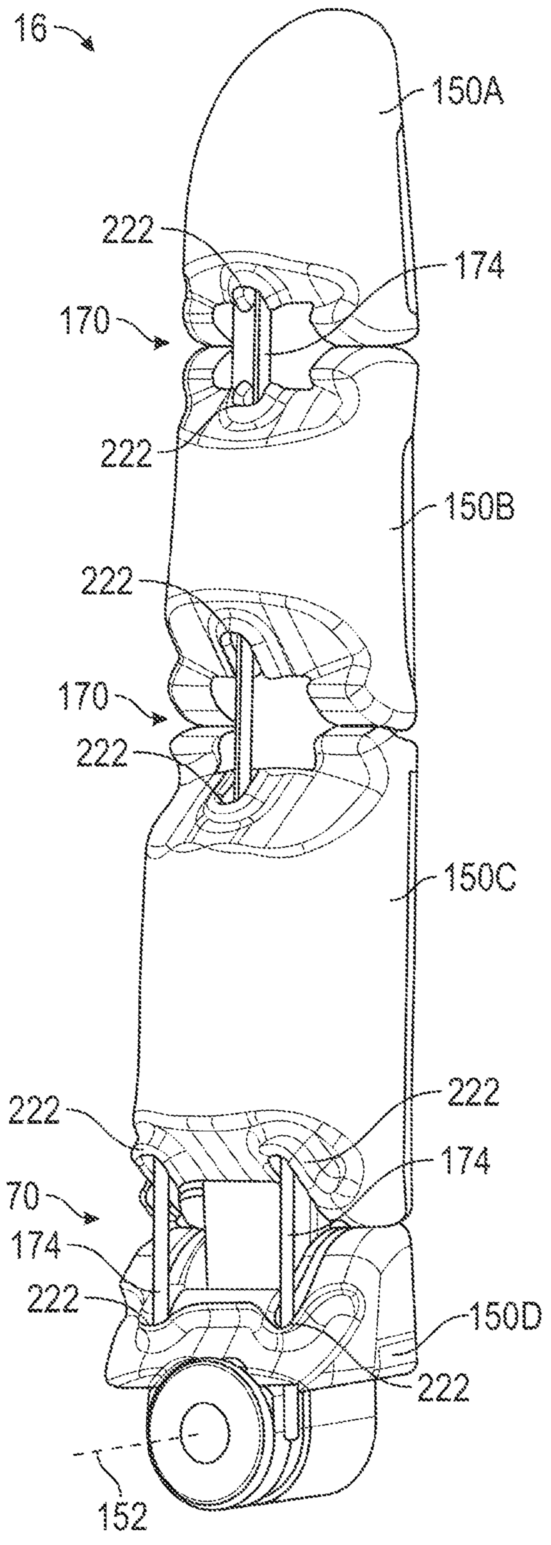

16
150A
222
174
170
222
150B
222
170
222
150C
222
222
170
174
174
222
150D
222
152

FIG. 6

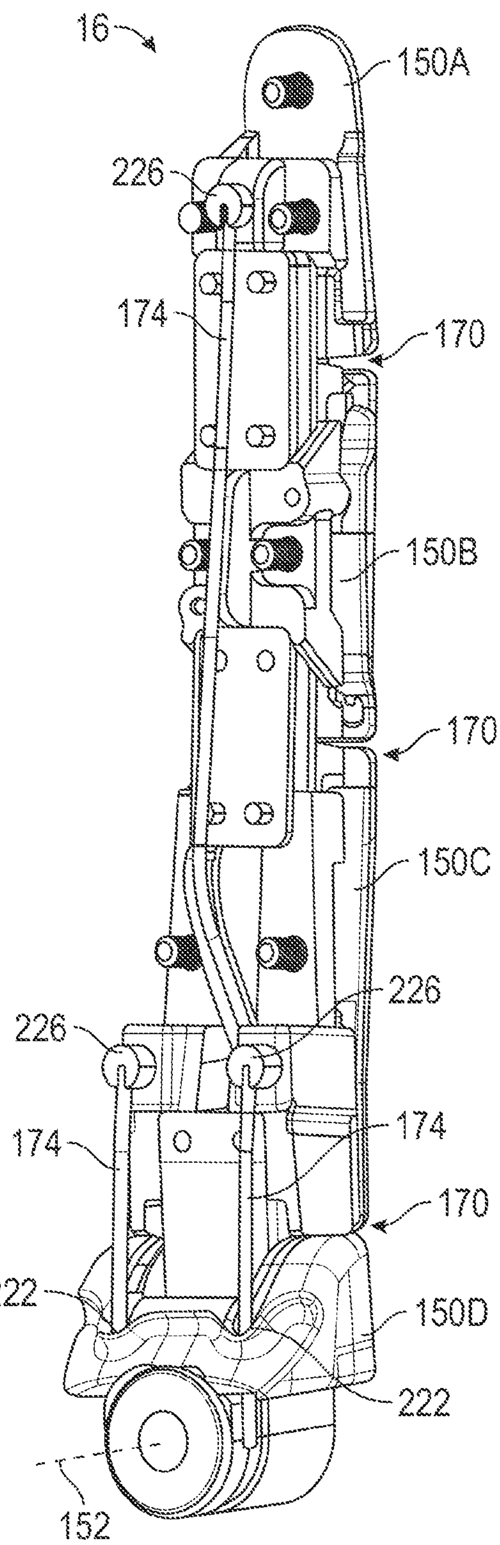

16
150A
226
174
170
150B
170
150C
226
226
174
174
170
222
150D
222
152

FIG. 7

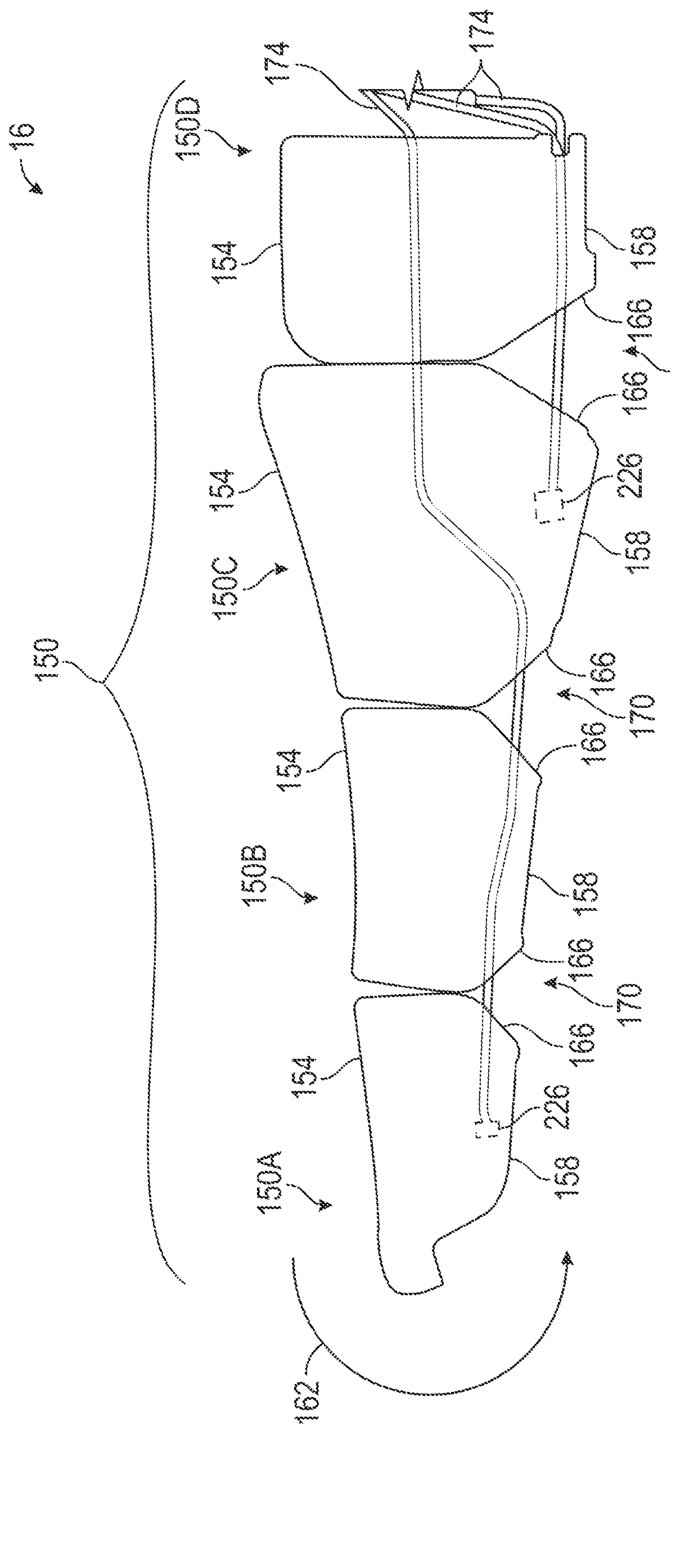

16
150
150D
150C
150B
150A
154
154
154
154
158
158
158
158
162
166
166
166
166
166
166
170
170
170
174
174
226
226

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2025/050210

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***A61F 2/58*** (2025.01); ***A61F 2/70*** (2025.01)

CPC: ***A61F2/583; A61F2/70;*** *A61F2002/5093; A61F2002/543; A61F2002/704*

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2007/0213842 A1 (SIMMONS RANDY S) 13 September 2007 (13.09.2007) para. [0027-0028][0034-0039][0044-0048]; figs. 1, 5-7, 10	1-5, 7-15 6
Y	US 2010/0275720 A1 (MILENKOVIC PAUL H) 04 November 2010 (04.11.2010) paras. [0007][0012][0044][0058]	6
A	US 2012/0150322 A1 (GOLDFARB MICHAEL) 14 June 2012 (14.06.2012) Entire Document	1-15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 December 2025 (03.12.2025)	**30 January 2026 (30.01.2026)**
Name and mailing address of the ISA/US **COMMISSIONER FOR PATENTS MAIL STOP PCT, ATTN: ISA/US P.O. Box 1450 Alexandria, VA 22313-1450 UNITED STATES OF AMERICA** Facsimile No. **571-273-8300**	Authorized officer **SHANE THOMAS** Telephone No. **PCT Helpdesk: (571) 272-4300**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2025/050210

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

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

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-15 are directed toward a robotic lower arm assembly.

Group II: Claims 16, 17 are directed toward a joint assembly.

Group III: Claims 18-20 are directed toward a joint assembly.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Group I include a robotic lower arm assembly comprising: a forearm member; a hand member including a plurality of appendage members; a plurality of control cables coupled with the forearm member at first ends thereof and coupled with the plurality of appendage members at second ends thereof, a control cable of the plurality of control cables configured to apply a force to an appendage member of the plurality of appendage members to actuate the appendage member; and a wrist joint pivotably coupled with the forearm member and the hand member, wherein the plurality of control cables is arranged in a first configuration at a forearm side of the wrist joint and is arranged in a second configuration different from the first configuration at a hand side of the wrist joint opposite the forearm side, which are not present in Groups II-III.

Group II include a fourth structure; a third control cable, wherein the third structure is pivotable relative to the fourth structure at a first joint; wherein the first control cable is coupled with the first structure and is routed behind the first joint and forward the second joint and the third joint, and wherein the second control cable and the third control cable are coupled with the third structure and are routed forward the first joint, which are not present in Groups I and III.

Group III include the first structure including a first control cable channel, the second structure including a second control cable channel and a third control cable channel, and the third structure including a fourth control cable channel; wherein the first control cable channel and the second control cable channel open to the first joint, wherein the third control cable channel and the fourth control cable channel open to the second joint, and wherein the first control cable channel, the second control cable channel, the third control cable channel, and the fourth control cable channel are configured to receive at least a portion of the control cable, which are not present in Groups I-II.

The common technical features of Groups I-III are a control cable; a joint.

The common technical features of Groups I and II are a plurality of control cables.

The common technical features of Groups II and III are a joint assembly comprising: a plurality of structures including a first structure, a second structure, a third structure; the second structure is pivotable relative to the third structure; the first structure is pivotable relative to the second structure.

These common technical features are disclosed US 2012/0150322 A1 to Goldfarb et al. (hereinafter 'Goldfarb'). Goldfarb discloses a control cable (cables 318; paragraph [0039]); a joint (joints 310; paragraph [0039]); a plurality of control cables (cables 318; paragraph [0039]); a joint assembly comprising: a plurality of structures including a first structure (308; figures 5A-C), a second structure (second structure 308; figures 5A-C), a third structure (third structure 308; figures 5A-C); the second structure is pivotable relative to the third structure (as shown; figures 5A-C); the first structure is pivotable relative to the second structure (as shown; figures 5A-C).

Since the common technical features are previously disclosed by the Goldfarb reference, the common features are not special and so Groups I-III lack unity.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2025/050210

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: **1-15**

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.