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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
04 April 2024 (04.04.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/073135 A1

(51) International Patent Classification:
B62D 57/032 (2006.01) *B25J 17/00* (2006.01)
B25J 9/12 (2006.01)

(21) International Application Number:
PCT/US2023/034300

(22) International Filing Date:
02 October 2023 (02.10.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/377,919 30 September 2022 (30.09.2022) US
63/378,034 30 September 2022 (30.09.2022) US

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

(72) Inventor: JAFARI, Rod; 1 Tesla Road, Austin, Texas 78725 (US).

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

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

(54) Title: SYSTEMS AND METHODS FOR A ROBOT KNEE JOINT ASSEMBLY

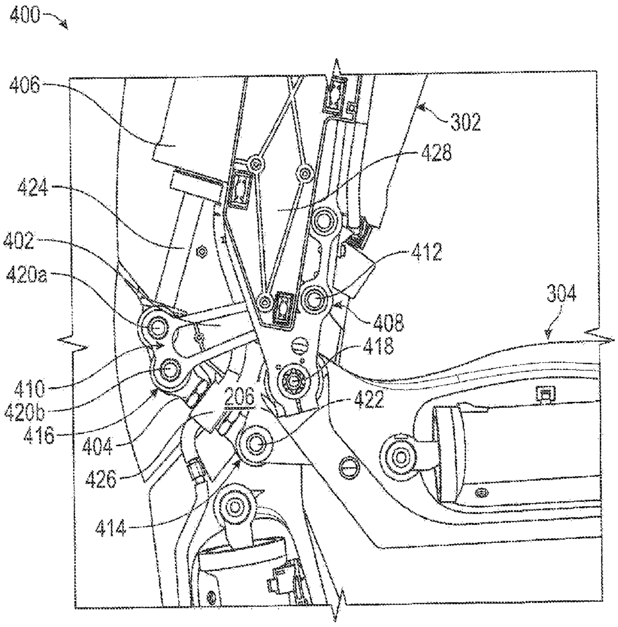

FIG. 4

(57) Abstract: Disclosed herein is a knee joint assembly including a first link member having a first end mechanically coupled to an upper leg of a robot and configured to rotate around a first pivot relative to the upper leg, and a second link member having a first end mechanically coupled to a lower leg of the robot. The lower leg can be mechanically coupled to the upper leg and configured to rotate around a second pivot relative to the upper leg. A linear actuator device can be mechanically coupled to a second end of the first link member and a second end of the second link member, and when actuated can cause the first link member to rotate around the first pivot relative to the upper leg of the robot and cause the leg to rotate around the second pivot relative to the upper leg.

WO 2024/073135 A1

[Continued on next page]

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

Published:

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

SYSTEMS AND METHODS FOR A ROBOT KNEE JOINT ASSEMBLY

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 systems and methods for robot joints. In particular, the current disclosure relates to systems and methods for a robot knee joint.

BACKGROUND

[0003] A robot can be viewed as a chain or collection of joints, that 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] The reliability and efficiency of robots depend significantly on the adopted joint designs. A well-designed joint can enhance the range of motion of adjacent elements and reduce the amount of power consumed by the robot. In the current disclosure, systems, and methods for a knee joint assembly configured to mimic the knee joints of humans are described. In particular, the knee joint assembly described herein allows for a range of rotation of the lower part of a robot leg similar to the range of rotation seen in humans. Also, the knee joint assembly described herein can be driven by a single linear actuator and enables to minimize or reduce power usage, or maximize or increase efficiency, while still meeting torque, speed and range of motion.

[0006] According to at least one aspect, a system can comprise a knee joint assembly. The knee joint assembly can include a first link member having a first end mechanically coupled to an upper portion of a leg of a robot and configured to rotate around a first pivot relative to the upper portion of the leg of the robot; a second link member having a first end mechanically coupled to a lower portion of the leg of the robot, the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a second pivot relative to the upper portion of the robot, and a linear actuator device mechanically coupled to a second end of the first link member and a second end of the second link member, the linear actuator device, when actuated, causes the first link member to rotate around the first pivot relative to the upper portion of the leg of the robot and causes the lower portion of the leg of the robot to rotate around the second pivot relative to the upper portion of the leg of the robot.

[0007] The first link member can be configured to rotate around a third pivot relative to the linear actuator device and the second link member can be configured to rotate around a fourth pivot relative to the linear actuator device. In some implementations, the fourth pivot can be the same as the third pivot, and the third pivot can mechanically couple both the second end of the first link member and the second end of the second link member to the linear actuator device. In some implementations, the fourth pivot can be different from the third pivot, the third pivot can mechanically couple the second end of the first link member to the linear actuator device, and the fourth pivot can mechanically couple the second end of the second link member to the second end of the first link member.

[0008] The lower portion of the leg of the robot can be configured to rotate around a third pivot relative to the second link member, the third pivot mechanically coupling the first end of the second link member to the lower portion of the leg of the robot.

[0009] The linear actuator device can include a moving structure mechanically coupled to the second end of the first link member and configured to cause the second end of the first link member to move according to a translational motion, when the linear actuator device is actuated, causing the first link member to rotate around the first pivot relative to the upper portion of the leg of the robot. The linear actuator device can include a servo motor configured to cause the moving structure to move according to the translational motion.

[0010] The first link member can have a rotation angle range of about 60 degrees. In some implementations, the lower portion of the leg of the robot has a rotation angle range of about 150 degrees. In some implementations, the second link member includes a force sensor. In some implementations, the robot can be a humanoid robot.

[0011] The system can include a processing circuitry including a memory and a processor and configured to control the linear actuator device. The processing circuitry can be configured to determine a desired orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot; determine, using the desired orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot, a displacement of a moving structure of the linear actuator device; and send instructions to the linear actuator device to cause the moving structure to move by the determined displacement. In some implementations, the processing circuitry is configured to compute the displacement of the moving structure using an orientation of the lower portion of the leg of the robot, a speed of the lower portion of the leg of the robot and a desired torque.

[0012] According to at least one aspect, a method can comprise determining, by a processing circuitry, an orientation of a lower portion of a leg of a robot relative to an upper portion of the leg of the robot, the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a first pivot relative to the upper portion of the robot; determining, by the processing circuitry using the orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot, a displacement of a moving structure of a linear actuator device, the moving structure of the linear actuator device mechanically coupled to a first end of the first link member and a first end of the second link member; sending instructions to the linear actuator device to cause the moving structure to move by the determined displacement; and causing, by the linear actuator device, the moving structure to move by the determined displacement leading to a rotation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot to reach the desired orientation. The first link member can have a second end mechanically coupled to the upper portion of the leg of the robot and can be configured to rotate around a second pivot relative to the upper portion of the leg of the robot. The second link member can have a second end mechanically coupled to the lower portion of the leg of the robot.

[0013] Determining the displacement of the moving structure can include computing the displacement of the moving structure in real time using an instantaneous orientation of the lower portion of the leg of the robot, a speed of the lower portion of the leg of the robot and a desired torque.

[0014] The first link member can be configured to rotate around a third pivot relative to the moving structure of the linear actuator device and the second link member can be configured to rotate around a fourth pivot relative to the moving structure of the linear actuator device.

[0015] The fourth pivot can be the same as the third pivot, and the third pivot can mechanically couple both the second end of the first link member and the second end of the second link member to the linear actuator device; or the fourth pivot can be different from the third pivot, the third pivot can mechanically couple the second end of the first link member to the linear actuator device, and the fourth pivot can mechanically couple the second end of the second link member to the second end of the first link member.

[0016] The lower portion of the leg of the robot can be configured to rotate around a third pivot relative to the second link member, the third pivot can mechanically couple the first end of the second link member to the lower portion of the leg of the robot.

[0017] The first link member can have a rotation angle range of about 60 degrees. In some implementations, the lower portion of the leg of the robot can have a rotation angle range of about 150 degrees.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] 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.

[0019] **FIG. 1** illustrates a diagram of an example humanoid robot where systems and methods described herein can be integrated, according to an embodiment.

[0020] **FIG. 2** illustrates diagrams depicting an analogy between the anatomy of the human knee joint and a high-level design of a knee joint for robots, according to an embodiment.

[0021] **FIGS. 3A** and **3B** illustrate two views of both legs of a humanoid robot, according to an embodiment.

[0022] **FIG. 4** illustrates an example knee joint assembly of the humanoid robot of **FIG. 3**, according to an embodiment.

[0023] **FIG. 5** illustrates a flow chart depicting a method for operating or controlling the knee joint assembly of **FIG. 4**, according to an embodiment.

[0024] **FIG. 6** depicts a graph showing simulation results for different candidate designs (e.g., with different parameters) of the knee joint assembly, according to an embodiment.

DETAILED DESCRIPTION

[0025] 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.

[0026] The robot can be viewed as a collection of joints that are designed to enable the movement of one or more links or elements adjacent to each joint. The design, structure, and mechanisms of a joint can significantly affect the stability, reliability, and efficiency of the robot. For example, a poorly designed joint can result in poor geometry, an increased number of used actuators, an increase in power consumption by the robot, and/or a limited motion range of one or more components of the robot. In the current disclosure, a joint assembly that is designed or configured to mimic the knee joints of humans is described. In particular, the knee joint assembly described herein allows for a relatively wide range of rotation, e.g., about 150 degrees (e.g., between 140 and 160 degrees), of the lower leg of a robot. Such range is similar to the range of rotation seen in humans. Also, the joint assembly described herein can be driven by a single linear actuator with improved efficiency. Specifically, while the range of rotation of the robot's lower leg can be about or close to 150 degrees, the linear actuator is configured or structured to cause rotation of a link that has a smaller range of rotation, e.g., about 60 degrees. This implies that a relatively large angle of rotation of the lower leg can be achieved with a relatively small movement by the linear actuator, which allows for a compact design of the knee joint.

[0027] **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. The robot **100** may include one or more sensors for sensing parameters of the robot **100** or the surroundings of robot **100**. The robot **100** may include one or more cameras.

[0028] 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**.

[0029] 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.

[0030] 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.

[0031] The processing circuitry **110** or the processor **114** can be configured to control the 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 the 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 the 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**.

[0032] 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 the 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.

[0033] While **FIG. 1** shows the controller as being integrated into the chest or upper body of the robot **100**, in general, the controller **108** can be placed or integrated into 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**.

[0034] **FIG. 2** illustrates diagrams **200A-C** depicting an analogy between the anatomy of the human knee joint and a high-level design of a knee joint for robots, according to an embodiment. In diagram **200A**, a side view of a knee anatomy is shown with arrows **202-204** depicting some of the forces applied within the knee joint. For instance, arrow **202** can be viewed as representing forces exerted by the quadriceps or quadriceps tendon on the patella. Arrow **204** can be viewed as representing forces exerted by the patella ligament on the patella. Arrow **206** can be viewed as representing forces exerted by the patella on the femur or the articular cartilage covering the end of the femur. These forces drive movements of the knee joint and maintain the structure and geometry of the knee joint. Other relevant forces include the forces between the femur and tibia along the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL), respectively.

[0035] Diagram **200B** shows an analogous mechanical system corresponding to the biological knee joint of diagram **200A**. The analogous mechanical system can be viewed as a four-point or four-node mechanical system. In other words, the mechanical system can include four points or nodes **208-214** representing points of force. Point or node **208** can be viewed as corresponding to the patella. Point or node **210** can be viewed as corresponding to the connection between the patella ligament and the tibia. Point or node **212** can be viewed as corresponding to the connection between the femur and the tibia, e.g., via the ACL and/or the PCL. Point or node **214** can be viewed as a point force representing or corresponding to the force applied by the patella on the femur.

[0036] In the analogous mechanical system, the four points or nodes **208-214** can be interconnected or coupled via four links or link members. Link **216** can couple or connect points **208** and **210**. Link **218** can couple or connect points **210** and **212**. Link **220** can couple or connect points **212** and **214**. Link **222** can couple or connect points **214** and **208**.

[0037] Diagram **200C** shows an example design of a knee joint assembly for robots based on the analogous mechanical system of diagram **200B**. The design of the knee joint assembly can include four connection points **224-230** corresponding to the points or nodes **208-214** of the analogous mechanical system, respectively. The design can include a mechanical link or link member **232** corresponding to the link **216** of the analogous mechanical system of diagram **200B**, a mechanical link or link member **234** corresponding to the link **220**, and a mechanical link or link member **236** corresponding to the link **222**. The connection points **226** and **228** can be arranged or implemented in a structure or component representing a lower portion of a robot's leg.

[0038] **FIG. 3A** illustrates a perspective view of both legs of a humanoid robot **300**, according to an embodiment. Both leges of the humanoid robot **300** are in a straight-up position. Each leg can include an upper portion **302**, a lower portion **304,** and a knee joint assembly **306**. An outer cover or housing of the upper portion 302 is removed from the left leg to expose internal components. **FIG. 3B** illustrates another view of the legs of the humanoid robot **300** with a different position of the lower portion, according to an embodiment.

[0039] The upper portion **302** corresponds to the thigh and can be referred to herein as an upper leg, thigh portion, or upper extremity of the robot leg. The lower portion **304** corresponds to the portion of the leg between the knee and ankle and can be referred to herein as the lower extremity or lower leg. The knee joint assembly **306** can include links (or link members) and/or other components configured or structured to cause movement of the lower portion **304** relative to the upper portion **302**. The knee joint assembly 306 and corresponding components and mechanisms are discussed in further detail below in relation to **FIGS. 4-5**.

[0040] **FIG. 4** illustrates an example of knee joint assembly **400** of the humanoid robot **300** of **FIG. 3**, according to an embodiment. The knee joint assembly **400** can be used or integrated into humanoid robot, such as robot **100** and **300**, or other types of robots. While it is referred to herein as a knee joint assembly, the joint assembly **400** can be used for other types of joints, e.g., not necessarily a knee joint. The knee joint assembly **400** can include a first link member **402** and a second link member **404**. The knee joint assembly **400** can include or can be associated with a corresponding linear actuator device **406**.

[0041] The first link member **402** can have a first end **408** and a second (or opposite) end **410**. The first end **408** of the first link member **402** can be mechanically coupled to the upper portion **302** of the leg of the robot **300**. The first link member **402** can be configured or structured to rotate around a first pivot **412** relative to the upper portion **302** of the leg of the robot **300**. The second link member **404** can have a first end **414** and a second (or opposite) end **416**. The first end **414** of the second link member **404** can be mechanically coupled to the lower portion **304** of the leg of the robot **300**. The lower portion **304** of the leg of the robot **300** can be mechanically coupled to the upper portion **302** of the leg of the robot **304**. The lower portion **304** of the leg of the robot **300** can be configured or structured to rotate around a second pivot **418** relative to the upper portion **302** of the leg of the robot **300**.

[0042] The linear actuator device **406** can be mechanically coupled to the second end 408 of the first link member **402** and mechanically coupled to the second end **416** of the second link member **404**. The linear actuator device **406**, when actuated, can cause the first link member **402** to rotate around the first pivot **412** relative to the upper portion **402** of the leg of the robot **300**. In particular, the linear actuator device **406**, when actuated, can exert a force on the second end **408** of the first link member **402** causing the first link member **402** to rotate around the first pivot **412** relative to the upper portion **402** of the leg of the robot **300**. The linear actuator device **406**, when actuated, also causes the lower portion **302** of the leg of the robot **300** to rotate around the second pivot **418** relative to the upper portion **402** of the leg of the robot **300**. In particular, the linear actuator device **406**, when actuated, can exert a force on the lower portion **302** via the second link member **404** causing the lower portion **302** of the leg of the robot **300** to rotate around the second pivot **418** relative to the upper portion **402** of the leg of the robot **300**.

[0043] The linear actuator device **406** can be mechanically coupled to the first link member **402** and the second link member **404** in various ways. For instance, the first link member **402** can be configured to rotate around a third pivot **420a** relative to the linear actuator device **406** and the second link member **404** can be configured to rotate around a fourth pivot **420b** relative to the linear actuator device **406**. As shown in **FIG. 4**, the third pivot **420a** can be different from the fourth pivot **420b**. The third pivot **420a** can mechanically couple the second end **408** of the first link member **402** to the linear actuator device **406** and the fourth pivot **420b** can mechanically couple the second end **416** of the second link member **404** to the second end **410** of the first link member **402**. In other words, the linear actuator device **406** can be directly coupled to the first link member **402** but mechanically coupled to the second link member **404** via the first link member **402**.

[0044] In some implementations, the pivots **420a** and **420b** can be the same pivot that mechanically couples both the second end **410** of the first link member **402** and the second end **416** of the second link member **404** to the linear actuator device **406**. In other words, the second end **410** of the first link member **402** can include a single pivot mechanically coupling the linear actuator device **406**, the first link member **402,** and the second link member **404**.

[0045] In some implementations, the lower portion **304** of the leg of the robot 300 can be configured to rotate around pivot **422** relative to the second link member **404**. The pivot **422** can mechanically couple the first end **414** of the second link member **404** to the lower portion **402** of the leg of the robot **300**. The capability of the lower portion **304** of the leg of the robot **300** to rotate around the pivot **422** and relative to the second link member **404** implies flexibility in the angle between the lower portion **304** of the leg of the robot **300** and the second link member **404**.

[0046] The linear actuator device **406** can include a moving structure **424**, such as a rod or shaft among others. The moving structure **424** can be mechanically coupled to the second end **410** of the first link member **402**. When the linear actuator device **406** is actuated, the moving structure **424** moves according to a translational motion and exerts some force on the second end **410** of the first link member **402** causing the second end **410** of the first link member **402** to move, e.g., according to the translational motion. The movement of the second end **410** results in the first link member **402** rotating around the first pivot **412** relative to the upper portion **302** of the leg of the robot **300**.

[0047] The linear actuator device **406** can include a servo motor configured to cause the moving structure **424** to move according to the translational motion. A servo motor can allow for precise displacements or displacement increments of the moving structure **424** of the linear actuator device **406**. Each displacement increment can correspond to an increment in the angle between the upper portion **302** and the lower portion **304** of the leg of the robot **300**.

[0048] Comparing the knee joint assembly **400** of **FIG. 4** to the analogous mechanical system and joint design of **FIG. 2**, the pivots **420a** and **420b** can be viewed as corresponding to point **208** and connection point **224** of **FIG. 2**. Pivot **422** can be viewed as corresponding to point **210** or connection point **226** of **FIG. 2**. Pivot **412** can be viewed as corresponding to point **214** or connection point **230**, and pivot **418** can be viewed as corresponding to point **212** or connection point **228** of **FIG. 2**. Also, the first link member **402** can be viewed as corresponding to links **222** and **236** of **FIG. 2** and the second link member **404** can be viewed as corresponding to links **216** and **232** of **FIG. 2**.

[0049] The knee joint assembly **400** enables or allows the use of a relatively simple and relatively small actuator, such as the linear actuator **406**. In other words, the design of the knee joint assembly **400** allows for linear motion produced by the linear actuator device **406** to be translated into a rotational motion of the lower portion **304** of the leg of the robot **300** relative to the upper portion **302**. The lower portion **304** of the leg of the robot **300** can have a rotation angle range of about 180 degrees. For example, the robot **300** can bend or move the lower portion **304** of the leg backward all the way up to 180 degrees or to an angle close to but smaller than 180 degrees, such as 175 or 170 degrees.

[0050] The knee joint assembly **400** enables such a wide range of rotational motion of the lower portion **304** without going into poor geometry and with a relatively high efficiency. For example, while the rotation angle range of the lower portion **304** of the leg is about 180 degrees, the corresponding rotation angle range of the first link member **402** on which the linear actuator device **406** exerts force can be about 60 degrees (e.g., between 50 to 70 degrees or between 45 to 75 degrees). In other words, to make the lower portion **302** rotate by about 180 degrees, the linear actuator device **406** can push or exert a force on the second end **410** of the first link member **402** to cause the first link member **402** to rotate by only about 60 degrees around the pivot **412**. This means that the moving structure **424** of the linear actuator device **406** is moved, in a linear motion, by a relatively small distance or displacement.

[0051] In some implementations, the second link member **404** can include a force sensor **426**, for example, to measure forces on the second link member **404**. The force sensor **426** can be communicatively coupled to the controller **108** or the processing circuitry **410**. In some implementations, the first link member **402** can be mechanically coupled to a structure **428** of the upper portion **402** via the pivot **412**. can be a humanoid robot. The linear actuator device **406** can installed or integrated in the upper portion **402** of the leg of the robot **300**.

[0052] The controller **108** or the processing circuitry **110** can control the linear actuator device **406**. For instance, the processing circuitry **110** or processor **114** can specify the amount of displacement or movement to be made by the moving structure **424** at any time instance. The mechanism of operating the knee joint assembly **400** is described in more detail below in relation with **FIG. 5**.

[0053] **FIG. 5** illustrates a flow chart depicting a method **500** for operating or controlling the knee joint assembly **400** of **FIG. 4**, according to an embodiment. In brief overview, the method 500 can include determining a desired orientation of the lower portion **304** of a robot leg relative to an upper portion **302** of the robot leg (STEP **502**), and determining, using the desired orientation, a displacement of the moving structure **424** of the linear actuator device **406** (STEP **504**). The method **500** can include sending or transmitting instructions to the linear actuator device **406** to cause the moving structure to move by the determined displacement (STEP **506**), and causing, by the linear actuator device **406**, the moving structure **424** to move by the determined displacement leading to a rotation of the lower portion **304** of the robot leg relative to the upper portion **302** of the robot leg to reach the desired orientation (STEP **508**).

[0054] The method **500** can be performed or executed by the processing circuitry **110** or the processor **114** in combination with the linear actuator device **406**. The processing circuitry **110** or the processor **114** can execute computer code instructions, e.g., stored in memory 116, to perm steps **502-506** of method **500**.

[0055] The method **500** can include the processing circuitry **110** or processor **114** determining a desired orientation of the lower portion **304** of the robot leg relative to an upper portion of the robot leg (STEP **502**). In particular, the processing circuitry **110** or processor **114** can determine a desired angle between the lower portion **304** of the robot leg relative to the upper portion **302** of the robot leg. The processing circuitry **110** or processor **114** can determine the desired angle or orientation based on or as part of a desired task (e.g., walking, jumping, kicking a ball, etc.) to be performed by the robot. The processing circuitry **110** or processor **114** can break the task into a sequence of movements to be performed over a period of time. In some implementations, the processing circuitry **110** or processor **114** can determine an instantaneous position or orientation of the lower portion **304** of the robot leg relative to an upper portion of the robot leg, a speed of the lower portion **304** of the robot leg and a desired torque. The processing circuitry **110** or processor **114** can use a function mapping actuator force to joint torque and/or a function from linkage force sensor to joint torque.

[0056] The method **500** can include the processing circuitry **110** or processor **114** determining, using the desired orientation, a displacement of the moving structure **424** of the linear actuator device **406** (STEP **504**). Given the geometry and design of the knee joint assembly **400**, each angle between the lower portion **304** of the robot leg and the upper portion **302** of the robot leg corresponds or maps to a corresponding position of the moving structure **424** (or a corresponding state of the linear actuator device **406**). In other words, the lower portion **304** of the robot leg is positioned or oriented at a given angle relative to the upper portion **302** when the moving structure **424** is at a corresponding specific displacement or position. The processing circuitry **110** or processor **114** can maintain a data structure, e.g., in memory **116**, storing mappings or associations between various values of the angle between the lower portion **304** of the robot leg and the upper portion **302** of the robot leg and corresponding positions or displacement values of the moving structure **424** (or corresponding states of the linear actuator device **406**). The processing circuitry **110** or processor **114** can determine a desired position or displacement of the moving structure **424** using the data structure and the desired orientation or angle of the lower portion **302** of the robot leg.

[0057] In some implementations, the processing circuitry **110** or processor **114** can compute the desired position or displacement of the moving structure **424** in real time, e.g., using closed form expressions or formulas for force, torque and/or speed. The processing circuitry **110** or processor **114** can use the instantaneous position the lower portion **304** of the robot leg (e.g., angle between the lower portion **304** of the robot leg and the upper portion **302**), the speed of the lower portion **304** and/or the desired torque to determine the position or displacement of the moving structure **424** in real time.

[0058] In some implementations, the processing circuitry **110** or processor **114** can keep track of a current angle between the lower portion **304** of the robot leg relative to the upper portion of the robot leg as well as a current state of the linear actuator device **406** or a current position of the moving structure **424**. The processing circuitry **110** or processor **114** can determine an additional displacement or movement to be made by the moving structure 424 using the data structure, the desired and current orientations of the lower part as well as the current position of the moving structure **424**.

[0059] The method **500** can include the processing circuitry **110** or processor **114** sending or transmitting instructions to the linear actuator device **406** to cause the moving structure to move by the determined displacement (STEP **506**), and the linear actuator device **406** causing the moving structure **424** to move by the determined displacement leading to a rotation of the lower portion **304** of the robot leg relative to the upper portion **302** of the robot leg to reach the desired orientation (STEP **508**). The processing circuitry **110** or processor **114** can send or transmit the instructions to the linear actuator device **406** via the communications interface **112**. The instructions can include an indication of a new or desired state of the linear actuator device

406, an indication of a new position of the moving structure **424,** or an indication of a direction and distance according to which to move moving structure **424**.

[0060] In some implementations, parameters of the knee joint design described herein, e.g., the lengths of the first link member **402** and a second link member **404**, can be selected or determined, e.g., via computer simulations, in a way to minimize or reduce power usage by the actuator **406**. Given a trajectory of the knee joint to perform a specific task, e.g., walking or running, a computer system including one or more processors and a memory can simulate the knee joint assembly **400** with different parameters and determine the set of parameters leading to the least consumed power by the actuator **406**. The trajectory of the knee joint can include the position or angle (e.g., of the lower portion **304** of the robot leg), speed and linkage joint torque over time to achieve the specific task.

[0061] Referring to **FIG. 6**, a graph **600** showing simulation results for different candidate designs (e.g., with different parameters) of the knee joint assembly **400** is illustrated, according to an embodiment. The x-axis shows the joint angle or position, e.g., angle of the lower portion **304** of the robot leg. The plots **602** and **604** represent the speed and linkage joint torque over time to achieve the specific task. The plots **606-610** represent the linkage joint torque for three different designs (e.g., with different parameters) of the knee joint assembly **400** determined by computer simulations. A computer system can determine the power used be the actuator **406** (e.g., using simulation data) for each design, and compare the determined power values. The design with the lowest power usage can be selected as the final model or design for the knee joint assembly **400**. In other words, before building or manufacturing the knee joint assembly **400**, the computer system can determine the desired parameters (e.g., of the lower portion **304** of the robot leg) to be used.

[0062] While **FIG. 6** shows three candidate designs, the computer system can simulate a larger number of designs to optimize or determine the “best” set of parameter values in terms of reducing or minimizing power usage. In some implementations, the simulations can be iterative where the set of parameters are modified in each new simulation based on results of previous simulations.

[0063] In response to the received instructions, a controller of the linear actuator device 106 can actuate the motor, e.g., servo motor, to cause the moving structure to be moved or displaced by the determined displacement or to the new position.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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.

[0070] 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 system comprising:

a knee joint assembly including:

a first link member having a first end mechanically coupled to an upper portion of a leg of a robot and configured to rotate around a first pivot relative to the upper portion of the leg of the robot;

a second link member having a first end mechanically coupled to a lower portion of the leg of the robot, the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a second pivot relative to the upper portion of the robot; and

a linear actuator device mechanically coupled to a second end of the first link member and a second end of the second link member, the linear actuator device, when actuated, causes the first link member to rotate around the first pivot relative to the upper portion of the leg of the robot and causes the lower portion of the leg of the robot to rotate around the second pivot relative to the upper portion of the leg of the robot.

2. The system of claim 1, wherein the first link member is configured to rotate around a third pivot relative to the linear actuator device and the second link member is configured to rotate around a fourth pivot relative to the linear actuator device.

3. The system of claim 2, wherein the fourth pivot is the same as the third pivot, and the third pivot mechanically couples both the second end of the first link member and the second end of the second link member to the linear actuator device.

4. The system of claim 2, wherein the fourth pivot is different from the third pivot, the third pivot mechanically couples the second end of the first link member to the linear actuator device, and the fourth pivot mechanically couples the second end of the second link member to the second end of the first link member.

5. The system of claim 1, wherein the lower portion of the leg of the robot is configured to rotate around a third pivot relative to the second link member, the third pivot

mechanically coupling the first end of the second link member to the lower portion of the leg of the robot.

6. The system of claim 1, wherein the linear actuator device includes a moving structure mechanically coupled to the second end of the first link member and configured to cause the second end of the first link member to move according to a translational motion, when the linear actuator device is actuated, causing the first link member to rotate around the first pivot relative to the upper portion of the leg of the robot.

7. The system of claim 6, wherein the linear actuator device includes a servo motor configured to cause the moving structure to move according to the translational motion.

8. The system of claim 1, wherein the first link member has a rotation angle range of about 60 degrees.

9. The system claim 1, wherein the lower portion of the leg of the robot has a rotation angle range of about 150 degrees.

10. The system claim 1, wherein the second link member includes a force sensor.

11. The system claim 1, further comprising a processing circuitry including a memory and a processor and configured to control the linear actuator device.

12. The system claim 11, wherein the processing circuitry is configured to:

determine a desired orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot;

determine, using the desired orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot, a displacement of a moving structure of the linear actuator device; and

send instructions to the linear actuator device to cause the moving structure to move by the determined displacement.

13. The system claim 12, wherein the processing circuitry is configured to compute the displacement of the moving structure in real time using an instantaneous orientation of the

lower portion of the leg of the robot, a speed of the lower portion of the leg of the robot and a desired torque.

14. The system claim 1, wherein the robot is a humanoid robot.

15. A method comprising:

determining, by a processing circuitry, an orientation of a lower portion of a leg of a robot relative to an upper portion of the leg of the robot, the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a first pivot relative to the upper portion of the robot;

determining, by the processing circuitry using the orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot, a displacement of a moving structure of a linear actuator device, the moving structure of the linear actuator device mechanically coupled to a first end of the first link member and a first end of the second link member;

sending instructions to the linear actuator device to cause the moving structure to move by the determined displacement; and

causing, by the linear actuator device, the moving structure to move by the determined displacement leading to a rotation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot to reach the desired orientation,

the first link member having a second end mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a second pivot relative to the upper portion of the leg of the robot, and the second link member having a second end mechanically coupled to the lower portion of the leg of the robot.

16. The method of claim 15, wherein determining the displacement of the moving structure includes computing the displacement of the moving structure in real time using an instantaneous orientation of the lower portion of the leg of the robot, a speed of the lower portion of the leg of the robot and a desired torque.

17. The method of claim 15, wherein the first link member is configured to rotate around a third pivot relative to the moving structure of the linear actuator device and the second

link member is configured to rotate around a fourth pivot relative to the moving structure of the linear actuator device.

18. The method of claim 17, wherein the fourth pivot is the same as the third pivot, and the third pivot mechanically couples both the second end of the first link member and the second end of the second link member to the linear actuator device; or

the fourth pivot is different from the third pivot, the third pivot mechanically couples the second end of the first link member to the linear actuator device, and the fourth pivot mechanically couples the second end of the second link member to the second end of the first link member.

19. The method of claim 15, wherein the lower portion of the leg of the robot is configured to rotate around a third pivot relative to the second link member, the third pivot mechanically coupling the first end of the second link member to the lower portion of the leg of the robot.

20. The method of claim 16, wherein the first link member has a rotation angle range of about 60 degrees and the lower portion of the leg of the robot has a rotation angle range of about 150 degrees.

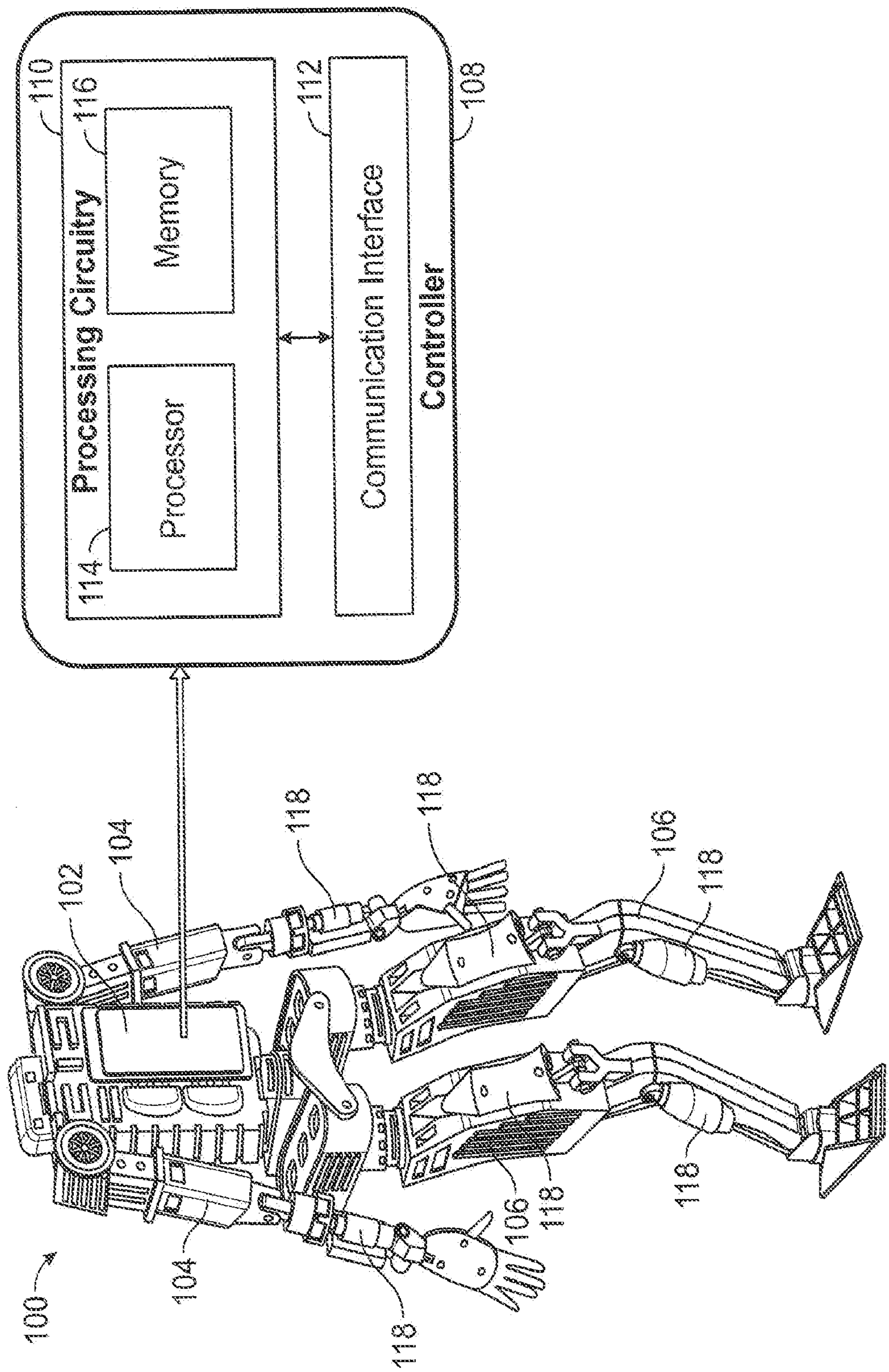
Processing Circuitry
Processor
Memory
Communication Interface
Controller
110
116
114
112
108
100
102
104
106
118

FIG. 1

2/7

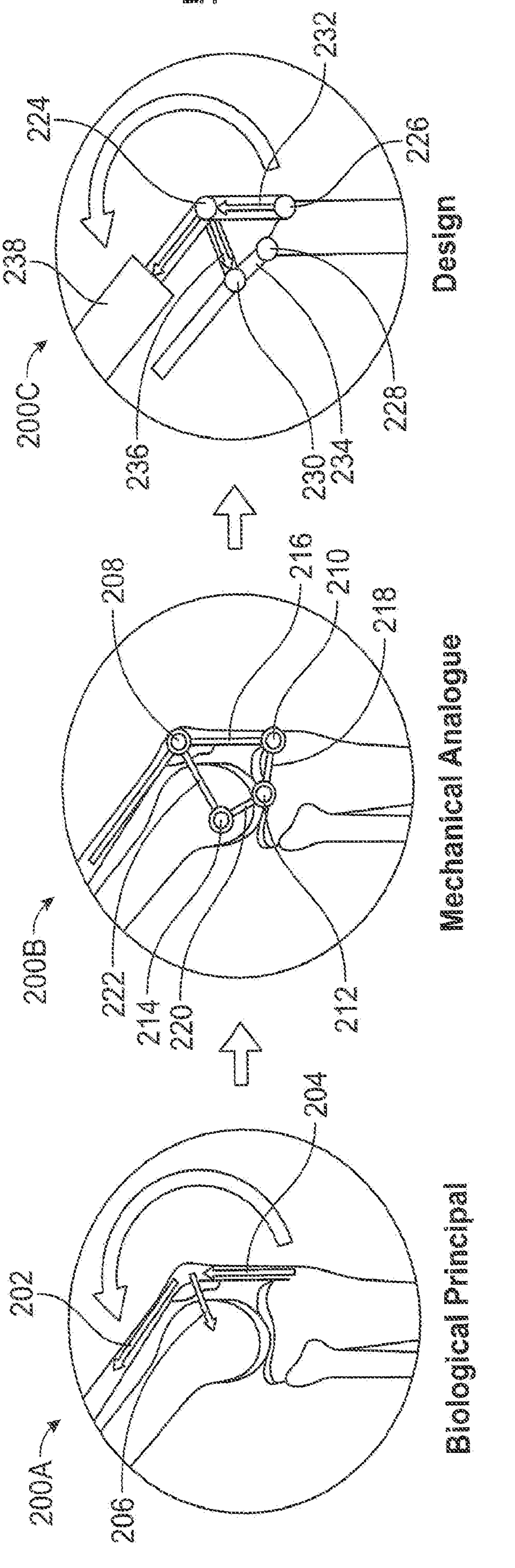
200A
202
204
206
Biological Principal
200B
208
216
210
218
222
214
220
212
Mechanical Analogue
200C
224
232
226
238
236
230
234
228
Design

FIG. 2

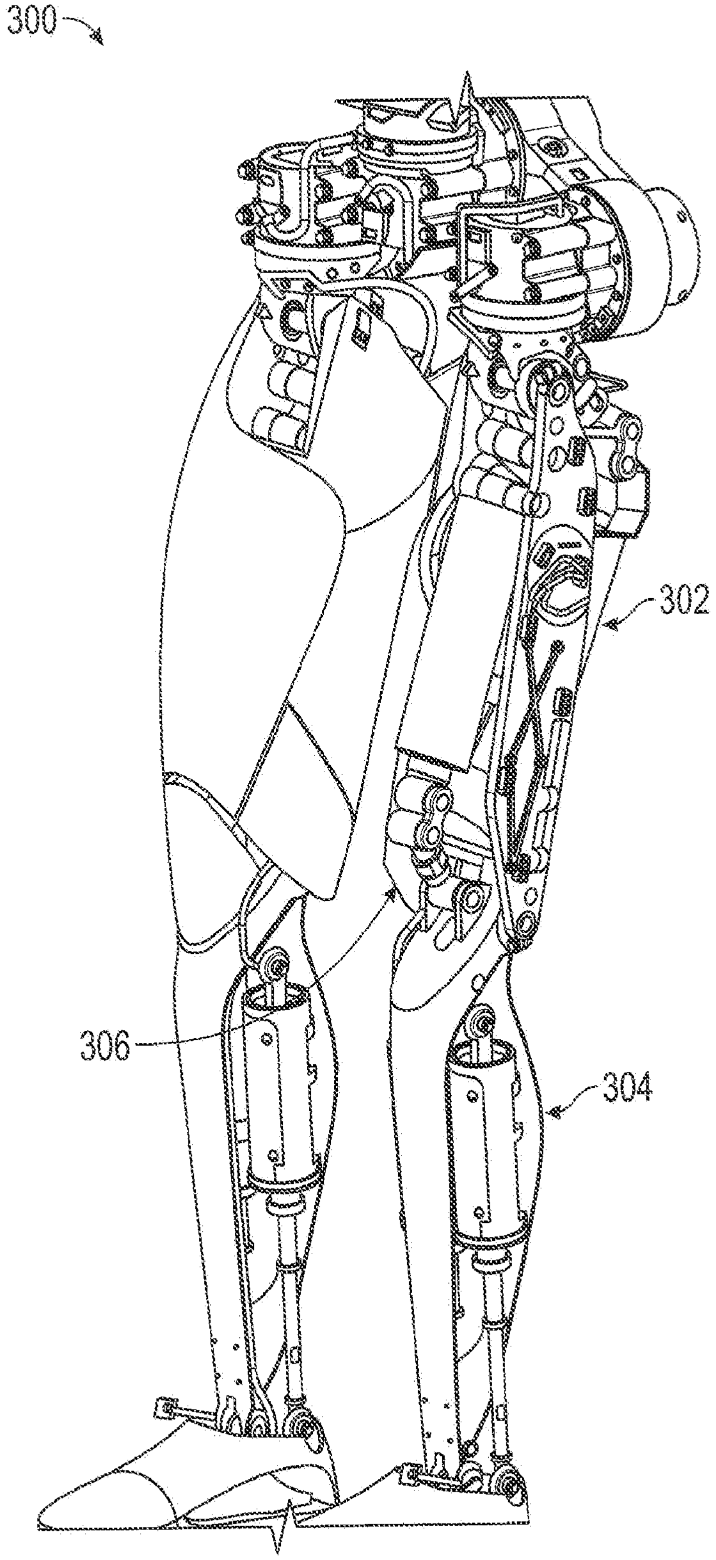

FIG. 3A

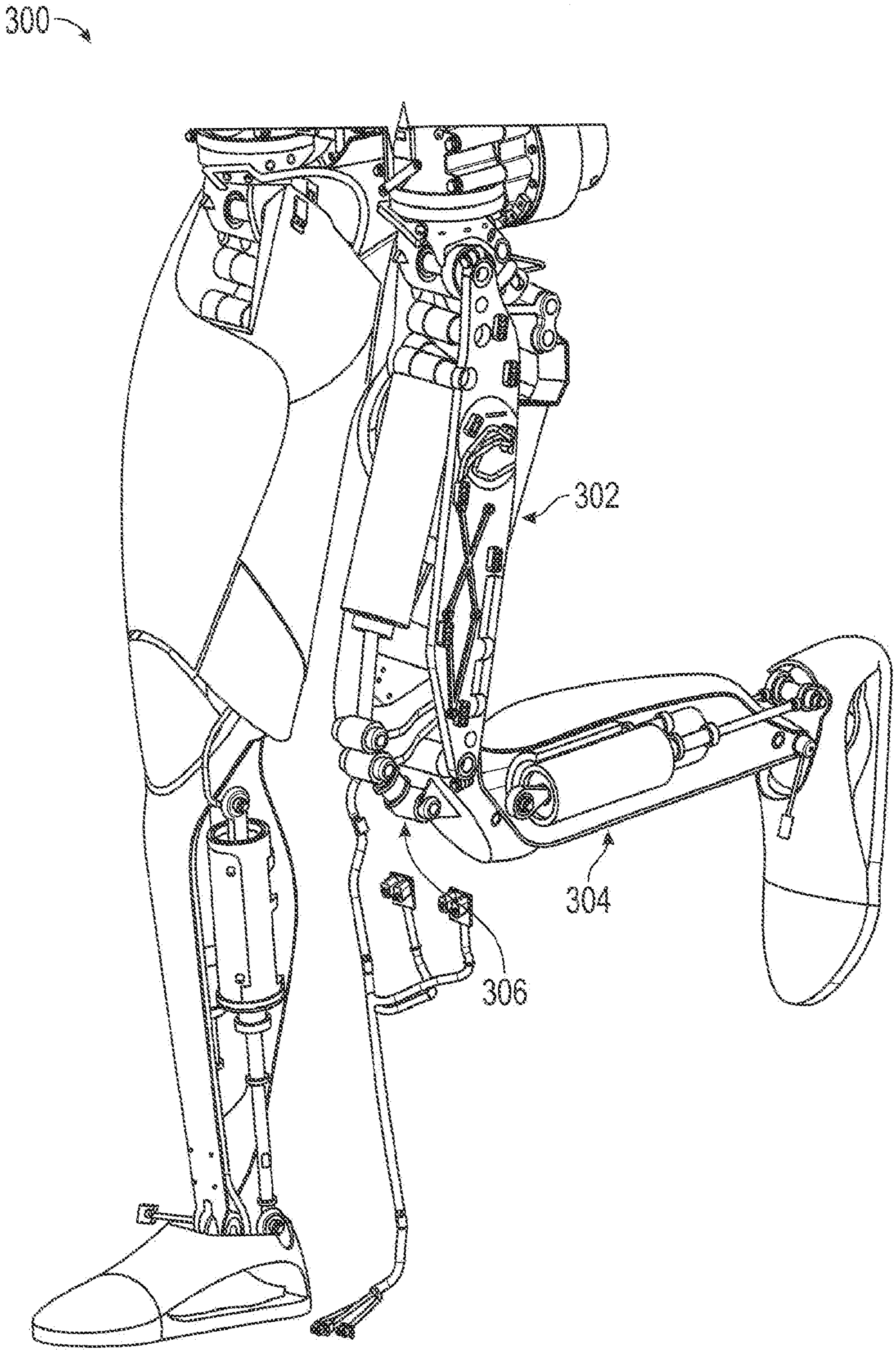

FIG. 3B

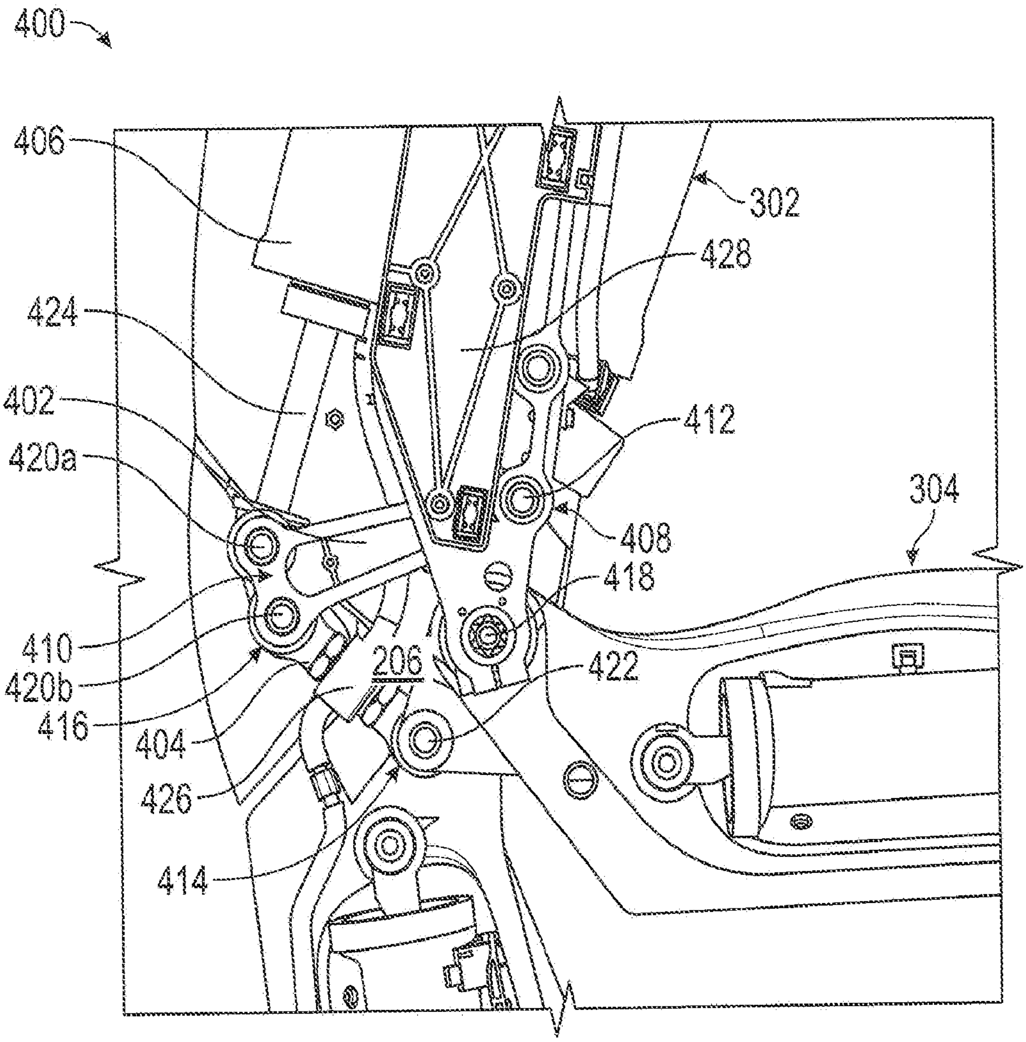
400
406
302
428
424
402
412
420a
304
408
418
410
206
422
420b
416
404
426
414

FIG. 4

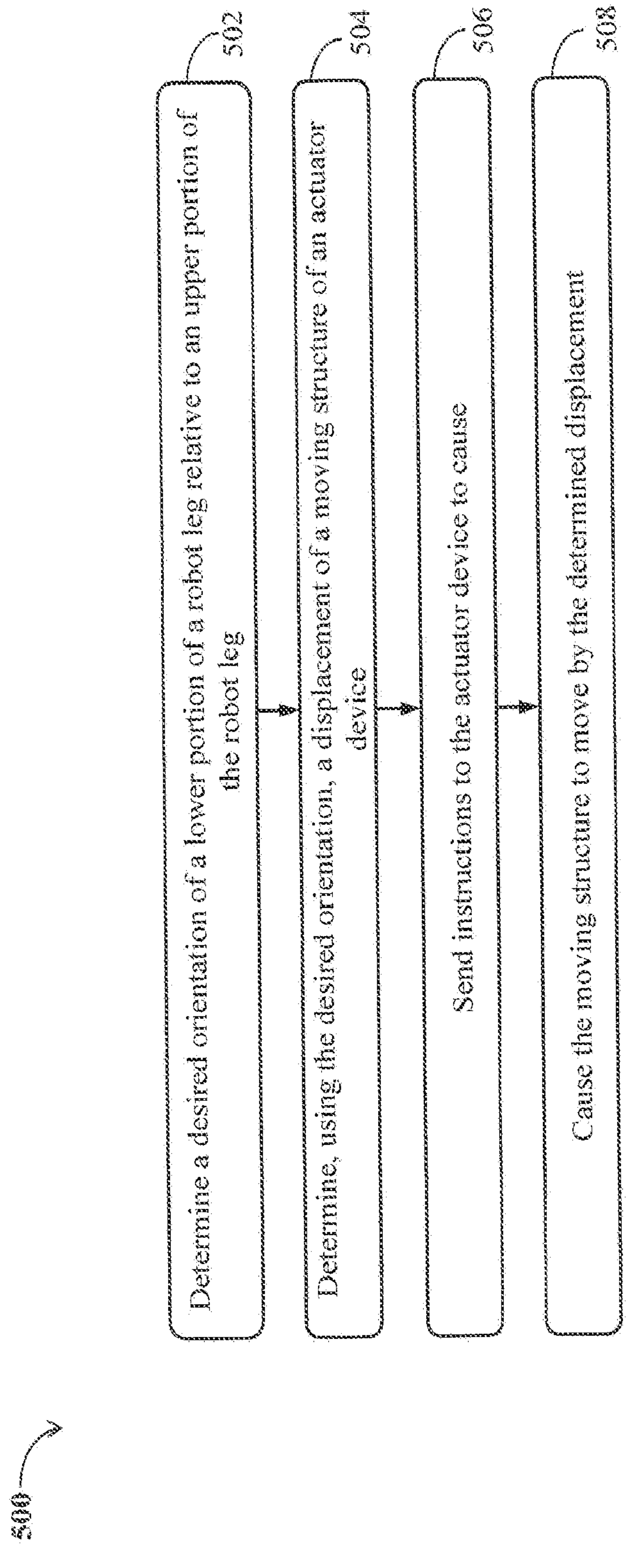
500
Determine a desired orientation of a lower portion of a robot leg relative to an upper portion of the robot leg
502
Determine, using the desired orientation, a displacement of a moving structure of an actuator device
504
Send instructions to the actuator device to cause
506
Cause the moving structure to move by the determined displacement
508

FIG. 5

600

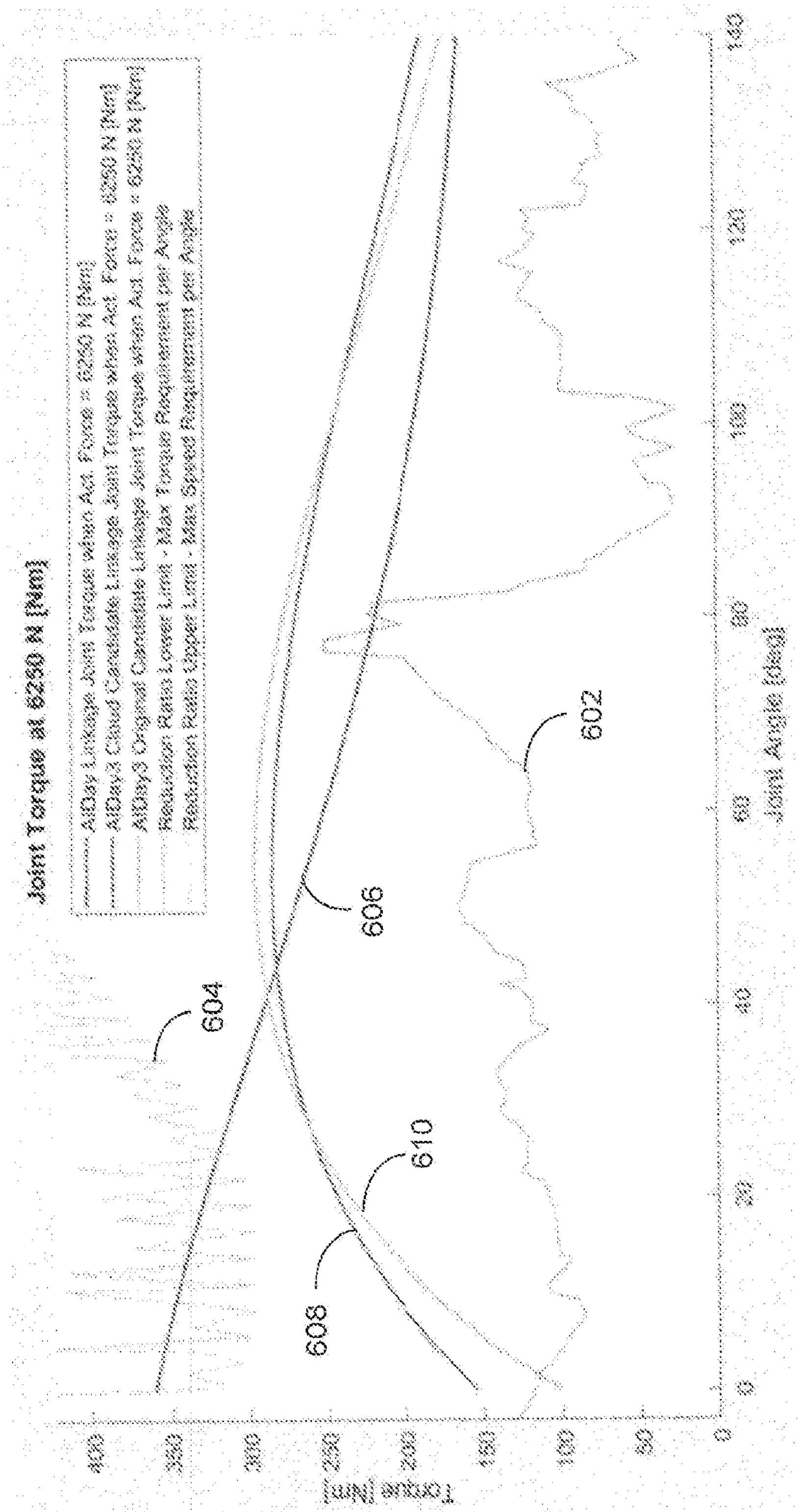
Joint Torque at 6250 N [Nm]
Torque [Nm]
Joint Angle [deg]
0
50
100
150
200
250
300
350
400
20
40
60
80
100
120
140
602
604
606
608
610

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/034300

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***B62D 57/032*** (2023.01); ***B25J 9/12*** (2023.01); ***B25J 17/00*** (2023.01)
CPC: ***B62D 57/032; B25J 9/123;*** *B25J 17/00*

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)

CPC: See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 20190240832 A1 (MITSUBISHI ELECTRIC CORPORATION) 08 August 2019 (08.08.2019)	
X	entire document	1-3, 5-9, 11, 12, 14
Y	entire document	4, 10, 13
	CN 208715326 U (CHANGSHA ZICHEN TECH DEVELOPMENT CO LTD) 09 April 2019 (09.04.2019)	
Y	see machine translation	4
	US 20200361101 A1 (UBTECH ROBOTICS CORP LTD) 19 November 2020 (19.11.2020)	
Y	entire document	10
	US 20160151911 A1 (GOOGLE INC.) 02 June 2016 (02.06.2016)	
Y	entire document	13
	US 20090009124 A1 (SUGA et al.) 08 January 2009 (08.01.2009)	
A	entire document	1-14

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 December 2023 (08.12.2023)	**18 January 2024 (18.01.2024)**

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US **Commissioner for Patents** **P.O. Box 1450, Alexandria, VA 22313-1450**	**MATOS** **TAINA**
Facsimile No. **571-273-8300**	Telephone No. **571-272-4300**

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

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

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

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

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: **1-14**

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

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

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

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

Group I, claims 1-14, is drawn to a system comprising: a knee joint assembly including: the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a second pivot relative to the upper portion of the robot.

Group II, claims 15-20, is drawn to a method comprising: determining, by a processing circuitry, an orientation of a lower portion of a leg of a robot relative to an upper portion of the leg of the robot.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: the lower portion of the leg of the robot mechanically coupled to the upper portion of the leg of the robot and configured to rotate around a second pivot relative to the upper portion of the robot; and a linear actuator device mechanically coupled to a second end of the first link member and a second end of the second link member, the linear actuator device, when actuated, causes the first link member to rotate around the first pivot relative to the upper portion of the leg of the robot and causes the lower portion of the leg of the robot to rotate around the second pivot relative to the upper portion of the leg of the robot as claimed therein is not present in the invention of Group II. The special technical feature of the Group II invention: determining, by the processing circuitry using the orientation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot, a displacement of a moving structure of a linear actuator device, the moving structure of the linear actuator device mechanically coupled to a first end of the first link member and a first end of the second link member; sending instructions to the linear actuator device to cause the moving structure to move by the determined displacement; and causing, by the linear actuator device, the moving structure to move by the determined displacement leading to a rotation of the lower portion of the leg of the robot relative to the upper portion of the leg of the robot to reach the desired orientation as claimed therein is not present in the invention of Group I.

Groups I and II lack unity of invention because even though the inventions of these groups require the technical feature of an assembly including: a first link member having a first end mechanically coupled to an upper portion of a leg of a robot and configured to rotate around a first pivot relative to the upper portion of the leg of the robot; a second link member having a first end mechanically coupled to a lower portion of the leg of the robot, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2009/0009124 to Suga et al. teaches an assembly including: a first link member having a first end mechanically coupled to an upper portion of a leg of a robot and configured to rotate around a first pivot relative to the upper portion of the leg of the robot; a second link member having a first end mechanically coupled to a lower portion of the leg of the robot (each of the legs includes a first link that extends along the lateral surface of the body trunk, a second link that extends along the bottom surface of the body trunk, and a third link that extends downward vertically. One end of the first link is rotatably connected to the lateral surface of the trunk via a leg connecting portion so as to be able to rotate with respect to the body trunk. The other end of the first link is connected to one end of the second link via a joint (pitch joint) that has a rotation axis extending along the pitch direction such that the second link is able to rotate. The other end of the second link is connected to one end of the third link by a roll joint that is positioned below the trunk so as to be able to rotate., para. 0017. Note that the second link can move along the bottom surface of the trunk by being connected to the other end of the first link that rotates with a pivot at the axis of rotation of the leg connecting portion, para. 0022).

Since none of the special technical features of the Group I or II inventions are found in more than one of the inventions, unity of invention is lacking.