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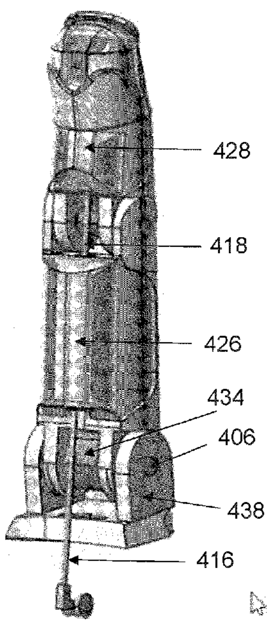

FIG. 4C

(57) Abstract: A robotic hand system can comprise a palm region and one or more fingers, each finger comprising an actuator device; a proximal member having a first end mechanically coupled to the palm region robot and configured to rotate around a first pivot relative to the palm region; a distal member having a first end mechanically coupled to a second end of the proximal member and configured to rotate around a second pivot relative to the proximal member; and a cable having a first portion coupled to the actuator and a second portion extending along the proximal member and the distal member, the second portion separated away from the first pivot and the second pivot and having an end with a higher dimension than a diameter of the cable, the end with higher dimension structured to engage the distal member when the cable is pulled by the actuator.

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UNDERACTUATED HAND WITH CABLE-DRIVEN FINGERS

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application No. 63/377,919, filed September 30, 2022, and claims priority to U.S. Provisional Application No. 63/378,034, filed September 30, 2022, both applications are incorporated by reference in their entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure generally relates to underactuated hands with cable-driven fingers. In particular, the current disclosure relates to cable-driven robot hands and fingers with adaptive grasp and an optimization framework for optimizing various design parameters of the cable-driven robot hands and fingers.

BACKGROUND

[0003] A robot can be viewed as a chain or collections of joints, which enable desired motions of the robot. Each joint enables adjacent structures or elements to move relative to one another. The motion of the adjacent elements is driven by one or more actuators associated with the joint. A computer system controls the actuator(s) to achieve the desired motion(s).

[0004] The design of a joint defines the range of motion of the corresponding adjacent elements. Also, the joint design can affect the number and/or type(s) of actuators to be used as well as the efficiency of the actuator(s).

SUMMARY

[0005] For various reasons, the hand and fingers are among the components of a robot that present very complex and difficult technical challenges when it comes to design and optimization of the design parameters. One first challenge is how to achieve an adaptive and stable grasp of objects. Adaptability relates to the capability of the fingers or respective joints to adapt their position and/or motion based on the place and characteristics of contact with another object. Stability refers to getting a good grasp of the object in a way the object does not slip or fall. A second technical challenge is the transmission or how forces or torques are transmitted to different links or members of a finger. Another technical challenge is how to optimize or enhance the efficiency of the forces applied to the abject. These and other technical challenges make the design of a robot hand and fingers a complex multi-dimensional problem and call for novel techniques to get closer to characteristics or capabilities of a human hand.

[0006] In the current disclosure, systems and methods for a robot hand and cable-driven fingers configured to mimic human hands and fingers are described. In particular, the systems and method described herein provide a novel routing of cables in cable-driven fingers to enable more adaptive, stable and efficient grasping of objects. The cable routing described herein leads to different transmission patterns of force and/or torque to various links or structures of the fingers and enables a range of motion and/or positions that mimic to some extent the motion or positions of human fingers. The fingers described herein are underactuated with a single actuator driving two joints of a finger.

[0007] Systems and methods described in the current disclosure also provide optimization and simulation frameworks to achieve enhanced adaptability, stability, and efficiency, especially with respect to grabbing an object by the hand and fingers described herein. Specifically, the optimization and simulation frameworks enable optimization of various parameters of the finger designs or finger systems described herein.

[0008] According to at least one aspect, a robotic hand system can comprise a palm region and one or more fingers, each finger comprising an actuator device; a respective proximal member having a first end mechanically coupled to the palm region robot and configured to rotate around a respective first pivot relative to the palm region; a respective distal member having a first end mechanically coupled to a second end of the proximal member and configured to rotate around a respective second pivot relative to the proximal member; and a respective cable having a first portion coupled to the actuator and a second portion extending along the proximal member and the distal member, the second portion separated away from the first pivot and the second pivot and having an end with a higher dimension than a diameter of the cable, the end with higher dimension structured to engage the distal member when the cable is pulled by the actuator.

[0009] The end with higher dimension may be floating within a region of the distal member. In some implementations, the end with higher dimension includes at least one of a potted end or an end with a potted insert.

[0010] Each finger may comprise a respective channel structure extending at least partially along the respective proximal member and the respective distal member, the respective channel structure hosting at least partially the second portion of the respective cable.

[0011] The end with higher dimension of the second portion of the respective cable may be structured to engage a ledge structure of the respective channel structure when the respective cable is pulled by the respective actuator.

[0012] Each finger may comprise a respective first torsion spring placed around the respective first pivot; and a respective second torsion spring placed around the respective second pivot.

[0013] Each finger may comprise a respective magnet coupled to the respective first pivot; and a respective hall effect sensor placed proximate to the respective magnet. In some implementations, the respective magnet includes a ring magnet placed around the respective first pivot.

[0014] Each finger may comprise a respective magnet coupled to the respective second pivot; and a respective hall effect sensor placed proximate to the respective magnet.

[0015] A distance between the respective cable and the respective first pivot may vary and/or a distance between the respective cable and the respective second pivot may vary.

[0016] According to at least one aspect, a finger device can comprise an actuator device; a proximal member having a first end mechanically coupled to base member and configured to rotate around a first pivot relative to the base member; a distal member having a first end mechanically coupled to a second end of the proximal member and configured to rotate around a second pivot relative to the proximal member; and a cable having a first portion coupled to the actuator and a second portion extending along the proximal member and the distal member, the second portion separated away from the first pivot and the second pivot and having an end with a higher dimension than a diameter of the cable, the end with higher dimension structured to engage the distal member when the cable is pulled by the actuator.

[0017] The end with higher dimension may be floating within a region of the distal member.

[0018] The end with higher dimension may include at least one of a potted end; or an end with a potted insert.

[0019] The finger device may comprise a channel structure extending at least partially along the proximal member and the distal member, the channel structure hosting at least partially the second portion of the cable.

[0020] The end with higher dimension of the second portion of the cable may be structured to engage a ledge structure of the channel structure when the respective cable is pulled by the respective actuator.

[0021] The finger device may further comprise: a first torsion spring placed around the first pivot; and a second torsion spring placed around the second pivot.

[0022] The finger device may further comprise a magnet coupled to the first pivot; and a hall effect sensor placed proximate to the magnet. In some implementations, the magnet includes a ring magnet placed around the first pivot.

[0023] In some implementations, the finger device system further comprises: a magnet coupled to the second pivot; and a hall effect sensor placed proximate to the magnet.

[0024] A distance between the cable and the first pivot may vary and/or a distance between the cable and the second pivot may vary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Non-limiting embodiments of the present disclosure are described by way of example concerning the accompanying figures, which are schematic and are not intended to be drawn to scale. Unless indicated as representing the background art, the figures represent aspects of the disclosure.

[0026] **FIG. 1** illustrates a diagram of an example humanoid robot where systems and methods described herein can be integrated, according to an embodiment.

[0027] **FIG. 2** illustrates a front view of a robot hand, according to an embodiment.

[0028] **FIGS. 3A-3C** illustrate various partially transparent views of the hand of **FIG. 2**, according to an embodiment.

[0029] **FIGS. 4A-4F** show various views of a cable-driven finger (or finger device), according to an embodiment.

[0030] **FIGS. 5A** and **5B** show internal views of another finger (or finger system), according to an embodiment.

[0031] **FIGS. 6A-6G**, motion simulated results for a system including two fingers are shown, according to an embodiment.

[0032] **FIGS. 7A-7C** show diagrams of a gearbox, according to an embodiment.

[0033] **FIGS. 8A** and **8B** depict the use of hall effect sensors to monitor the position of a finger or the corresponding members, according to an embodiment.

[0034] **FIG. 9** shows a framework for optimizing the parameters of cable-driven finger, according to an embodiment.

[0035] **FIGS. 10A-10B** show an optimization model and a simulation od an optimized hand model, according to an embodiment.

[0036] **FIGS. 11A-11C** show simulation results depicting effective lever arms, a feasible force range, a contact vector field, and energy loss, according to an embodiment.

DETAILED DESCRIPTION

[0037] Reference will now be made to the illustrative embodiments depicted in the drawings, and specific language will be used here to describe the same. It will nevertheless be understood that no limitation of the scope of the claims or this disclosure is thereby intended. Alterations and further modifications of the inventive features illustrated herein, and additional applications of the principles of the subject matter illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the subject matter disclosed herein. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the present disclosure. The illustrative embodiments described in the detailed description are not meant to be limiting to the subject matter presented.

[0038] In the current disclosure systems devices and methods for robotic hands and cable-driven fingers are described. The robotic hands and cable-driven fingers described herein enable adaptive and stable finger motion. Adaptability refers to the motion of finger links being adaptive to points of contact or points of forces of contact. Also, robotic hands and cable-driven fingers described herein enable more stable and more efficient grasping of objects. The robotic hands and cable-driven fingers described herein mimic at least some extent the human hand and fingers.

[0039] **FIG. 1** is a diagram of an example humanoid robot **100** where the systems and methods described herein can be integrated, according to an example embodiment. The humanoid robot **100** can include an upper body **102**, two arms **104** and two legs **106**. The upper body **102** can include a controller **108** for controlling the robot **100**. The controller **108** can include a processing circuitry **110** and a communication interface **112**. The processing circuitry **110** can be communicatively coupled to the communication interface **112**. The processing circuitry **110** can include a processor **114** and a memory **116**. The robot **100** can include a plurality of actuators **118** associated with a plurality of joints. Each arm **104** can include a corresponding hand **120**. The robot **100** may include one or more sensors for sensing parameters of the robot **100** or the surrounding of robot **100**. The robot **100** may include one or more cameras.

[0040] The processor **114** may be implemented as a 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. The processor **114** may be a microprocessor. The processor **114** 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 implementations, the controller **108** may include one or more processors **114**.

[0041] The memory **116** (e.g., memory unit and/or 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 described in the present disclosure. The memory **116** may be communicably connected to the processor **114** to provide computer code or instructions to the processor **114** for executing at least some of the processes described herein. Moreover, the memory **116** may be or include tangible, non-transient volatile memory or non-volatile memory. For instance, the memory **116** 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 herein.

[0042] The communications interface **112** may include any combination of wired and/or wireless interfaces (e.g., jacks, antennas, transmitters, receivers, transceivers, wire terminals) for conducting data communications with various systems or devices of the robot 100. For instance, the communications interface **112** can enable communications between the processing circuitry **110** (or the processor **114**) and the actuators **118**, sensors or cameras integrated into the robot **100**. In some implementations, the communications interface 112 can enable communications with remote systems or devices.

[0043] The processing circuitry **110** or the processor **114** can be configured to control joints of the robot **100**. The processing circuitry **110** or the processor **114** can control a joint or movements associated with the joint by controlling the corresponding actuator(s) **118**. In particular, each joint can include or can be associated with one or more actuators **118** configured to drive motion of robot components or elements connected via the joint. As discussed in further detail below, the processing circuitry **110** or the processor **114** can send instructions to the actuator(s) **118** to cause or trigger precise motion of one or more elements or components of the robot **100**. The processing circuitry **110** or the processor **114** can control multiple joints simultaneously to achieve a coordinated movement of the robot **100**.

[0044] The processing circuitry **110** or the processor **114** can receive data from sensors and/or cameras integrated in the robot **100**, and make decisions, e.g., with regard to which elements of the robot **100** to move and how, based on the received data. For example, the data received from the sensors and/or cameras can be indicative of an obstacle in the path of the robot **100**. The processing circuitry **110** or the processor **114** can decide to modify the path and determine movements of one or more limbs or components of the robot **100** based on the modified path. In some implementations, the processing circuitry **110** or the processor **114** can receive data from a remote device or system indicative of a task to be performed by the robot **100** and determine a sequence of movements of the limbs or components of the robot **100** to perform the task.

[0045] While **FIG. 1** shows the controller as being integrated in the chest or upper body of the robot **100**, in general, the controller **108** can be placed or integrated in other regions or parts of the robot **100**. For example, the robot **100** can include a head and the controller 108 can be integrated into or on the head. In some implementations, the controller **108** can be placed on the back, in or on the waist region and/or in or on one of the limbs of the robot **100**.

[0046] **FIG. 2** illustrates a front view of a robot hand **200**, according to an embodiment. The hand **200** can include a palm region **202** and a plurality of fingers, such as fingers **204a-204e**, which are also referred to herein individually or collectively as finger(s) **204**. The hand **200** is similar in structure to a human hand with a thumb finger **204a** and four forefingers **204b-204e**. Each of the fingers **204a-204e** can include a respective proximal member, e.g., among the proximal members **206a-206e**, and a respective distal member, e.g., among the distal members **2081-208e**.

[0047] The proximal members **206a-206e** are also referred to herein as proximal member(s) **206** or proximal link(s) **206**. The distal members **208a-208e** are also referred to herein as distal member(s) **206** or distal link(s) **204**. As described in further detail below, each proximal member **206** can be configured or structured to rotate relative to the palm region **202**, e.g., around a corresponding first pivot coupling the proximal member **206** to the palm region. Also, each distal member **208** can be configured or structured to rotate relative to the corresponding proximal member **206**, e.g., around a corresponding second pivot coupling the distal member **208** to the corresponding proximal member **206**.

[0048] In some implementations, each of the fingers **204a-204e** (or a subset thereof) can include a respective base member, e.g., among the base members **210a-210e**. The base members **210a-210e** are also referred to herein as base member(s) **210** or base link(s) **210**. Each base member **210** can be mechanically fixed to the palm region **202** and mechanically coupled to the corresponding proximal member **206** in the same finger **204**. For instance, each proximal member **204** can be mechanically coupled to the corresponding base member **210** via the corresponding first pivot. Each proximal member **206** can be configured or structured to rotate relative to the corresponding base member **210**, e.g., around the corresponding first pivot.

[0049] Each of the fingers **204** can be actuated independently of other fingers **204**. The hand (or hand device) **200** as shown in **FIG. 2** is an anthropomorphic hand structured to mimic the human hand. In particular, the hand **200** includes a thumb finger **204** and four forefingers **204b-204e**. It is to be noted however that the systems described herein can be employed in other types of robot hands having any number of fingers **204**. For instance, the systems and methods described herein can integrated or employed in single-finger robot hands or multi-finger robot hands. More generally, the systems and methods described herein can be used or integrated in other components of a robot, e.g., other than the fingers and/or hands.

[0050] **FIGS. 3A-3C** illustrate various partially transparent views of the hand **200** of **FIG. 2**, according to an embodiment. **FIG. 3A** shows a front view of the hand **200** with the palm region **202** partially transparent. **FIG. 3B** shows the hand **200** without the thumb finger **204a** and with the palm region transparent. **FIG. 3C** shows the hand **200** with the thumb finger **204a** but not the forefingers **204b-204e** and with the palm region transparent.

[0051] The hand **200** can include six actuators **302a-302f**. Each of the forefingers **204b-204e** can include or can be associated with a corresponding actuator **302b-302e**. For instance, actuator **302b** can actuate motion of the proximal member **206b** and the distal member **208b** of finger **204b**, actuator **302c** can actuate motion of the proximal member **206c** and the distal member **208c** of finger **204c**, actuator **302d** can actuate motion of the proximal member **206d** and the distal member **208d** of finger **204d**, and actuator **302e** can actuate motion of the proximal member **206e** and the distal member **208e** of finger **204e**. Each of the actuators **302b-302e** can be placed or integrated in the palm region **202** and can be aligned or substantially with the corresponding finger **204**. More generally, the actuators **302b-302e** can be arranged or placed in the palm region **202** along a longitudinal direction of the hand **200** and/or fingers **204**.

[0052] Each of the actuator **302b-302e** can be viewed as being part of the corresponding finger (or finger device) **204**. For instance, finger (or finger device) **204b** can include the corresponding actuator **302b**, finger (or finger device) **204c** can include the corresponding actuator **302c**, finger (or finger device) **204d** can include the corresponding actuator **302d** and finger (or finger device) **204e** can include the corresponding actuator **302e**. Each of the actuators **302b-302e** can include a corresponding gearbox, e.g., among the gearboxes **304b-304e**. For instance, actuator **302b** can include gearbox **304b**, actuator **302c** can include gearbox **304c**, actuator **302c** can include gearbox **304d** and actuator **302e** can include gearbox **304e**.

[0053] Referring now to **FIG. 3C**, the thumb finger **204a** can include or can be associated with two actuators **302a** and **302f.** Actuator **302a** can be a thumb drive actuator similar to the actuators **302b-302e**. In other words, actuator **302a** can be configured or structured to cause movement of the proximal member **206a** and distal member 308a in a similar way as actuators **302b-302e** do with respect to the corresponding proximal members **206b-206e** and distal members **208b-208e**, respectively. Actuator **302f** can be an abduction/Adduction (Ab/Ad) actuator configured or structured to cause abduction and adduction movements of the thumb. In some implementations, the actuators **302a** and **302f** can be arranged or integrated in the palm region and can be horizontally or substantially perpendicular to the longitudinal direction of the hand **200** or the forefingers **204b-204e**. Actuator **302a** can include a gearbox **304a** and actuator **302f** can include a gearbox **304f**.

[0054] Each of the actuators **302a-302f** can be referred to herein individually or collectively as actuator(s) **302**. Also, gearboxes 304a-304f can be referred to herein individually or collectively as gearbox(es) **304**. The actuators **302** and gearboxes **304** are described in further detail below.

[0055] Referring now to FIGS. **4A-4F**, various views of a cable-driven finger (or finger device) **400** are shown, according to an embodiment. **FIGS. 4A and 4C** represent front pictorial views of the finger **400** in straight position and **FIG. 4B** represents a rear pictorial view of the finger **400** in straight position. **FIG. 4D** depicts a side view of the finger **400** in straight position and **FIG. 4E** depicts a side view of the finger **400** in bent position. **FIG. 4F** depicts an exploded view of the finger **400**, according to an embodiment.

[0056] Referring to **FIGS. 4A-4C**, the finger **400** can include a proximal member **402** having a first end **404** that is mechanically coupled to the palm region **202** and configured to rotate around a first pivot **406** relative to the palm region **202**. The first pivot **406** can be referred to herein as a pivot structure and can include a pin, a dowel or some other coupling structure that would enable rotation of the proximal member **402**. The finger **400** can include a distal member **408** having a first end **410** mechanically coupled to a second end **412** of the proximal member **402** and configured to rotate around a second pivot **414** relative to the proximal member **402**. The second pivot **414** can be referred to herein as a pivot structure and can include a pin, a dowel or some other coupling structure that would enable rotation of distal member **408** relative to the proximal member **402**.

[0057] The finger **400** can include a cable **416** that is coupled (or mechanically coupled) to an actuator **302**. A first end or first portion of the cable **416** can be coupled to the actuator **302** .and a second portion **418**. In some implementations, a first portion of the cable **416** can be wrapped around a pulley of the actuator **302** or of the corresponding gearbox **304**. The cable **416** can include a second portion **418** extending or floating along the proximal member **402** and the distal member **408**. For instance, the second portion **418** can be free to move along the finger **400** when the cable **416** is actuated (e.g., pulled) by the actuator **302**. In some implementations, the cable **416** or the second portion **418** may not be pinned or fixed at any location to the proximal member **402** and may not be pinned or fixed at any location to the distal member **408**.

[0058] The cable **416** or the second portion **418** can be routed along the proximal member and the distal member **408** in a way to be separated away from the first pivot **406** and the second pivot **414**. In other words, the cable 416 or the second portion 418 may not be wrapped around the first pivot **406** and may not be wrapped the second pivot **414**. For instance, the cable **416** or the second portion **418** can be routed towards (or closer) the front of the finger **400** relative to the first pivot **406** and may not be wrapped around the second pivot **414**. In particular, when the route or path of the cable **416** or the second portion **418** may not pass around the first pivot **406** and may not be pass around the second pivot **414**, especially when the proximal member **402** rotates around the first pivot **406** and/or the distal member 408 rotates around the second pivot **414**.

[0059] Referring to **FIGS. 4D** and **4E**, an end **420** of the cable **416** or of the second portion **418** can be associated with or having a larger dimension (e.g., thickness or diameter) than a diameter of the cable **416**. The end **420** associated with or having the larger dimension can be located in or at the distal member **408** and can be structured to engage the distal member **408** when the cable **416** is pulled by the actuator **302**. For example, the end **420** can include a potted end, an end with a potted insert or an end coupled to a knob or other structure having a larger dimension than the diameter of the cable **416**. When the cable **416** is pulled by the actuator **302**, the end **420** can engage the distal member **408** or a structure thereof to cause movement of at least one of the proximal member **402** or the distal member **408**. For example, when the cable **416** is pulled by the actuator **302**, the end **420** can engage the distal member **408** or a structure thereof causing the proximal member **402** to rotate around the first pivot **406** and/or the distal member **408** to rotate around the second pivot **414**.

[0060] In some implementations, the finger **400** can include a channel structure **424** extending at least partially along the proximal member **402** and the distal member **408**. The channel structure can receive or host, at least partially, the second portion **418** of the cable **416**. In some implementations, the channel structure **424** can include one or more groves, troughs, or tubes. The channel structure **424** can provide a conduit to the cable **416** or the second portion **418** to move back and forth along the finger **400** when actuated by the actuator **302**. In some implementations, and as shown in **FIGS. 4D** and **4E**, the channel structure **424** can include a first channel portion **426** located in or at the proximal member **402** and a second channel portion **428** located in or at the distal member **408**. In other words, the channel structure **424** can be discontinuous around the joint between the proximal member **402** and the distal member **408**.

[0061] In some implementations, the second channel portion **428** located in or at the distal member **408** can include a ledge structure **430**. The end **420** (of the cable **416** or the second portion **418**) associated with or having the larger dimension can be structured to engage the ledge structure **430** of the second channel portion **428** located at the distal member **408** when the cable **416** is pulled by the actuator **302**. In some implementations, the end **420** (of the cable **416** or the second portion **418**) associated with or having the larger dimension can be structured to engage an end of the second channel portion **428** (or of the channel structure **424**) located at the distal member **408** when the cable **416** is pulled by the actuator **302**.

[0062] In some implementations, the end **420** of the cable (or the second portion **418**) can be floating in the second channel portion **428** (or in the channel structure **424**). In other words, the end **420** of the cable (or the second portion **418**) may not be connected of fixed to the distal member **408**. In some implementations, the end **420** of the cable **416** (or the second portion **418**) can be floating in a pocket or space located within the distal member **408**. For example, the pocket or space can be located at the end of the distal member **408** beyond the second channel portion **428** (or the channel structure **424**).

[0063] In some implementations and as shown in **FIGS. 4D** and **4E**, the proximal member **402** and the distal member **408** can structured to form a convex curved surface **432**, e.g., between the first channel portion **426** and the second channel portion **428**, to enable or cause the cable **416** to bend according to a predefined radius when the finger **400** bends or when the distal member **408** rotates around the pivot **414**. Cables usually have small bending radii, which may cause them to break when bending. By causing the cable **416** to bend according to a relatively larger radius, e.g., larger than the typical bending radius of the cable **416**, breaking of the cable **416** can be avoided, which implies improved cable stability. Part of the convex curved surface **432** can in the proximal member **402** and another part can be in the distal member **408**.

[0064] Referring back to **FIGS. 4A-4C**, the finger **400** can include a first torsion spring **434** placed around or at the first pivot **406** and a second torsion spring **436** placed around or at the second pivot **414**. The first torsion spring **434** can be structured or configured to create some stiffness at the joint between the proximal member **402** and the palm region **202** and the second torsion spring **436** can be structured or configured to create some stiffness at the joint between the proximal member **402** and the distal member **408**. The stiffness at the joints or at pivots **406** and **414** contributes to the stability of finger system **400**.

[0065] In some implementations, the finger (or finger system) **400** can include a base member **438**. The base member **438** can be fixed to the palm region **202**. The proximal member **402** can be coupled to the palm region **202** via the base member **438**. For instance, the proximal member **402** can be coupled to the base member **438** via the pivot **406** and can be structured to rotate around the pivot **406** relative to the base member **438**.

[0066] **FIG. 4F** shows an exploded view of the finger (or finger system) **400**, according to an embodiment. Each of the pivots **406** and **414** can include a dowel. The torsion spring **436** (referred to in **FIG. 4F** as distal torsional spring) can be placed on the dowel, and the dowel can be fixed to the distal member (or distal link) **408** and/or the proximal member (or proximal link) **402** via bearings. The torsion spring **434** (referred to in **FIG. 4F** as proximal torsional spring) can be larger than (e.g., having a larger diameter than) the torsion spring **436** and may have larger stiffness than torsion spring **436**. A spring standoff can be placed on the dowel to hold the torsion spring **434**, and the spring standoff can be fixed to the distal member (or distal link) **408** and/or the proximal member (or proximal link) **402** via bearings.

[0067] The cable **416** is referred to as tendon in **FIG. 4F**. The end of **420** of the cable **416** located in the distal member **408** can be attached or connected to a manual tensioner to engage the distal member **408** when the cable **416** is actuated by the actuator **302**. The manual tensioner can float within an auto-tensioner (having a spring). The auto-tensioner can be arranged in a pocket or space of the distal member **408** at the end of the channel structure **424**.

[0068] In some implementations and as shown in **FIGS. 4D-4F**, the channel portion **428** hosting the floating end **420** of the cable **416** can be at an angle relative or with respect to a back surface of the finger **400**.

[0069] Referring now to **FIGS. 5A and 5B**, internal views of another finger (or finger system) **500** are shown according to an embodiment. Similar to the finger **400**, finger **500** can include a proximal member **502** and a distal member **502**. The finger **500** may also include a base member **506**. The distal member **502** can be structured or configured to rotate around a pivot

506 relative to the base member **506** or relative to a palm region **202**. The distal member **504** can be configured to rotate around a pivot **510** relative to the proximal member. The finger **500** can include a cable **512** connected to actuator **302** at first end and can include a second end placed in the distal region **504**. The cable **512** or a part thereof can extend along the proximal region **502** and the distal region 505 and can be separated away from the pivots **508** and **510**.

[0070] The finger **500** can include one or more tubes, e.g., tubes **514** and **516**, forming a channel that partially hosts or receives cable **512**. The second end of the cable **512** can be floating (not connected, fastened, or fixed) in a region (or pocket region) **518** of the distal member **504**. The second end of the cable **512** can have a potted insert **520** that is structured to engage an end of the pocket region **518** when the cable **512** is pulled by the actuator **302**.

[0071] The fingers (or finger systems) **400** and **500** or mechanisms thereof can be used or integrated in hand **200** of **FIG. 2**. Any of the fingers **204a-204e** of **FIG. 2** can be implemented as finger **400** or finger **500**. It is to be noted that features described in different figures or embodiments can be combined in a single embodiment. For example, the pocket region **518** of finger **500** can be implemented in finger **400**. Also, the potted insert **520** may be integrated in finger **400** of **FIG. 4**.

[0072] The routing of the cable **416**, **512** discussed in relation with **FIGS. 4A-4F** and **5A-5B** has multiple technical advantages over conventional cable driven systems. Specifically, conventional cable-driven fingers wrap the cable **416** around the pivots **406** and **414**. The cable **416** can include a metal cable and metal cables have a fixed bend radius. In conventional systems, the cable **416** would be wrapped around the pivots at the joints to keep it at a constant radius when it bends and avoid breaking the cable because these cables have really small bend radiances. However, wrapping the cable **416** around the pivots **406** and **414** limits the range of motion of the finger (or the range in of motion of the proximal member **402** and the distal member **408**).

[0073] The cable routing described in **FIGS. 4A-4F** and **5A-5B** enables a lot more force to be applied, especially as the angle between the proximal member **402** and the distal member **408** decreases. The amount of force that is applied is actually a function of how far the cable **416** is from the joint. As the cable **416** gets separated further away from the joint, more force can be applied as the hand **200** closes, which allows to fine tune the torque graph in space. The cable routing described herein (not wrapped around the pivots) also helps produce a more equal joint torque and helps fine tune the torque instead of fine tuning the gearbox as usually done in conventional systems. Fine tuning the gearbox causes various issues such as using non-concentric and/or asymmetric gears that makes the design more complex. By fine tuning the torque using the structure of the finger (e.g., the cable location relative to joints, the lengths of the finger members and/or other parameters) instead of fine tuning the gearbox leads to a reduction in parts count and reducing part complexity.

[0074] Another advantage of the described cable routing is the fact that two joints of the finger **400** are driven by the same actuator **302** with more adaptability. The finger **400** is adaptive in the sense that as the position of contact (or contact force by an object) changes, different links or members will move. In other words, which member among the proximal member **402** and distal member **408** will move may change depending on the point of contact.

[0075] Also, maintaining the end of the cable **420** to be floating in the distal member **408** prevents the cable **416** from breaking or being damaged. Specifically, when the finger **400** gets in contact or pushes other objects, the fact that the cable **416** is floating provides some flexibility and avoids breaking or denting the cable **416**. In addition, the use of the torsion springs **434** and **436** provides some stability to the finger system **400**, especially when the finger **400** grabs an object or is under some external force. The torsion springs **434** and **436** also prevent anti-backlash.

[0076] Referring now to **FIGS. 6A-6G**, motion simulated results for a system **600** including two fingers are shown, according to an example embodiment. **FIG. 6A** shows a system **600** including a thumb finger **602** and a forefinger **604**. **FIGS. 6B-6G** show sample frames of a video sequence depicting motion of the fingers **602** and **604** towards each other.

[0077] As the cables for both fingers **602** and **604** get pulled by the actuator **302** or the gearbox **304**, the fingers **602** and **604** move toward each other. The circles shown in **FIGS. 6B-6G** are indicative of divots (or curved surfaces) in the finger **400** that allows the cable not to bend and also allow to tune the torque. As the fingers **602** and **604** bend, the distances between the corresponding cables (shown in black lines) and corresponding joints increases, implying a changing radius or distance between each joint and the cable. The motion of the proximal member and distal member of each finger indicates that the cable is acting pretty much similar to a tendon in a human finger. Also, the fact that the cable is changing radius (or distance from the joints) helps moving some of the complexity from the gearbox **304** into the finger itself.

[0078] **FIGS. 7A-7C** show diagrams of a gearbox **304**, according to an embodiment. The gearbox **304** can include a gear **702** (e.g., a worm gear) and a worm wheel **704**. The gear **702** can be fixed to a shaft of the actuator **302**. As the shaft is rotated by a motor, the gear rotates and cause the worm wheel **704** to rotate. The worm wheel **704** can include a pulley **706** and the cable **416** can be connected to the pulley **706**. For instance, a portion of the cable **416** can be wrapped around the pulley **706**. As the gear **702** rotates, the cable gets pulled or unwrapped from the pulley **706**.

[0079] **FIGS. 8A** and **8B** depict the use of hall effect sensors **802** to monitor the position of a finger or the corresponding members, according to an embodiment. A finger, such as finger **400**, can include a magnet **804**, such as a ring magnet. The magnet **304** can be coupled to the pivot **406** between the proximal member **402** and the palm region **202** (or the base member **438**). The finger **400** can include a hall effect sensor **302** placed proximate to the respective magnet **804**. For example, the hall effect sensor **803** can be placed or located in the base member **438** or in the palm region **202**. The hall effect sensor **802** can sense or measure the magnetic field produced by the magnet **804**. As the proximal member **402** rotates, so does the magnet **804**. The hall effect sensor **804** does not move with the proximal member **402** and can detect changes in the magnetic field as the proximal member **402** rotates. The hall effect sensor **802** can be communicatively coupled to the processor **114**. The processor **114** can determine based on the measured magnetic field the position or angle of rotation of the proximal member **402**.

[0080] In some implementations, each finger in the hand **200** can include a respective hall effect sensor **802** and a respective magnet **804**. In some implementations, a finger **400** (or each finger of hand **200**) can include a magnet positioned at or around the pivot **414** and hall effect sensor **802** arranged in the proximal member proximate to magnet **804**. The hall effect sensor **802** can be used by the processor **114** to detect a position or rotation angle of the distal member relative to the proximal member **402**. In some implementations finger **400** or each finger of hand **200**) can include a first hall effect sensor and a first magnet to monitor the position of the proximal member **402**, and a second hall effect sensor and a second magnet to monitor the position of the distal member **408** relative to the proximal member **402**. In some implementations, the magnet 804 can include a ring magnet placed around the pivot **406** or the pivot **414**.

[0081] **FIG. 9** shows a framework **900** for optimizing the parameters of cable-driven finger, according to an embodiment. The framework includes two fingers and an object grasped (or to be grasped by the two fingers. Each finger can have a corresponding proximal link and a corresponding distal link. Each finger can be driven by a corresponding cable. Each finger exerts a corresponding force on the object.

[0082] Adaptive finger mechanisms are inherently unstable. A goal of the optimization is to solve for optimal parameters of the fingers, including finger lengths (e.g., lengths of proximal and distal members of the finger), joint stiffness (e.g., stiffness introduced by corresponding torsion spring), joint locations and cable routings (e.g., distances from joints). The optimization can include minimizing post contact work (e.g., object displacement relative to fingers) and maximizing resistible external forces. Minimizing post contact work means minimizing movement of object relative to the fingers once grasped (e.g., slipping). This is expected to lead to more reliable and stable grasping. Maximizing resistible external forces means maximizing resistance to any external forces after grasping the object. This will prevent or mitigate the chances of the object falling if running into an obstacle, for example.

[0083] The forces F_{xL} and F_{yL} represent the forces of the left finger in the x and y axes. The forces F_{xR} and F_{yR} represent the forces of the right finger in the x and y axes. Both forces depend on the location or routing of the cable. The optimization can be performed subject to a set of constraints, such as for equilibriums, torque equilibrium, hand model constraints, closure constraints and/or a kinematic constraint, among other constraints.

[0084] In some implementations, grasping a large variety of objects can be modeled or simulated in different positions and a computer system, including a memory and processor, can solve for optimal parameters (e.g., optimal components and component locations). Failure modes can include object ejection, loss of grip and/or loss of stability. Solving the optimization problem can include determining cable location or distance from joints, stiffness of springs and/or lengths of fingers or links thereof.

[0085] **FIGS. 10A and 10B** show an optimization model and a simulation od an optimized hand model. In particular, **FIG. 10A** shows the variables considered for the proximal member and the distal member in the optimization. **FIG. 10B** shows a simulation of an example hand model with estimated cable position and representative geometry determined by solving the optimization problem by a computer system as depicted in **FIG. 10A**.

[0086] **FIGS. 11A-11C** show simulation results depicting the effective lever arms, the feasible force range, the contact vector field, and energy loss for an example of the cable-driven finger as described herein.

[0087] While embodiments described herein are discussed in relation with a knee joint assembly of a humanoid robot, the embodiments can be used or applied in other types of joints and/or other types of robots.

[0088] The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of this disclosure or the claims.

[0089] Embodiments implemented in computer software may be implemented in software, firmware, middleware, microcode, hardware description languages, or any combination thereof. A code segment or a machine-executable instruction may represent a procedure, function, subprogram, program, routine, subroutine, module, software package, class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

[0090] The actual software code or specialized control hardware used to implement these systems and methods is not limiting of the claimed features or this disclosure. Thus, the operation and behavior of the systems and methods were described without reference to the specific software code, it being understood that software and control hardware can be designed to implement the systems and methods based on the description herein.

[0091] When implemented in software, the functions may be stored as one or more instructions or code on a non-transitory, computer-readable, or processor-readable storage medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module, which may reside on a computer-readable or processor-readable storage medium. A non-transitory computer-readable or processor-readable media includes both computer storage media and tangible storage media that facilitates the transfer of a computer program from one place to another. A non-transitory, processor-readable storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such non-transitory, processor-readable media may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other tangible storage medium that may be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer or processor. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), Blu-ray disc, and floppy disk, where “disks” usually reproduce data magnetically, while “discs” reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory, processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

[0092] The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the embodiments described herein and variations thereof. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the principles defined herein may be applied to other embodiments without departing from the spirit or scope of the subject matter disclosed herein. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the following claims and the principles and novel features disclosed herein.

[0093] While various aspects and embodiments have been disclosed, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. A robotic hand system comprising:

a palm region; and

one or more fingers, each finger comprising:

an actuator device;

a respective proximal member having a first end mechanically coupled to the palm region robot and configured to rotate around a respective first pivot relative to the palm region;

a respective distal member having a first end mechanically coupled to a second end of the proximal member and configured to rotate around a respective second pivot relative to the proximal member; and

a respective cable having a first portion coupled to the actuator and a second portion extending along the proximal member and the distal member, the second portion separated away from the first pivot and the second pivot and having an end with a higher dimension than a diameter of the cable, the end with higher dimension structured to engage the distal member when the cable is pulled by the actuator.

2. The robotic hand system of claim 1, wherein the end with higher dimension is floating within a region of the distal member.

3. The robotic hand system of claim 1, wherein the end with higher dimension includes at least one of:

a potted end; or

an end with a potted insert.

4. The robotic hand system of claim 1, wherein each finger comprises a respective channel structure extending at least partially along the respective proximal member and the respective distal member, the respective channel structure hosting at least partially the second portion of the respective cable.

5. The robotic hand system of claim 4, wherein the end with higher dimension of the second portion of the respective cable is structured to engage a ledge structure of the respective channel structure when the respective cable is pulled by the respective actuator.

6. The robotic hand system of claim 1, wherein each finger comprises:
a respective first torsion spring placed around the respective first pivot; and
a respective second torsion spring placed around the respective second pivot.

7. The robotic hand system of claim 1, wherein each finger comprises:
a respective magnet coupled to the respective first pivot; and
a respective hall effect sensor placed proximate to the respective magnet.

8. The robotic hand system of claim 7, wherein the respective magnet includes a ring magnet placed around the respective first pivot.

9. The robotic hand system of claim 1, wherein each finger comprises:
a respective magnet coupled to the respective second pivot; and
a respective hall effect sensor placed proximate to the respective magnet.

10. The robotic hand system of claim 1, a distance between the respective cable and the respective first pivot varies and/or a distance between the respective cable and the respective second pivot varies.

11. A finger device, comprising:
an actuator device;
a proximal member having a first end mechanically coupled to base member and configured to rotate around a first pivot relative to the base member;
a distal member having a first end mechanically coupled to a second end of the proximal member and configured to rotate around a second pivot relative to the proximal member; and
a cable having a first portion coupled to the actuator and a second portion extending along the proximal member and the distal member, the second portion separated away from the first pivot and the second pivot and having an end with a higher dimension than

a diameter of the cable, the end with higher dimension structured to engage the distal member when the cable is pulled by the actuator.

12. The finger device of claim 11, wherein the end with higher dimension is floating within a region of the distal member.

13. The finger device of claim 11, wherein the end with higher dimension includes at least one of:

a potted end; or

an end with a potted insert.

14. The finger device of claim 11, further comprises a channel structure extending at least partially along the proximal member and the distal member, the channel structure hosting at least partially the second portion of the cable.

15. The finger device system of claim 14, wherein the end with higher dimension of the second portion of the cable is structured to engage a ledge structure of the channel structure when the respective cable is pulled by the respective actuator.

16. The finger device of claim q1, further comprises:

a first torsion spring placed around the first pivot; and

a second torsion spring placed around the second pivot.

17. The finger device of claim 11, further comprises:

a magnet coupled to the first pivot; and

a hall effect sensor placed proximate to the magnet.

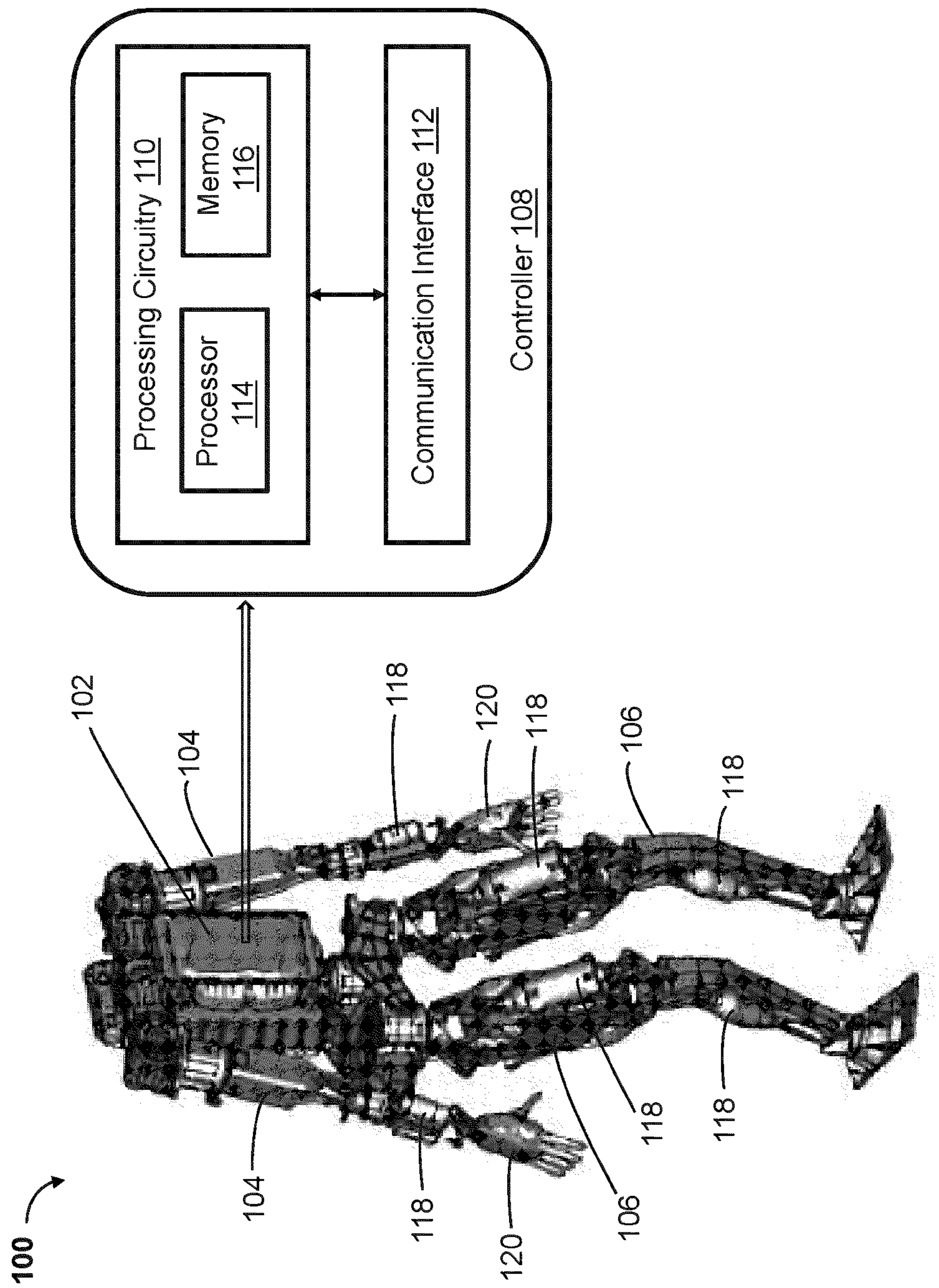
18. The finger device of claim 17, wherein the magnet includes a ring magnet placed around the first pivot.

19. The finger device system of claim 11, further comprises:

a magnet coupled to the second pivot; and

a hall effect sensor placed proximate to the magnet.

20. The finger device of claim 1, a distance between the cable and the first pivot varies and/or a distance between the cable and the second pivot varies.


Processing Circuitry 110
Processor 114
Memory 116
Communication Interface 112
Controller 108
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104
104
106
106
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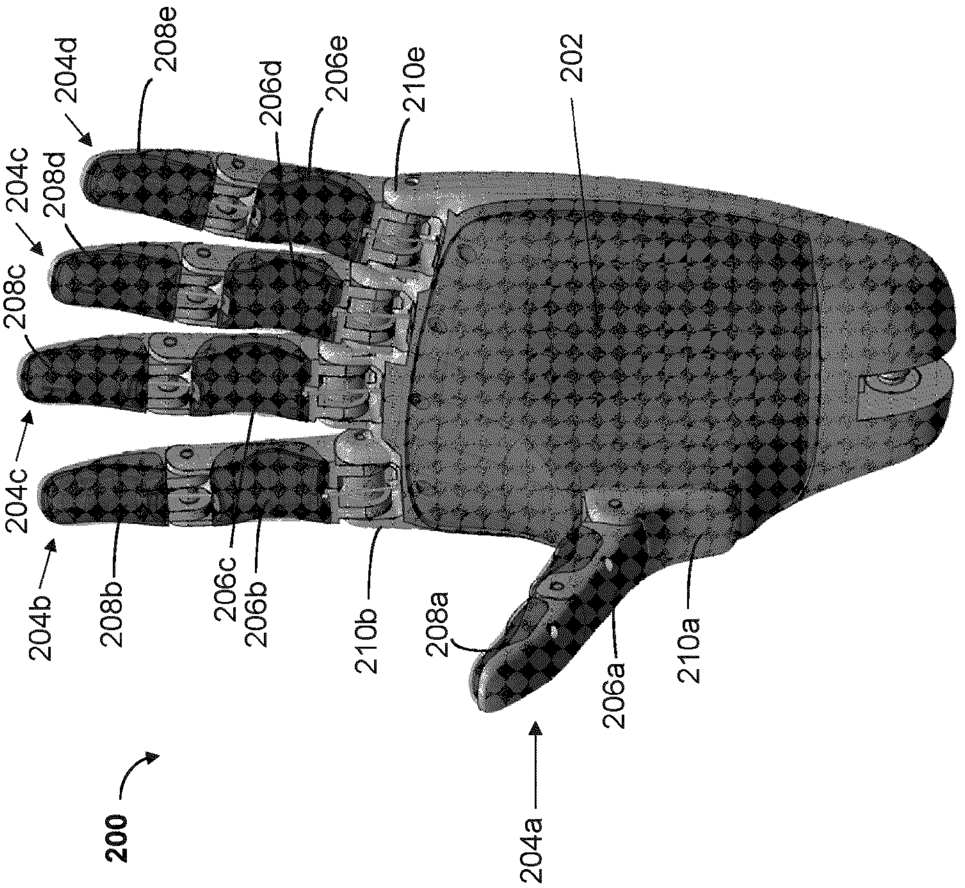
120
120

FIG. 1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204a
204b
204c
204c
204d
202
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206d
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208c
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210a
210b
210e

FIG. 2

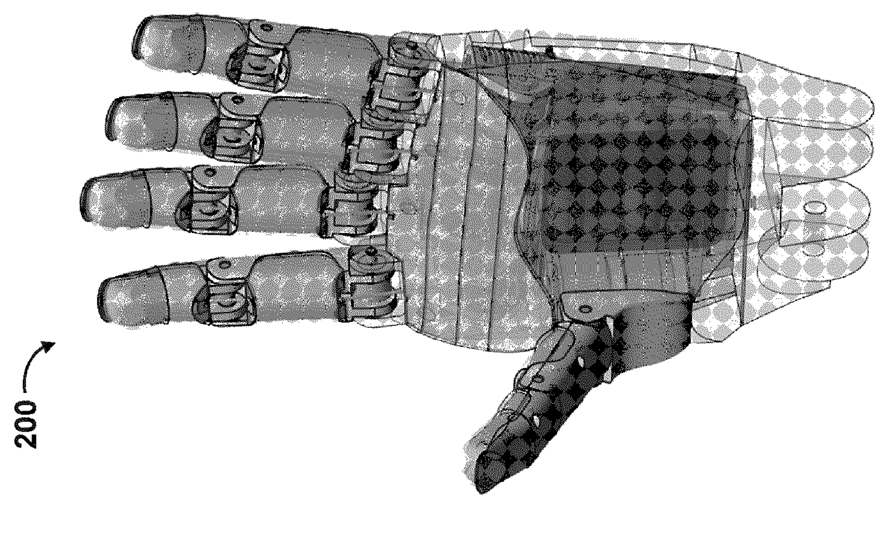


FIG. 3A

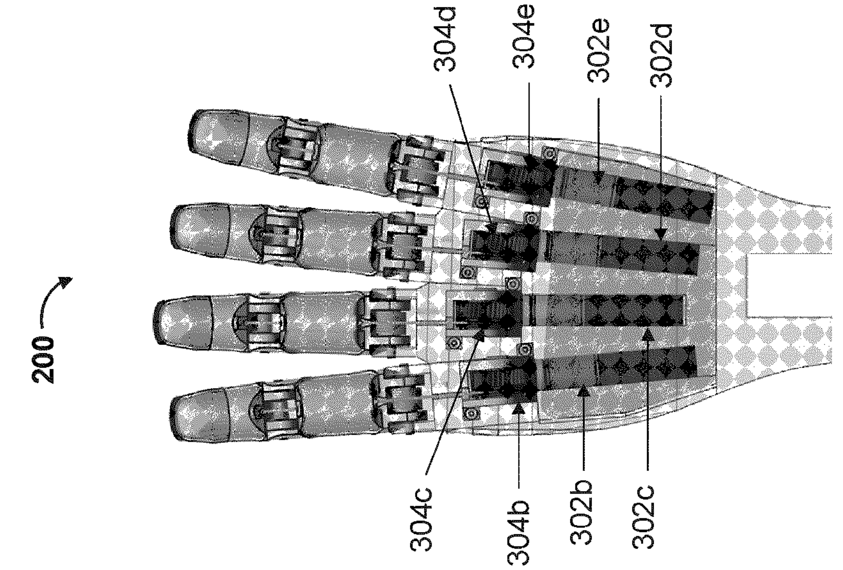


FIG. 3B

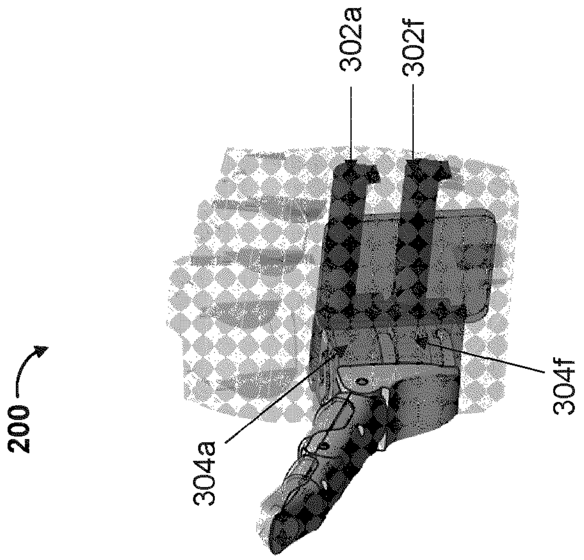


FIG. 3C

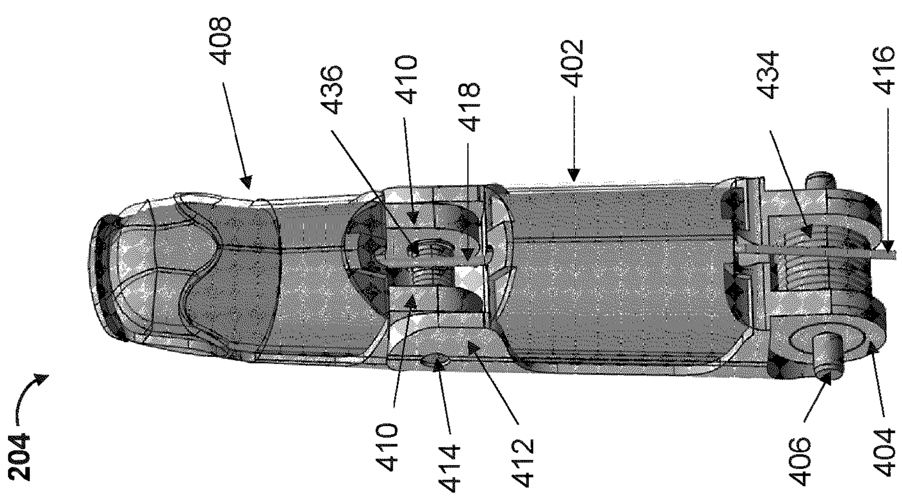


FIG. 4A

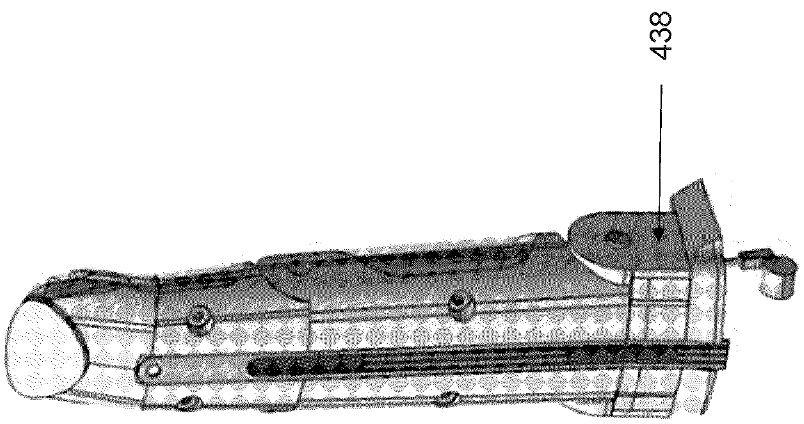


FIG. 4B

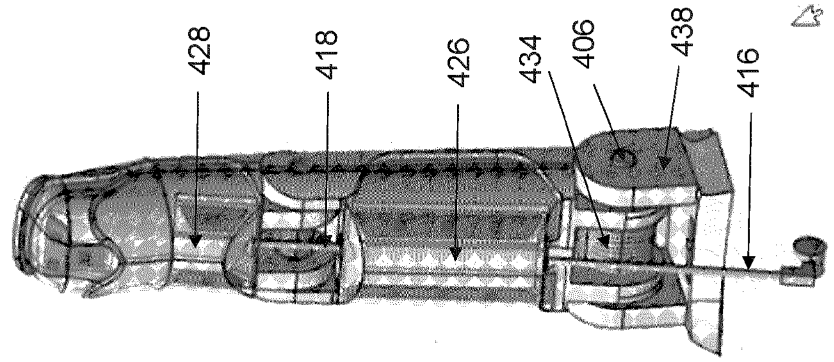


FIG. 4C

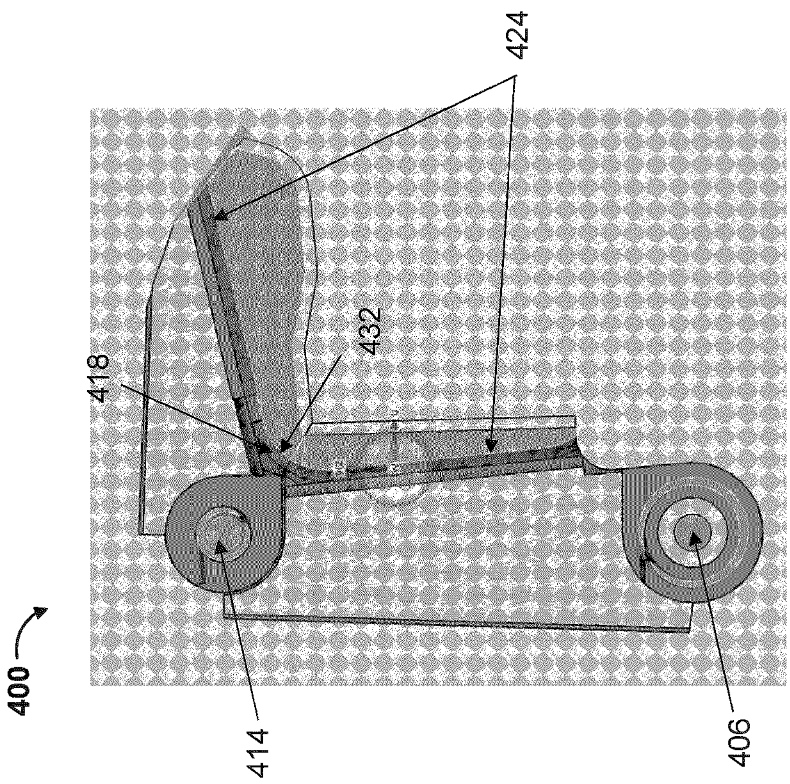

424
418
432
400
414
406

FIG. 4E

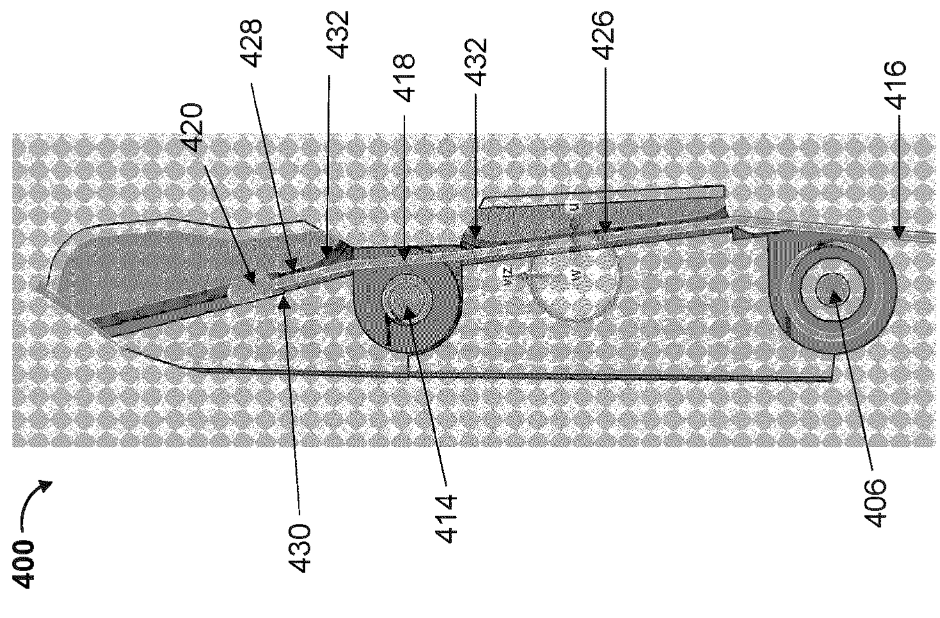
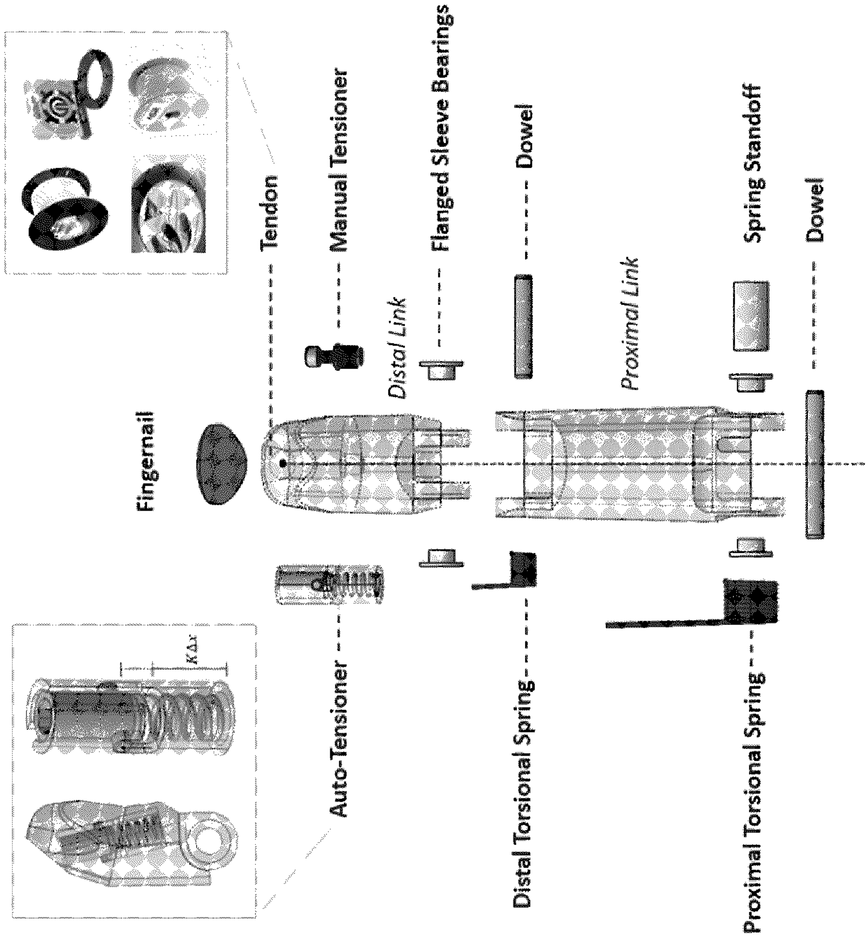

420
428
432
418
432
426
416
400
430
414
406

FIG. 4D

400



Fingernail
Tendon
Manual Tensioner
Flanged Sleeve Bearings
Dowel
Distal Link
Proximal Link
Spring Standoff
Dowel
Auto-Tensioner
Distal Torsional Spring
Proximal Torsional Spring
$K\Delta x$

FIG. 4F

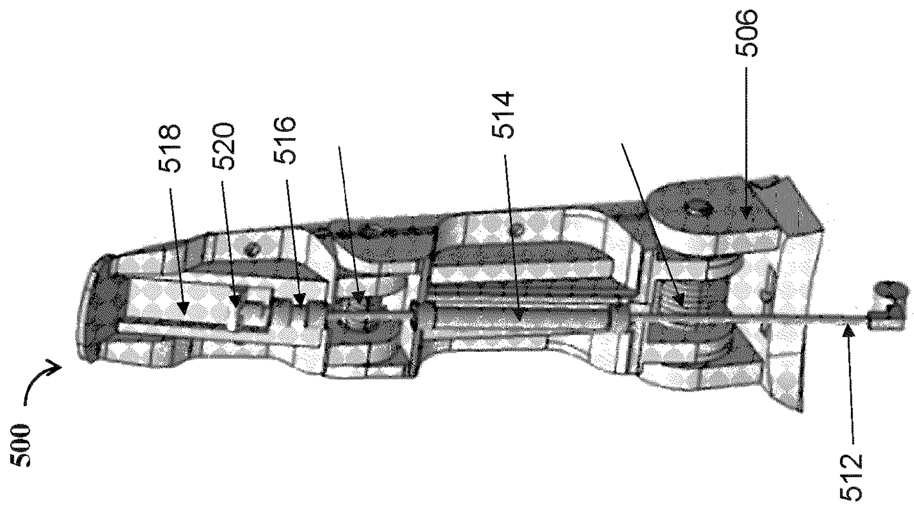


FIG. 5B

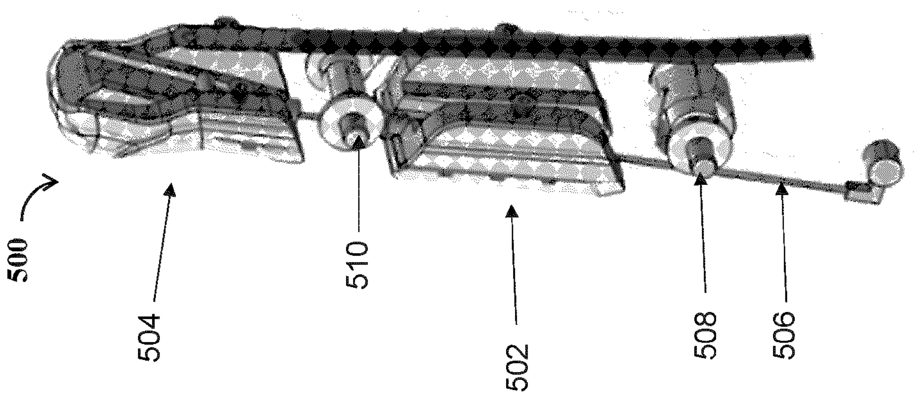


FIG. 5A

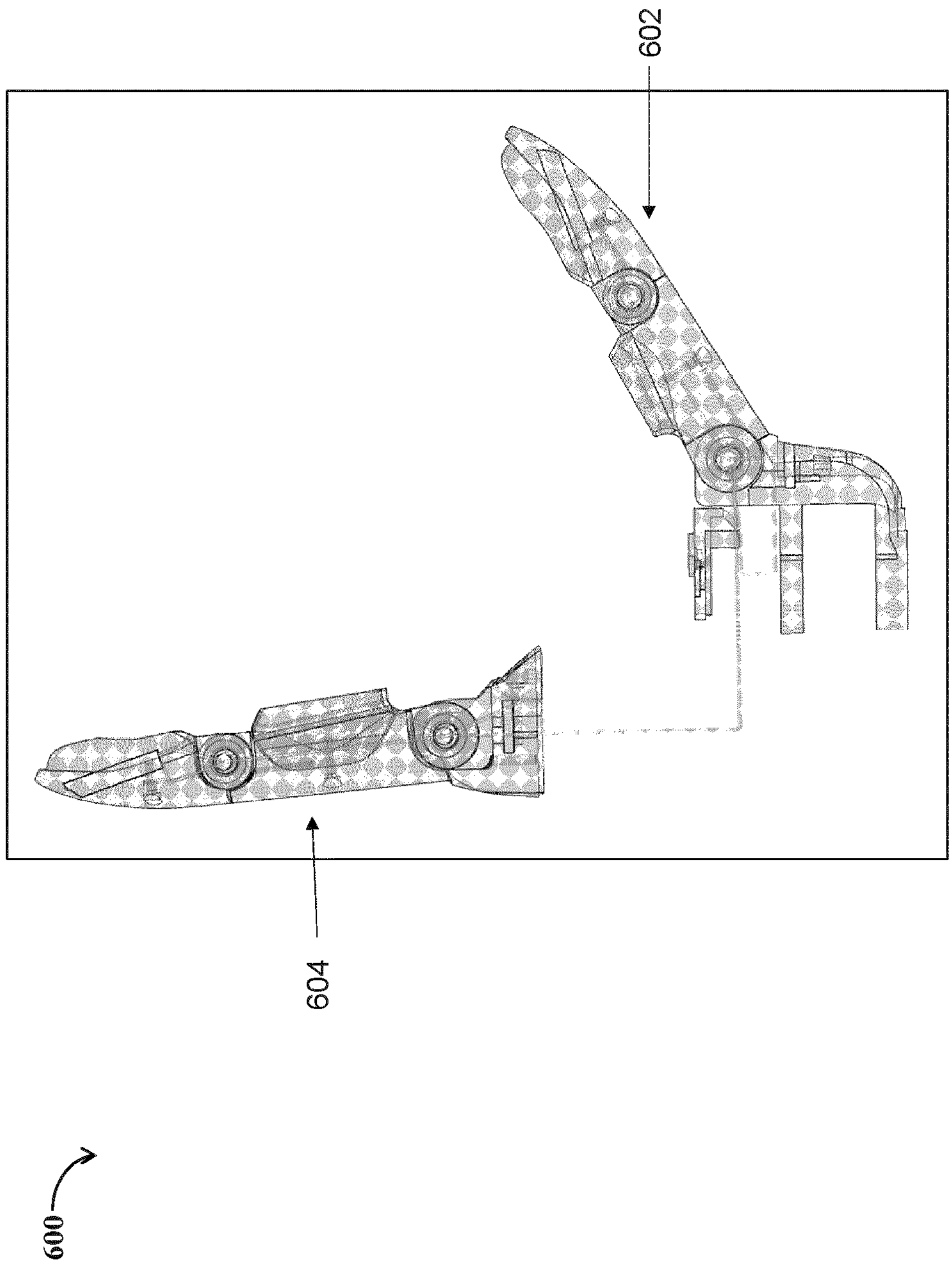


FIG. 6A

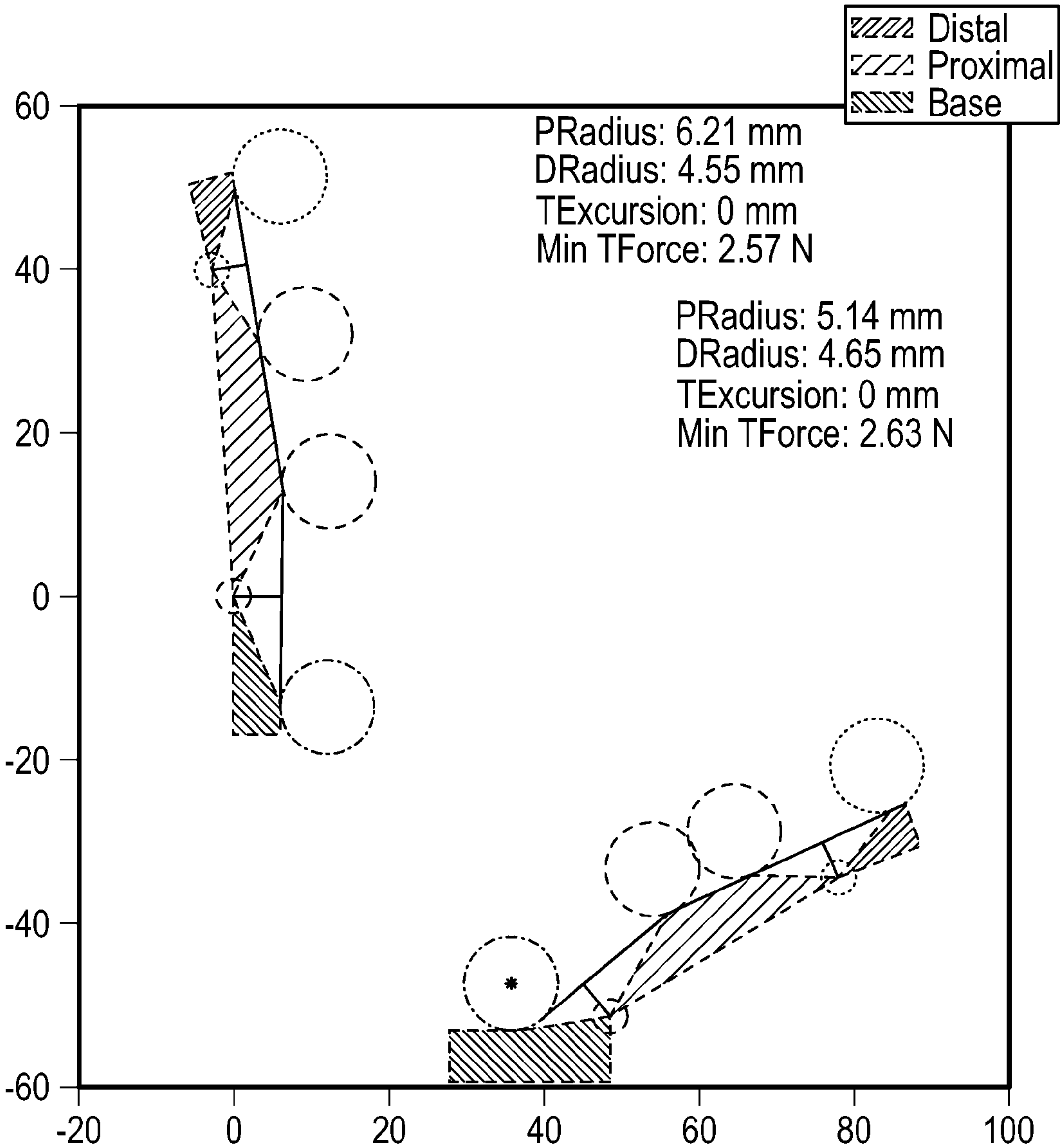

Distal
Proximal
Base
PRadius: 6.21 mm
DRadius: 4.55 mm
TExcursion: 0 mm
Min TForce: 2.57 N
PRadius: 5.14 mm
DRadius: 4.65 mm
TExcursion: 0 mm
Min TForce: 2.63 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6B

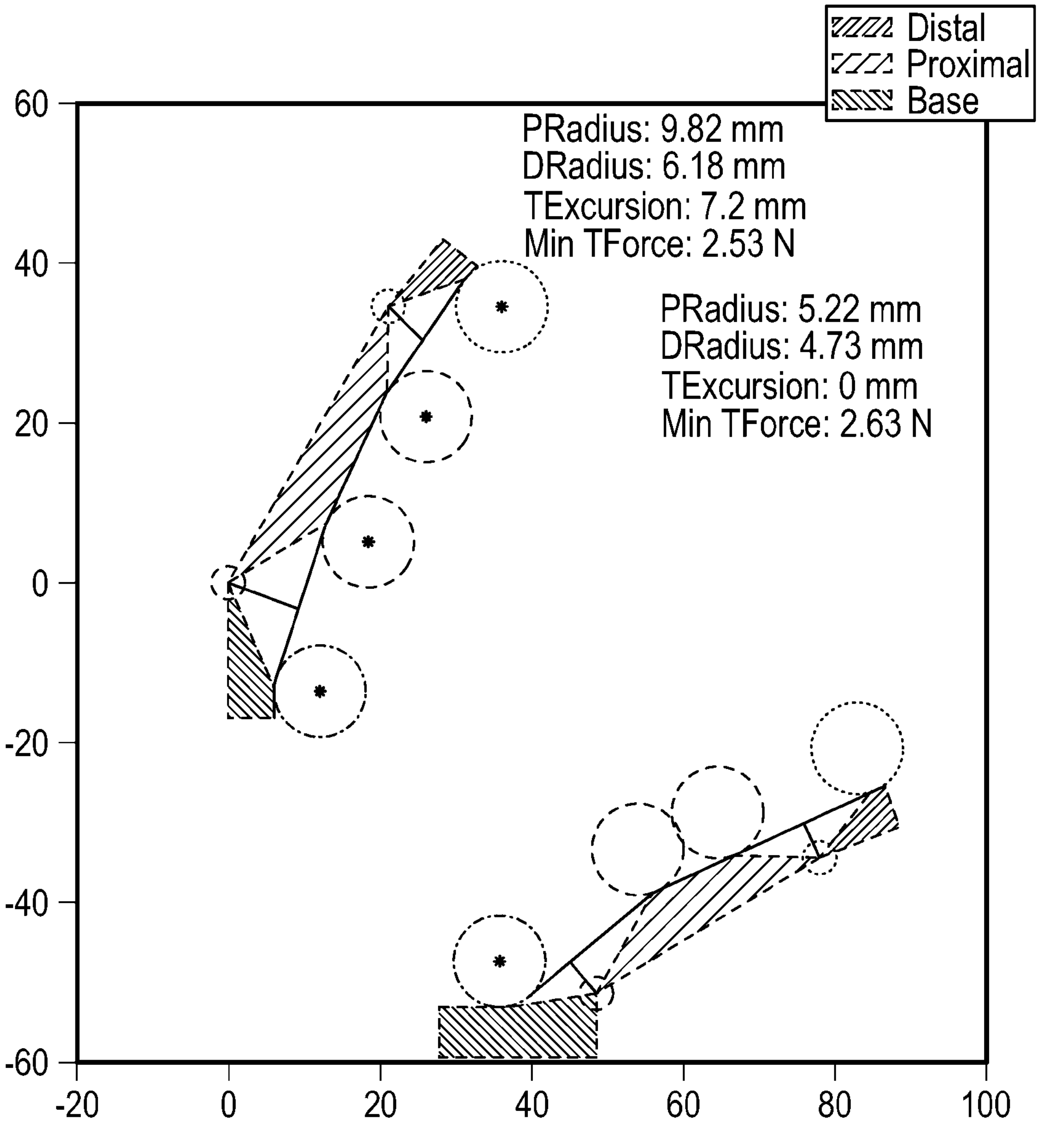

Distal
Proximal
Base
PRadius: 9.82 mm
DRadius: 6.18 mm
TExcursion: 7.2 mm
Min TForce: 2.53 N
PRadius: 5.22 mm
DRadius: 4.73 mm
TExcursion: 0 mm
Min TForce: 2.63 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6C

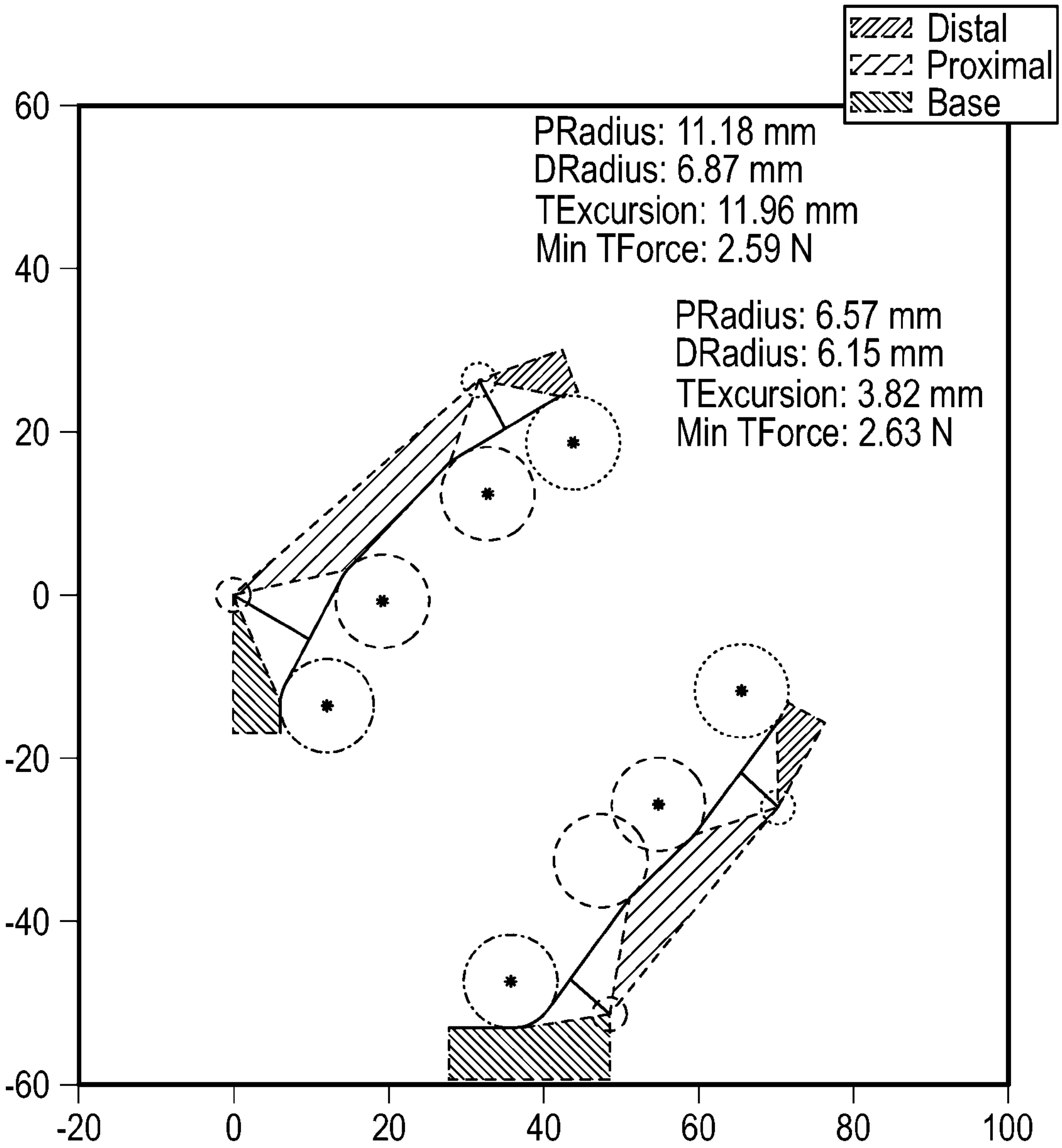

Distal
Proximal
Base
PRadius: 11.18 mm
DRadius: 6.87 mm
TExcursion: 11.96 mm
Min TForce: 2.59 N
PRadius: 6.57 mm
DRadius: 6.15 mm
TExcursion: 3.82 mm
Min TForce: 2.63 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6D

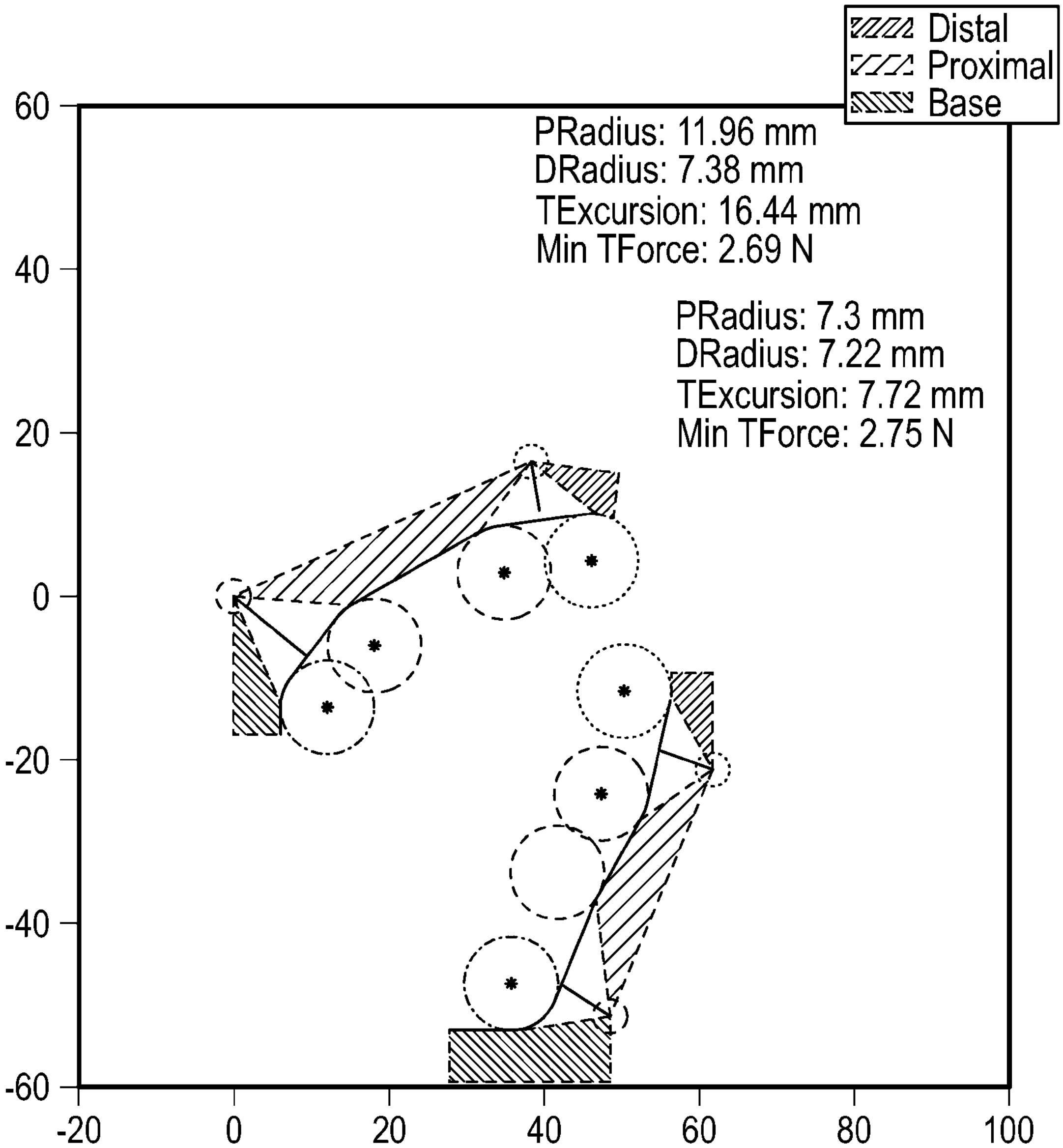

Distal
Proximal
Base
PRadius: 11.96 mm
DRadius: 7.38 mm
TExcursion: 16.44 mm
Min TForce: 2.69 N
PRadius: 7.3 mm
DRadius: 7.22 mm
TExcursion: 7.72 mm
Min TForce: 2.75 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6E

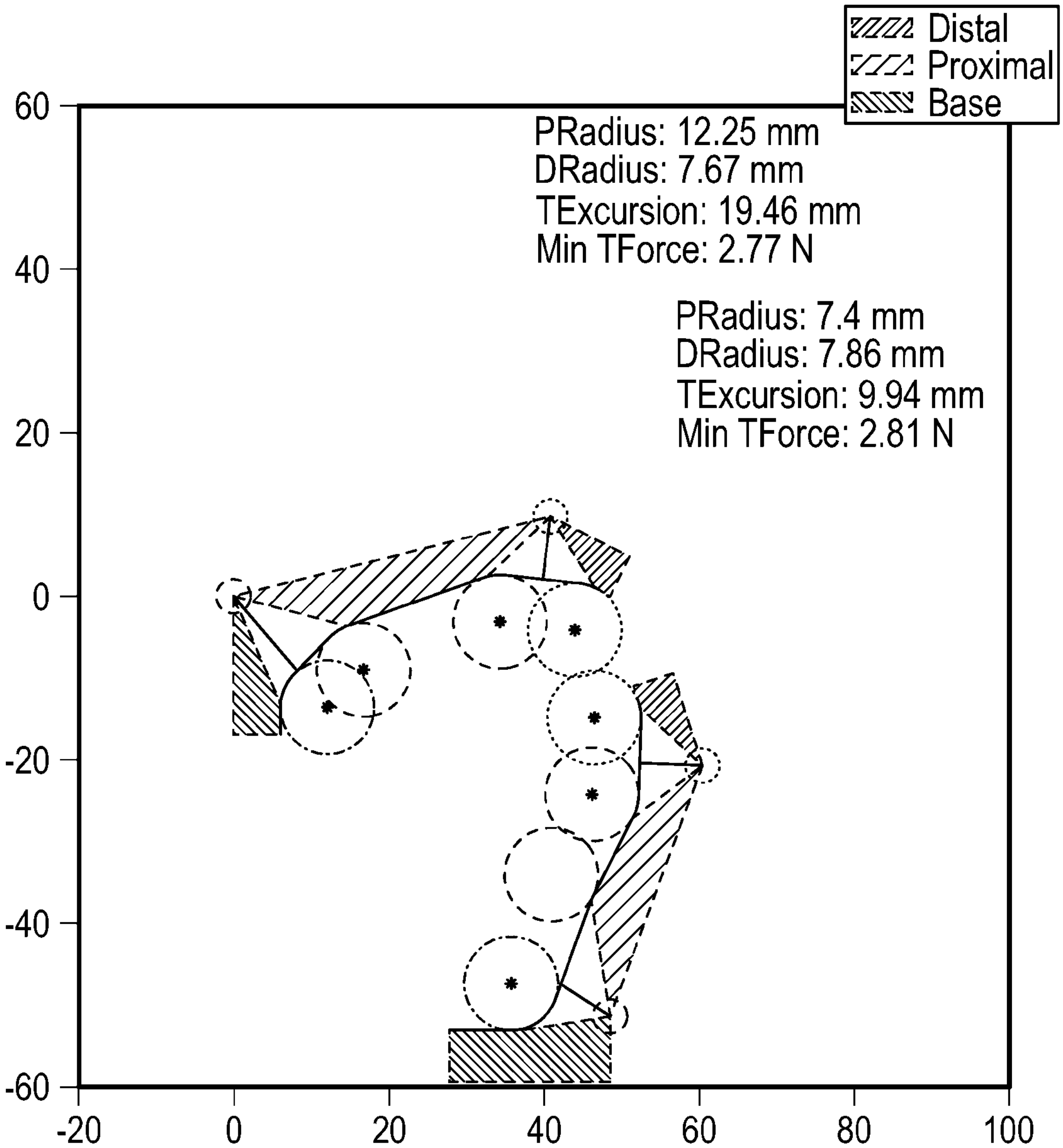

Distal
Proximal
Base
PRadius: 12.25 mm
DRadius: 7.67 mm
TExcursion: 19.46 mm
Min TForce: 2.77 N
PRadius: 7.4 mm
DRadius: 7.86 mm
TExcursion: 9.94 mm
Min TForce: 2.81 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6F

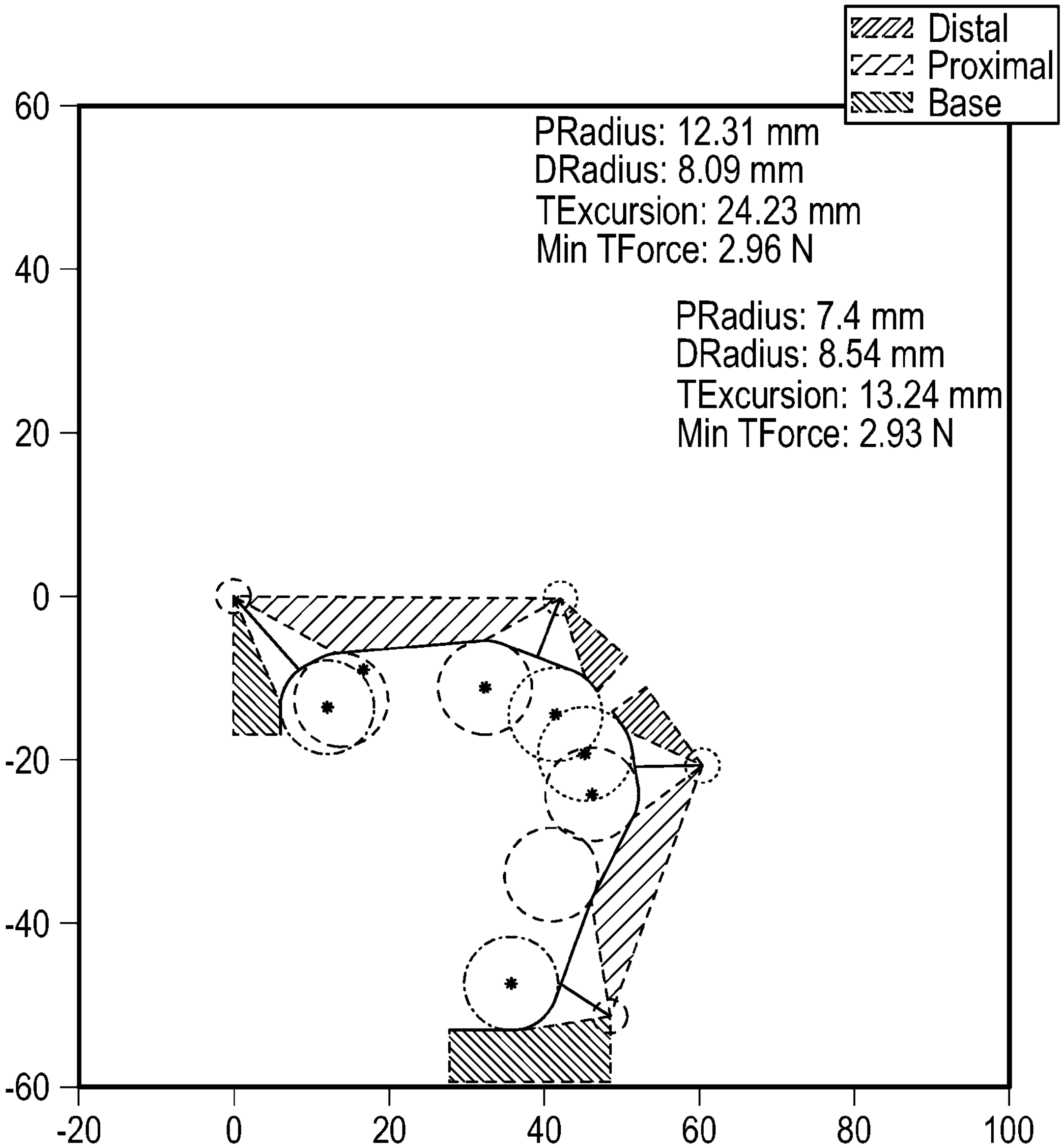

Distal
Proximal
Base
PRadius: 12.31 mm
DRadius: 8.09 mm
TExcursion: 24.23 mm
Min TForce: 2.96 N
PRadius: 7.4 mm
DRadius: 8.54 mm
TExcursion: 13.24 mm
Min TForce: 2.93 N
60
40
20
0
-20
-40
-60
-20
0
20
40
60
80
100

FIG. 6G

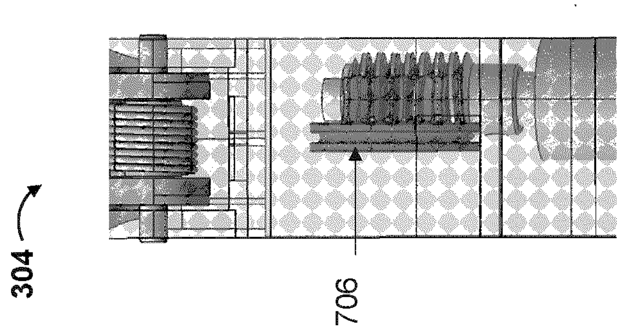


FIG. 7C

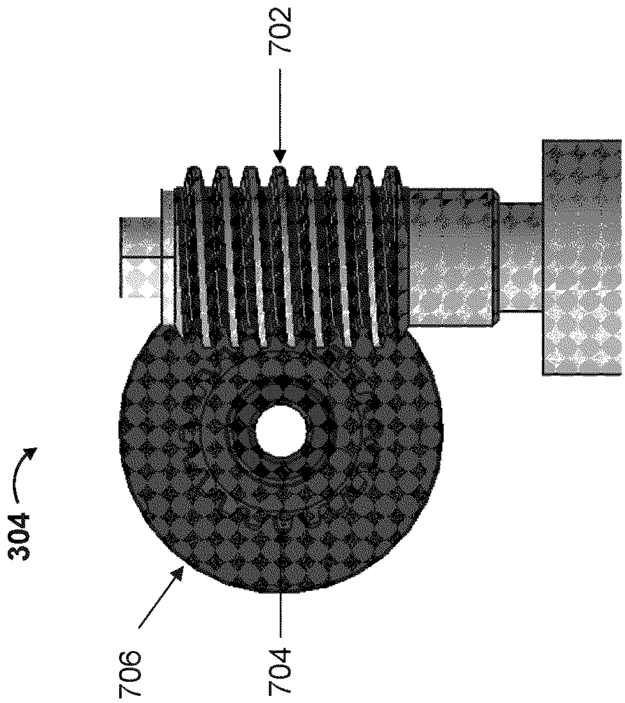


FIG. 7B

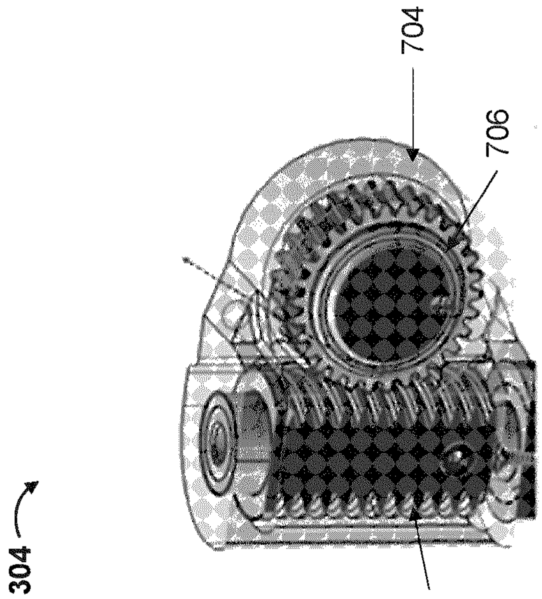


FIG. 7A

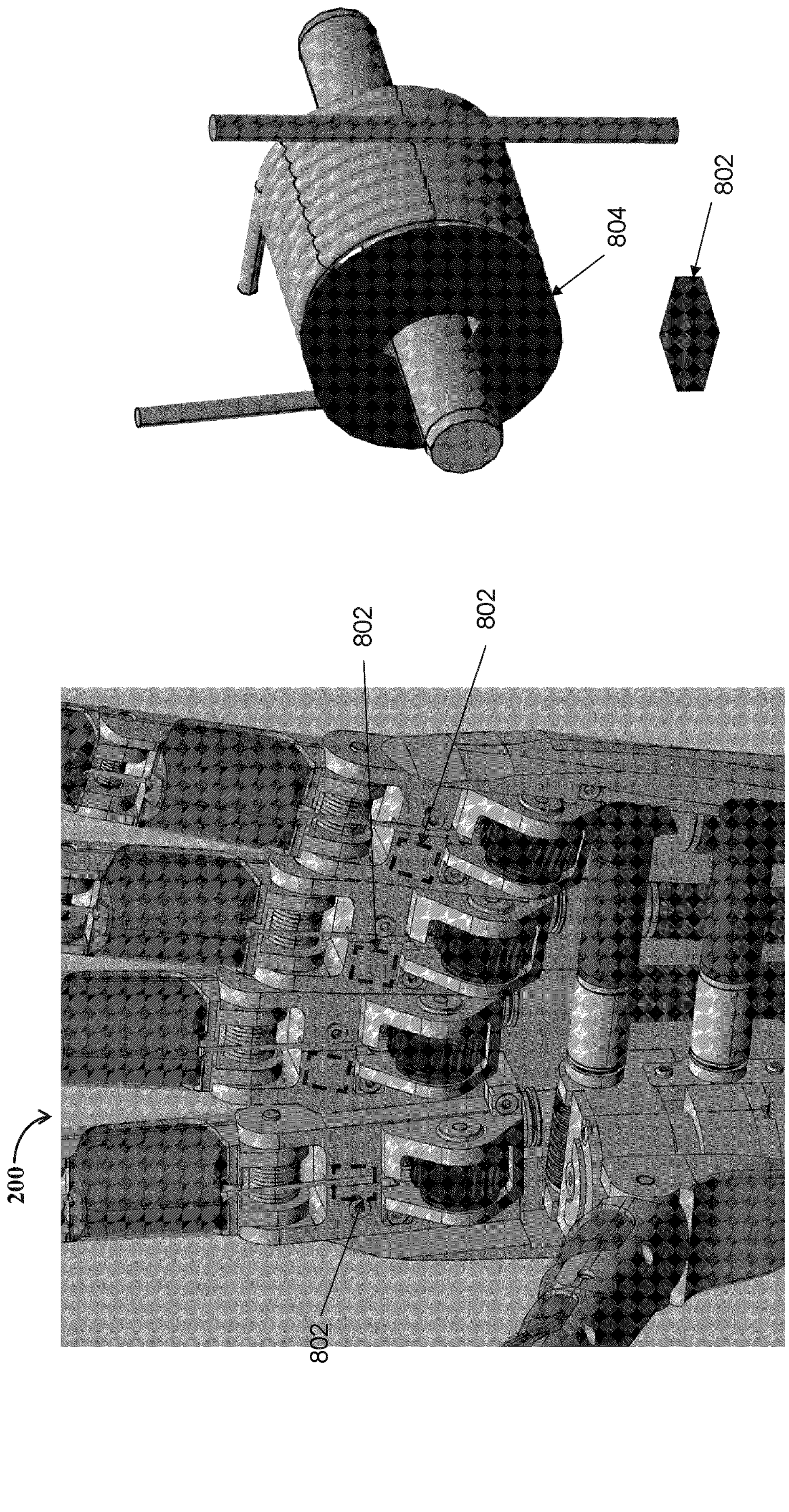


FIG. 8A

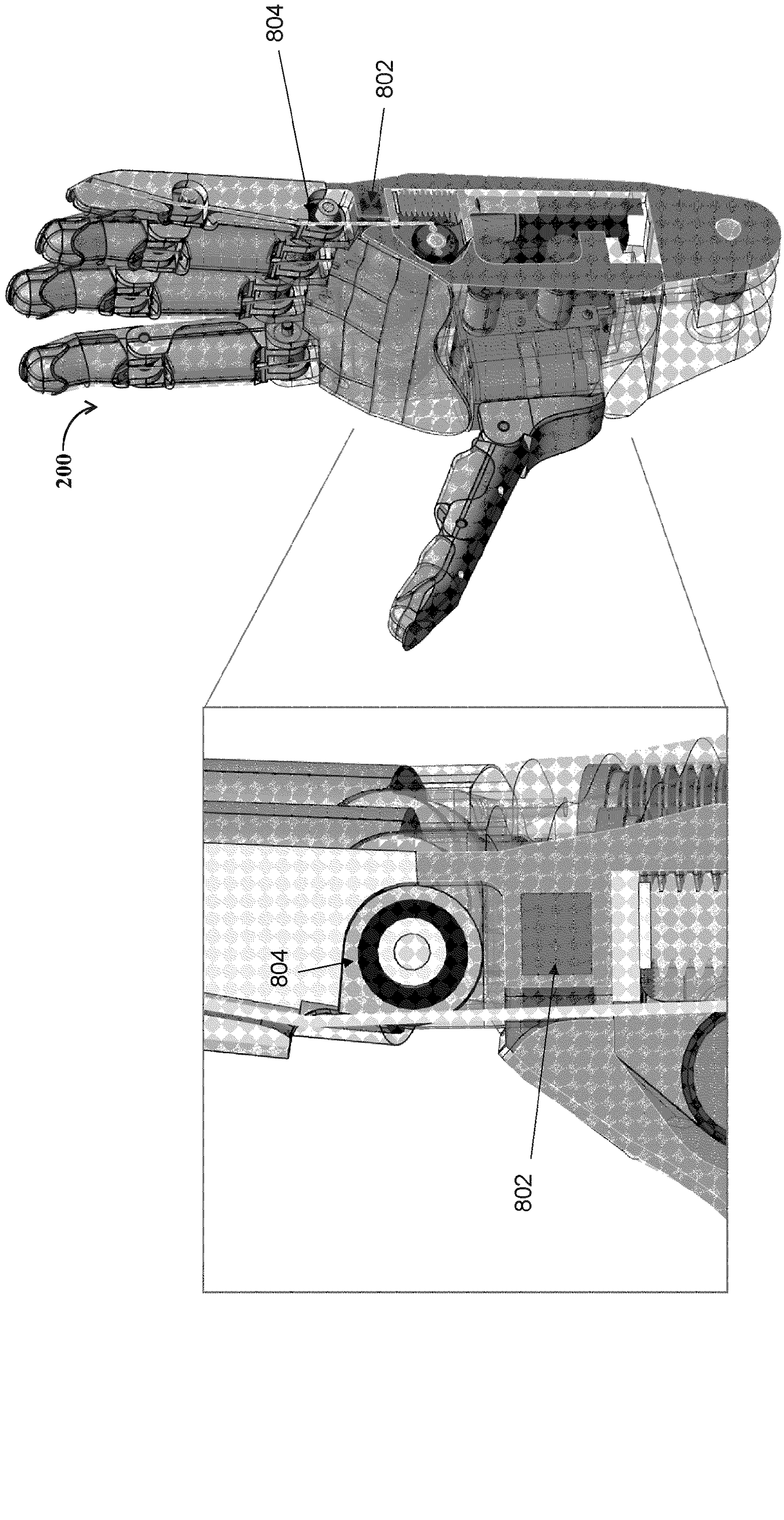


FIG. 8B

900

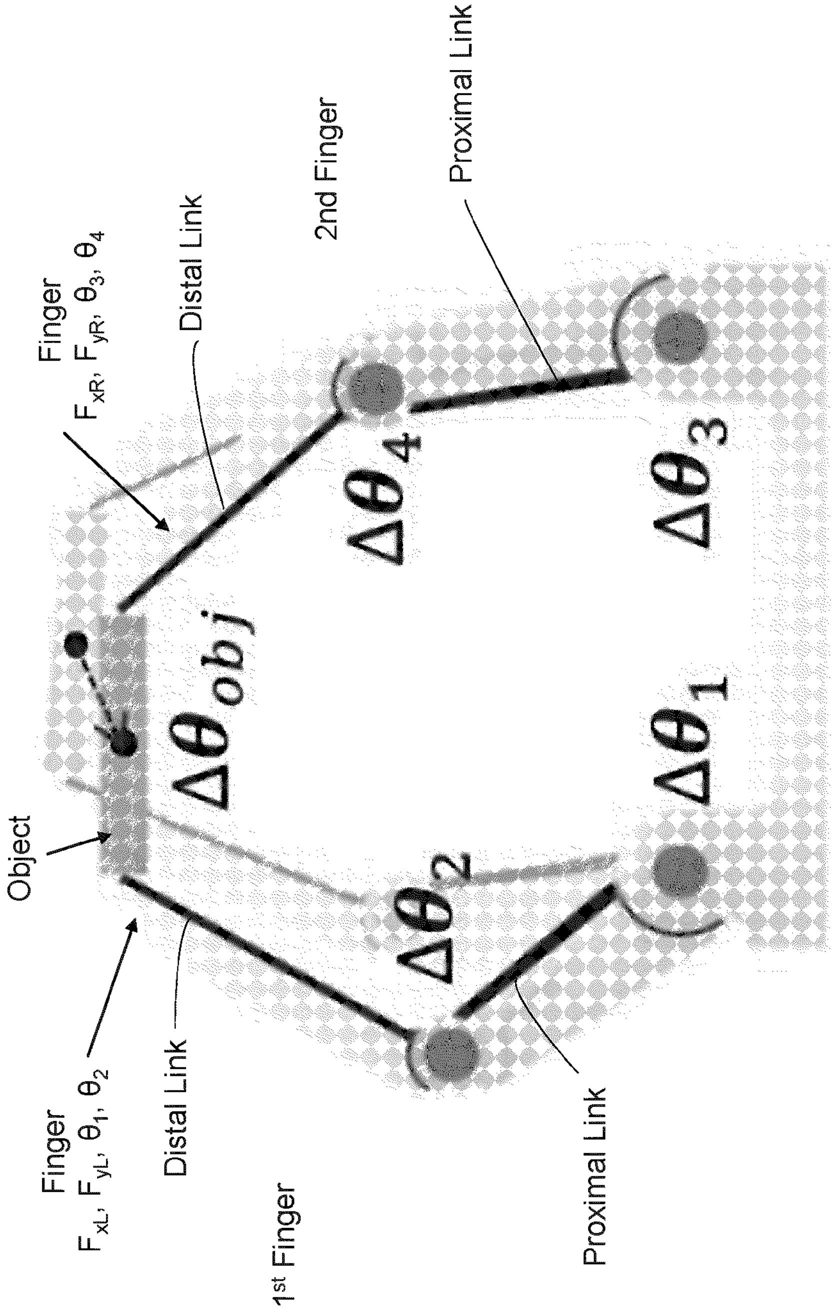

Object
Finger
F_{xL}, F_{yL}, θ_1, θ_2
Distal Link
1st Finger
Proximal Link
Finger
F_{xR}, F_{yR}, θ_3, θ_4
Distal Link
2nd Finger
Proximal Link
$\Delta\theta_{obj}$
$\Delta\theta_1$
$\Delta\theta_2$
$\Delta\theta_3$
$\Delta\theta_4$

FIG. 9

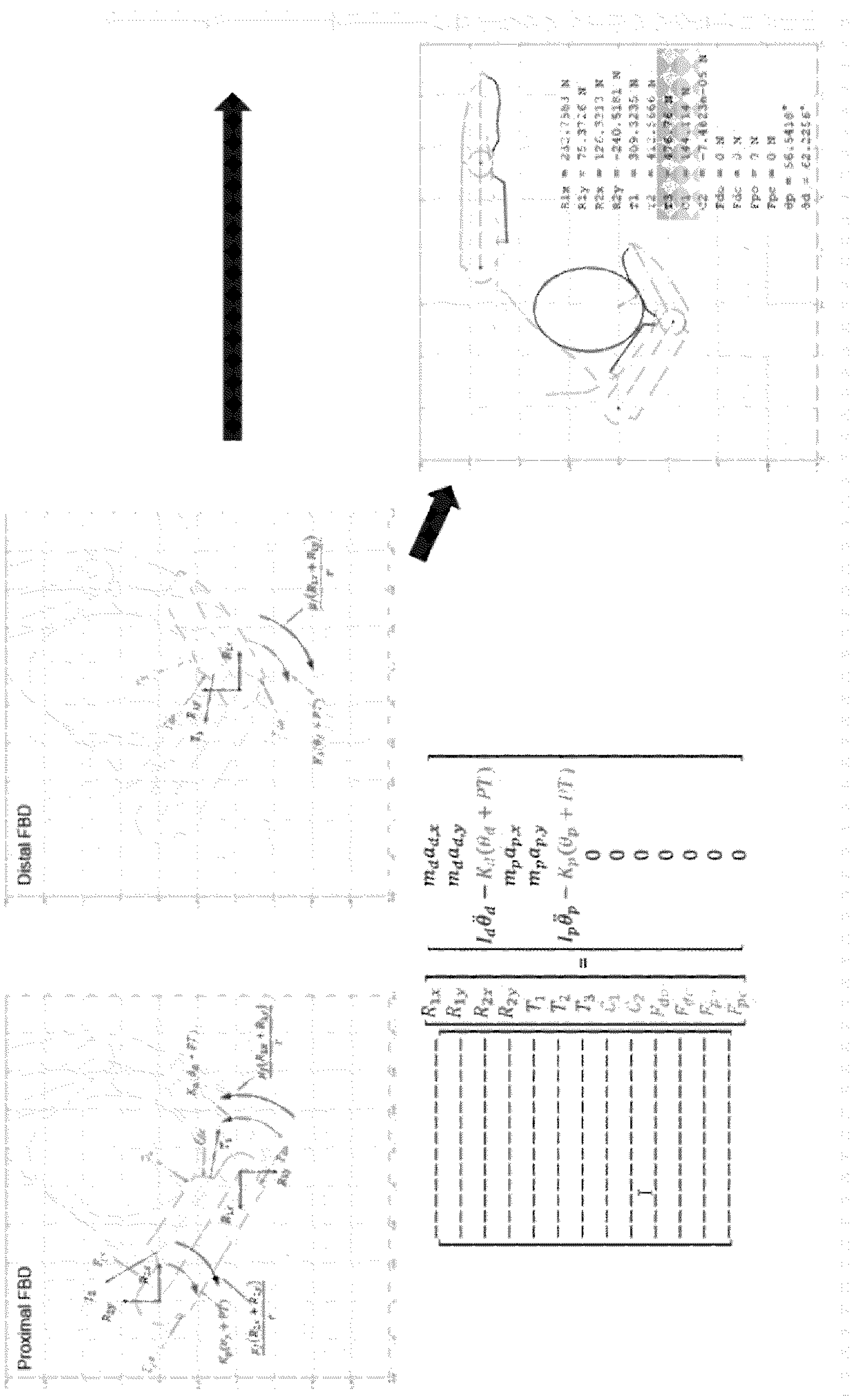


FIG. 10A

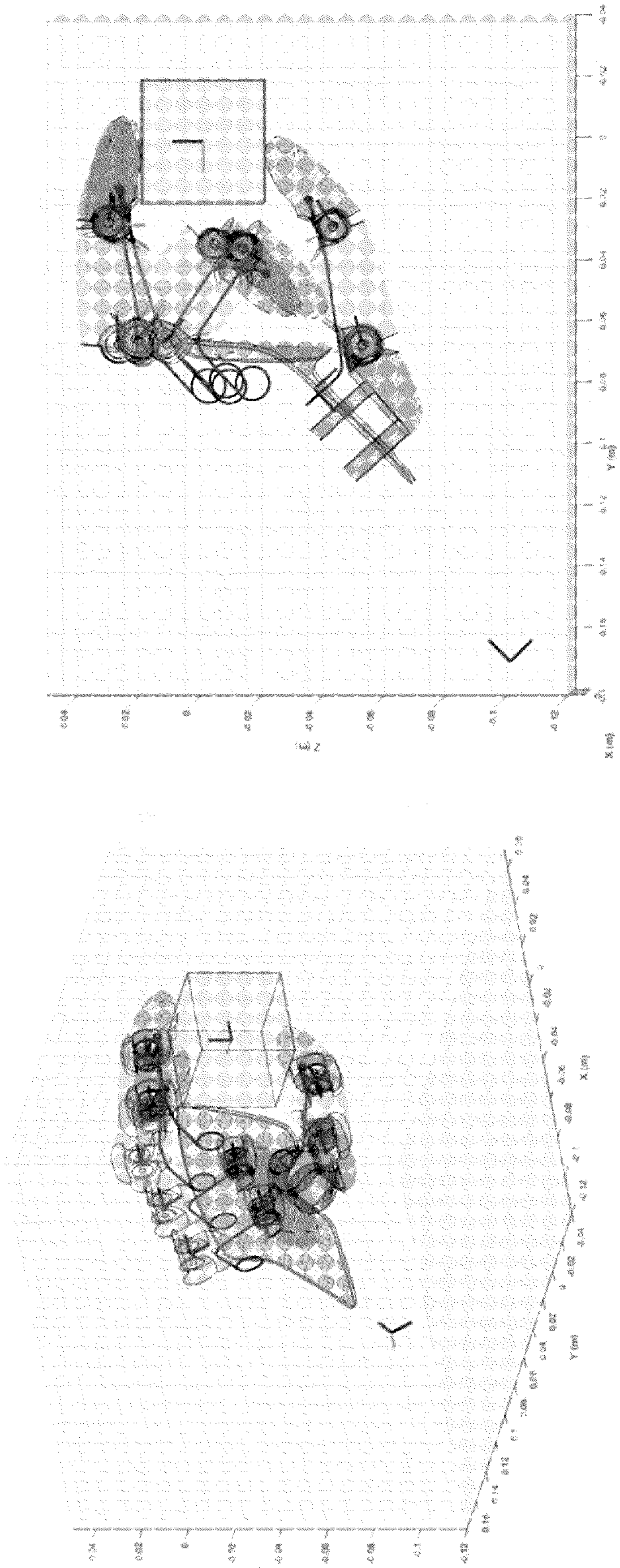


FIG. 10B

Effective Lever Arms

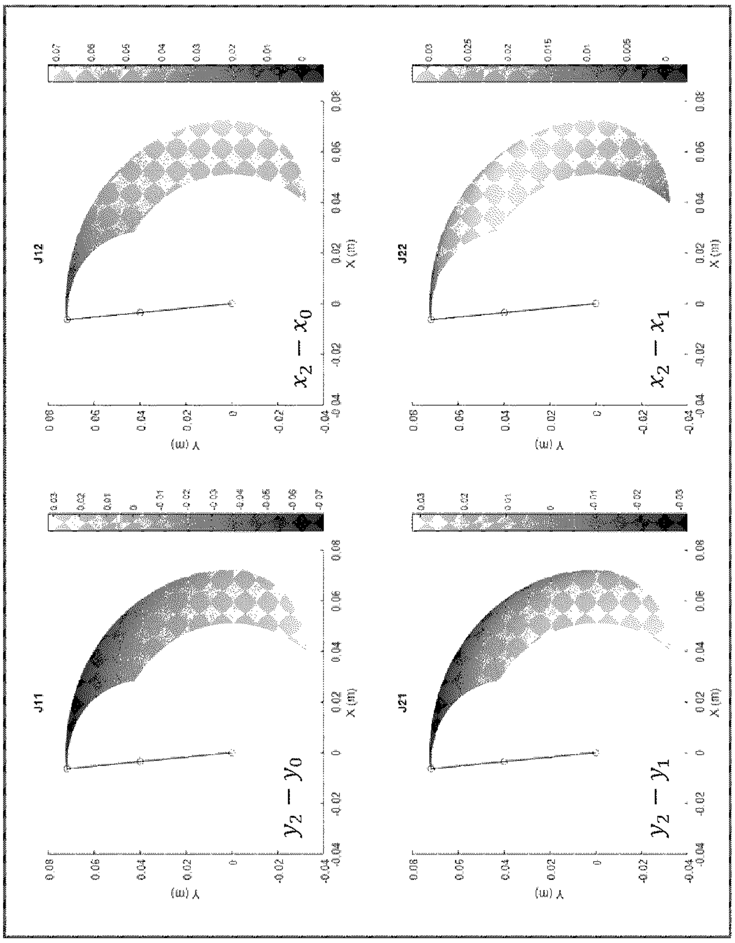


FIG. 11A

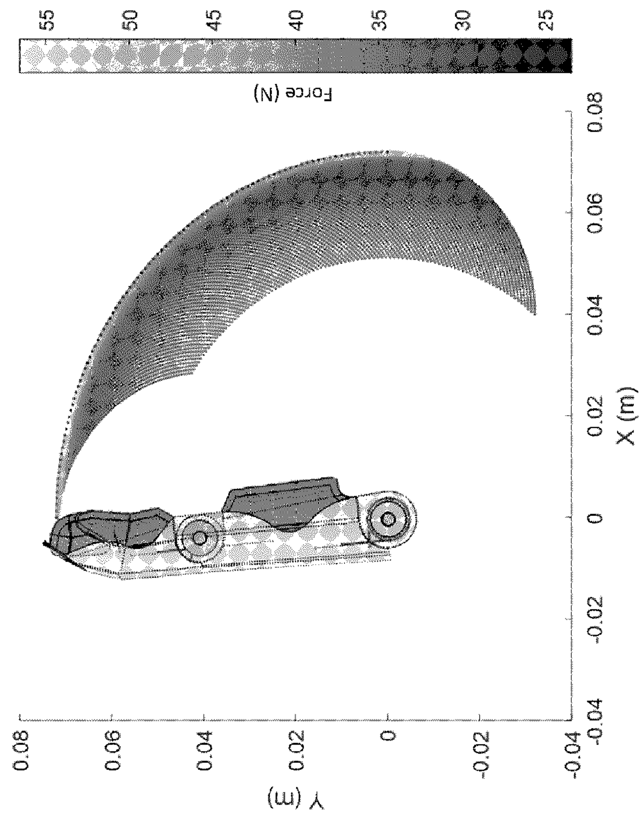


FIG. 11B

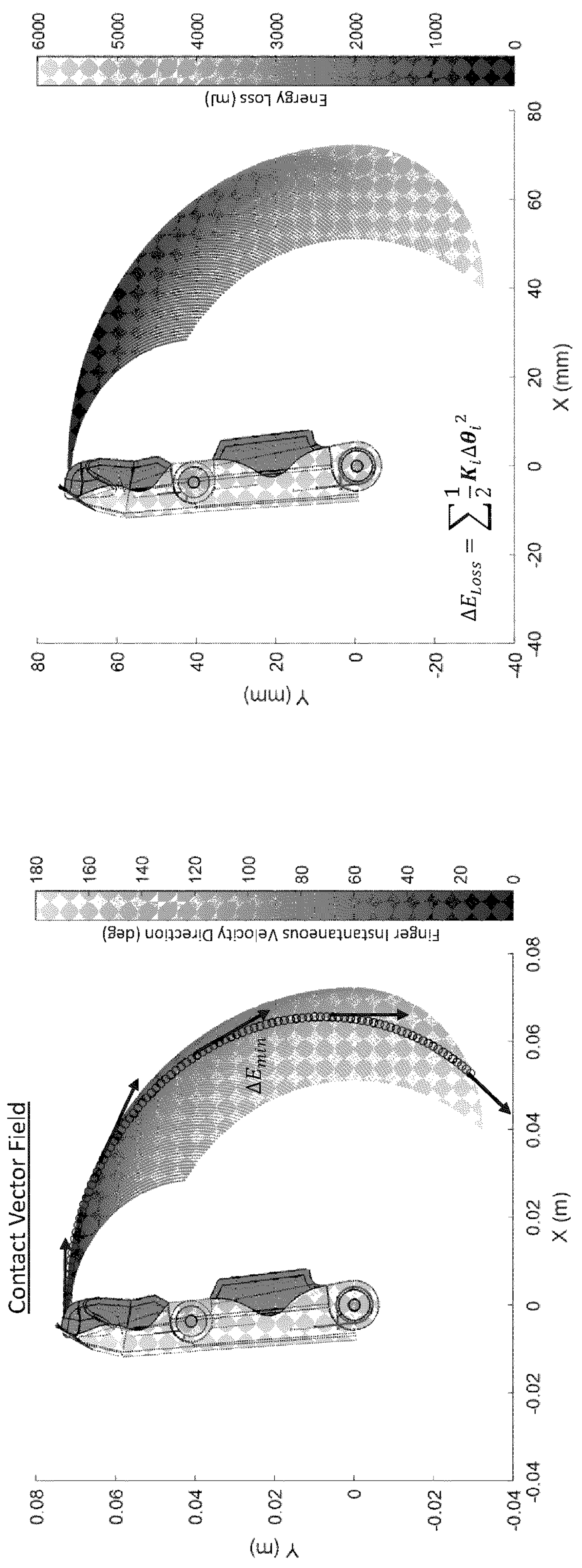

Contact Vector Field
Finger Instantaneous Velocity Direction (deg)
180
160
140
120
100
80
60
40
20
0
0.08
0.06
0.04
0.02
0
-0.02
-0.04
Y (m)
X (m)
ΔE_{min}
Energy Loss
Energy Loss (mJ)
6000
5000
4000
3000
2000
1000
0
80
60
40
20
0
-20
-40
Y (mm)
X (mm)
$\Delta E_{Loss} = \sum \frac{1}{2} \boldsymbol{K}_i \Delta \boldsymbol{\theta}_i^{\,2}$

FIG. 11C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US23/34306

A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. B25J 15/00; B25J 9/10; B25J 15/02 (2023.01)

ADD.

CPC - INV. B25J 15/0009; B25J 9/1045; B25J 15/0233

ADD.

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 database consulted during the international search (name of database 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	DE 102020207037 B4 (KUKA DEUTSCHLAND GMBH) 13 January 2022; See Figs. 1-7; paragraphs [0017], [0069], [0071], [0072], [0077]; machine translation	1-6, 10-16, 20 --- 7-9, 17-19
Y	US 2013/0193704 A1 (GM GLOBAL TECHNOLOGY OPERATIONS, INC. ET AL.) 01 August 2013; See Figs. 3, 12; paragraph [0046]	7-9, 17-19
A	US 2011/0071678 A1 (IHRKE ET AL.) 24 March 2011; See Fig. 4; Abstract	1-20

☐ 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
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"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
18 December 2023 (18.12.2023)	FEB 16 2024
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas Telephone No. PCT Helpdesk: 571-272-4300