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CYCLOID GEAR ASSEMBLY WITH PARTIAL CONTACT AND RELATED TECHNOLOGY

Abstract

A gear assembly in accordance with at least some embodiments of the present technology includes first and second supports extending circumferentially around an assembly axis in first and second planes, respectively. The gear assembly includes a first transfer member having first lobes and first troughs circumferentially alternating around the assembly axis in a third plane. The gear assembly includes a second transfer member having second lobes and second troughs circumferentially alternating around the assembly axis in a fourth plane. The third and fourth planes are between the first and second planes along the assembly axis. The gear assembly includes first and second pins circumferentially interspersed around the assembly axis and extending between the first and second supports. The gear assembly transfers torque at least primarily via contact between the first pins and the first lobes and via contact between the second pins and the second lobes.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This claims the benefit of U.S. Provisional Application No. 63/554,680, filed Feb. 16, 2024, U.S. Provisional Application No. 63/569,683, filed Mar. 25, 2024, and U.S. Provisional Application No. 63/691,950, filed Sep. 6, 2024. Each of the foregoing applications is incorporated herein by reference in its entirety. To the extent the foregoing applications or any other material incorporated by reference conflicts with the present disclosure, the present disclosure controls.

TECHNICAL FIELD
[0002] The present technology relates to cycloid gear assemblies, such as cycloid gear assemblies of robot actuators.
BACKGROUND
[0003] Much of the work that humans currently perform is amenable to automation using robotics. For example, large numbers of human workers currently focus on executing actions that require little or no reasoning, such as predefined relocations of items and containers at order-fulfillment centers. Such actions may occur millions of times a day at a single order-fulfillment center and billions of times a day across a network of order-fulfillment centers. Human effort would be better applied to more complex tasks, particularly those involving creativity, advanced problem solving, and social interaction. Presently, however, the need for order-fulfillment centers is large and rapidly increasing. Some analysts forecast a shortage of a million or more workers to staff order-fulfillment centers within the next ten to fifteen years. Due to the importance of this field, even small improvements in efficiency can have major impacts on macroeconomic productivity. For at least these reasons, there is a significant and growing need for innovation that supports automating tasks that humans currently perform at order-fulfillment centers and elsewhere.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0004] Certain aspects of the present technology can be better understood with reference to the following drawings. The relative dimensions in the drawings may be to scale with respect to some embodiments of the present technology. With respect to other embodiments, the drawings may not be to scale. The drawings may also be enlarged arbitrarily. For clarity, reference-number labels for analogous components or features may be omitted when the appropriate reference-number labels for such analogous components or features are clear in the context of the specification and all of the drawings considered together. Furthermore, the same reference numbers may be used to identify analogous components or features in multiple described embodiments.
[0005] FIG. **1** is a perspective view of an actuator in accordance with at least some embodiments of the present technology.
[0006] FIG. **2** is a partially schematic side profile view of a robot joint assembly including the actuator of FIG. **1** in accordance with at least some embodiments of the present technology.
[0007] FIG. **3** is an exploded perspective view of selected components of the actuator of FIG. **1**.
[0008] FIG. **4** is a front profile view of a first support of the actuator of FIG. **1**.
[0009] FIG. **5** is a cross-sectional perspective view of the first support of the actuator of FIG. **1** taken along the line **5-5** in FIG. **4**.

[0010] FIG. **6** is a side profile view of a first pin of the gear assembly of the actuator of FIG. **1**.
[0011] FIG. **7** is a perspective view of the first pin and a circumferentially neighboring second pin of the gear assembly of the actuator of FIG. **1**.
[0012] FIG. **8** is a front profile view of a roller bearing of the gear assembly of the actuator of FIG. **1**.
[0013] FIG. **9** is a cross-sectional perspective view of the roller bearing of the gear assembly of the actuator of FIG. **1** taken along the line **9-9** in FIG. **8**.
[0014] FIGS. **10** and **11** are a side profile view and a front profile view, respectively, of transfer members and pins of the gear assembly of the actuator of FIG. **1**.
[0015] FIG. **12** is a perspective view of transfer members of the gear assembly of the actuator of FIG. **1**.
[0016] FIG. **13** is an enlargement of a portion of FIG. **12**.
[0017] FIGS. **14**, **15**, **16** and **17** are, respectively, a side profile view of a pin, a side profile view of a pin array, a side profile view of a first transfer member, and a side profile view of a second transfer member of a gear assembly of an actuator in accordance with another embodiment of the present technology.
[0018] FIGS. **18**, **19** and **20** are, respectively, a perspective view of transfer members, pins, and roller bearings, a side profile view of a first transfer member, and a side profile view of a second transfer member of a gear assembly of an actuator in accordance with another embodiment of the present technology.
[0019] FIG. **21** is an enlargement of a portion of FIG. **20**.
[0020] FIGS. **22** and **23** are, respectively, a perspective view and a side profile view of transfer members, pins, and roller bearings of a gear assembly of an actuator in accordance with another embodiment of the present technology.
[0021] FIG. **24** is a front profile view of a roller bearing of the gear assembly of the actuator of FIGS. **22** and **23**.
[0022] FIG. **25** is a cross-sectional perspective view of the roller bearing of the gear assembly of the actuator of FIGS. **22** and **23** taken along the line **25-25** in FIG. **24**.
[0023] FIG. **26** is a perspective view of a mobile robot including an actuator in accordance with at least some embodiments of the present technology.
[0024] FIG. **27** is a block diagram corresponding to a method involving an actuator in accordance with at least some embodiments of the present technology.

DETAILED DESCRIPTION

[0025] Robots perform mechanical work via actuators. A typical actuator in an electromechanical robot includes an electrical motor and a gear assembly. The electrical motor uses electricity from a power source to rotate a shaft at a relatively high speed. The gear assembly converts this high-speed rotation into lower-speed rotation more suitable for a controlled mechanical action, such as moving a robot link via a robot joint. Rolling-contact cycloid and strain-wave are two types of gear assemblies used in advanced robotics. Performance categories that differentiate these types of gear assemblies include torque-to-weight ratio, torque-to-size ratio, reduction ratio, backlash, efficiency, transparency, miniaturizability, and shock resistance. Reduction ratio is the ratio of the number of revolutions per time of the input to the gear assembly divided by the number of revolutions per time of the output from the gear assembly. Backlash is the clearance or play between gears during operation, which, in excess, can cause imprecise and jerky movements. With exceptions, strain-wave gear assemblies tend to perform relatively well with respect to torque-to-weight ratio, torque-to-size ratio, backlash, and miniaturizability. Also with exceptions, rolling-contact cycloid gear assemblies tend to perform relatively well with respect to efficiency, transparency, and shock resistance. Strain-wave gear assemblies have certain advantages at high reduction ratios whereas rolling-contact cycloid gear assemblies have certain advantages at lower reduction ratios. Different applications call for different reduction ratios, so the desirability of compatibility with higher or lower reduction ratios tends to be application specific. Furthermore, the noted performance differentiators are not universal. For example, a high-quality rolling-contact cycloid gear assembly may exhibit lower backlash than a low-quality strain-wave gear assembly.

[0026] With respect to most performance categories, the differences between strain-wave and rolling-contact cycloid gear assemblies are small enough that either one is acceptable for a given application. Indeed, it is typical to accept performance tradeoffs in connection with selecting an actuator type for an application instead of attempting to maximize performance in all categories. Three notable exceptions to this approach, however, are shock resistance, miniaturizability, and transparency. Performance in these categories tends to be determinative. Strain-wave gear assemblies often exhibit unacceptably low shock resistance. Moreover, this feature of strain-wave gear assemblies can be difficult to avoid because operating a strain-wave gear assembly involves deforming a flexspline, which must be flexible enough to accommodate the deformation. Good shock resistance and sufficient deformability tend to be mutually exclusive in practice. Accordingly, rolling-contact cycloid gear assemblies of all sizes tend to significantly outperform counterpart strain-wave gear assemblies in the category of shock resistance.

[0027] Moreover, strain-wave gear assemblies often exhibit relatively poor transparency. Transparency describes how readily output torque from an actuator can be predicted. Actuators operate at different efficiencies depending on load and speed. When these efficiencies fall within a relatively wide range, transparency is low. In contrast, when these efficiencies fall within a relatively narrow range, transparency is high. The latter is beneficial for control and simulation processes, among other things. As with shock resistance, rolling-contact cycloid gear assemblies reliably outperform strain-wave gear assemblies with regard to transparency. For example, the efficiency of a conventional strain-wave gear assembly may fall within a range from 50% to 85%. In contrast, the efficiency of a rolling-contact cycloid gear assembly in accordance with at least some embodiments of the present technology is expected to fall within a range from 89% to 99%.

[0028] Conventional rolling-contact cycloid gear assemblies, however, are prohibitively difficult to miniaturize beyond a certain level. Thus, where size is limited and high shock forces are possible and/or high transparency is necessary, neither conventional strain-wave gear assemblies nor conventional rolling-contact cycloid gear assemblies are suitable. Moreover, there is room for improvement in conventional gear assemblies of all sizes and types, particularly with regard to cost and complexity. Conventional rolling-contact cycloid gear assemblies, for example, tend to have relatively large numbers of high-precision parts, which can make them expensive and difficult to manufacture. For the foregoing and/or other reasons, there is a need for innovation in this field.

[0029] Gear assemblies and related devices, systems, and methods in accordance with embodiments of the present technology at least partially address one or more problems or limitations associated with conventional technologies. A gear assembly in accordance with at least some embodiments of the present technology has generally a rolling-contact cycloidal architecture, but with a partial rather than a full set of circumferential contact areas relative to conventional counterparts. This feature is characterized in at least some instances herein as “partial contact.” Partial contact includes features characterized herein as “sparse contact” and “alternating contact,” among others. These features are described in detail below. Partial contact can have a variety of advantages. For example, it can facilitate direct contact between transfer members (e.g., cycloid disks) and pins without the need for intervening roller bearings. This, in turn, can allow for a higher reduction ratio in a smaller overall actuator size than would otherwise be possible. Relatedly, partial contact can allow roller bearings to be offset from transfer members, which can likewise reduce overall actuator size. In addition or alternatively, partial contact can allow for the use of fewer roller bearings and/or roller bearings of a type (e.g., drawn-cup) of relatively low cost and small size. Still other advantages in addition to or instead of the foregoing are also possible.

[0030] A gear assembly in accordance with a particular embodiment includes pins that bridge an area adjacent to two transfer members and engage the transfer members unequally during operation. This unequal engagement can include contacting one of the transfer members and remaining out of contact with the other. In an example, pins configured to engage a first transfer member and to avoid engaging a second transfer member are circumferentially interspersed with pins configured to engage the second transfer member and to avoid engaging the first transfer member. The unequal engagement can be associated with a difference in the shape of the pins, a difference in the orientation of the pins, a difference in the shape of the transfer members, and/or a difference in the orientation of the transfer members, among other possibilities. Furthermore, as mentioned above, the pins can extend between roller bearings of a type well suited to miniaturization and low-cost production. For example, the pins can extend between drawn-cup needle roller bearings at circumferentially distributed sockets of axially spaced apart supports. Gear assemblies in accordance with at least some embodiments of the present technology are expected to exhibit advantageous characteristics, such as a previously unavailable combination of high miniaturizability, high shock resistance, and high reduction ratio.

[0031] The foregoing and other features of devices, systems, and methods in accordance with various embodiments of the present technology are further described below with reference to FIGS. **1-27**. Although methods, devices, and systems may be described herein primarily or entirely in the context of actuators of mobile robots, other contexts are within the scope of the present technology. For example, suitable features of described methods, devices, and systems can be implemented in the context of stationary robots or in non-robot contexts that call for actuators with cycloid-type gearing, such as certain vehicles, pumps, winches, etc. Furthermore, it should be understood, in general, that other methods, devices, and systems in addition to those disclosed herein are within the scope of the present technology. For example, methods, devices, and systems in accordance with embodiments of the present technology can have different and/or additional configurations, components, procedures, etc. than those disclosed herein. Moreover, methods, devices, and systems in accordance with embodiments of the present technology can be without one or more of the configurations, components, procedures, etc. disclosed herein without deviating from the present technology.

Examples of Actuators

[0032] FIG. **1** is a perspective view of an actuator **100** in accordance with at least some embodiments of the present technology. FIG. **2** is a partially schematic side profile view of a robot joint assembly **102** including the actuator **100** in accordance with at least some embodiments of the present technology. With reference to FIGS. **1** and **2** together, the robot joint assembly **102** can include a link **104** and rod **106** (both shown schematically) connected to one another via the actuator **100**. In the illustrated embodiment, the actuator **100** is configured to move the rod **106** relative to the link **104**. In another embodiment, as discussed below, a counterpart of the actuator **100** can be configured to cause an opposite relative motion. With reference again to FIGS. **1** and **2**, the actuator **100** can include a motor **108** configured to convert electricity into torque. In at least some cases, the motor **108** is configured to rotate a shaft (not shown in FIGS. **1** and **2**) about an assembly axis **110**. The actuator **100** can further include a gear assembly **112** through which the rod **106** is connected to the motor **108**. The gear assembly **112** can include a crank **114** including a plate **116** shaped as a disk in a plane perpendicular to the assembly axis **110**. The crank **114** can further include a yoke **118** carried by the plate **116** and a pivot **120** carried by the yoke **118**. The pivot **120** can be cylindrical, have a laterally offset position relative to the assembly axis **110**, and have a length parallel to the assembly axis **110**. The rod **106** can be configured to rotate relative to the crank **114** via the pivot **120** as the actuator **100** moves the crank **114** relative to the link **104**. Thus, the crank **114** can be an output member of the gear assembly **112**. Other output members are also possible. For example, a counterpart of the actuator **100** can include an output shaft or another link in place of the crank **114**.

[0033] With reference again to the illustrated embodiment, FIG. **3** is an exploded perspective view of selected components of the actuator **100**. As shown in FIG. **3**, the gear assembly **112** can include cycloid-type internal structures. The gear assembly **112** can include an input assembly **122** kinematically downstream from the motor **108**. As parts of the input assembly **122**, the gear assembly **112** can include an input shaft **124** configured to rotate about the assembly axis **110**, a first eccentric bearing **126** carried by the input shaft **124**, and a second eccentric bearing **128** also carried by the input shaft **124**. The first and second eccentric bearings **126**, **128** can be connected to the input shaft **124** at different respective positions along the assembly axis **110**. Furthermore, the first and second eccentric bearings **126**, **128** can protrude radially from the input shaft **124** in circumferentially opposite respective directions relative to the assembly axis **110**. In at least some cases, the first and second eccentric bearings **126**, **128** are not rotatable relative to the input shaft **124** about the assembly axis **110**. For example, the input shaft **124** and the first and second eccentric bearings **126**, **128** can include complementary locking features (not shown), such as key and slot features, non-cylindrical interface features, etc. Thus, as the input shaft **124** rotates about the assembly axis **110**, protruding portions of the first and second eccentric bearings **126**, **128** rotate out-of-phase with one another. The respective rotation of these protruding portions of the first and second eccentric bearings **126**, **128** can be radially symmetrical about the assembly axis **110**. This can reduce or prevent vibration during operation of the actuator **100**, provide internal load balancing, and/or have other advantages.

[0034] The actuator **100** can further include a first transfer member **130** at a position along the assembly axis **110** corresponding to a position of the first eccentric bearing **126** along the assembly axis **110**. The actuator **100** can also include a second transfer member **132** at a position along the assembly axis **110** corresponding to a position of the second eccentric bearing **128** along the assembly axis **110**. The first transfer member **130** can define a first central opening **134** at which the first eccentric bearing **126** is rotatably disposed. The second transfer member **132** can define a second central opening **136** at which the second eccentric bearing **128** is rotatably disposed. Rotating the first and second eccentric bearings **126**, **128** within the first and second central openings **134**, **136**, respectively, via the input shaft **124** can induce an eccentric wobble in the first and second transfer members **130**, **132**. This can include urging the first and second transfer members **130**, **132** radially outward from the assembly axis **110** in concert with the out-of-phase rotation of the protruding portions of the first and second eccentric bearings **126**, **128**. Thus, at any given time, a peripheral portion of the first transfer member **130** farthest from the assembly axis **110** can be circumferentially opposite to a peripheral portion of the second transfer member **132** farthest from the assembly axis **110**. This relationship can persist as the first and second transfer members also rotate about the assembly axis **110** in response to interaction with other components of the gear assembly **112**, as discussed below. In some cases, the actuator **100** includes annular roller bearings (not shown) at interfaces between the first and second eccentric bearings **126**, **128** and the first and second transfer members **130**, **132**, respectively. In other cases, outer surfaces of the first and second eccentric bearings **126**, **128** slidingly contact inner surfaces of the first and second transfer members **130**, **132** respectively.

[0035] With reference again to FIG. **3**, the gear assembly **112** can further include structures that interact directly or indirectly with the first and second transfer members **130**, **132** to transfer torque. Among these structures, the gear assembly **112** can include a pin array **138**, a first support **140**, and a second support **142**. Individual pins (not labeled in FIG. **3**) of the pin array **138** can be elongate and can extend between the first and second supports **140**, **142**. A distribution of the pins within the pin array **138** can be radially symmetrical about the assembly axis **110**. The number of pins along with the peripheral shapes of the first and second transfer members **130**, **132** can correspond to a reduction ratio of the actuator **100**. In at least some cases, the actuator **100** has an input-to-output reduction ratio within a range from 20:1 to 40:1, such as from 25:1 to 35:1. As discussed in detail below, there may be less load sharing among the pins in the gear assembly **112** and among the pins of other gear assemblies in accordance with at least some embodiments of the present technology than would occur in a conventional gear assembly. Although not necessary for realizing advantages of various embodiments of the present technology, a relatively high number of pins in the pin array **138** (e.g., at least 15 or at least 20) and a corresponding relatively high input-to-output reduction ratio (e.g., at least 15:1 or at least 20:1) can be advantageous to reduce or eliminate any difference in performance associated with this lesser load sharing.

[0036] In some embodiments, individual pins of the pin array **138** are configured to rotate relative to the first and second supports **140**, **142**. To facilitate this rotation, the gear assembly **112** can include a first roller bearing array **144** and a second roller bearing array **146** at the first and second supports **140**, **142**, respectively. In another embodiment, a counterpart of the gear assembly **112** can include stationary pins configured to slidingly contact the first and second transfer members **130**, **132**. In general, however, the rotatability of the pins of the pin array **138** in the illustrated embodiment is expected to significantly increase the efficiency of the actuator **100**. Furthermore, in still other embodiments, all pins can contact both transfer members. In these and other cases, contact between the pins and transfer members can be via roller bearings rather than direct. This can reduce or eliminate antagonistic forces from the respective transfer members acting on the pins. As described below, partial contact can still be present in these cases, such as based on a ratio of the total number of pins to the total number of contact features (e.g., lobes) of the corresponding transfer members.

[0037] With reference again to the illustrated embodiment, the gear assembly **112** can include a carrier **148** having a base **150** and rods **152** (one labeled) individually extending from the base **150**. The individual rods **152** can be cylindrical rollers with respective long axes (not shown) parallel to the assembly axis **110**. Furthermore, the rods **152** can be circumferentially distributed around the assembly axis **110**. In at least some cases, the first transfer member **130** defines first peripheral openings **154** (one labeled) also distributed circumferentially around the assembly axis **110** and outwardly positioned relative to the first central opening **134**. Similarly, the second transfer member **132** can define second peripheral openings **154** (one labeled) distributed circumferentially around the assembly axis **110** and outwardly positioned relative to the second central opening **136**. The individual rods **152** can extend through different respective pairs of one of the first peripheral openings **154** and one of the second peripheral openings **156**. The crank **114** can be fixedly connected to the rods **152** via the base **150** such that force exerted against the rods **152** via rotation of the first and second transfer members **130**, **132** about the assembly axis **110** causes rotation of the crank **114** about the assembly axis **110**.

[0038] In some cases, the gear assembly **112** is configured to rotate the crank **114** or another output member relative to the link **104** or another mount fixedly connected to the first and second supports **140**, **142**. With regard to the carrier **148**, this rotation can be in response to force exerted by the first and second transfer members **130**, **132** against the base **150** via the rods **152**. In other cases, output can be in the opposite direction. For example, a counterpart of the gear assembly **112** can include a mount (instead of the crank **114**) fixedly connected to the base **150**. This counterpart of the gear assembly **112** can be configured to rotate the first and second supports **140**, **142** relative to the mount in response to force exerted by the first and second transfer members **130**, **132** against the first and second supports **140**, **142** via the pin array **138**. In still other cases, a counterpart of the gear assembly **112** can be in a kinematic chain in which it causes a kinematically upstream component and a kinematically downstream component to rotate relative to one another simultaneously. Still other operational configurations are also possible.

[0039] With reference again to the illustrated embodiment, FIG. **4** is a front profile view of the first support **140**. FIG. **5** is a cross-sectional perspective view of the first support **140** taken along the line **5-5** in FIG. **4**. With reference to FIGS. **1-5** together, the first and second supports **140**, **142** can be configured to be connected to one another around an annular area at peripheral portions of the first and second transfer members **130**, **132**. The first support **140** can include a plate **200** extending around the assembly axis **110** and a collar **202** at an outer periphery of the plate **200** and extending from the plate **200** toward the second support **142** in a direction parallel to the assembly axis **110**.

The plate **200** and the collar **202** can be formed together as a single part (as shown) or formed separately and then connected. The first support **140** can define first fastener holes **204** (one labeled) extending through the plate **200** and the collar **202** in a direction parallel to the assembly axis **110**. The gear assembly **112** can include fasteners (e.g., threaded fasteners, pins, etc.) extending through the first fastener holes **204** that secure the first and second supports **140**, **142** to one another. In at least some cases, these fasteners individually extend between and are in contact with the first and second supports **140**, **142**. The first support **140** can further define second fastener holes **206** (one labeled) extending through the plate **200**. The gear assembly **112** can include fasteners (e.g., threaded fasteners, pins, etc.) extending through the second fastener holes **206** that secure the first support **140** to the motor **108**.

[0040] The plate **200** can further define through holes **208** (one labeled) circumferentially distributed around the assembly axis **110**. The first support **140** can include sockets **210** (one labeled) at the through holes **208**. The sockets **210** can also be circumferentially distributed around the assembly axis **110**. In some cases, the sockets **210** encompass the entire through holes **208**. In other cases, the sockets **210** encompass portions of the through holes **208**. Furthermore, counterparts in another embodiment of the present technology can be blind holes. With reference again to the illustrated embodiment, the second support **142** can have features similar to or the same as those of the first support **140**. Features of the second support **142** may be referenced herein with reference numbers matching the reference numbers of corresponding features of the first support **140**, but with an appended prime symbol. In another embodiment, a counterpart of the second support **142** can have different features. In addition or alternatively, counterparts of the first and second supports **140**, **142** can be different portions of a unitary structure rather than separate structures.

[0041] FIG. **6** is a side profile view of a first pin **250** of the gear assembly **112**. As shown in FIG. **6**, the first pin **250** can be elongate and can define a pin axis **252**. The first pin **250** can include a first end portion **254** and a second end portion **256** opposite to one another along the pin axis **252**. The first pin **250** can further include a first intermediate portion **258** between the first and second end portions **254**, **256** and a second intermediate portion **260** between the first intermediate portion **258** and the second end portion **256**. The first pin **250** can be configured to contact the first transfer member **130** via the first intermediate portion **258** during operation of the gear assembly **112** as the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. In contrast, the first pin **250** can be configured to remain out of contact with the second transfer member **132** during operation of the gear assembly **112** as the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. Relatedly, the first pin **250** can have a non-uniform transverse cross-sectional area along the pin axis **252**. In particular, the first pin **250** can include an annular recess **262** at the second intermediate portion **260**. In the gear assembly **112**, the first end portion **254** of the first pin **250** can be at the first support **140**, the second end portion **256** of the first pin **250** can be at the second support **142**, the first intermediate portion **258** of the first pin **250** can contact the first transfer member **130**, and the second intermediate portion **260** of the first pin **250** can remain out of contact with the second transfer member **132** via the annular recess **262**. As discussed in detail below, the alternating contact relationship between the first and second pins **250**, **300** and the first and second transfer members **130**, **132** can facilitate miniaturization of the actuator **100** and/or have other advantages.

[0042] FIG. **7** is a perspective view of the first pin **250** and a second pin **300** of the gear assembly **112** that circumferentially neighbors the first pin **250** within the pin array **138**. Features of the second pin **300** are labeled in FIG. **7** and may be referenced herein with reference numbers matching the reference numbers of corresponding features of the first pin **250**, but with an appended prime symbol. As shown in FIG. **7**, the second pin **300** can be the same or similar to the first pin **250**, but with the annular recess **262**′ at the first intermediate portion **258**′ rather than at the second intermediate portion **260′**. Thus, in the gear assembly **112**, the first end portion **254′** of the second pin **300** can be at the first support **140**, the second end portion **256′** of the second pin **300** can be at the second support **142**, the first intermediate portion **258′** of the first pin **250** can remain out of contact with the first transfer member **130** via the annular recess **262′**, and the second intermediate portion **260′** of the second pin **300** can contact the second transfer member **132**. Within the pin array **138**, the illustrated first pin **250** and other first pins **250** with the same features and orientation relative to the assembly axis **110** as the illustrated first pin **250** can be circumferentially interspersed around the assembly axis **110** with the illustrated second pin **300** and other second pins **300** with the same features and orientation relative to the assembly axis **110** as the illustrated second pin **300**. Distributions of the first and second pins **250**, **300** around the assembly axis **110** can be radially symmetrical.

[0043] FIG. **8** is a front profile view of a roller bearing **350** of the gear assembly **112**. FIG. **9** is a cross-sectional perspective view of the roller bearing **350** taken along the line **9-9** in FIG. **8**. With reference to FIGS. **1-9** together, the individual first pins **250** can be configured to rotate relative to the first and second supports **140**, **142** in response to force (e.g., camming) from the first transfer member **130** (e.g., via a peripheral portion of the first transfer member **130**) during operation of the gear assembly **112** as the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. Similarly, the individual second pins **300** can be configured to rotate relative to the first and second supports **140**, **142** in response to force (e.g., camming) from the second transfer member **132** (e.g., via a peripheral portion of the second transfer member **132**) during operation of the gear assembly **112** as the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. The roller bearing **350** and other roller bearings **350** within the first and second roller bearing arrays **144**, **146** can reduce friction during operation of the gear assembly **112** and thereby increase the efficiency of the actuator **100**. Locating the roller bearings **350** at interfaces between the first and second pins **250**, **300** and the first and second supports **140**, **142** rather than at interfaces between the first and second pins **250**, **300** and the first and second transfer members **130**, **132** can facilitate miniaturization of the actuator **100** and/or have other advantages.

[0044] As shown in FIGS. **8** and **9**, the roller bearing **350** can define a cylindrical cavity **352** having a diameter corresponding to a diameter of the first and second end portions **254**, **256**, **254′**, **256′** of the first and second pins **250**, **300**. The roller bearing **350** can include rollers **354** (one labeled) aligned with and circumferentially distributed around the cylindrical cavity **352**. The roller bearing **350** can further include an annular frame **356** carrying the rollers **354**. The annular frame **356** can include a cylindrical casing **358** extending around the rollers **354**, a first lip **360** extending inwardly from the cylindrical casing **358** at one end of the cylindrical cavity **352** and a second lip **362** extending inwardly from the cylindrical casing **358** at an opposite end of the cylindrical cavity **352**. The roller bearing **350** can further include a spacer **364** defining slots **366** in which the rollers **354** are respectively disposed. The individual rollers **354** can define a cylindrical outer surface **368** partially covered by the spacer **364** and the cylindrical casing **358** and partially exposed at the cylindrical cavity **352**. The cylindrical casing **358** can be configured to resist hertzian contact stress, but not operating loads. Accordingly, the cylindrical casing **358** can be relatively thin and lightweight. The roller bearing **350** can be configured to resist deformation from operating loads at least primarily via encasement in an external structure.

[0045] In at least some cases, the roller bearing **350** is a drawn-cup needle roller bearing. Furthermore, the first and second pins **250**, **300** can contact the cylindrical outer surfaces **368** of the rollers **354** directly. Due to these and/our other features, the roller bearings **350** can be well suited to miniaturization. In contrast to other types of roller bearings (e.g., machined-ring needle roller bearings), it can be advantageous for drawn-cup needle roller bearings to be supported externally to reduce or prevent deformation in response to high loads. In the illustrated embodiment, the roller bearings **350** are at the first and second supports **140**, **142**. For example, the individual roller bearings **350** can be at least partially disposed within the individual sockets **210**. In the gear assembly **112**, the first and second pins **250**, **300** can individually extend between different respective pairs of one of the roller bearings **350** at the first support **140** and one of the roller bearings **350** at the second support **142**.

[0046] FIGS. **10** and **11** are a side profile view and a front profile view, respectively, of the first and second transfer members **130**, **132** and all of the first and second pins **250**, **300** of the gear assembly **112** at a given time during operation of the gear assembly **112**. FIG. **10** also shows four planes **400***a*-**400***d* related to the relative positions of various portions of the gear assembly **112**. With reference to FIGS. **1-11** together, the planes **400***a*-**400***d* can intersect the assembly axis **110** and be spaced apart from one another along the assembly axis **110** at successively farther positions from the crank **114**. The first support **140** can extend circumferentially around the assembly axis **110** in the plane **400***a*. Correspondingly, the first end portions **254**, **254′** of the first and second pins **250**, **300** can also be at the plane **400***a*. The second support **142** can extend circumferentially around the assembly axis **110** in the plane **400***d*. Correspondingly, the second end portions **256**, **256′** of the first and second pins **250**, **300** can also be at the plane **400***d*. The first and second transfer members **130**, **132** can be at the planes **400***b*, **400***c*, respectively. The first intermediate portions **258**, **258′** of the first and second pins **250**, **300** can be at the plane **400***b*. Similarly, the second intermediate portions **260**, **260′** of the first and second pins **250**, **300** can be at the plane **400***c*. Due to the circumferentially staggered arrangement of the annular recesses **262**, **262′**, a transverse cross-sectional area of the individual first pins **250** perpendicular to the pin axis **252** can be smaller at the plane **400***c* than at the plane **400***b* and, likewise, a transverse cross-sectional area of the individual second pins **300** perpendicular to the pin axis **252′** can be smaller at the plane **400***b* than at the plane **400***c*.

[0047] FIG. **12** is a perspective view of the just first and second transfer members **130**, **132**. FIG. **13** is an enlargement of a portion of FIG. **12**. With reference now to FIGS. **1-13** together, the first transfer member **130** can include first lobes **450** and first troughs **452** circumferentially alternating around the assembly axis **110** in the plane **400***b*. The first lobes **450** and first troughs **452** can form a first continuous cycloidal profile through which the first transfer member **130** contacts the first pins **250** during operation of the gear assembly **112**. Similarly, the second transfer member **132** can include second lobes **454** and second troughs **456** circumferentially alternating around the assembly axis **110** in the plane **400***c*. The second lobes **454** and second troughs **456** can form a second continuous cycloidal profile through which the second transfer member **132** contacts the second pins **300** during operation of the gear assembly **112**. In other embodiments, counterparts of the first and second transfer members **130**, **132** can have other suitable profiles, such as non-cycloidal and/or discontinuous profiles. With reference again to the illustrated embodiment, the gear assembly **112** can be configured to transfer torque at least primarily via contact between the first pins **250** and the first lobes **450** and via contact between the second pins **300** and the second lobes **454** as the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110** throughout a complete rotational cycle of gear assembly **112**.

[0048] The alternating contact discussed above is different than a conventional rolling-contact cycloid gear assembly in which each counterpart of the first and second lobes **450**, **454** engages each and every counterpart of the first and second pins **250**, **300**. Among other things, this difference can facilitate locating the rolling interface between the pins and the supports rather than between the pins and the transfer members. This is because, in a conventional rolling-contact cycloid gear assembly, a lobe of one transfer member and a trough of the other transfer member contact the same pin simultaneously. The lobe contact area and the trough contact area have different velocities. Rolling interfaces between the pins and the transfer members can accommodate this velocity differential whereas rolling interfaces between the pins and the supports would not. In contrast, with the alternating contact of the gear assembly **112**, this limitation is reduced or eliminated such that the roller bearings **350** can be at the first and second supports **140**,

142. Moreover, because the first and second supports **140**, **142** have space for the sockets **210**, the roller bearings **350** can be of a smaller and less expensive type (e.g., drawn-cup needle type as discussed above) than would otherwise be possible. Still further, the circumferential load distribution characteristic of the cycloid-type gearing modality is such that eliminating every other pin-to-transfer-member interface is not expected to adversely affect performance particularly when the number of pins is relatively high (e.g., greater than 15 or greater than 20). For the foregoing and/or one or more other reasons, the gear assembly **112** is expected to be more amenable to miniaturization than conventional counterparts. Moreover, the gear assembly **112** is expected to exhibit a higher torque-to-weight ratio and a higher torque-to-size ratio relative to conventional counterparts without unduly compromising backlash, efficiency, or shock resistance. Other advantages over conventional counterparts (e.g., reduced cost, reduced complexity, etc.) in addition to or instead of the foregoing advantages are also possible.

[0049] FIGS. **14**, **15**, **16** and **17** are, respectively, a side profile view of a pin **500**, a side profile view of a pin array **501**, a side profile view of a first transfer member **502**, and a side profile view of a second transfer member **504** of a gear assembly of an actuator in accordance with certain additional embodiments of the present technology. In this actuator, the pin **500** can be both a counterpart of the individual first pins **250** and a counterpart of the individual second pins **300**. The pins **500** can be circumferentially distributed around an assembly axis **505** and collectively arranged in the pin array **501** as a counterpart of the pin array **138**. Also in this actuator, the first and second transfer members **502**, **504** can be counterparts of the first and second transfer members **130**, **132**, respectively. As illustrated, a total number of the pins **500** in the pin array **501** can be one more than a total number of the first and second pins **250**, **300** in the pin array **138**. As further illustrated, peripheral profiles of the first and second transfer members **502**, **504** can be significantly different than the peripheral profiles of the first and second transfer members **130**, **132**. Other features of the first and second transfer members **502**, **504** can be generally similar to or the same as corresponding features of the first and second transfer members **130**, **132**. For example, although different in quantity relative to the first and second peripheral openings **154**, **156**, counterpart peripheral openings defined by the first and second transfer members **502**, **504** can be functionally similar to the first and second peripheral openings **154**, **156**. Furthermore, the first and second transfer members **502**, **504** can define fastener openings and voids for weight reduction as shown for the first and second transfer members **130**, **132**. Other features of the actuator can likewise be the same as or similar to corresponding features of the actuator **100**.

[0050] At a high level, the actuator corresponding to FIGS. **14-17** can cause alternating contact between the first and second transfer members **502**, **504** and the pins **500** via omitted lobes at the peripheral profiles of the first and second transfer members **502**, **504** rather than via non-uniform transverse cross-sectional areas of the pins **500**. Accordingly, as shown in FIG. **14**, the pin **500** can define a pin axis **506** and can have a uniform transverse cross-sectional area perpendicular to the pin axis **506**. As shown in FIG. **16**, the first transfer member **502** can include first lobes **508** and first troughs **510** that form a first profile through which the first transfer member **502** contacts some of the pins **500**. An average circumferential span of the first lobes **508** about a first central axis **512** defined by the first transfer member **502** can be smaller than an average circumferential span of the first troughs **510** about the first central axis **512**. Similarly, as shown in FIG. **17**, the second transfer member **504** can include second lobes **514** and second troughs **516** that form a second profile through which the second transfer member **504** contacts some of the pins **500**. An average circumferential span of the second lobes **514** about a second central axis **518** defined by the second transfer member **504** can be smaller than an average circumferential span of the second troughs **516** about the second central axis **518**. In at least some cases, an average angle A**1** (FIG. **15**) relative to the first central axis **512** between circumferentially neighboring pairs of the pins **500** is no more than one third an average angle A**2** (FIG. **16**) between circumferentially neighboring pairs of the first lobes **508**. Similarly, A**1** may be no more than one third an average angle A**3** (FIG. **17**) between circumferentially neighboring pairs of the second lobes **514**. In these and other cases, a total quantity of the first lobes **508** can be at most one third a total quantity of the pins **500**. Furthermore, a total quantity of the second lobes **514** can be at most one third a total quantity of the pins **500**. More particularly, the total quantity of the first lobes **508** and the total quantity of the second lobes **514** can individually be equal to (P−1)/3, where P is the total quantity of pins **500**.

[0051] Operating the actuator corresponding to FIGS. **14-17** can include bypassing contact between the first transfer member **502** and some of the pins **500** via the first troughs **510** and bypassing contact between the second transfer member **504** and some of the pins **500** via the second troughs **516**. In the illustrated case, the number of first lobes **508** is equal to (P−1)/3, where P is the total quantity of pins **500** in the pin array **501**. Likewise, the number of second lobes **514** is equal to (P−1)/3, where P is the total quantity of pins **500** in the pin array **501**. In particular, the pin array **501** includes 31 of the pins **500**, the first transfer member **502** includes ten of the first lobes **508**, and the second transfer member **504** includes ten of the second lobes **514**. In other cases, the counterparts of the pin array **501**, the first transfer member **502**, and the second transfer member **504** can include other suitable quantities of constituent elements circumferentially distributed evenly about the respective axes in the same or other suitable ratios. With reference again the illustrated embodiment, it is expected that the illustrated relationships between the quantity of the first lobes **508** and the quantity of the pins **500** and between the quantity of the second lobes **514** and the quantity of the pins **500** will result in the desired alternating contact between the first and second transfer members **502**, **504** and the pins **500** without causing excessive antagonistic forces. For example, it is expected that instances of any of the pins **500** contacting both the first and second transfer members **502**, **504** simultaneously will be eliminated relative to counterparts in which the lobe-to-pin ratio is lower (e.g., about 2:1 rather than about 3:1). Counterpart embodiments in which the lobe-to-pin ratio is higher may operate with desired alternating contact, but with potentially disadvantageous reduction in load sharing. Still other embodiments can include a combination of pin nonuniformity and lobe omission.

[0052] In addition to or instead of having less than a full set of lobes, actuators in accordance with at least some embodiments of the present technology can have less than a full set of circumferential contact areas (e.g., pin and roller bearing assemblies) through which the lobes transfer torque. As an example, FIG. **18** illustrates selected components of a gear assembly of an actuator in accordance with another embodiment of the present technology. Within the gear assembly, the actuator can include an array **550** the same as or similar to an assembly of the pin array **138** and the first and second roller bearing arrays **144**, **146** of the gear assembly **112** described above. Also within the gear assembly, the actuator can include a first transfer member **552** and a second transfer member **554** operably associated with the array **550**. The first and second transfer members **552**, **554** can be similar to the first and second transfer members **130**, **132**, respectively, of the gear assembly **112** described above, but with a different circumferential edge profile such that the array **550** provides less than a full set of circumferential contact areas through which lobes of the first and second transfer members **552**, **554** transfer torque during operation of the actuator.

[0053] FIGS. **19** and **20** are side profile views of the first and second transfer members **552**, **554**, respectively. FIG. **21** is an enlargement of a portion of FIG. **20**. With reference to FIGS. **18-21** together, the first transfer member **552** can include first lobes **556** and first troughs **558** that form a first profile through which the first transfer member **552** contacts some pins of the array **550**. Similarly, the second transfer member **554** can include second lobes **560** and second troughs **562** that form a second profile through which the second transfer member **554** contacts other pins of the array **550**. As shown in FIGS. **19-21**, the first lobes **556**, first troughs **558**, second lobes **560**, and second troughs **562** can be relatively small. By way of comparison, although the pin array **138** (FIG. **3**) and the array **550** (FIG. **18**), as illustrated, each include 30 pins, the first transfer member **552**, as illustrated, includes 59 of the first lobes **556** whereas the first transfer member **130**, as illustrated, includes 29 of the first lobes **450**. Similarly, the second transfer member **554**, as illustrated, includes 59 of the second lobes **560** whereas the second transfer member **132**, as illustrated, includes 29 of the second lobes **454**. In these and other cases, the number of lobes of each transfer member can be one less than the number of pins times an integer. In the case of the actuator **100**, the integer is one, representing a full set of circumferential contact elements for a given number of lobes. In the case of the actuator corresponding to FIGS. **18-21**, the integer is two. In other embodiments, the integer can be three, four, or even higher. The integer being greater than one can correspond to the presence of less than a full set of circumferential contact elements for a given number of lobes.

[0054] Partial contact in actuators in accordance with at least some embodiments of the present technology can include alternating contact and/or partial-complement contact. In alternating contact, individual circumferential contact elements (e.g., pins) transfer force via interaction with one transfer member rather than via interaction with two transfer members. In partial-complement contact, the number of circumferential contact elements is less than a full set for a given number of lobes and/or the number of lobes is less than a full set for a given number of circumferential contact elements. The actuator **100** (FIG. **1-13**) exhibits alternating contact due to the configuration of the pin array **138**. The actuator corresponding to FIGS. **14-17** exhibits both alternating contact and partial-complement contact due to the omitted lobes of the first and second transfer members **502**, **504**. Finally, the actuator corresponding to FIGS. **18-21** exhibits both alternating contact and partial-complement contact due to configuration of the array **550** and due to the edge profiles of the first and second transfer members **552**, **554**. Other types of partial contact as also possible

[0055] With reference again to FIGS. **18-21**, the relatively small sizes of the first lobes **556**, first troughs **558**, second lobes **560**, and second troughs **562** can be associated with direct contact of the first and second transfer members **552**, **554** with pins of the array **550**. The transverse diameters of the pins can be much smaller than the transverse diameters of the roller bearings of the array **550**. Correspondingly, unlike the roller bearings, the pins can interact with the first and second transfer members **552**, **554** directly without simultaneously contacting neighboring lobes even when the lobes and intervening troughs are relatively small. Given this size flexibility, more lobes and troughs can be included on the first and second transfer members **552**, **554** without increasing the overall sizes of the first and second transfer members **552**, **554**. This can allow the corresponding actuator to have a higher reduction-ratio-to-size than would otherwise be possible. In at least some cases, the actuator has an input-to-output reduction ratio greater than 50:1, such as within a range from 50:1 to 70:1. Of course, high reduction ratios are not always desirable. When high reduction ratios are desirable, however, partial contact in accordance with at least some embodiments of the present technology can facilitate achieving such ratios in a more compact, lightweight, and/or robust form than was previously possible.

[0056] As discussed above, partial contact can involve partial-complement contact in addition to or instead of alternating contact. In at least some examples of partial-complement contact without alternating contact, individual pins may still interact with two transfer members yet be present in a quantity smaller than a quantity corresponding to the number of lobes. As an example, FIGS. **22** and **23** are, respectively, a perspective view and a side profile view of an assembly **570** including transfer members **572** (one labeled), pins **574** (one labeled), and roller bearings **576** (one labeled) of a gear assembly of an actuator in accordance with another embodiment of the present technology. The array **570** includes 14 of the pins **574**. The transfer members **572** individually include 27 lobes. To avoid antagonistic forces, the transfer members **572** can interact with the pins **574** via the roller bearings **576** rather than directly. Relatedly, the positions of the roller bearings **576** can be incompatible with support from counterparts of the first and second supports **140**, **142** (FIG. **3**). Without this support, a drawn-cup configuration of the roller bearings **576** may be unsuitable.

[0057] Rather than having a drawn-cup configuration, the roller bearings **576** can have a machined-ring configuration or another suitable configuration. FIG. **24** is a front profile view of one of the roller bearings **576**. FIG. **25** is a cross-sectional perspective view of the roller bearing **576** taken along the line **25-25** in FIG. **24**. As shown in FIGS. **24** and **25**, the roller bearing **576** can define a cylindrical cavity **578** having a diameter corresponding to a diameter of one of the pins **574**. The roller bearing **576** can include rollers **580** (one labeled) aligned with and circumferentially distributed around the cylindrical cavity **578**. The roller bearing **350** can further include an outer ring **582** carrying the rollers **580**. The roller bearing **576** can further include a spacer **584** defining slots **586** (one labeled) in which the rollers **580** are respectively disposed. The outer ring **582** can be more robust than the cylindrical casing **358** of the roller bearing **350** (FIGS. **8-9**). In at least some cases, the outer ring **582** is configured to resist hertzian contact stress and operating loads. In these and other cases, the outer ring **582** can be a tube segment having a generally consistent wall thickness.

Examples of Robot Systems

[0058] FIG. **26** is a perspective view of a mobile robot **600** including an actuator in accordance with at least some embodiments of the present technology. As shown in FIG. **26**, the mobile robot **600** can include structures resembling human anatomy with respect to the features, positions, and/or other characteristics of such structures. In at least some cases, the mobile robot **600** defines a midsagittal plane about which the mobile robot **600** is bilaterally symmetrical. In these and other cases, the mobile robot **600** can be configured for bipedal locomotion similar to that of a human. Counterparts of the mobile robot **600** can have other suitable forms and features. For example, a counterpart of the mobile robot **600** can have a non-humanoid form, such as a canine form, an insectoid form, an arachnoid form, or a form with no animal analog. Furthermore a counterpart of the mobile robot **600** can be asymmetrical or have symmetry other than bilateral. Still further, a counterpart of the mobile robot **600** can be configured for non-bipedal locomotion. For example, a counterpart of the mobile robot **600** can be configured for another type of legged locomotion (e.g., quadrupedal locomotion, octopedal locomotion, etc.) and/or non-legged locomotion (e.g., wheeled locomotion, continuous-track locomotion, etc.).

[0059] The mobile robot **600** can include a centrally disposed body **602** through which other structures of the mobile robot **600** are interconnected. As all or a portion of the body **602**, the mobile robot **600** can include a torso **604** having a superior portion **606**, an inferior portion **608**, and an intermediate portion **610** therebetween. The mobile robot **600** can further include articulated appendages carried by the torso **604**. Among these articulated appendages, the mobile robot **600** can include arms **612***a*, **612***b* and legs **614***a*, **614***b*. In at least some cases, the mobile robot **600** is configured to manipulate objects via the arms **612***a*, **612***b*, such as bimanually. In these and other cases, the mobile robot **600** can be configured to ambulate via the legs **614***a*, **614***b*, such as bipedally. The arms **612***a*, **612***b* and the legs **614***a*, **614***b* can define kinematic chains. The kinematic chains corresponding to the arms **612***a*, **612***b*, for example, can provide at least five degrees of freedom, such as exactly five or exactly six degrees of freedom. In these and other cases, the kinematic chains corresponding to the legs **614***a*, **614***b* can provide at least four degrees of freedom, such as exactly four, exactly five, or exactly six degrees of freedom. As parts of the arms **612***a*, **612***b*, the mobile robot **600** can include end effectors **616***a*, **616***b* at distalmost portions of the corresponding kinematic chains. Similarly, as parts of the legs **614***a*, **614***b*, the mobile robot **600** can include feet **618***a*, **618***b* at distalmost portions of the corresponding kinematic chains. In the illustrated embodiment, the end effectors **616***a*, **616***b* and the feet **618***a*, **618***b* are not articulated. In other embodiments, counterparts of some or all of the end effectors **616***a*, **616***b* and the feet **618***a*, **618***b* can be articulated, such as with one or more movable fingers or toes.

[0060] At the individual articulations of the arms **612***a*, **612***b* and legs **614***a*, **614***b*, the mobile robot **600** can include a joint and a corresponding actuator. At least one of these actuators can correspond to the actuator **100**, the actuator corresponding to FIGS. **14-17**, the actuator corresponding to FIGS. **18-21**, the actuator corresponding to FIGS. **22-25**, or another actuator in accordance with at least some embodiments of the present technology. For example, the mobile robot **600** can include actuators with cycloid-type gearing and partial contact (e.g., alternating contact and/or partial-complement contact) in accordance with at least some embodiments of the present technology at joints of the arms **612***a*, **612***b*, at joints of the legs **614***a*, **614***b*, and/or elsewhere. In an example, the mobile robot **600** can include elbow joints **620***a*, **620***b* at or near midpoints along lengths of the respective arms **612***a*, **612***b*. The mobile robot **600** can include actuators in accordance with at least some embodiments of the present technology at the respective elbow joints **620***a*, **620***b*. As another example, the mobile robot **600** can include foot actuators **622***a*-**622***d* and connector rods **624***a*-**624***d* operably associated with the feet **618***a*, **618***b*. In particular, the foot actuators **622***a*, **622***b* can be connected to the foot **618***a* via the connector rods **624***a*, **624***b*, respectively. Similarly, the foot actuators **622***c*, **622***d* can be connected to the foot **618***b* via the connector rods **624***c*, **624***d*, respectively. The mobile robot **600** can include actuators in accordance with at least some embodiments of the present technology as one, some, or all of the foot actuators **622***a*-**622***d*. Actuators in accordance with at least some embodiments of the present technology can be useful in many other locations in addition or alternatively. Furthermore, the mobile robot **600** is merely one example of a system in which features of at least some embodiments of the present technology can be implemented.

Examples of Methods

[0061] FIG. **27** is a block diagram corresponding to a method **700** in accordance with at least some embodiments of the present technology. Although the method **700** will be described primarily in the context of the actuator **100**, it should be understood that suitable features of the method **700** can likewise be practiced in the contexts of the actuator corresponding to FIGS. **14-17**, the actuator corresponding to FIGS. **18-21**, the actuator corresponding to FIGS. **22-25**, or another actuator in accordance with at least some embodiment of the present technology. With reference to FIGS. **1-27** together, the method **700** can include causing the first and second transfer members **130**, **132** to move out-of-phase (e.g., 180-degrees out-of-phase) with one another about the assembly axis **110** (block **702***a*). This can include rotating the first and second eccentric bearings **126**, **128** within the first and second central openings **134**, **136**, respectively. The method **700** can further include transferring force between a portion (e.g., a peripheral portion) of the first transfer member **130** and the first pins **250** (block **702***b*) (e.g., via a camming interaction therebetween) while the first and second transfer members **130**, **132** move out-of-phase with one another about the assembly axis **110**. This can include contacting the first pins **250** and the first continuous cycloidal profile defined by the first transfer member **130**. Furthermore, this can include transferring force between the first lobes **450** and the first pins **250**, such as by camming the first lobes **450** against the first pins **250**. The contact between the first transfer member **130** and the first pins **250** can be at the first intermediate portion **258** of the first pins **250**.

[0062] In at least some cases, the force transfer between the first transfer member **130** and the first pins **250** is preferential relative to force transfer (if any) between the first transfer member **130** and the second pins **300** throughout a complete rotational cycle of the gear assembly **112**. The individual first pins **250** can avoid or otherwise reduce contact and/or force transfer with the second transfer member **132** while contacting and transferring force with the first transfer member **130**. The lack of contact or otherwise non-preferential contact with the second transfer member **132** can be via the annular recesses **262** at the second intermediate portions **260** of the first pins **250**. Relatedly, the method **700** can include maintaining clearance between the first pins **250** and the second transfer member **132** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. In the context of the pins **500** and the first and second transfer members **502**, **504** (FIGS. **14-17**), the pins **500** can include counterparts of the first pins **250** that avoid or otherwise reduce contact and/or force transfer with the second transfer member **504** while contacting and transferring force with the first transfer member **502**. The lack of contact or otherwise non-preferential contact with the second transfer member **504** can be via the second troughs **516**. Relatedly, the method **700** can include maintaining clearance between the counterparts of the first pins **250** and the second transfer member **504** while the first and second transfer members **502**, **504** move out-of-phase with one another relative to the assembly axis **110**.

[0063] The method **700** can also include transferring force between a portion (e.g., a peripheral portion) of the second transfer member **132** and the second pins **300** (block **702***c*) (e.g., via a camming interaction therebetween) while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. This can include contacting the second pins **300** and the second continuous cycloidal profile defined by the second transfer member **132**. Furthermore, this can include transferring force between the second lobes **454** and the second pins **300**, such as by camming the second lobes **454** against the second pins **300**. The contact between the second transfer member **132** and the second pins **300** can be at the second intermediate portions **260′** of the second pins **300**.

[0064] In at least some cases, the force transfer between the second transfer member **132** and the second pins **300** is preferential relative to force transfer (if any) between the second transfer member **132** and the first pins **250** throughout a complete rotational cycle of the gear assembly **112**. The individual second pins **300** can avoid or otherwise reduce contact and/or force transfer with the first transfer member **130** while contacting and transferring force with the second transfer member **132**. The lack of contact or otherwise non-preferential contact with the first transfer member **130** can be via the annular recesses **262′** at the first intermediate portions **258′** of the second pins **300**. Relatedly, the method **700** can include maintaining clearance between the second pins **300** and the first transfer member **130** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. In the context of the pins **500** and the first and second transfer members **502**, **504** (FIGS. **14-17**), the pins **500** can include counterparts of the second pins **300** that avoid or otherwise reduce contact and/or force transfer with the first transfer member **502** while contacting and transferring force with the second transfer member **504**. The lack of contact or otherwise non-preferential contact with the first transfer member **502** can be via the first troughs **510**. Relatedly, the method **700** can include maintaining clearance between the counterparts of the second pins **300** and the first transfer member **502** while the first and second transfer members **502**, **504** move out-of-phase with one another relative to the assembly axis **110**.

[0065] In connection with the force transfer between the first transfer member **130** and the first pins **250** and the force transfer between the second transfer member **132** and the second pins **300**, the method **700** can include causing rotation of the individual first and second pins **250**, **300** relative to the first and second supports **140**, **142** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. In these and/or other cases, the method **700** can include rotatably carrying the first end portions **254**, **254′** of the individual first and second pins **250**, **300** at respective ones of the roller bearings **350** at the first support **140** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. The method **700** can further include carrying the roller bearings **350** of the first roller bearing array **144** at the sockets **210** of the first support **140** and/or at the through holes **208** of the plate **200** of the first support **140** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. Likewise, the method **700** can include rotatably carrying the second end portions **256**, **256′** of the individual first and second pins **250**, **300** at respective ones of the roller bearings **350** at the second support **142** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. The method **700** can further include carrying the roller bearings **350** of the second roller bearing array **146** at the sockets **210′** of the second support **142** and/or at the through holes **208′** of the plate **200′** of the second support **142** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**. The method **700** can further include directly contacting the first and second pins **250**, **300** and the cylindrical outer surfaces **368** of the rollers **354** while the first and second transfer members **130**, **132** move out-of-phase with one another relative to the assembly axis **110**.

[0066] Finally, the method **700** can include rotating an output member (block **702***d*), such as the crank **114**. This too can occur while causing the first and second transfer members **130**, **132** to move out-of-phase with one another relative to the assembly axis **110**. In some cases, rotating the output member is relative to a mount. For example, the link **104** (FIG. **2**) can be a mount relative to which actuator **100** rotates the crank **114**. In these and other cases, rotating the output member can be in response to force exerted by the first and second transfer members **130**, **132** against the base **150** via the rods **152**. Alternatively or in addition, the method **700** can include operating the actuator **100** in the opposite direction. For example, the method **700** can include rotating the first and second supports **140**, **142** relative to a mount in response to force exerted by the first and second transfer members **130**, **132** against the first and second supports **140**, **142** via the first and second pins **250**, **300**. Regardless of the direction, operating the actuator **100** can cause an input-to-output reduction ratio. In at least some cases, the method **700** includes causing an input-to-output reduction ratio within a range from 20:1 to 40:1, such as from 25:1 to 35:1, via the gear assembly **112** or another gear assembly in accordance with at least some embodiments of the present technology. Similarly, the method **700** can include causing an input-to-output reduction ratio greater than 50:1, such as within a range from 50:1 to 70:1, via the gear assembly corresponding to FIGS. **18-21** or another gear assembly in accordance with at least some embodiments of the present technology.

Conclusion

[0067] This disclosure is not intended to be exhaustive or to limit the present technology to the precise forms disclosed herein. Although specific embodiments are disclosed herein for illustrative purposes, various equivalent modifications are possible without deviating from the present technology, as those of ordinary skill in the relevant art will recognize. In some cases, well-known structures and functions have not been shown or described in detail to avoid unnecessarily obscuring the description of the embodiments of the present technology. Although steps of methods may be presented herein in a particular order, in alternative embodiments the steps may have another suitable order. Similarly, certain aspects of the present technology disclosed in the context of particular embodiments can be combined or eliminated in other embodiments. Furthermore, while advantages associated with certain embodiments may be disclosed herein in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages or other advantages disclosed herein to fall within the scope of the present technology. This disclosure and the associated technology can encompass other embodiments not expressly shown or described herein.

[0068] Throughout this disclosure, the singular terms “a,” “an,” and “the” include plural referents unless the context clearly indicates otherwise. Similarly, unless the word “or” is expressly limited to mean only a single item exclusive from the other items in reference to a list of two or more items, then the use of “or” in such a list is to be interpreted as including (a) any single item in the list, (b) all of the items in the list, or (c) any combination of the items in the list. As used herein, the terms “generally,” “substantially,” “about,” and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent variations in measured or calculated values that would be recognized by those of ordinary skill in the art. Additionally, the terms “comprising,” “including,” “having,” and the like are used throughout this disclosure to mean including at least the recited feature(s) such that any greater number of the same feature(s) and/or one or more additional types of features are not precluded. This is the case even if a particular number of features is specified unless that specified number is preceded by the word “exactly” or another clear indication that it is intended to be closed ended. In a particular example, “comprising two arms” means including at least two arms. References herein to any of receiving, determining, or generating information in accordance with various embodiments of the present technology encompass, when feasible, the others of receiving, determining, and generating the information and indicate that such operations can occur at least partially via the relevant computing subsystem.

[0069] Directional terms, such as “upper,” “lower,” “front,” “back,” “vertical,” and “horizontal,” may be used herein to express and clarify the relationship between various structures. It should be understood that such terms do not denote absolute orientation. Reference herein to “one embodiment,” “an embodiment,” or similar phrases means that a particular feature, structure, or operation described in connection with such phrases can be included in at least one embodiment of the present technology. Thus, such phrases as used herein are not all referring to the same embodiment. Unless preceded with the word “conventional,” reference herein to “counterpart” devices, systems, methods, features, structures, or operations refers to devices, systems, methods, features, structures, or operations in accordance with at least some embodiments of the present technology that are similar to a described device, system, method, feature, structure, or operation in certain respects and different in other respects. Finally, it should be noted that various particular features, structures, and operations of the embodiments described herein may be combined in any suitable manner in additional embodiments in accordance with the present technology.

Claims

1. A gear assembly comprising: a first support extending circumferentially around an assembly axis in a first plane intersecting the assembly axis; a second support extending circumferentially around the assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced apart from one another along the assembly axis; a first transfer member including first lobes and first troughs circumferentially alternating in a third plane intersecting the assembly axis, wherein the third plane is between the first and second planes along the assembly axis; a second transfer member including second lobes and second troughs circumferentially alternating in a fourth plane intersecting the assembly axis, wherein the fourth plane is between the first and third planes along the assembly axis; and pins individually extending between the first and second supports along respective pin axes, wherein the individual pins are configured to rotate relative to the first and second supports about the respective pin axes in response to force from at least one of the first and second transfer members during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis, wherein a total quantity of the first lobes is at least two times a total quantity of the pins minus one, and wherein a total quantity of the second lobes is at least two times the total quantity of the pins minus one.
2. The gear assembly of claim 1, wherein: the total quantity of the first lobes is three times the total quantity of the pins minus one; and the total quantity of the second lobes is three times the total quantity of the pins minus one.
3. The gear assembly of claim 1, wherein the individual pins directly contact one of the first and second transfer members and remain out of contact with the other of the first and second transfer members during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis.
4. A gear assembly comprising: a first support extending circumferentially around an assembly axis in a first plane intersecting the assembly axis; a second support extending circumferentially around the assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced apart from one another along the assembly axis; a first transfer member including first lobes and first troughs circumferentially alternating in a third plane intersecting the assembly axis, wherein the third plane is between the first and second planes along the assembly axis; a second transfer member including second lobes and second troughs circumferentially alternating in a fourth plane intersecting the assembly axis, wherein the fourth plane is between the first and third planes along the assembly axis; pins individually extending between the first and second supports along respective pin axes; first roller bearings circumferentially distributed around the assembly axis at the third plane; and second roller bearings circumferentially distributed around the assembly axis at the fourth plane, wherein: the pins indirectly contact the first transfer member via the first

roller bearings, and the pins indirectly contact the second transfer member via the second roller bearings, a total quantity of the first lobes is at least two times a total quantity of the pins minus one, and a total quantity of the second lobes is at least two times the total quantity of the pins minus one.

5. The gear assembly of claim 1, wherein: the first and second pins are at respective positions circumferentially alternating about the assembly axis; and the gear assembly is configured to transfer torque at least primarily via contact between the first pins and the first lobes and via contact between the second pins and the second lobes as the first and second transfer members move out-of-phase with one another relative to the assembly axis.

6. The gear assembly of claim 1, wherein: the gear assembly further comprises: first roller bearings at the first support, and second roller bearings at the second support; and the pins individually extend between different respective pairs of one of the first roller bearings and one of the second roller bearings.

7. The gear assembly of claim 6, wherein: the first support includes first sockets circumferentially distributed around the assembly axis; the first roller bearings are at least partially disposed within the first sockets; the second support includes second sockets circumferentially distributed around the assembly axis; and the second roller bearings are at least partially disposed within the second sockets.

8. The gear assembly of claim 7, wherein: the first support includes a first plate defining first through holes; the first sockets are at the first through holes; the second support includes a second plate defining second through holes; and the second sockets are at the second through holes.

9. The gear assembly of claim 6, wherein the first and second roller bearings are drawn-cup needle roller bearings.

10. The gear assembly of claim 1, wherein: the pins include: first pins that remain out of contact with the second transfer member during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis, and second pins that remain out of contact with the first transfer member during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis; and the individual first and second pins are elongate and have a non-uniform transverse cross-sectional area along the corresponding pin axis.

11. The gear assembly of claim **12**, wherein: a transverse cross-sectional area of the individual first pins is smaller at the fourth plane than at the third plane; and a transverse cross-sectional area of the individual second pins is smaller at the third plane than at the fourth plane.

12. A gear assembly comprising: a first support extending circumferentially around an assembly axis in a first plane intersecting the assembly axis; a second support extending circumferentially around the assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced apart from one another along the assembly axis; a first transfer member including first lobes and first troughs circumferentially alternating in a third plane intersecting the assembly axis, wherein the third plane is between the first and second planes along the assembly axis; a second transfer member including second lobes and second troughs circumferentially alternating in a fourth plane intersecting the assembly axis, wherein the fourth plane is between the first and third planes along the assembly axis; and pins individually extending between the first and second supports along respective pin axes, wherein the individual pins are configured to rotate relative to the first and second supports about the respective pin axes in response to force from at least one of the first and second transfer members during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis, wherein: the pins include: first pins that remain out of contact with the second transfer member during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis, and second pins that remain out of contact with the first transfer member during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis; and the individual first and second pins are elongate and have a non-uniform transverse cross-sectional area along the corresponding pin axis, a total quantity of the first lobes is at least two times a total quantity of the pins minus one, a total quantity of the second lobes is at least two times the total quantity of the pins minus one, the individual first and second pins include: a first end portion at the first support, a second end portion at the second support, a first intermediate portion between the first and second end portions, and a second intermediate portion between the first intermediate portion and the second end portion, the individual first pins are configured to contact the first transfer member via the first intermediate portion, and the individual second pins are configured to contact the second transfer member via the second intermediate portion.

13. The gear assembly of claim 12, wherein: the individual first pins include a first annular recess at the second intermediate portion; and the individual second pins include a second annular recess at the first intermediate portion.

14. The gear assembly of claim 12, wherein: the first lobes and first troughs form a first continuous cycloidal profile through which the first transfer member contacts the first pins; and the second lobes and second troughs form a second continuous cycloidal profile through which the second transfer member contacts the second pins.

15. The gear assembly of claim 12, wherein a distribution of the first and second pins around the assembly axis is radially symmetrical.

16. The gear assembly of claim 1, wherein: the gear assembly further comprises a carrier including a base and rods individually extending from the base; the first transfer member defines first peripheral openings distributed circumferentially around the assembly axis; the second transfer member defines second peripheral openings distributed circumferentially around the assembly axis; and the individual rods extend through different respective pairs of one of the first peripheral openings and one of the second peripheral openings.

17. The gear assembly of claim 16, wherein: the gear assembly further comprises: a mount fixedly connected to the first and second supports, and an output member fixedly connected to the base; and the gear assembly is configured to rotate the output member relative to the mount in response to force exerted by the first and second transfer members against the base via the rods.

18. The gear assembly of claim 16, wherein: the gear assembly further comprises a mount fixedly connected to the base; and the gear assembly is configured to rotate the first and second supports relative to the mount in response to force exerted by the first and second transfer members against the first and second supports via the pins.

19. The gear assembly of claim 1, further comprising: an input shaft configured to rotate about the assembly axis; and a first eccentric bearing carried by the input shaft, wherein the first transfer member defines a first central opening at which the first eccentric bearing is rotatably disposed; and a second eccentric bearing carried by the input shaft, wherein the second transfer member defines a second central opening at which the second eccentric bearing is rotatably disposed.

20. The gear assembly of claim 1, wherein the gear assembly has an input-to-output reduction ratio within a range from 50:1 to 70:1.