



(51) International Patent Classification:

B25J 17/02 (2006.01) B25J 9/10 (2006.01)
B25J 18/04 (2006.01)

(21) International Application Number:

PCT/US2025/050213

(22) International Filing Date:

09 October 2025 (09.10.2025)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/706,005 10 October 2024 (10.10.2024) US

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(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).

(54) Title: WRIST JOINT FOR ROBOTIC HAND

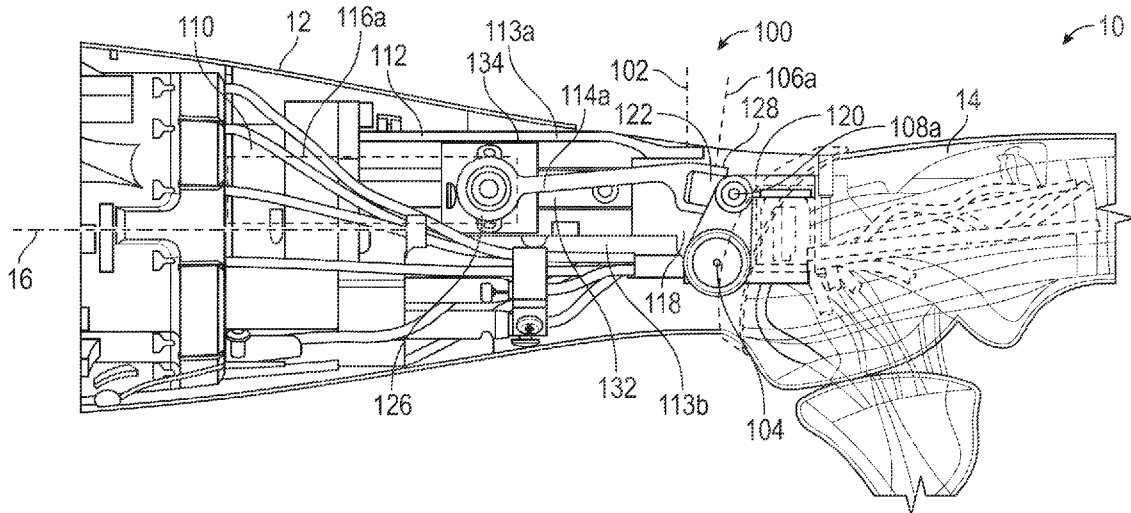


FIG. 1

(57) Abstract: A joint assembly includes: a first structure defining a first contact surface that is curved; a second structure defining a second contact surface that is curved and faces toward the first contact surface; and a flexible member having a first end portion fixedly coupled to the first structure and a second end portion fixedly coupled to the second structure. The flexible member movably couples the first structure to the second structure such that the second structure is pivotable relative to the first structure about a lateral axis that moves along the first contact surface and the second contact surface as the second structure pivots.



Published:

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

WRIST JOINT FOR ROBOTIC HAND

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional Application No. 63/706,005, 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 a joint assembly for movably connecting sections of 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 linkage for a robotic appendage includes: a bracket, a structure, a universal joint, a first actuator, a second actuator, a first link, and a second link. The bracket is fixed to a first member of the robotic appendage. The structure is fixed to a second member of the robotic appendage. The universal joint is pivotally coupled with the bracket about a yaw axis and is pivotally coupled with the structure about a pitch axis. The first actuator is coupled with the first member. The second actuator is coupled with the first member. The first link is couple with the first actuator at a proximate end and is coupled with the structure at a distal end. The second link is coupled with the second actuator at a proximate end and is coupled with the structure at a distal end.

[0005] In some embodiments, the robotic appendage includes a robotic arm. The linkage is a wrist joint for the robotic arm to pivotally couple a forearm and a hand.

[0006] In some embodiments, the yaw axis and the pitch axis are perpendicular with each other. The first actuator and the second actuator are operable to extend and retract to pivot the universal joint, the second member, and the structure about the yaw axis relative to the bracket. The first actuator and the second actuator are operable to extend and retract to pivot the second member and the structure about the pitch axis relative to the universal joint.

[0007] In some embodiments, the first link and the first actuator are positioned on a first side of the yaw axis. The second link and the second actuator are positioned on a second side of the yaw axis. The first link and the second link extend above the pitch axis.

[0008] In some embodiments, the universal joint is a central universal joint that couples the bracket with the structure. The linkage also includes a first coupling universal joint and a second coupling universal joint. The distal end of the first link is coupled with the structure via the first coupling universal joint. The distal end of the second link is coupled with the structure via the second coupling universal joint.

[0009] In some embodiments, the first coupling universal joint and the second coupling universal joint define first axes that are substantially parallel with the pitch axis of the central universal joint and second axes that are radially offset from the yaw axis and non-parallel with the yaw axis.

[0010] In some embodiments, the linkage further includes a track extending lengthwise along the first member and the bracket. The track is configured to receive a first slider on a first side and a second slider on a second side. The proximate end of the first link is coupled with the first slider and the proximate end of the second link is coupled with the second slider. The first actuator is configured to move the first slider along the first side of the track and the second actuator is configured to move the second slider along the second side of the track.

[0011] In some embodiments, the universal joint is coupled with the bracket about the yaw axis in a cantilevered arrangement. In the cantilevered arrangement, a bearing is coupled with the bracket and the universal joint, and a volume is defined beneath the universal joint. The volume provides space for control cables.

[0012] In some embodiments, the structure defines a notch facing the universal joint and the bracket. The notch is configured to receive an end of the bracket and a portion of the universal joint as the second member and the structure are pivoted about the pitch axis in an extension direction.

[0013] In at least one embodiment, a robotic lower arm assembly includes: a forearm member, a hand member, and a wrist assembly. The wrist assembly include a universal joint, a first actuator, and a second actuator. The universal joint is pivotally coupled with a bracket of the forearm member about a yaw axis and is pivotally coupled with the hand member about a pitch axis. The yaw axis and the pitch axis are perpendicular with each other. The first actuator is configured to provide a first force to a first side of the hand member. The second actuator is configured to provide a second force to a second side of the hand member. The first actuator and the second actuator are operable to provide the first force and the second force to the hand member in order to at least one of (i) pivot the universal joint and the hand member about the yaw axis relative to the forearm member, or (ii) pivot the hand member about the pitch axis relative to the universal joint.

[0014] In some embodiments, the wrist assembly includes a first link and a second link. The first link is coupled with the first actuator at a proximate end and is coupled with the hand member at a distal end. The second link is coupled with the second actuator at a proximate end and is coupled with the hand member at a distal end. The first actuator and the second actuator are configured to provide the first force and the second force to the hand member through the first link and the second link, respectively.

[0015] In some embodiments, the first link and the first actuator are positioned on a first side of the yaw axis and the second link and the second actuator are positioned on a second side of the yaw axis.

[0016] In some embodiments, the universal joint is a central universal joint that couples the hand member with the forearm member. The wrist assembly includes a first coupling universal joint and a second coupling universal joint. The distal end of the first link is coupled with the hand member via the first coupling universal joint, and the distal end of the second link is coupled with the hand member via the second coupling universal joint.

[0017] In some embodiments, the first coupling universal joint and the second coupling universal joint include first axes that are substantially parallel with the pitch axis of the central universal joint and second axes that are radially offset from the yaw axis and non-parallel with the yaw axis.

[0018] In some embodiments, the robotic lower arm assembly includes a track extending lengthwise from the forearm member. The track is configured to receive a first slider on a first side and a second slider on a second side. A proximate end of a first link is coupled with the first slider and a proximate end of a second link is coupled with the second slider. The first actuator is configured to move the first slider along the first side of the track and the second actuator configured to move the second slider along the second side of the track.

[0019] In at least one embodiment, a wrist assembly for a robotic arm includes a bracket, a structure, a universal joint, a first actuator, a second actuator, a first connecting member, and a second connecting member. The bracket is fixed to a forearm of the robotic arm. The structure is fixed to a hand of the robotic arm. The universal joint is pivotally coupled with the bracket about a yaw axis and is pivotally coupled with the structure about a pitch axis. The yaw axis and the pitch axis are perpendicular with each other. The first actuator is coupled with the forearm. The second actuator is coupled with the forearm. The first connecting member is coupled with the first actuator at a proximate end and is coupled with the structure at a distal end. The second connecting member is coupled with the second actuator at a proximate end and is coupled with the structure at a distal end. The first actuator and the second actuator are operable to independently control position of the hand relative to the forearm about the yaw axis and the pitch axis.

[0020] In some embodiments, the universal joint is a central universal joint that couples the bracket with the structure. The wrist assembly further includes a first coupling universal joint and a second coupling universal joint. The distal end of the first connecting member is coupled with the structure via the first coupling universal joint, and the distal end of the second connecting member coupled with the structure via the second coupling universal joint.

[0021] In some embodiments, the first coupling universal joint and the second coupling universal joint define first axes that are substantially parallel with the pitch axis of the central

universal joint and second axes that are radially offset from the yaw axis and non-parallel with the yaw axis.

[0022] In some embodiments, the wrist assembly includes a track extending lengthwise along the forearm and the bracket. The track is configured to receive a first slider on a first side and a second slider on a second side. The first actuator is configured to move the first slider along the first side of the track and the second actuator configured to move the second slider along the second side of the track.

[0023] In some embodiments, the structure defines a notch facing the universal joint and the bracket. The notch is configured to receive an end of the bracket and a portion of the universal joint as the hand and the structure are pivoted about the pitch axis in an extension direction.

[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 including a wrist assembly, according to an embodiment.

[0026] FIG. 2 is a top view of the robotic arm assembly of FIG. 1.

[0027] FIG. 3 is a perspective view of the wrist assembly of the robotic arm assembly of FIG. 1 in a first position about a pivot axis.

[0028] FIG. 4 is a perspective view of the wrist assembly of FIG. 1 in a second position about the pivot axis.

[0029] FIG. 5 is a perspective view of the wrist assembly of FIG. 1 in a first position about a yaw axis.

[0030] FIG. 6 is a perspective view of the wrist assembly of FIG. 1 in a second position about the yaw axis.

[0031] FIG. 7 is side view of a bearing of the wrist assembly of FIG. 1.

DETAILED DESCRIPTION

[0032] 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.

[0033] Referring generally to the figures, a robotic appendage for a robot includes a first member (e.g., a forearm) and a second member (e.g., a hand). The second member is coupled with the first member through a linkage (e.g., a wrist assembly). The linkage allows rotation of the second member relative to the first member about a yaw axis and a pitch axis. The second member can be driven to rotate about the yaw axis or the pitch axis by a pair of actuators. The linkage includes a universal joint (e.g., a central universal joint) that defines the yaw axis. In particular, the universal joint is rotatably coupled with a bracket of the first member about the yaw axis such that the universal joint can be rotated in a first or second direction (e.g., clockwise or counter-clockwise, radial and ulnar deviation, etc.) relative to the first member. The linkage also includes a structure that is pivotally coupled with the universal joint about the pitch axis. The pitch axis is perpendicular to the yaw axis. The pitch axis is disposed forwards of the first axis positioned more proximate the structure than the yaw axis.

[0034] The linkage also includes a pair of links. The pair of links are each coupled, at a first end, with an end of a corresponding one of the linear actuators. The pair of links are each coupled, at a second end, with a corresponding one of a pair of coupling universal joints. The pair of links are constrained at their first ends to move in a linear direction without lateral movement. The second ends of the pair of links are pivotally coupled to the coupling universal joints and can rotate relative to the coupling universal joints about first axes of the coupling universal joints. The coupling universal joints can also define second axes that are parallel with the pitch axis. The linkage can include a track extending centrally through the bracket and can include sliders that are slidably coupled with the track on opposite sides of the track. The first ends of the links are coupled with the sliders on opposite sides of the track to constrain

the first ends of the links and ends of the actuators to linear motion (e.g., translation) along the track. The universal joint can be coupled with the bracket through a bearing in a cantilevered arrangement such that a space is provided beneath the universal joint for control cables (e.g., tendons). The actuators can be operated to rotate the second member about the yaw axis or the pitch axis relative to the first member. For example, if the actuators are both extended or retracted at a same speed or rate, the second member can be rotated relative to the first member about the pitch axis. Likewise, if the actuators are extended or retracted at a different speed or rate, the second member can be rotated relative to the first member about the yaw axis.

Overview

[0035] Referring to FIG. 1, a humanoid appendage, a robotic appendage, a limb, a jointed assembly, a posable assembly, or a digit, is shown as robotic arm assembly 10. The robotic arm assembly 10 includes a forearm 12 (e.g., a first member, a forearm member, an upper member, etc.) and a hand 14 (e.g., a second member, a hand member, a hand assembly, a lower member, an articulatable member, etc.). The hand 14 is coupled with the forearm 12 via a joint assembly 100 (e.g., a linkage, a wrist assembly, a joint, etc.). 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 16 or in a direction parallel with the centerline 16 (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 16 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. 1–6, 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 16 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 16, and a second portion that is angled inwards towards the distal ends 128 relative to the centerline 16. 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. 1–6, 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 16 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 16. In this way, the first axes 106 are angled both towards the hand 14 and also inwards towards the centerline 16. 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. 1 and 3-6, the joint assembly 100 includes a track 132 (e.g., an elongated member, etc.). The track 132 is disposed between the upper member 113a and the lower member 113b of the bracket 112. The actuators 116 can also be positioned between the upper member 113a and the lower member 113b and are configured to extend and retract in directions parallel with the centerline 16. The track 132 likewise extends in a direction parallel with the centerline 16 (e.g., lengthwise). The track 132 is configured to receive a pair of track members 134 (e.g., sliders, slidable members, etc.) that slidably couple with the track 132. Ends of the actuators 116 are coupled with the track members 134. The proximate ends 126 of the links 114 are also coupled with the corresponding track members 134. In particular, the proximate end 126 of the first link 114a is coupled with a first of the track members 134 (e.g., a first slider) on a first side of the track 132, and the proximate end 126 of the second link 114b is coupled with a second of the track members 134 (e.g., a second slider) on a second side of the track 132.

[0045] The track members 134 constrain movement of ends of the actuators 116 and proximate ends 126 of the links 114 to linear motion along the track 132. The actuators 116 are configured to extend or retract to drive motion of the respective track members 134 along the track 132. The links 114 are coupled to the track members 134 at their proximate ends 126 in order to constrain motion of the proximate ends 126 of the links 114 to linear motion along the track 132.

[0046] As shown in FIGS. 3 and 4, the actuators 116 are operable to drive rotation of the hand structure 120 about the pitch axis 104. The actuators 116 may both extend at a same rate or a same amount of displacement in a same direction in order to rotate the hand structure 120 and the hand 14 in a first direction about the pitch axis 104 (e.g., in a flexion direction). The actuators 116 can both retract at a same rate or a same amount of displacement in order to rotate the hand structure 120 and the hand 14 in a second direction about the pitch axis 104 (e.g., in an extension direction). In this way, the actuators 116 can be operated to cause the hand

structure 120 and the hand 14 to undergo extension or flexion relative to the forearm 12, the forearm frame member 110, the bracket 112, and the universal joint 118. For example, both the first actuator 116a and the second actuator 116b can be operable to extend or retract in unison in order to rotate the hand structure 120 about the pitch axis 104 in either the flexion or the extension direction. The flexion direction of rotation about the pitch axis 104 is the direction of rotation that the hand structure 120 undergoes when moving from the position shown in FIG. 3 to the position shown in FIG. 4. On the contrary, the hand structure 120 undergoes extension direction of rotation about the pitch axis 104 from the position shown in FIG. 4 to the position shown in FIG. 3.

[0047] Referring to FIGS. 2, 3, and 4, the hand structure 120 includes a notch 124 (e.g., a space, an area, a void, a recess, etc.) that faces the universal joint 118. The hand structure 120 can generally have a U-shape that defines the notch 124. The notch 124 can have a width corresponding to or greater than an outer diameter of the bracket 112 at the yaw axis 102. In this way, the upper member 113a of the bracket 112 at the yaw axis 102 can be received within the notch 124 when the hand structure 120 is rotated in the extension direction to an extension bounds (e.g., an outer limit of rotation in the extension direction), as shown in FIG. 3. The notch 124 can enable further movement or increased range of the hand structure 120 about the pitch axis 104 in the extension direction.

[0048] As shown in FIGS. 5 and 6, the actuators 116 are operable to drive rotation of the hand structure 120 and the universal joint 118 about the yaw axis 102. The actuators 116 can extend at different rates or different amounts of displacement in a same or different directions in order to rotate the hand structure 120, the hand 14, and the universal joint 118 about the yaw axis 102. The actuators 116 can be operated to rotate the hand structure 120, the hand 14, and the universal joint 118 in a first direction about the yaw axis 102 (e.g., a radial deviation direction) or in a second direction about the yaw axis 102 (e.g., an ulnar deviation direction). For example, the first actuator 116a and the second actuator 116b can extend or retract at different rates in order to rotate the hand structure 120, the hand 14, and the universal joint 118 in the ulnar or radial direction about the yaw axis 102.

[0049] Referring to FIG. 7, the universal joint 118 can be coupled with the bracket 112 via a cantilevered bearing arrangement. The cantilevered bearing arrangement includes a bearing

assembly 200 having a bearing 202 disposed within and extending between openings in the upper member 113a and the lower member 113b. In some embodiments, a portion of the universal joint 118 is positioned between the upper member 113a and the lower member 113b. The universal joint 118 can be supported from and hang from the upper member 113a and the lower member 113b of the bracket 112. The universal joint 118 is rotatably coupled with the bracket 112 via the bearing 202. In some embodiments, the universal joint 118 is coupled to an outer race of the bearing 202. For example, the universal joint 118 can include a bore at the first portion within which the bearing 202 is positioned. In some embodiments, the universal joint 118 is coupled to an outer race of the bearing 202 via an inner surface of the bore. The upper member 113a and the lower member 113b can be coupled with an inner race of the bearing 202 via a first fastener 204 and a second fastener 206, respectively.

[0050] In some embodiments, the cantilevered arrangement is provided such that a volume 130 (e.g., a space, an area, a void, etc.) is formed beneath the bearing 202. The volume 130 provides clearance for control cables 208 (e.g., hand tendons, hand control lines, etc.) such that the control cables 208 do not interfere with each other or with movement of the hand 14. In some embodiments, the volume 130 provides space so that hand control cables and finger control cables have sufficient clearance.

[0051] In some embodiments, the spatial arrangement of the universal joint 118, actuators 116, links 114, and associated track 132 within the forearm 12 (e.g., the forearm member) is specifically configured to optimize available interior volume of the forearm 12. This arrangement, including the cantilevered mounting of the universal joint 118 to create cable clearance beneath the joint and the positioning of the actuators 116 along opposite sides of a central track, enables the forearm 12 to accommodate a greater number of finger actuators than would otherwise be possible in conventional wrist joint configurations. By reducing interference between wrist actuation components and finger tendon routing, the design allows for an increased actuator capacity within the forearm 12, thereby providing enhanced dexterity, strength, and range of motion in the robotic hand without increasing the overall size of the forearm assembly.

[0052] 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.

[0053] 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).

[0054] 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.

[0055] 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.

[0056] The hardware and data processing components used to implement the various processes, operations, illustrative logics, logical blocks, modules and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some embodiments, particular processes and methods may be performed by circuitry that is specific to a given function. The memory (e.g., memory, memory unit, storage device) may include one or more devices (e.g., RAM, ROM, Flash memory, hard disk storage) for storing data and/or computer code for completing or facilitating the various processes, layers and modules described in the present disclosure. The memory may be or include volatile memory or non-volatile memory, and may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. According to an exemplary embodiment, the memory is communicably connected to the processor via a processing circuit and includes computer code for executing (e.g., by the processing circuit or the processor) the one or more processes described herein.

[0057] The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure may be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-

executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

[0058] 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.

[0059] It is important to note that the construction and arrangement of the finger 10 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. For example, the actuator cables 30 of the exemplary embodiment shown in at least FIG. 2 may be incorporated in the finger 10 of the exemplary embodiment shown in at least FIG. 1. Although only one example of an element from one embodiment that can be incorporated or utilized in another embodiment has been described above, it should be appreciated that other elements of the various embodiments may be incorporated or utilized with any of the other embodiments disclosed herein.

CLAIMS

What is claimed is:

1. A linkage for a robotic appendage, the linkage comprising:
 - a bracket fixed to a first member of the robotic appendage;
 - a structure fixed to a second member of the robotic appendage;
 - a universal joint pivotally coupled with the bracket about a yaw axis and pivotally coupled with the structure about a pitch axis;
 - a first actuator coupled with the first member;
 - a second actuator coupled with the first member;
 - a first link coupled with the first actuator at a proximate end and coupled with the structure at a distal end; and
 - a second link coupled with the second actuator at a proximate end and coupled with the structure at a distal end.

2. The linkage of claim 1, wherein the robotic appendage comprises a robotic arm, the linkage being a wrist joint for the robotic arm to pivotally couple a forearm and a hand.

3. The linkage of claim 1,
 - wherein the yaw axis and the pitch axis are perpendicular with each other;
 - wherein the first actuator and the second actuator are operable to extend and retract to pivot the universal joint, the second member, and the structure about the yaw axis relative to the bracket; and
 - wherein the first actuator and the second actuator are operable to extend and retract to pivot the second member and the structure about the pitch axis relative to the universal joint.

4. The linkage of claim 1, wherein the first link and the first actuator are positioned on a first side of the yaw axis and wherein the second link and the second actuator are positioned on a second side of the yaw axis, the first link and the second link extending above the pitch axis.

5. The linkage of claim 1, wherein the universal joint is a central universal joint that couples the bracket with the structure, the linkage further comprising a first coupling universal joint and a second coupling universal joint, the distal end of the first link coupled with the structure via the first coupling universal joint, and the distal end of the second link coupled with the structure via the second coupling universal joint.
6. The linkage of claim 5, wherein the first coupling universal joint and the second coupling universal joint define first axes that are radially offset from the yaw axis and non-parallel with the yaw axis and second axes that are substantially parallel with the pitch axis of the central universal joint and.
7. The linkage of claim 1, further comprising a track extending lengthwise along the first member and the bracket, the track configured to receive a first slider on a first side and a second slider on a second side, the proximate end of the first link coupled with the first slider and the proximate end of the second link coupled with the second slider, the first actuator configured to move the first slider along the first side of the track and the second actuator configured to move the second slider along the second side of the track.
8. The linkage of claim 1, wherein the universal joint is coupled with the bracket about the yaw axis in a cantilevered arrangement in which a bearing is coupled with the bracket and the universal joint and a volume is defined beneath the universal joint, wherein the volume provides space for control cables.
9. The linkage of claim 1, wherein the structure defines a notch facing the universal joint and the bracket, the notch configured to receive an end of the bracket and a portion of the universal joint as the second member and the structure are pivoted about the pitch axis in an extension direction.
10. A robotic lower arm assembly, the robotic lower arm assembly comprising:
 - a forearm member;
 - a hand member; and

a wrist assembly, comprising:

a universal joint pivotally coupled with a bracket of the forearm member about a yaw axis and pivotally coupled with the hand member about a pitch axis, the yaw axis and the pitch axis perpendicular with each other;

a first actuator configured to provide a first force to a first side of the hand member; and

a second actuator configured to provide a second force to a second side of the hand member,

wherein the first actuator and the second actuator are operable to provide the first force and the second force to the hand member to at least one of (i) pivot the universal joint and the hand member about the yaw axis relative to the forearm member, or (ii) pivot the hand member about the pitch axis relative to the universal joint.

11. The robotic lower arm assembly of claim 10, wherein the wrist assembly further comprises:

a first link coupled with the first actuator at a proximate end and coupled with the hand member at a distal end; and

a second link coupled with the second actuator at a proximate end and coupled with the hand member at a distal end;

wherein the first actuator and the second actuator are configured to provide the first force and the second force to the hand member through the first link and the second link, respectively.

12. The robotic lower arm assembly of claim 11, wherein the first link and the first actuator are positioned on a first side of the yaw axis and the second link and the second actuator are positioned on a second side of the yaw axis.

13. The robotic lower arm assembly of claim 11, wherein the universal joint is a central universal joint that couples the hand member with the forearm member, the wrist assembly further comprising a first coupling universal joint and a second coupling universal joint, the distal end of the first link coupled with the hand member via the first coupling universal joint,

and the distal end of the second link coupled with the hand member via the second coupling universal joint.

14. The robotic lower arm assembly of claim 13, wherein the first coupling universal joint and the second coupling universal joint comprise first axes that are radially offset from the yaw axis and non-parallel with the yaw axis and second axes that are substantially parallel with the pitch axis of the central universal joint.

15. The robotic lower arm assembly of claim 10, further comprising a track extending lengthwise from the forearm member, the track configured to receive a first slider on a first side and a second slider on a second side, a proximate end of a first link coupled with the first slider and a proximate end of a second link coupled with the second slider, the first actuator configured to move the first slider along the first side of the track and the second actuator configured to move the second slider along the second side of the track.

16. A wrist assembly for a robotic arm, the wrist assembly comprising:
a bracket fixed to a forearm of the robotic arm;
a structure fixed to a hand of the robotic arm;
a universal joint pivotally coupled with the bracket about a yaw axis and pivotally coupled with the structure about a pitch axis, the yaw axis and the pitch axis being perpendicular with each other;
a first actuator coupled with the forearm;
a second actuator coupled with the forearm;
a first connecting member coupled with the first actuator at a proximate end and coupled with the structure at a distal end; and
a second connecting member coupled with the second actuator at a proximate end and coupled with the structure at a distal end,
wherein the first actuator and the second actuator are operable to independently control position of the hand relative to the forearm about the yaw axis and the pitch axis.

17. The wrist assembly of claim 16, wherein the universal joint is a central universal joint that couples the bracket with the structure, the wrist assembly further comprising a first coupling universal joint and a second coupling universal joint, the distal end of the first connecting member coupled with the structure via the first coupling universal joint, and the distal end of the second connecting member coupled with the structure via the second coupling universal joint.

18. The wrist assembly of claim 17, wherein the first coupling universal joint and the second coupling universal joint define first axes that are substantially parallel with the pitch axis of the central universal joint and second axes that are radially offset from the yaw axis and non-parallel with the yaw axis.

19. The wrist assembly of claim 16, further comprising a track extending lengthwise along the forearm and the bracket, the track configured to receive a first slider on a first side and a second slider on a second side, the first actuator configured to move the first slider along the first side of the track and the second actuator configured to move the second slider along the second side of the track.

20. The wrist assembly of claim 16, wherein the structure defines a notch facing the universal joint and the bracket, the notch configured to receive an end of the bracket and a portion of the universal joint as the hand and the structure are pivoted about the pitch axis in an extension direction.

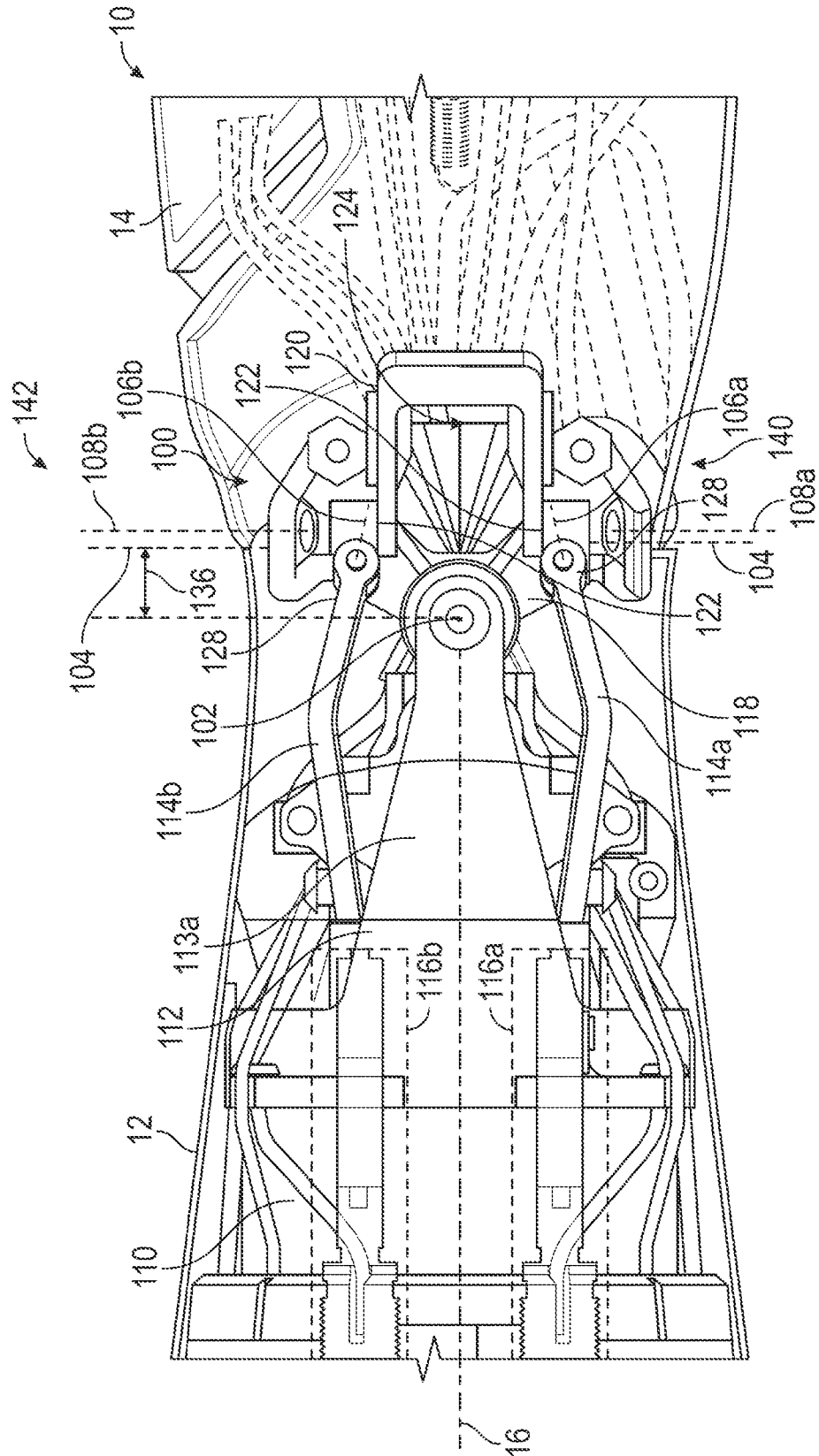


FIG. 2

3/5

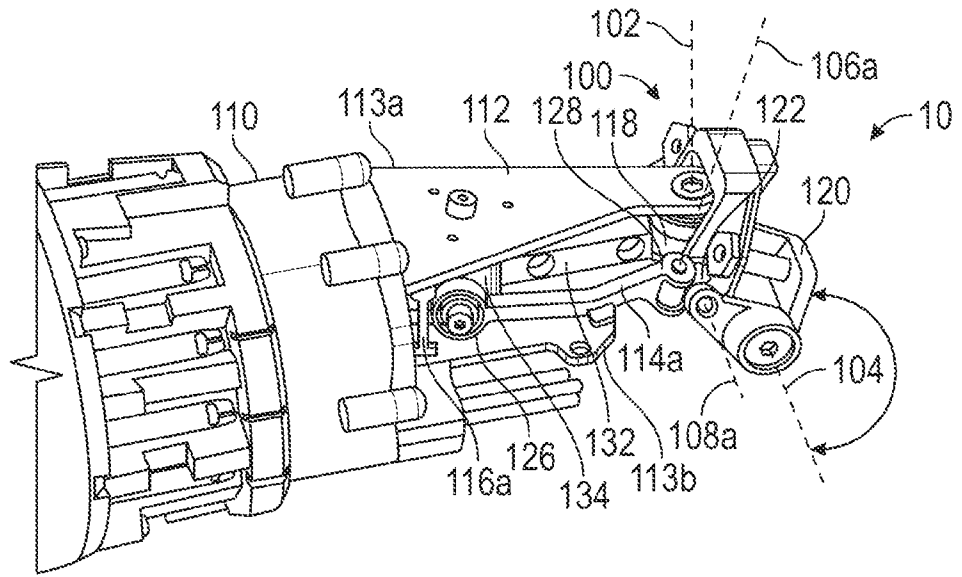


FIG. 3

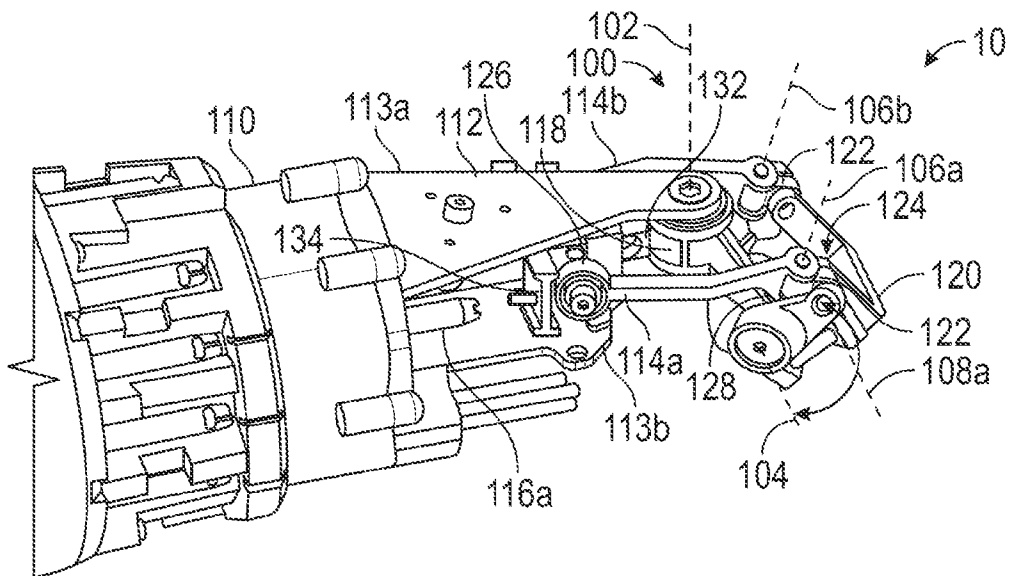


FIG. 4

4/5

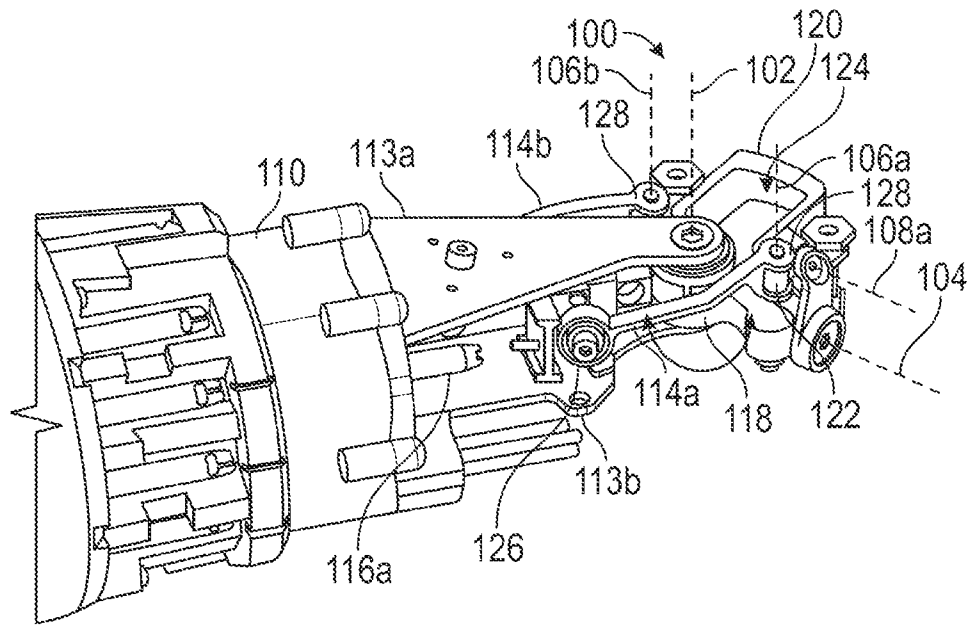


FIG. 5

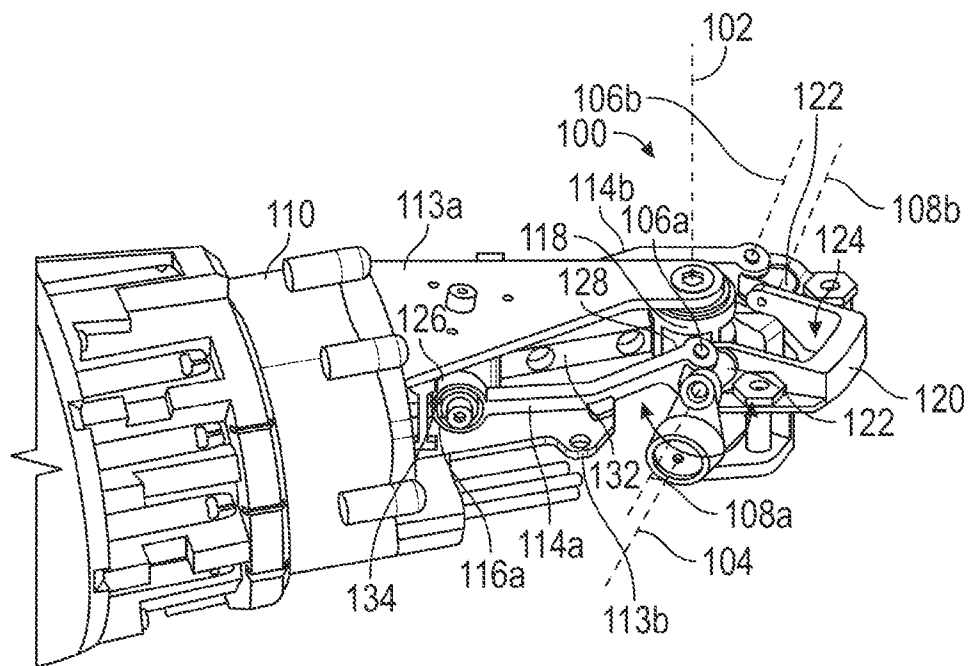


FIG. 6

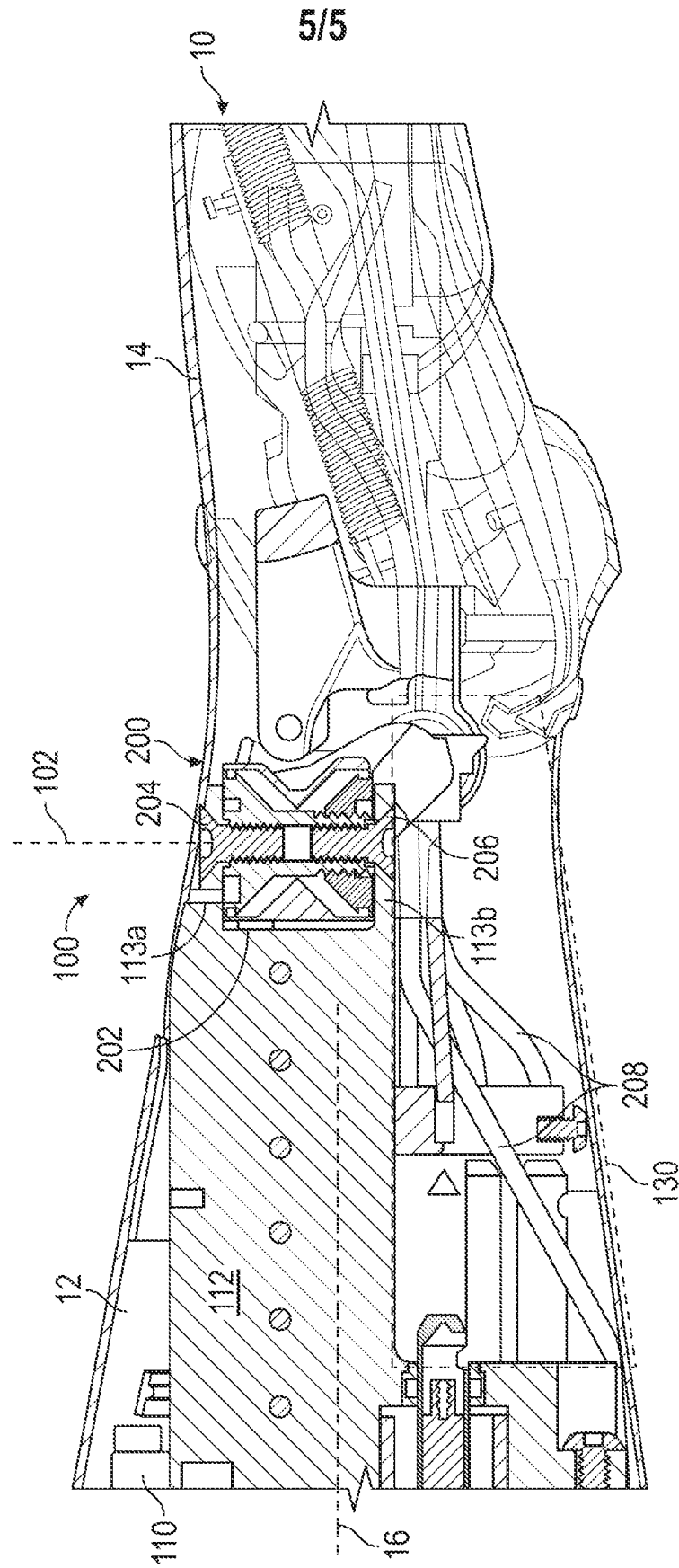


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2025/050213

<p>A. CLASSIFICATION OF SUBJECT MATTER IPC: B25J 17/02 (2025.01); B25J 18/04 (2025.01); B25J 9/10 (2025.01) CPC: B25J 17/0275; B25J 18/04; B25J 9/10 According to International Patent Classification (IPC) or to both national classification and IPC</p>																										
<p>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</p>																										
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1" style="width:100%; border-collapse: collapse;"> <thead> <tr> <th style="width:10%;">Category*</th> <th style="width:70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width:20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="text-align:center;">X</td> <td>US 2018/0073614 A1 (IROBOT CORPORATION) 15 March 2018 (15.03.2018) entire document</td> <td style="text-align:center;">1-4, 10-12, 16</td> </tr> <tr> <td style="text-align:center;">Y</td> <td>entire document</td> <td style="text-align:center;">5, 7-9, 13, 15, 17, 19, 20</td> </tr> <tr> <td style="text-align:center;">Y</td> <td>US 2009/0071282 A1 (TAKEMURA) 19 March 2009 (19.03.2009) entire document</td> <td style="text-align:center;">5, 9, 13, 17, 20</td> </tr> <tr> <td style="text-align:center;">Y</td> <td>CN 112809730 B (SHENZHEN UBTECH ROBOTICS) 17 May 2022 (17.05.2022) see machine translation</td> <td style="text-align:center;">7, 15, 19</td> </tr> <tr> <td style="text-align:center;">Y</td> <td>US 2009/0173177 A1 (SUGAWARA et al.) 09 July 2009 (09.07.2009) entire document</td> <td style="text-align:center;">8</td> </tr> <tr> <td style="text-align:center;">A</td> <td>US 2011/0196509 A1 (JANSEN et al.) 11 August 2011 (11.08.2011) entire document</td> <td style="text-align:center;">1-20</td> </tr> <tr> <td style="text-align:center;">A</td> <td>US 2014/0238177 A1 (THK CO. LTD.) 28 August 2014 (28.08.2014) entire document</td> <td style="text-align:center;">1-20</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	US 2018/0073614 A1 (IROBOT CORPORATION) 15 March 2018 (15.03.2018) entire document	1-4, 10-12, 16	Y	entire document	5, 7-9, 13, 15, 17, 19, 20	Y	US 2009/0071282 A1 (TAKEMURA) 19 March 2009 (19.03.2009) entire document	5, 9, 13, 17, 20	Y	CN 112809730 B (SHENZHEN UBTECH ROBOTICS) 17 May 2022 (17.05.2022) see machine translation	7, 15, 19	Y	US 2009/0173177 A1 (SUGAWARA et al.) 09 July 2009 (09.07.2009) entire document	8	A	US 2011/0196509 A1 (JANSEN et al.) 11 August 2011 (11.08.2011) entire document	1-20	A	US 2014/0238177 A1 (THK CO. LTD.) 28 August 2014 (28.08.2014) entire document	1-20
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<table style="width:100%; border:none;"> <tr> <td style="width:50%; border:none;"> * 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 </td> <td style="width:50%; border:none;"> "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 </td> </tr> </table>			* 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																						
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