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(54) ACTUATOR SYSTEM WITH A MULTI-MOTOR ASSEMBLY FOR EXTENDING AND FLEXING A JOINT

(76) Inventors: **Robert W. Horst**, San Jose, CA (US); **Kern Bhugra**, San Jose, CA (US); **Robert L. Jardine**, Cupertino, CA (US)

Correspondence Address:
SCHOX PLC
500 3rd Street, Suite 515
San Francisco, CA 94107 (US)

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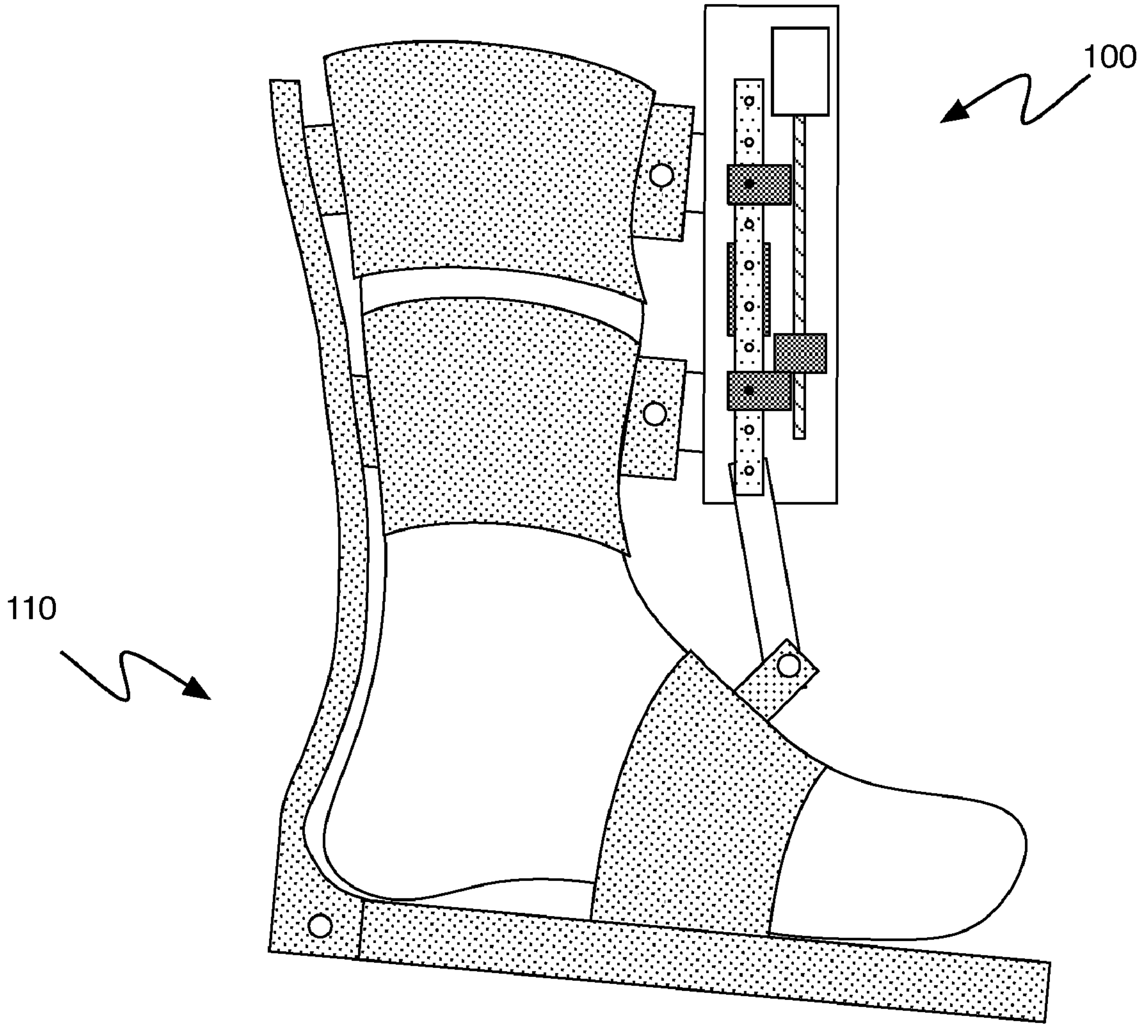
(57) ABSTRACT

An actuator system for extending and flexing a joint, including a multi-motor assembly for providing a rotational output, a rotary-to-linear mechanism for converting the rotational output from the multi-motor assembly into an extension and flexion of the joint, and a controller for operating the actuator system in several operational modes. The multi-motor assembly preferably combines power from two different sources, such that the multi-motor assembly can supply larger forces at slower speeds ("Low Gear") and smaller forces at higher speeds ("High Gear"). The actuator has been specifically designed for extending and flexing a joint (such as an ankle, a knee, an elbow, or a shoulder) of a human. The actuator system may, however, be used to move any suitable object through any suitable movement (linear, rotational, or otherwise).



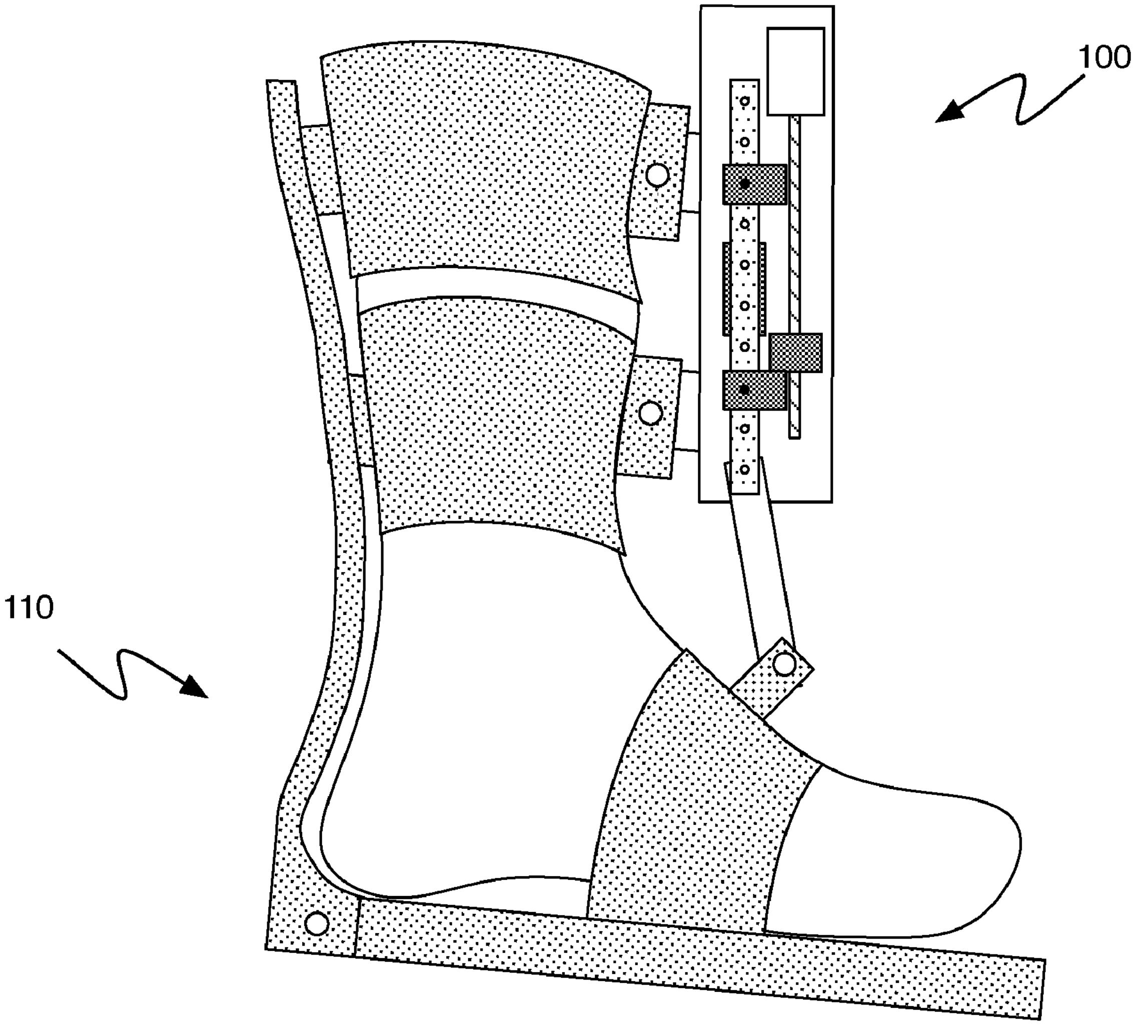


FIGURE 1

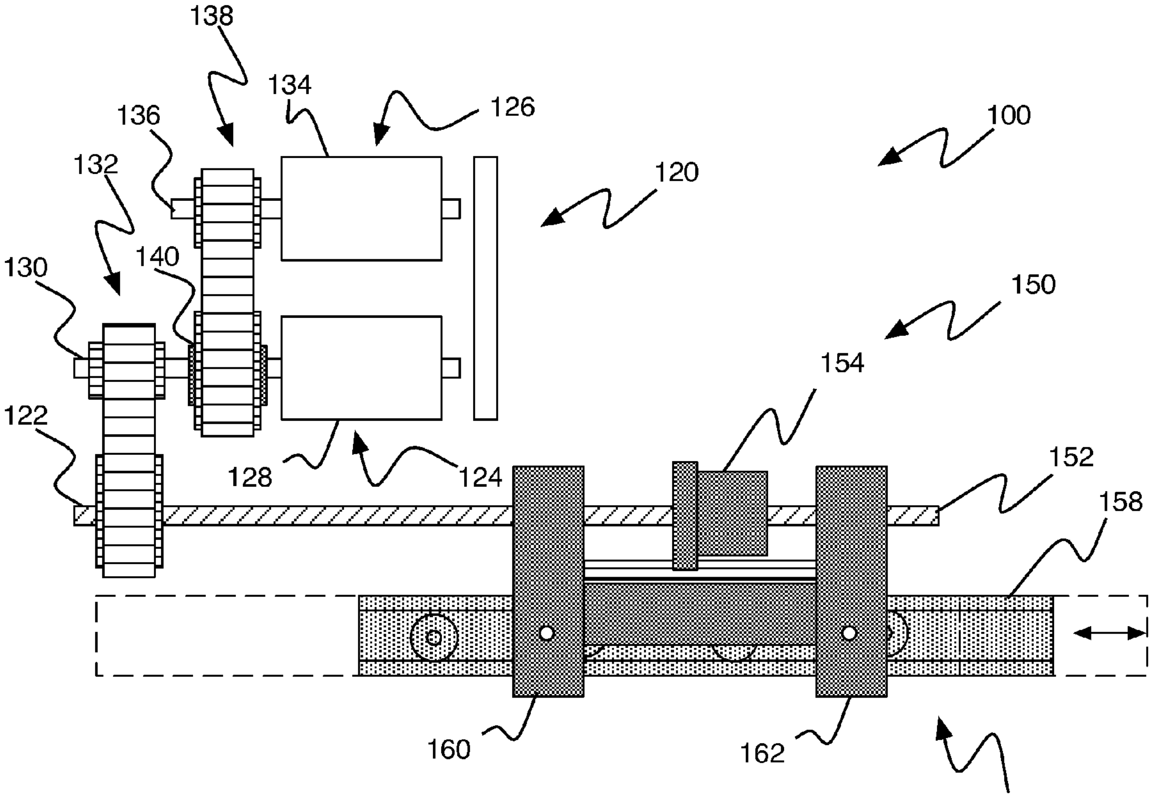

138
134
126
136
100
132
120
130
140
150
154
122
152
128
124
158
160
162
156

FIGURE 2

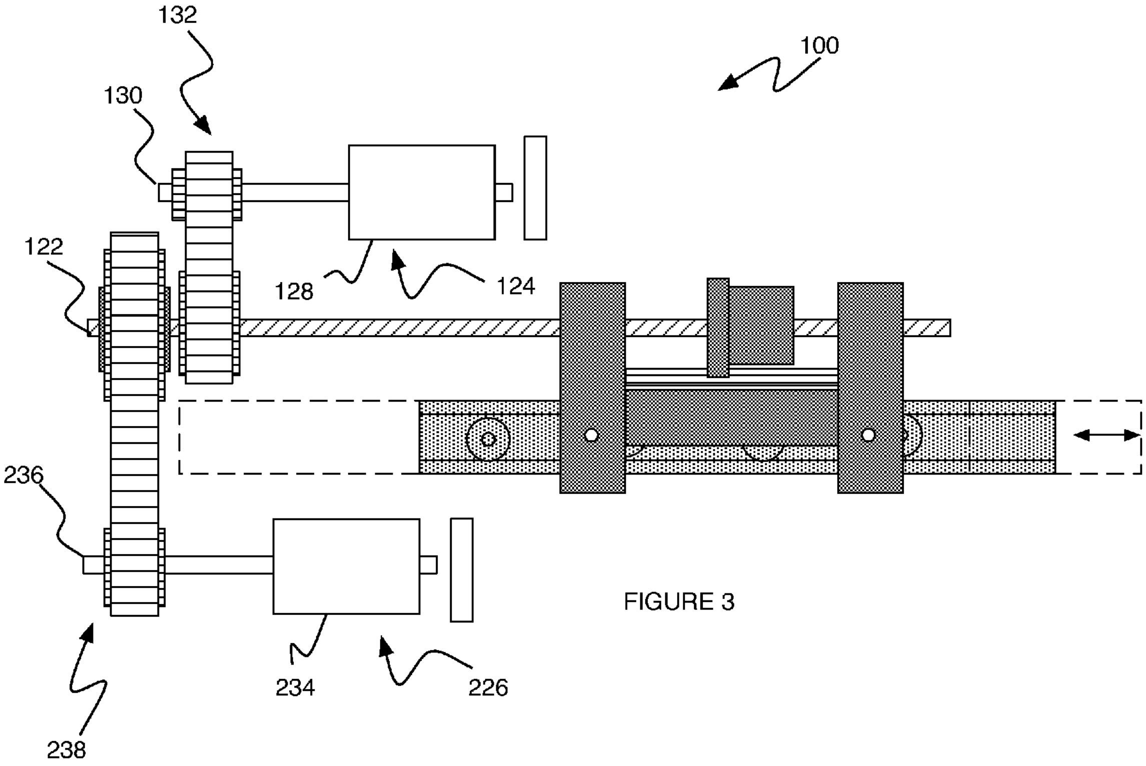


FIGURE 3

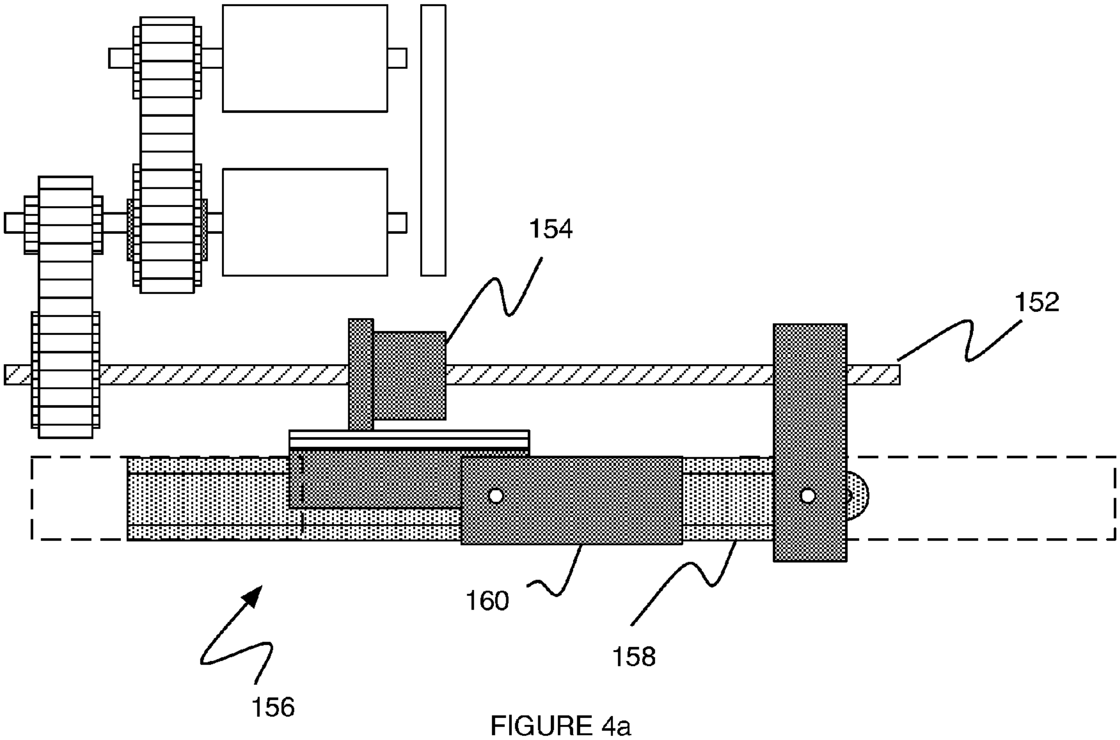


FIGURE 4a

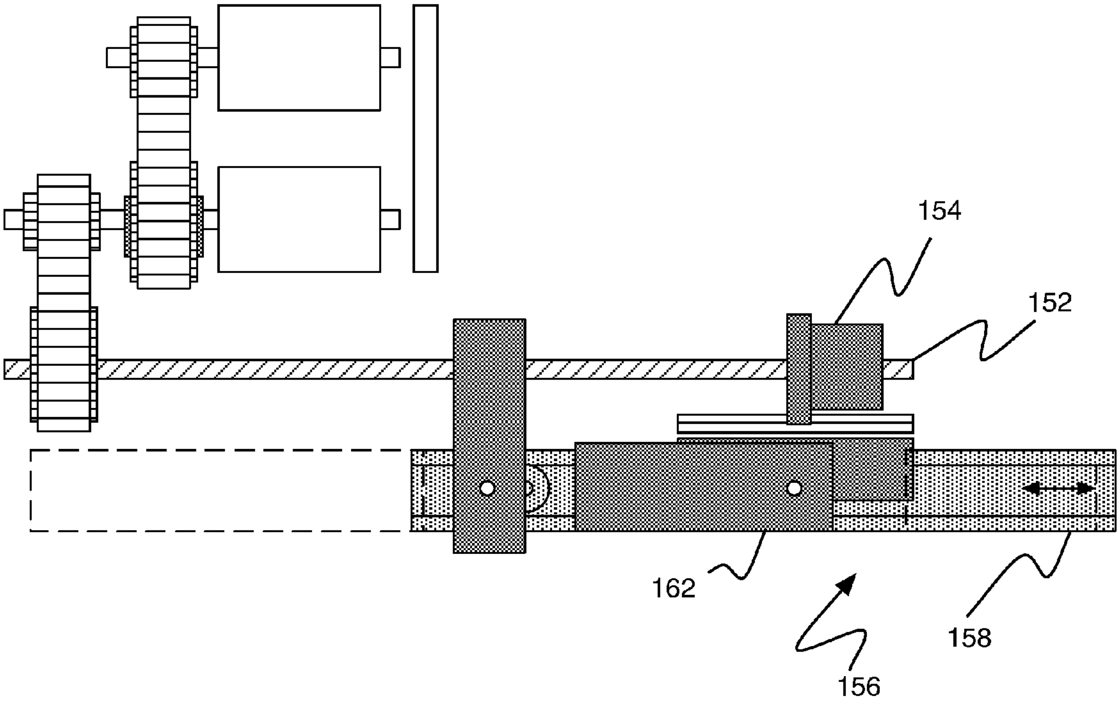


FIGURE 4b

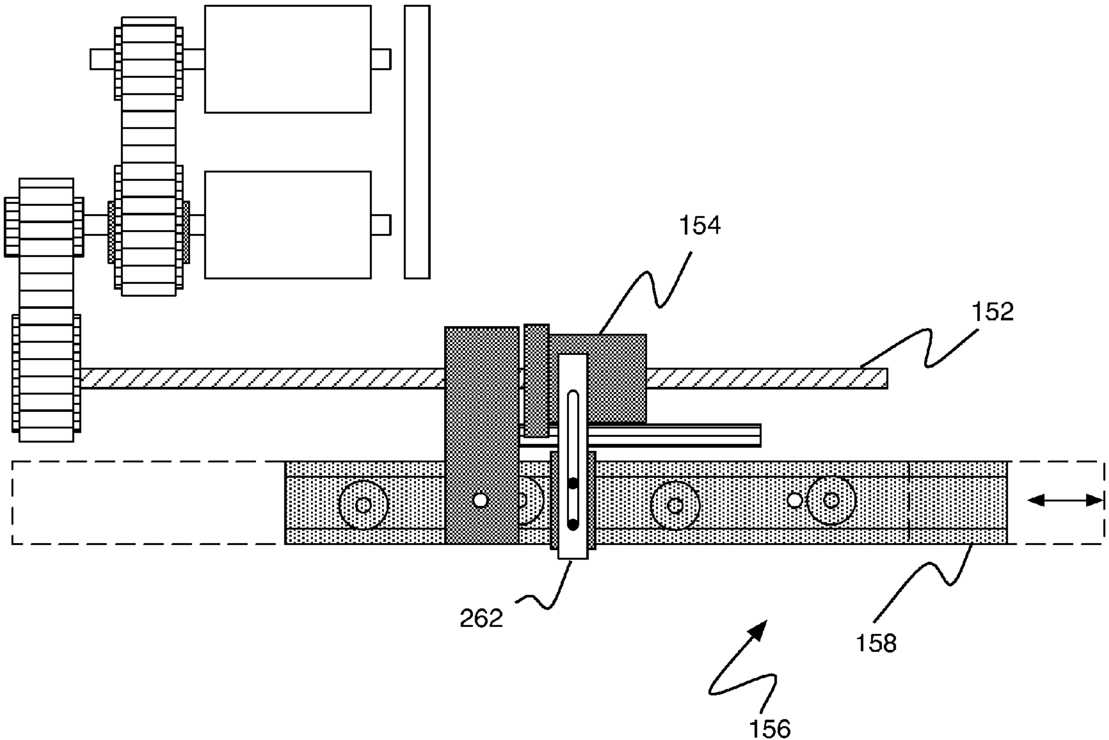


FIGURE 4c

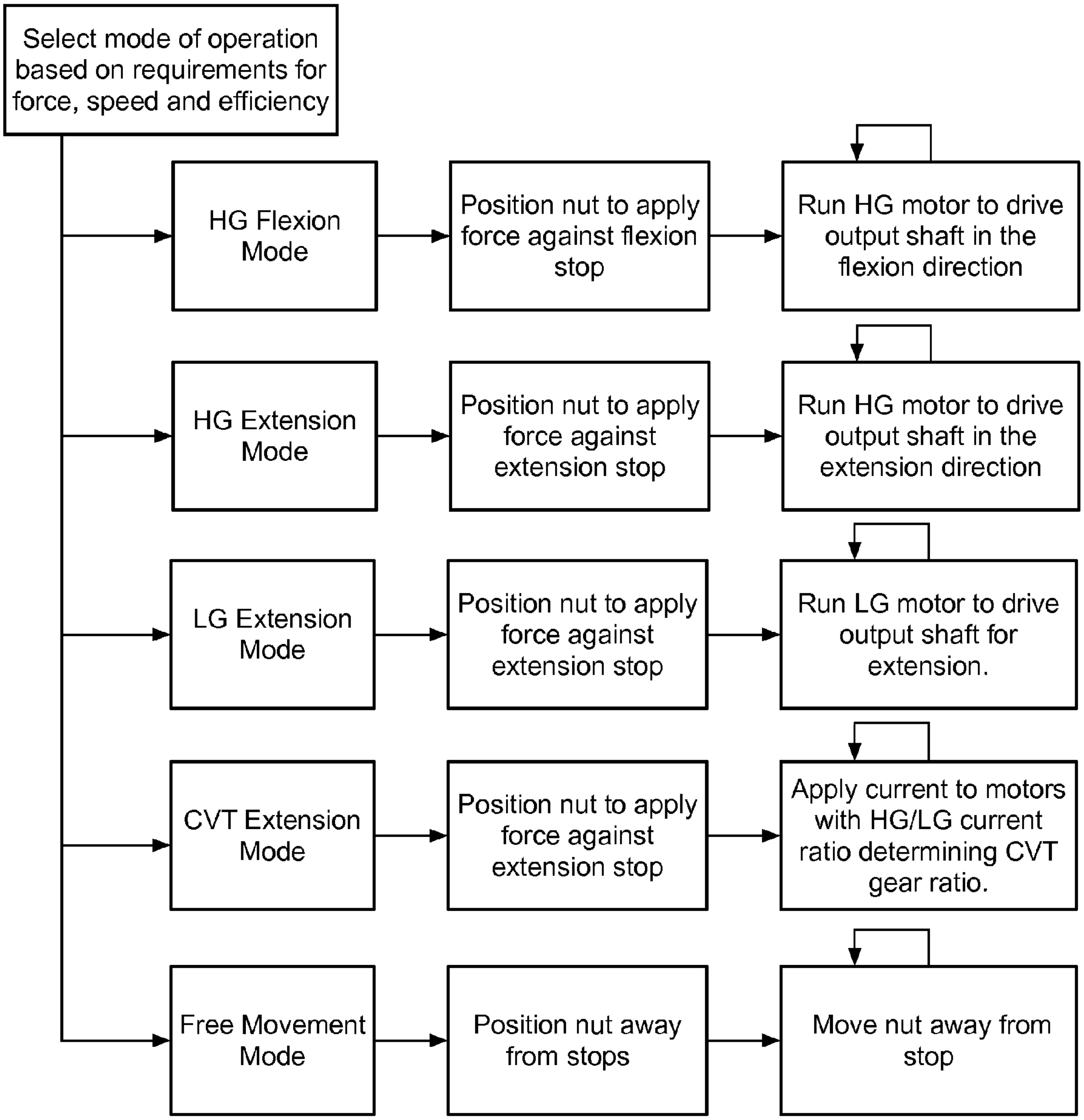

Select mode of operation based on requirements for force, speed and efficiency
HG Flexion Mode
Position nut to apply force against flexion stop
Run HG motor to drive output shaft in the flexion direction
HG Extension Mode
Position nut to apply force against extension stop
Run HG motor to drive output shaft in the extension direction
LG Extension Mode
Position nut to apply force against extension stop
Run LG motor to drive output shaft for extension.
CVT Extension Mode
Position nut to apply force against extension stop
Apply current to motors with HG/LG current ratio determining CVT gear ratio.
Free Movement Mode
Position nut away from stops
Move nut away from stop

FIGURE 5

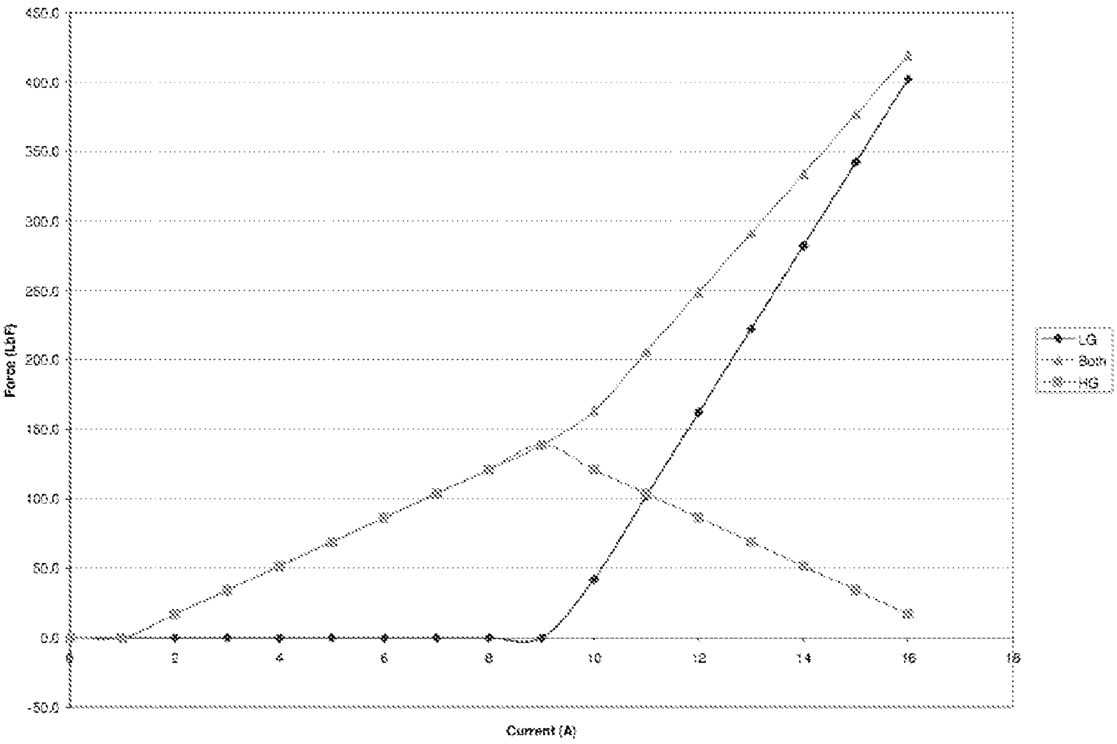

450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
Force (LbF)
0
2
4
6
8
10
12
14
16
18
Current (A)
LG
Both
HG

FIGURE 6

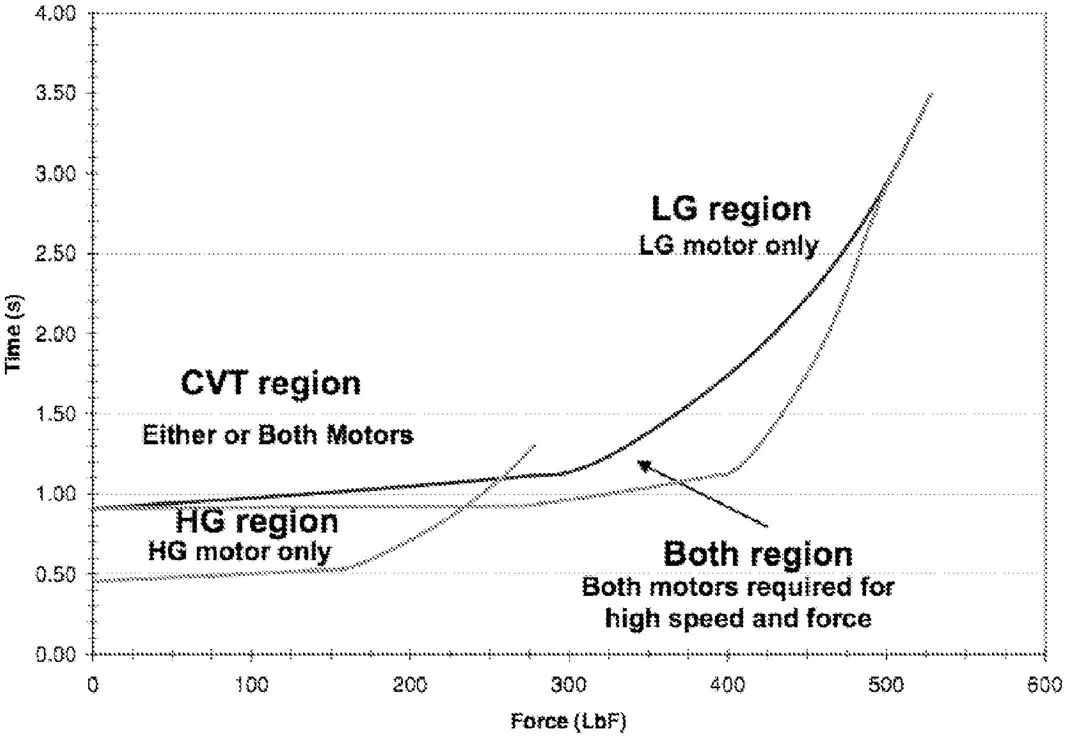

4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Time (s)
0
100
200
300
400
500
600
Force (LbF)
LG region
LG motor only
CVT region
Either or Both Motors
HG region
HG motor only
Both region
Both motors required for
high speed and force

FIGURE 7

ACTUATOR SYSTEM WITH A MULTI-MOTOR ASSEMBLY FOR EXTENDING AND FLEXING A JOINT

TECHNICAL FIELD

[0001] This invention relates generally to the actuator field, and more specifically to a new and useful actuator system with a multi-motor assembly in the actuator field.

BACKGROUND

[0002] Motors and actuators are used in a wide variety of applications. Many applications, including robotics and active orthotics, require characteristics similar to human muscles. The characteristics include the ability to deliver high force at a relatively low speed and to allow free-movement when power is removed, thereby allowing a limb to swing freely during portions of the movement cycle. This may call for an actuator that can supply larger forces at slower speeds and smaller forces at higher speeds, or a variable ratio transmission (VRT) between the primary driver input and the output of an actuator.

[0003] VRTs have been conventionally implemented as Continuously Variable Transmissions (CVTs). The underlying principle of most previous CVTs is to change the ratio of one or more gears by changing the diameter of the gear, changing the place where a belt rides on a conical pulley, or by coupling forces between rotating disks with the radius of the intersection point varying based on the desired ratio. Prior art CVTs have drawbacks in efficiency and mechanical complexity.

[0004] Motors have been used in a variety of applications, but typically a single motor is directly or indirectly coupled to provide motion for each output direction. Use of a single motor limits the speed/torque range or requires the extra cost and complexity of a transmission between the motor and output. Thus, there is a need in the actuator field to create a new and useful actuator system that can supply larger forces at slower speeds and smaller forces at higher speeds, but that minimizes or avoids the disadvantages of the conventional CVTs. This invention provides such a new and useful actuator system.

BRIEF DESCRIPTION OF THE FIGURES

[0005] FIG. **1** is a schematic of the actuator system of the preferred embodiment in an orthotic that extends and flexes a joint of a user.

[0006] FIG. **2** is a schematic of the actuator system of the preferred embodiment, with the first variation of the multi-motor assembly and with both the extension stop and the flexion stop of the rotary-to-linear mechanism in the force positions.

[0007] FIG. **3** is a schematic of the actuator system of the preferred embodiment, with the second variation of the multi-motor assembly.

[0008] FIGS. **4***a* and **4***b* are schematics of the actuator system of the preferred embodiment, with the extension stop in the pass position and the flexion stop in the pass position, respectively.

[0009] FIG. **5** is a flow diagram of the operation modes for the controller of the actuator system of the preferred embodiment.

[0010] FIG. **6** is an exemplary current ramping scheme for the controller of the actuator system of the preferred embodiment.

[0011] FIG. **7** is a chart of the speed/force profile of the first motor subsystem, the second motor subsystem, and the combination of the first and second motor subsystems.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] The following description of the preferred embodiments of the invention is not intended to limit the invention to these preferred embodiments, but rather to enable any person skilled in the art of actuator systems to make and use this invention.

[0013] As shown in FIGS. **1** and **2**, the actuator system **100** of the preferred embodiments for extending and flexing a joint **110** of a user includes a multi-motor assembly **120** for providing a rotational output, a rotary-to-linear mechanism **150** for converting the rotational output from the multi-motor assembly **120** into a linear motion that ultimately extends and flexes the joint, and a controller for operating the actuator system **100** in several operational modes. The multi-motor assembly **120** preferably combines power from two different sources, such that the multi-motor assembly **120** can supply larger forces at slower speeds ("Low Gear") and smaller forces at higher speeds ("High Gear"). The actuator has been specifically designed for extending and flexing a joint **110** (such as an ankle, a knee, an elbow, or a shoulder) of a human or robot. The actuator system **100** may, however, be used to move any suitable object through any suitable movement (linear, rotational, or otherwise).

1. Multi-Motor Assembly

[0014] As shown in FIG. **2**, the multi-motor assembly **120** of the preferred embodiments functions to provide rotational output to the rotary-to-linear mechanism **150**. The multi-motor assembly **120** includes a drive shaft **122**, a first motor subsystem **124**, and a second motor subsystem **126**. The drive shaft **122** functions to deliver the rotational output from the multi-motor assembly **120**. The first motor subsystem **124** functions to provide a component of the rotational output of the multi-motor assembly **120**. The first motor subsystem **124** includes a first motor **128**, a first output shaft **130**, and a first transmission **132**. The second motor subsystem **126** functions to provide another component of the rotational output of the multi-motor assembly **120**. The second motor subsystem **126** includes a second motor **134**, a second output shaft **136**, and a second transmission **138**.

[0015] The first motor **128** of the first motor subsystem **124** functions to provide a first source of power, and the first output shaft **130** functions to deliver this power to the other elements of the first motor subsystem **124**. The first motor **128** is preferably a three phase brushless electric motor with an outer rotor and seven pole pairs. The first motor **128**, which is preferably supplied by Hyperion under the model number G2220-14, has a peak current of 35 A and a peak power of 388 W. The first motor **128** may, of course, be a different type with different specifications and parameters depending on the design of the actuator system **100**.

[0016] The first transmission **132** of the first motor subsystem **124** functions to transmit the power from the first output shaft **130** to the drive shaft **122**. The first transmission **132** preferably includes two pulleys (one mounted on the first output shaft **130** and one mounted on the drive shaft **122**) and a belt or chain connecting the two pulleys. The first transmission **132** may alternatively include gears or any other suitable device or method that transmits the power from the first output shaft **130** to the drive shaft **122**. The first transmission **132** also preferably functions to define a first gear ratio of the rotation of the drive shaft **122** to the rotation of the first output shaft **130**. In the preferred embodiment, the pulley (or gear) mounted to the first output shaft **130** is smaller than the pulley (or gear) mounted to the drive shaft **122**, such that the first gear ratio is less than 1:1 (e.g., 1:4). In alternative embodiments, the first gear ratio may be 1:1 or may be greater than 1:1 (e.g., 4:1) depending on the design of the actuator system **100**.

[0017] The second motor **134** of the second motor subsystem **126** functions to provide a second source of power, and the second output shaft **136** functions to deliver this power to the other elements of the second motor subsystem **126**. The second motor **134**, like the first motor **128**, is preferably a three phase brushless electric motor with an outer rotor and seven pole pairs. The second motor **134**, which is preferably supplied by Hyperion under the model number G2220-14, has a peak current of 35 A and a peak power of 388 W. The second motor **134** is preferably identical to the first motor **128** in design and performance characteristics, which functions to reduce part count and manufacturing complexity. The second motor **134** may, however, be a different type with different specifications and parameters depending on the design of the actuator system **100**. The second output shaft **136** functions to deliver the power of the second motor **134** to the other elements of the second motor subsystem **126**.

[0018] The second transmission **138** of the second motor subsystem **126** functions to transmit the power from the second output shaft **136** to the drive shaft **122**. The second transmission **138** preferably includes two pulleys (one mounted on the second output shaft **136** and one mounted on the drive shaft **122**) and a belt or chain connecting the two pulleys. The second transmission **138** may alternatively include gears or any other suitable device or method that transmits the power from the second output shaft **136** to the drive shaft **122**. The second transmission **138** also preferably functions to at least partially define the second gear ratio of the rotation of the drive shaft **122** to the rotation of the second output shaft **136**. In the preferred embodiment, the pulley (or gear) mounted to the second output shaft **136** is smaller than the pulley (or gear) mounted to the drive shaft **122**, such that the second gear ratio is less than 1:1 (e.g., 1:4). In alternative embodiments, the second gear ratio may be 1:1 or may be greater than 1:1 (e.g., 4:1) depending on the design of the actuator system **100**.

[0019] The power from the first motor subsystem **124** and the power from the second motor subsystem **126** preferably have different characteristics, such that the multi-motor assembly **120** can supply larger forces at slower speeds ("Low Gear") and smaller forces at higher speeds ("High Gear"). This may be accomplished by using different motors in the first motor subsystem **124** and the second motor subsystem **126**. In the preferred embodiment, however, this is accomplished by using identical motors, but with transmissions that define different gear ratios for the first motor subsystem **124** and the second motor subsystem **126**. The second gear ratio is preferably lower than the first gear ratio, but the actuator system **100** may be re-arranged such that the second gear ratio is higher than the first gear ratio.

[0020] The second transmission **138** of the second motor subsystem **126** preferably connects the second output shaft **136** to the first output shaft **130**. With this arrangement, the power from the second motor **134** is transmitted through both the second transmission **138** and the first transmission **132** before reaching the drive shaft **122**. Thus, the second transmission **138** and the first transmission **132** cooperatively define the second gear ratio. The effective gear ratio from motor **134** to the drive shaft **122** is a product of the first transmission **132** and the second transmission **138**. For example, if the gear ratios of both the first transmission **132** and the second transmission **138** were 1:3, then the effective gear ratio from motor **134** to the drive shaft **122** would be 1:9. By leveraging the first transmission **132**, this variation provides a compact form factor. Using the example, the system would be able to provide an effective gear ratio of 1:9 without the need for a large pulley or gear system.

[0021] As shown in FIG. **3**, a second transmission **238** of a variation of the second motor subsystem **226** connects the second output shaft **236** to the drive shaft **122**. In this variation, the power from the second motor **234** is transmitted through only the second transmission **238** before reaching the drive shaft **122** (and, thus, the second transmission **238** defines the second gear ratio). By separately connecting the first motor **128** and the second motor **234** to the drive shaft **122**, the first gear ratio and the second gear ratio may be specifically tailored for the actuator system **100**.

[0022] As shown in FIG. **2**, the multi-motor assembly **120** of the preferred embodiment also includes a one-way clutch **140** located between the second motor **134** and the drive shaft **122**. The one-way clutch **140** functions to facilitate the following motor modes:

- **[0023]** High Gear motor mode—the first motor subsystem **124** provides powers in a first direction without spinning the second output shaft **136** and imparting drag from the second motor subsystem **126**,
- **[0024]** Low Gear motor mode—the second motor subsystem **126** provides power in the first direction (with drag from the first motor subsystem **124**),
- **[0025]** Combined motor mode—the first motor subsystem **124** and the second motor subsystem **126** provide power in the first direction, and
- **[0026]** High Gear motor mode—the first motor subsystem **124** provides power in an opposite direction (with drag from the second motor subsystem **126**).

In a first variation of the multi-motor assembly **120**, as introduced above, the one-way clutch **140** is preferably located within the second transmission **138** and, more specifically, in the pulley mounted on the first output shaft **130**. In other variations, the one-way clutch **140** may be mounted in any suitable location between the second motor **134** and the drive shaft **122**.

[0027] The multi-motor assembly **120** of the preferred embodiment also includes a power source (not shown). The power source is preferably six lithium polymer battery cells, supplied by Emerging Power under the model number 603462H1. The battery cells are preferably arranged in both series and parallel (3S2P) to provide a voltage of 11.1V (nominal) and a capacity of 2640 maH. The power source may, however, be any suitable type, including both power supplied by the power grid and other portable sources (e.g., fuel cells), depending on the design of the actuator system **100**.

2. Rotary-to-Linear Mechanism

[0028] The rotary-to-linear mechanism **150** of the preferred embodiment functions to convert the rotational output from the multi-motor assembly **120** into a linear movement that ultimately extends and flexes the joint of the user. In the preferred embodiment, the rotary-to-linear mechanism **150** includes a ball screw **152** that accepts the rotational output of the multi-motor assembly **120** and a ball nut **154** that connects to the ball screw **152** and cooperates with the ball screw **152** to convert rotational movement of the ball screw **152** to linear movement of the ball nut **154**. The drive shaft **122** of the multi-motor assembly **120** and the ball screw **152** of the rotary-to-linear mechanism **150** are preferably different sections of the same shaft. One section includes a pulley (or gear) from the first transmission **132**, while another section includes a semi-circular, helical groove of the ball screw **152**. The drive shaft **122** and the ball screw **152** may, however, be separate shafts connected in any suitable manner, such as through a pulley or gear arrangement. In alternative embodiments, the rotary-to-linear mechanism **150** may include any suitable device or method that converts the rotational output from the multi-motor assembly **120** into an extension and flexion of the joint.

[0029] The rotary-to-linear mechanism **150** of the preferred embodiment also includes a linear slide **156** with a moving rail **158** that moves in a flexion direction and an extension direction. The linear slide **156** functions to provide a supported structure when the joint is fully flexed, and a compact structure when the joint is fully extended. The linear slide **156** preferably includes stationary wheels and moving wheels, but may alternatively include any suitable device or method to allow the moving rail **158** to move in the flex and extended directions.

[0030] As shown in FIGS. **2** and **4***a*, the moving rail **158** of the linear slide **156** preferably includes an extension stop **160**, which functions to translate linear movement of the ball nut **154** in an extension direction into an extension of the joint. In the preferred embodiment, the extension stop **160** is movable between a force position (shown in FIG. **2**) that allows the ball nut **154** to apply force against the extension stop **160**, and a pass position (shown in FIG. **4***a*) that prevents the ball nut **154** from applying force against the extension stop **160**. The extension stop **160** is preferably U-shaped and pivotally mounted on the moving rail **158**, but may alternatively be shaped and mounted in any manner to allow movement from the force position to the pass position. In an alternative embodiment, the extension stop **160** may be permanently (or semi-permanently) fixed or fastened in the force position.

[0031] In a first variation, as shown in FIGS. **2** and **4***b*, the moving rail **158** of the linear slide **156** also includes a flexion stop **162**, which functions to translate linear movement of the ball nut **154** in a flexion direction into a flexion of the joint. In the preferred embodiment, the flexion stop **162** is movable between a force position (shown in FIG. **2**) that allows the ball nut **154** to apply force against the flexion stop **162**, and a pass position (shown in FIG. **4***b*) that prevents the ball nut **154** from applying force against the flexion stop **162**. The flexion stop **162**, like the extension stop **160**, is preferably U-shaped and pivotally mounted on the moving rail **158**, but may alternatively be shaped and mounted in any manner to allow movement from the force position to the pass position. In an alternative embodiment, the flexion stop **162** may be permanently (or semi-permanently) fixed or fastened in the force position.

[0032] In a second variation, as shown in FIG. **4***c*, the moving rail **158** of the linear slide **156** may additionally or alternatively include a latch **262**, which functions to translate linear movement of the ball nut **154** in both the flexion and extension directions into a flexion and extension of the joint. In the preferred embodiment, the latch **262** is movable between an engaged position (shown in FIG. **4***c*) that allows the ball nut **154** to move the latch **262** and the moving rail, and a disengaged position (not shown) that prevents the ball nut **154** from applying force against the latch **262**. The latch **262**, unlike the extension stop **160**, is preferably mounted to engage in slidable manner with the ball nut **154**, but may alternatively be shaped and mounted in any manner to allow movement from the engaged position to the disengaged position.

[0033] In a third variation, the flexion stop **162** and latch **262** may be omitted to allow unpowered flexion of the joint.

[0034] The extension stop **160** and the flexion stop **162** are preferably located relatively far from each other, which allows the joint of the user to experience "free movement", essentially moving the moving rail **158** back and forth between the extension stop **160** and the flexion stop **162** without the need to move the ball nut **154** or back-drive the multi-motor assembly **120**. In a variation, the extension stop **160** and the flexion stop **162** are located relatively close to each other, which prevents the joint of the user from experiencing little or no "free movement". In other words, movement of the moving rail **158** will move the ball nut **154** and back-drive the multi-motor assembly **120**.

[0035] As shown in FIG. **1**, the actuator system **100** of the preferred embodiments for extending and flexing a joint **110** of a user includes a rotary-to-linear mechanism that functions to convert the linear movement of the moving rail into an extension and flexion (both rotational movements) of the joint of the user. In other variations, the actuator system **100** may include gears, pulleys, or any other suitable mechanism to ultimately extend and flex the joint of the user.

3. Controller

[0036] The controller of the preferred embodiment functions to operate the actuator system **100** in one of several operation modes. The controller preferably includes sensors (such as encoders on the first motor **128** and the second motor **134**) to estimate the position of the moving rail **158**, and sensors on the ball nut **154** to estimate the force either provided by the multi-motor assembly **120** or applied to the joint through external factors (such as gravitational force on the body of the user). The controller may also include other sensors to predict or determine future forces applied to the joint or needed by the multi-motor assembly **120**. The controller may, however, use any suitable method or device to estimate the position of the moving rail **158** and the force needed by the multi-motor assembly **120**.

[0037] Based on the position of the moving rail **158** and the force needed by the multi-motor assembly **120**, the controller provides current to the first motor subsystem **124**, the second motor subsystem **126**, or both the first motor subsystem **124** and the second motor subsystem **126**. As shown in FIG. **5**, the controller preferably operates the multi-motor assembly **120** of the actuator system **100** in the following operation modes: High Gear Flexion mode, High Gear Extension mode, Low Gear Extension mode, and Continuously Variable Transmission Extension mode.

[0038] In the High Gear Flexion mode, the controller provides current only to the first motor subsystem **124** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150**. The ball screw **152** is driven in the direction such that the ball nut **154** applies a force against the flexion stop **162** (if positioned in the force position) and drives the moving rail **158** in the flexion direction. The High Gear Flexion mode supplies a smaller force at a higher speed to quickly flex the joint of the user.

[0039] The High Gear Extension mode is similar to the High Gear Flexion mode, except the first motor subsystem **124** is driven in the opposite direction. In the High Gear Extension mode, the controller provides current only to the first motor subsystem **124** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150** and the ball nut **154** applies a force against the extension stop **160**. The ball screw **152** is driven in the direction such that the ball nut **154** applies a force against the extension stop **160** (if positioned in the force position) and drives the moving rail **158** in the extension direction. The High Gear Extension mode supplies a smaller force at a higher speed to quickly extend the joint of the user.

[0040] The Low Gear Extension mode is similar to the High Gear Extension mode, except the second motor subsystem **126** is driven instead of the first motor subsystem **124**. In the Low Gear Extension mode, the controller provides current only to the second motor subsystem **126** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150** and the ball nut **154** applies a force against the extension stop **160**. The ball screw **152** is driven in the direction such that the ball nut **154** applies a force against the extension stop **160** (if positioned in the force position) and drives the moving rail **158** in the extension direction. The Low Gear Extension mode supplies a larger force at a lower speed to forcefully extend the joint of the user.

[0041] In the Continuously Variable Transmission Extension mode, the controller provides current to both the first motor subsystem **124** and the second motor subsystem **126** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150** and the ball nut **154** applies a force against the extension stop **160**. In this mode, as exemplified in FIG. **6**, the controller varies the ratio of current provided to the first motor subsystem **124** and current provided to the second motor subsystem **126** to achieve a desired rotational output in the Continuously Variable Transmission Extension mode. As the controller senses an increased force needed by the multi-motor assembly **120**, the controller preferably first ramps up the current to the first motor subsystem **124** (the High Gear or "HG"), then ramps down the current to the first motor subsystem **124** while ramping up the current to the second motor subsystem **126** (the Low Gear or "LG"). The Continuously Variable Transmission Extension mode can supply both a smaller force at a higher speed to quickly extend the joint of the user ("High Gear"), and a larger force at a lower speed to forcefully extend the joint of the user ("Low Gear"). More importantly, as shown in FIG. **7**, by varying the ratio of current provided to the first motor subsystem **124** and current provided to the second motor subsystem **126**, the controller can achieve a desired force and speed from the multi-motor subsystem that is outside the range of possible forces and speeds supplied by just the first motor **128** or the second motor **134**. The actuator system **100** provides these advantages and features without providing a conventional multi-gear transmission or conventional CTV (with gears, conical pulleys, etc.).

[0042] As shown in FIG. **5**, the controller of the preferred embodiment also operates the actuator system **100** in a Free Movement mode. In one variation of the Free Movement mode, the controller provides current to the first motor subsystem **124** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150** and the ball nut **154** moves away from the extension stop **160**. In another variation of the Free Movement mode, the controller provides current to the first motor subsystem **124** such that the multi-motor assembly **120** provides a rotational output to the rotary-to-linear mechanism **150** and the ball nut **154** maintains a general position between—but not contacting—the extension stop **160** or the flexion stop **162**.

4. Further Embodiments

[0043] As a person skilled in the art of actuator system **100***s* will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the preferred embodiments of the invention without departing from the scope of this invention defined in the following claims. As a first example, while the actuator system **100** has been described to include a multi-motor assembly **120** with a first motor **128** and a second motor **134**, the multi-motor assembly **120** may include additional motors (with or without additional one-way clutches **140**). As an additional example, while the actuator system **100** has been described to include a rotary-to-linear mechanism **150**, it is possible that the rotational output of the multi-motor assembly **120** may be used without a mechanism that converts the rotational output to a linear output.

We claim:

1. An actuator system for extending and flexing a joint, comprising:

a multi-motor assembly for providing a rotational output;

a rotary-to-linear mechanism for converting the rotational output from the multi-motor assembly into an extension and flexion of the joint; and

a controller for operating the actuator system in several operational modes.

2. The actuator system of claim **1**, wherein the multi-motor assembly includes:

a drive shaft that provides the rotational output to the rotary-to-linear mechanism;

a first motor subsystem having a first output shaft and a first transmission connecting the first output shaft to the drive shaft; and

a second motor subsystem having a second output shaft and a second transmission coupling the second output shaft to the drive shaft.

3. The actuator system of claim **2**, wherein the first transmission defines a first gear ratio of the rotation of the drive shaft to the rotation of the first output shaft, and wherein the second transmission at least partially defines a second gear ratio of the rotation of the drive shaft to the rotation of the second output shaft, wherein the second gear ratio is different than the first gear ratio.

4. The actuator system of claim **3**, wherein the second gear ratio is lower than the first gear ratio.

5. The actuator system of claim **3**, wherein the second transmission connects the second output shaft to the first output shaft, and wherein the second transmission and the first transmission cooperatively define the second gear ratio.

6. The actuator system of claim **5**, wherein the second motor subsystem further includes a one-way clutch located between the second motor and the first motor.

7. The actuator system of claim **3**, wherein the second transmission connects the second output shaft to the drive shaft, and wherein the second transmission defines the second gear ratio.

8. The actuator system of claim **7**, wherein the first motor subsystem includes a first motor, wherein the second motor subsystem includes a second motor, and wherein the first motor and the second motor have substantially identical performance characteristics.

9. The actuator system of claim **3**, wherein the controller operates the actuator system in the following motor modes:

Continuously Variable Transmission motor mode—in which the controller provides current to both the first motor subsystem and the second motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism; and

High Gear motor mode—in which the controller provides current only to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism.

10. The actuator system of claim **9**, wherein the controller varies the ratio of current provided to the first motor subsystem and current provided to the second motor subsystem to achieve a desired rotational output in the Continuously Variable Transmission motor mode.

11. The actuator system of claim **1**, wherein the rotary-to-linear mechanism includes a screw that accepts the rotational output of the multi-motor assembly; a nut that connects to the screw; wherein the screw and the nut cooperate to convert rotational movement of the screw to linear movement of the nut.

12. The actuator system of claim **11**, further comprising a moving rail having an extension stop that translates linear movement of the nut in an extension direction into linear movement of the moving rail in an extension direction.

13. The actuator system of claim **12**, wherein linear movement of the moving rail in the extension direction causes an extension of the joint.

14. The actuator system of claim **12**, wherein the extension stop is movable between a force position that allows the nut to apply force against the extension stop, and a pass position that prevents the nut from applying force against the extension stop.

15. The actuator system of claim **12**, wherein the moving rail also has a flexion stop that translates linear movement of the nut in a flexion direction into linear movement of the moving rail in a flexion direction.

16. The actuator system of claim **15**, wherein linear movement of the moving rail in the flexion direction causes a flexion of the joint.

17. The actuator system of claim **15**, wherein the flexion stop is movable between a force position that allows the nut to apply force against the flexion stop, and a pass position that prevents the nut from applying force against the flexion stop.

18. The actuator system of claim **15**, wherein the extension stop and the flexion stop are located such that they allow significant movement of the moving rail back and forth between the extension stop and the flexion stop without moving the ball nut or back-driving the multi-motor assembly.

19. The actuator system of claim **12**,

wherein the multi-motor assembly includes

a drive shaft that provides rotational output,

a first motor subsystem having a first output shaft and a first transmission connecting the first output shaft to the drive shaft, and

a second motor subsystem having a second output shaft and a second transmission coupling the second output shaft to the drive shaft;

wherein the controller operates the actuator system in the following operational modes:

Continuously Variable Transmission Extension mode—in which the controller provides current to both the first motor subsystem and the second motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop; and

High Gear Flexion mode—in which the controller provides current only to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the flexion stop.

20. The actuator system of claim **19**, wherein the controller varies the ratio of current provided to the first motor subsystem and current provided to the second motor subsystem to achieve a desired rotational output in the Continuously Variable Transmission Extension mode.

21. The actuator system of claim **19**, wherein the controller also operates the actuator system in the following operational modes:

Low Gear Extension mode—in which the controller provides current only to the second motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop;

High Gear Extension mode—in which the controller provides current only to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop.

22. The actuator system of claim **19**, wherein the controller also operates the actuator system in the following operational mode:

Free Movement mode—in which the controller provides current to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut moves away from the extension stop.

23. An actuator system for extending and flexing a joint, comprising:

a multi-motor assembly including a drive shaft that provides rotational output, a first motor subsystem having a first output shaft and a first transmission connecting the first output shaft to the drive shaft, and a second motor subsystem having a second output shaft and a second transmission coupling the second output shaft to the drive shaft, wherein the first transmission defines a first gear ratio of the rotation of the drive shaft to the rotation of the first output shaft, and wherein the second transmission at least partially defines a second gear ratio of the rotation of the drive shaft to the rotation of the second output shaft, wherein the second gear ratio is lower than the first gear ratio;

a rotary-to-linear mechanism including a screw that accepts the rotational output of the drive shaft, a nut that cooperates with the screw to convert rotational movement of the screw to linear movement of the nut;

a moving rail including an extension stop that translates linear movement of the nut in an extension direction into an extension of the joint, and a flexion stop that translates linear movement of the nut in a flexion direction into a flexion of the joint,

a controller for operating the actuator system in the following operational modes:

Continuously Variable Transmission Extension mode—in which the controller provides current to both the first motor subsystem and the second motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop; and

High Gear Flexion mode—in which the controller provides current only to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the flexion stop.

24. The actuator system of claim **23**, wherein the second transmission connects the second output shaft to the first output shaft, wherein the second motor subsystem further includes a one-way clutch located between the second motor and the first motor, wherein the second transmission and the first transmission cooperatively define the second gear ratio, and wherein the drive shaft and the screw are axially connected as a unitary part.

25. The actuator system of claim **23**, wherein the controller varies the ratio of current provided to the first motor subsystem and current provided to the second motor subsystem to achieve a desired rotational output in the Continuously Variable Transmission Extension mode.

26. The actuator system of claim **23**, wherein the controller also operates the actuator system in the following operational modes:

Low Gear Extension mode—in which the controller provides current only to the second motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop;

High Gear Extension mode—in which the controller provides current only to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut applies a force against the extension stop.

27. The actuator system of claim **23**, wherein the controller also operates the actuator system in the following operational mode:

Free Movement mode—in which the controller provides current to the first motor subsystem such that the multi-motor assembly provides a rotational output to the rotary-to-linear mechanism and the nut moves away from the extension stop.

28. A method for controlling an actuator system that extends and flexes a joint, the method comprising the steps of:

providing a multi-motor assembly including a drive shaft, a first motor subsystem having a first output shaft, and a second motor subsystem having a second output shaft;

coupling the first output shaft to the drive shaft with a first transmission;

coupling the second output shaft to the drive shaft with a second transmission;

providing current only to the first motor subsystem in High Gear mode; and

providing current to both the first motor subsystem and the second motor subsystem in a Continuously Variable Transmission mode.

29. The method of claim **28**, wherein the step of providing current to both the first motor subsystem and the second motor subsystem includes varying the ratio of current provided to the first motor subsystem and current provided to the second motor subsystem to achieve a desired output.

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