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(54) ROTARY EXERCISE EQUIPMENT APPARATUS AND METHOD OF USE THEREOF

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(60) Provisional application No. 61/091,240, filed on Aug. 22, 2008.

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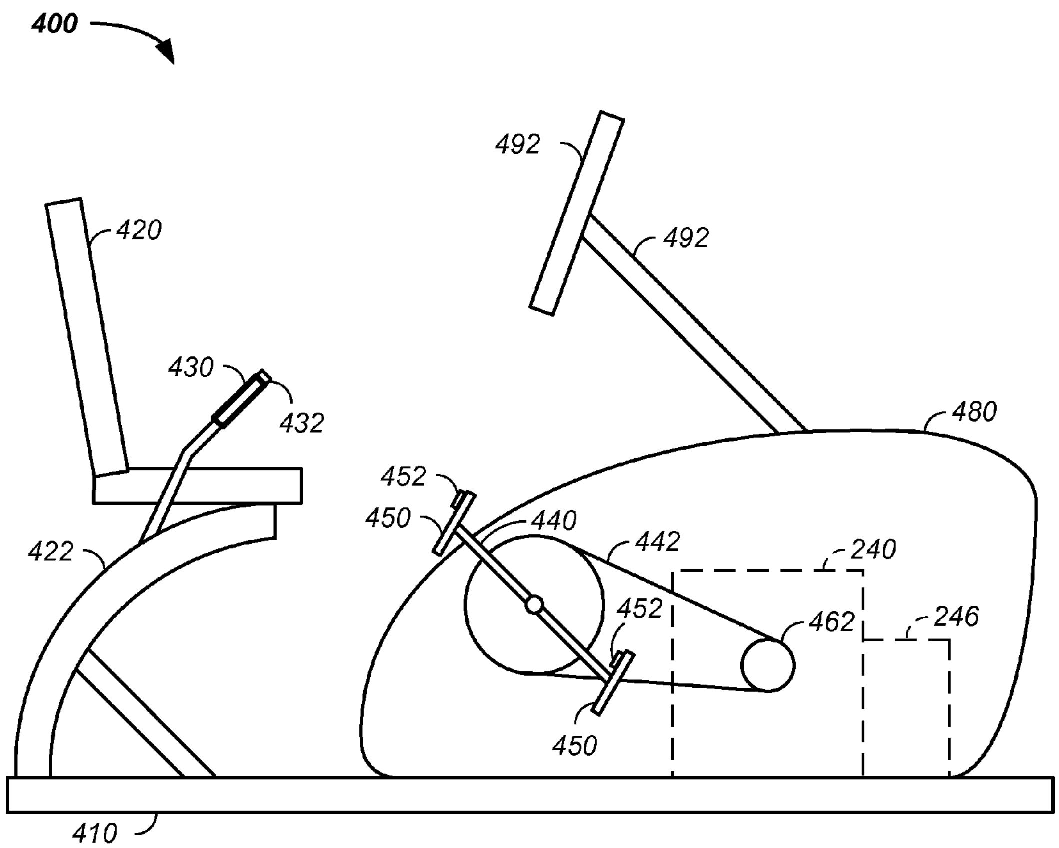
(52) **U.S. Cl.** **482/5**

(57) **ABSTRACT**

The invention comprises a method and/or an apparatus using computer configured exercise equipment and an electric motor. A computer-controlled robotic resistance system is used for training, diagnosis and/or therapy. The resistance system comprises: a subject interface, software control, a controller, an electric servo assist/resist motor, an actuator, and/or a subject sensor. The system overcomes the limitations of the existing robotic rehabilitation, weight training, and cardiovascular training systems by providing a training and/or rehabilitation system that adapts a resistance or force applied to a user interactive element in response to the user's interaction with the training system, a physiological strength curve, and/or sensor feedback. For example, the system optionally provides for an automatic reconfiguration and/or adaptive load adjustment based upon real time measurement of a user's interaction with the system or sensor based observation by the exercise system as it is operated by the subject.



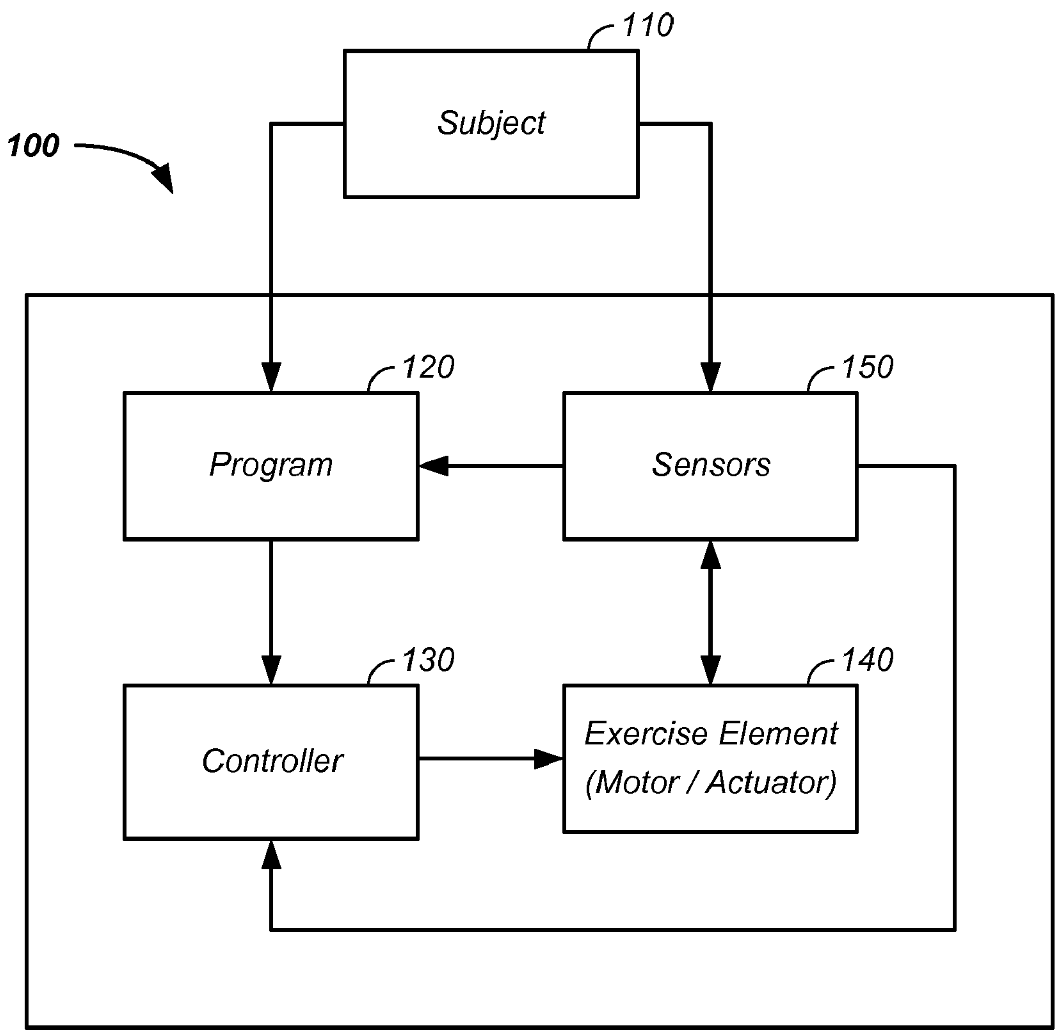

110
Subject
100
120
Program
150
Sensors
130
Controller
140
Exercise Element
(Motor / Actuator)

FIG. 1

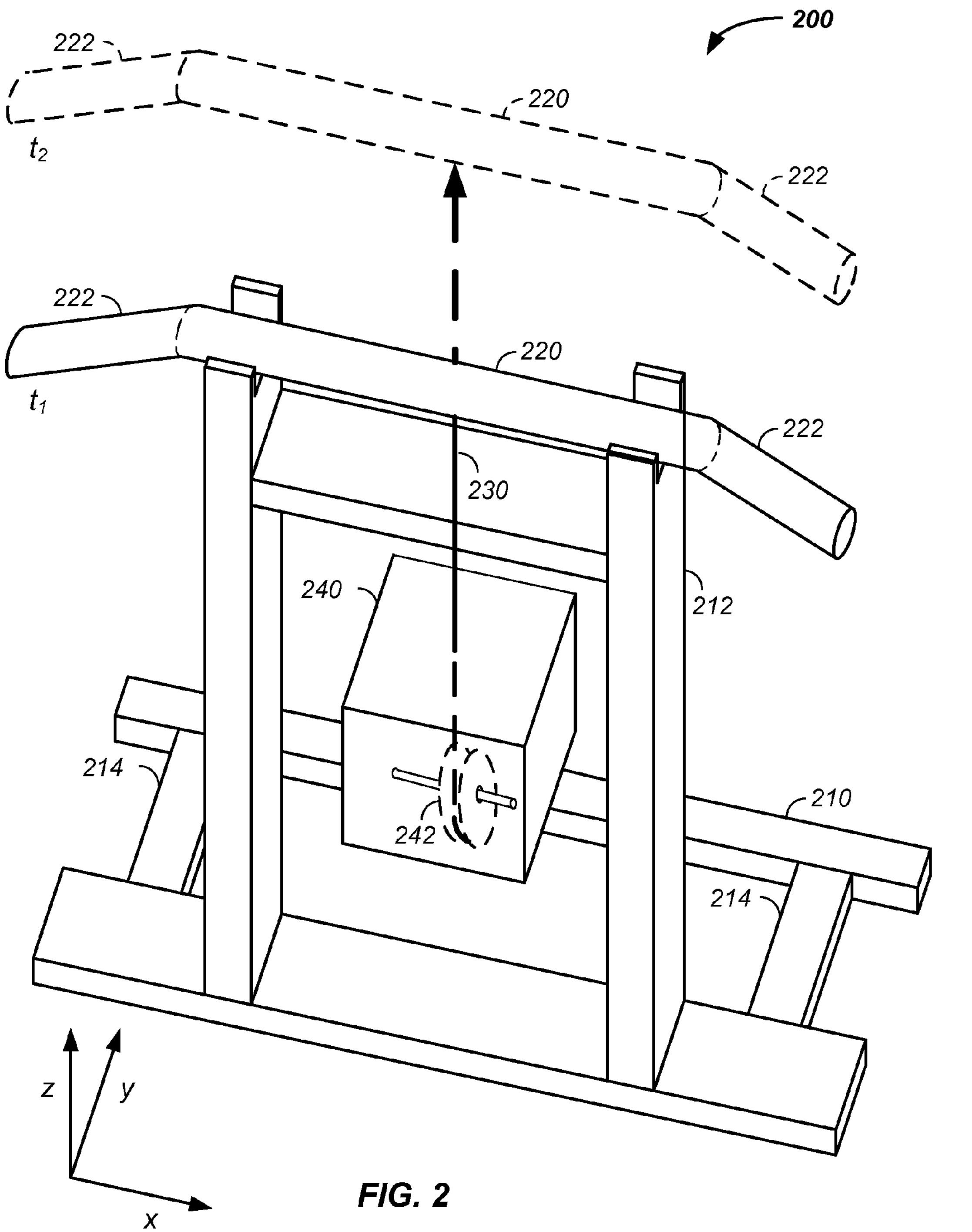


FIG. 2

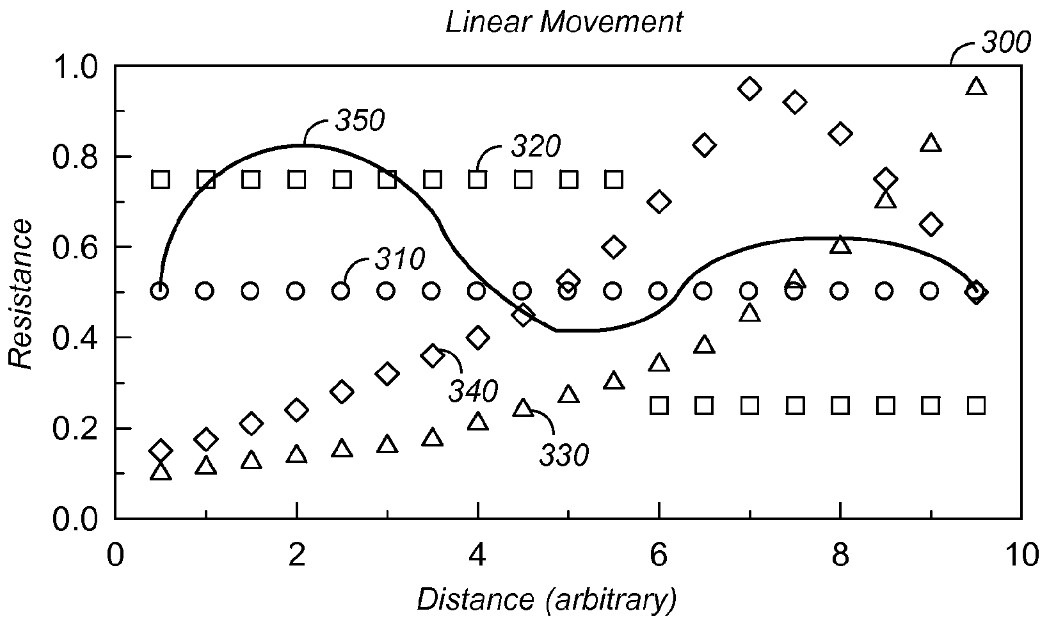

Linear Movement
300
350
320
310
340
330
Resistance
Distance (arbitrary)
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10

FIG. 3

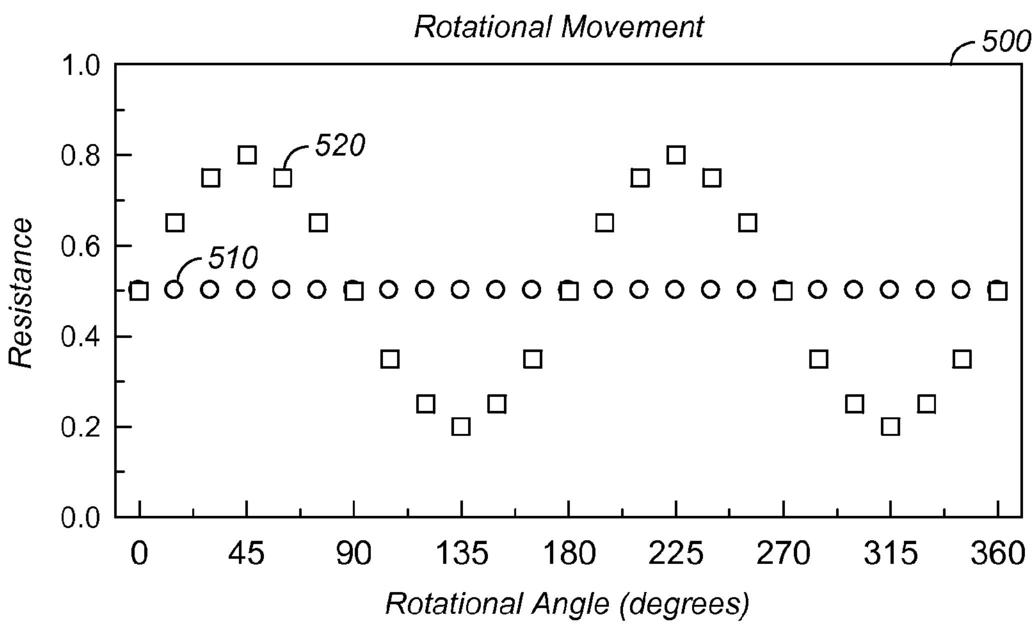

Rotational Movement
500
520
510
Resistance
Rotational Angle (degrees)
1.0
0.8
0.6
0.4
0.2
0.0
0
45
90
135
180
225
270
315
360

FIG. 5

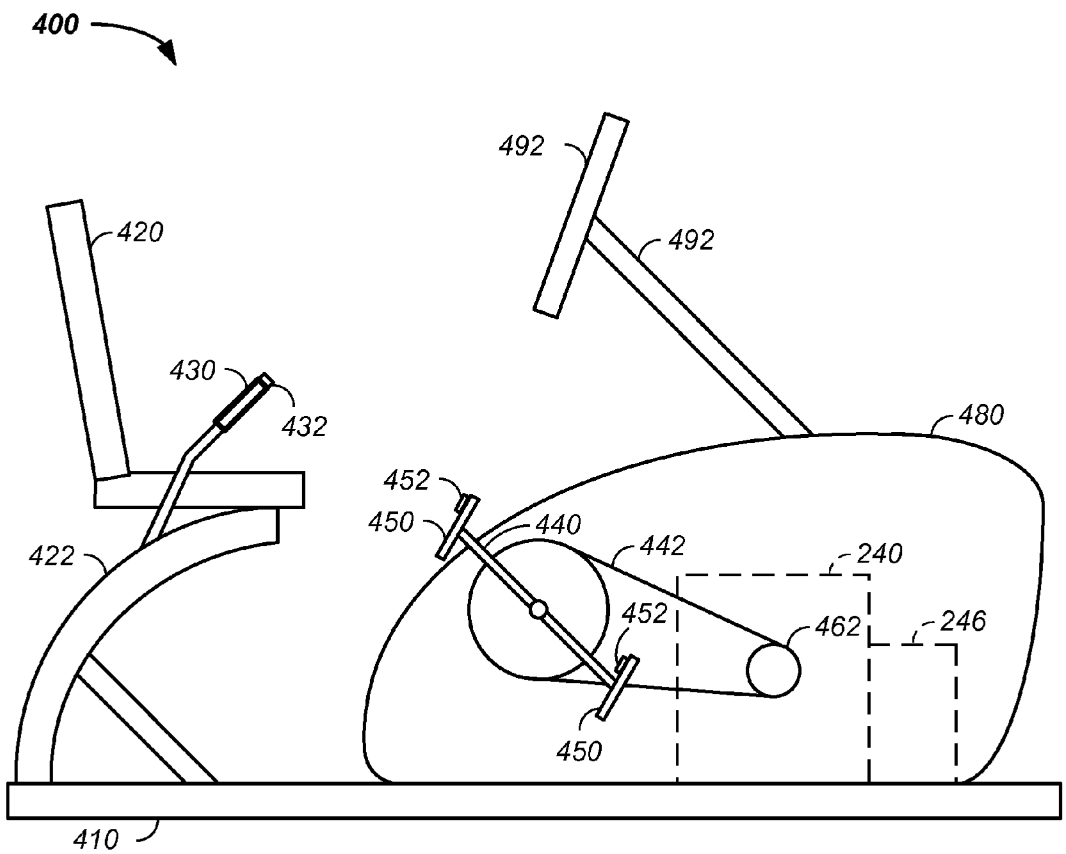

400
492
492
420
430
432
480
452
450
440
442
240
422
452
462
246
450
410

FIG. 4

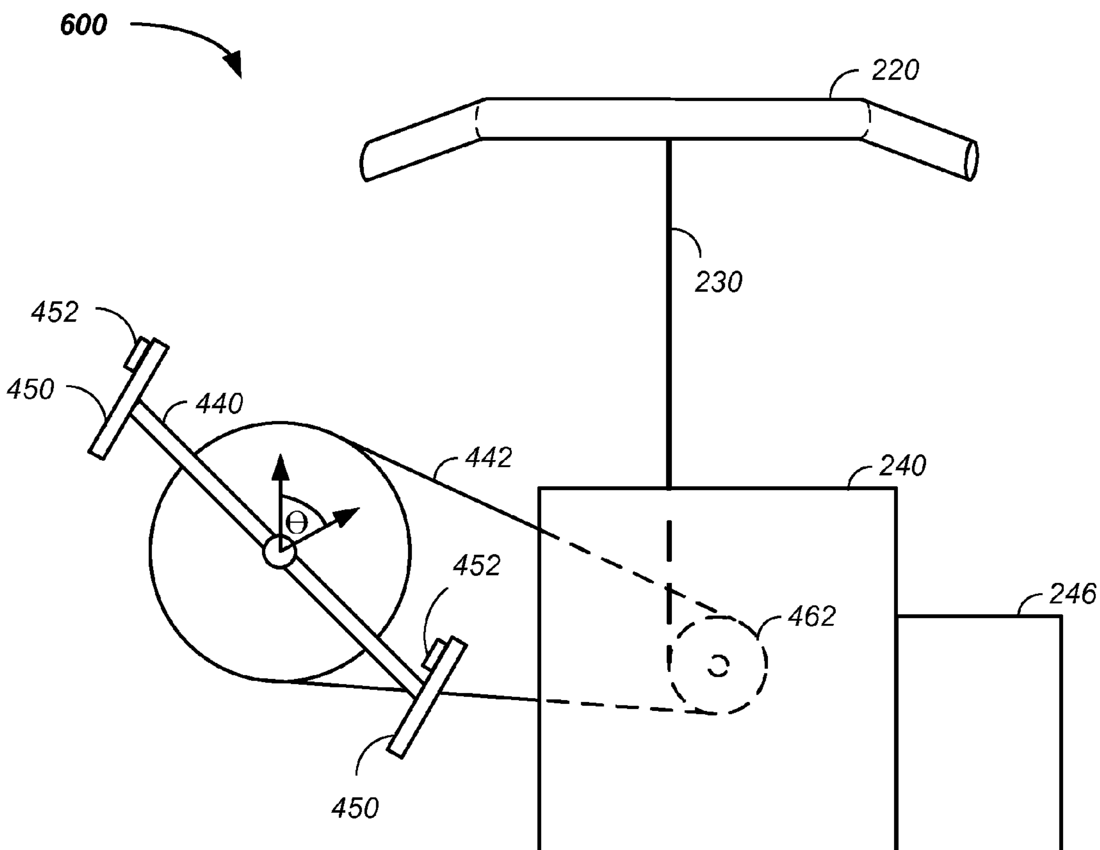


FIG. 6

ROTARY EXERCISE EQUIPMENT APPARATUS AND METHOD OF USE THEREOF

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application:

[0002] is a continuation in part of U.S. patent application Ser. No. 12/545,324, filed Aug. 21, 2009, which under 35 U.S.C. 120 claims benefit of U.S. provisional patent application No. 61/091,240 filed Aug. 22, 2008; and

[0003] claims benefit of U.S. provisional patent application No. 61/387,772 filed Sep. 29, 2010,

[0004] all of which are incorporated herein in their entirety by this reference thereto.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0005] The U.S. Government may have certain rights to this invention pursuant to NASA SBIR Contract number: NNX10CB13C dated Feb. 5, 2010.

BACKGROUND OF THE INVENTION

[0006] 1. Field of the Invention

[0007] The present invention relates generally to computer and motor assisted exercise equipment methods and apparatus.

[0008] 2. Discussion of the Related Art

[0009] Patents related to computer controlled variable resistance exercise equipment are summarized herein.

Sensors and Resistive Force

[0010] J. Casler, "Electronically Controlled Force Application Mechanism for Exercise Machines", U.S. Pat. No. 5,015,926 (May 14, 1991) describes an exercise machine equipped with a constant speed electric drive mechanically coupled to a dynamic clutch, which is coupled to an electromagnetic coil or fluid clutch to control rotary force input. An electronic sensor connected to a computer senses the speed, motion, and torque force of the system's output shaft and a control unit directed by the computer controls the clutch.

[0011] G. Stewart, et. al., "Computer Controlled Exercise Machine", U.S. Pat. No. 4,869,497 (Sep. 26, 1989) describe a computer controlled exercise machine where the user selects an exercise mode and its profile by programming a computer. Signals are produced by the program to control a resistive force producing device. Sensors produce data signals corresponding to the actuating member of the system, velocity of movement, and angular position. The sampled data are used to control the amount of resistive force.

Pressure/Movement Sensors

[0012] M. Martikka, et. al., "Method and Device for Measuring Exercise Level During Exercise and for Measuring Fatigue", U.S. Pat. No. 7,764,990 B2 (Jul. 27, 2010) describe sensors for measuring electrical signals produced by muscles during exercise and use of the electrical signals to generate a fatigue estimate.

[0013] E. Farinelli, et. al., "Exercise Intra-Repetition Assessment System", U.S. Pat. No. 7,470,216 B2 (Dec. 30, 2008) describe an intra-repetition exercise system comparing actual performance to a pre-established goal with each repetition of the exercise, where displayed indicia includes travel distance and speed.

[0014] R. Havriluk, et. al., "Method and Apparatus for Measuring Pressure Exerted During Aquatic and Land-Based Therapy, Exercise and Athletic Performance", U.S. Pat. No. 5,258,927 (Nov. 2, 1993) describe a device for monitoring exercise pressure on systems using an enclosed compressible fluid chamber. Measurements are taken at pressure ports and are converted to a digital signal for computer evaluation of type and degree of exercise performed.

Hand Controls

[0015] S. Owens, "Exercise Apparatus Providing Resistance Variable During Operation", U.S. Pat. No. 4,934,692 (Jun. 19, 1990) describes an exercise device having a pedal and hand crank connected to a flywheel provided with a braking mechanism. To vary the amount of braking, switches located on the hand crank are used making removal of the hand from the crank unnecessary to operation of the switches.

Resistance/Varying Resistance Exercise

[0016] D. Munson, et. al., "Exercise Apparatus Based on a Variable Mode Hydraulic Cylinder and Method for Same", U.S. Pat. No. 7,762,934 B1 (Jul. 27, 2010) describe an exercise machine having a hydraulic cylinder sealed with spool valves adjustable to permit entrance and exit of water with forces corresponding to forces exerted on the cylinder.

[0017] C. Hulls, "Multiple Resistance Curves Used to Vary Resistance in Exercise Apparatus", U.S. Pat. No. 7,682,295 B2 (Mar. 23, 2010) describes an exercise machine having varying resistance based on placement of a cable pivot point within a channel, where placement of the pivot point within the channel alters the resistance pattern along the range of motion of an exercise.

[0018] D. Ashby, et. al., "System and Method for Selective Adjustment of Exercise Apparatus", U.S. Pat. No. 7,645,212 B2 (Jan. 12, 2010) describe an electronic interface allowing adjustment of speed and grade level via a computer based interface mounted on an exercise machine, such as on a treadmill.

[0019] M. Anjanappa, et. al., "Method of Using and Apparatus for Use with Exercise Machines to Achieve Programmable Variable Resistance", U.S. Pat. No. 5,583,403 (Dec. 10, 1996) describes an exercise machine having a constant torque, variable speed, reversible motor and associated clutches. The motor and clutch are chosen in a predetermined combination through use of a computer controller.

[0020] J. Daniels, "Variable Resistance Exercise Device", U.S. Pat. No. 5,409,435 (Apr. 25, 1995) describes a programmable variable resistance exercise device providing a resisting force to a user supplied force. The user supplied force is resisted by varying the viscosity of a variable viscosity fluid that surround plates rotated by the user applied force. A gear and clutch system allow resistance to a pulling force.

[0021] M. Brown, et. al., "User Force Application Device for an Exercise, Physical Therapy, or Rehabilitation Apparatus", U.S. Pat. No. 5,362,298 (Nov. 8, 1994) describe an exercise apparatus having a cable connected to a resistive weight and a detachable handle connected to the cable via a tension transmitting device.

Physiological Response

[0022] M. Lee, et. al., "Exercise Treadmill with Variable Response to Foot Impact Induced Speed Variation", U.S. Pat.

No. 5,476,430 (Dec. 19, 1995) describe an exercise treadmill having a plurality of rates of restoration of the tread belt speed upon occurrence of change in the load on the moving tread belt resulting from the user's foot plant, where the user can select a desired rate of response referred to as stiffness or softness.

Power Generation/Energy Consumption

[0023] J. Seliber, "Resistance and Power Monitoring Device and System for Exercise Equipment", U.S. Pat. No. 7,351,187 B2 (Apr. 1, 2008) describes an exercise bike including pedals, a belt, and a hydrodynamic brake. User applied force to the pedals is transferred to a flywheel and relative rotation speeds of impellers of the fluid brake are used to estimate generated wattage.

[0024] J. Seo, et. al., "Apparatus and Method for Measuring Quantity of Physical Exercise Using Acceleration Sensor", U.S. Pat. No. 7,334,472 B2 (Feb. 26, 2008) describe a method for measuring calorie consumption when using an exercise device based upon generating acceleration information from an acceleration sensor.

[0025] S. Shu, et. al., "Power Controlled Exercising Machine and Method for Controlling the Same", U.S. Pat. No. 6,511,402 B2 (Jan. 28, 2003) describe a self-contained exercise machine with a generator and an alternator used to recharge a battery with power supplied from a stepper interface used by a subject.

STATEMENT OF THE PROBLEM

[0026] While a wide variety of computer-controlled exercise machines for training and rehabilitation exist, some of which can be automatically adjusted to vary resistance or incline, such systems provide for preprogrammed changes in load or resistance.

[0027] What is needed is a system that overcomes the limitations of the existing robotic rehabilitation systems by providing a training and/or rehabilitation system that adapts a resistance or force applied to a user interactive element in response to the user's interaction with the user interactive element, the system, and/or observations of the user by the system.

SUMMARY OF THE INVENTION

[0028] The invention comprises a computer assisted exercise equipment method and apparatus.

DESCRIPTION OF THE FIGURES

[0029] FIG. **1** provides a block diagram of an electric motor resistance based exercise system;

[0030] FIG. **2** illustrates hardware elements of an exemplary computer aided motorized resistance exercise system;

[0031] FIG. **3** provides exemplary resistance profiles for a linear movement;

[0032] FIG. **4** illustrates a rotary exercise system configured with electric motor resistance;

[0033] FIG. **5** provides exemplary resistance profiles for a rotary movement; and

[0034] FIG. **6** illustrates a combined linear and rotary exercise system.

DETAILED DESCRIPTION OF THE INVENTION

[0035] The invention comprises a method and/or an apparatus using a computer and rotary exercise equipment configured with an electric motor.

[0036] In one embodiment, exercise equipment configured with a rotatable crank and means for varying resistance to rotation of the rotatable crank using an electric motor is described.

[0037] In another embodiment, exercise equipment is configured with an electric motor resistance system. Resistance to movement supplied by the electric motor optionally varies dependent upon input from one or more subject sensors. Variation in resistive force optionally occurs:

- **[0038]** within a single direction of a weight training repetition;
- **[0039]** between directions of a weight training repetition; and/or
- **[0040]** between repetitions within a single set of repetitions.

[0041] Herein, a repetition is one complete movement of an exercise and repetitions refers to the number of times each exercise is completed in a row or in a set.

[0042] In yet another embodiment, a computer-controlled robotic resistance system or mechanical resistance training system is used for:

- **[0043]** strength training;
- **[0044]** aerobic conditioning;
- **[0045]** low gravity training;
- **[0046]** physical therapy;
- **[0047]** rehabilitation; and/or
- **[0048]** medical diagnosis.

[0049] The resistance system comprises: a subject interface, software control, a controller, an electric motor, an electric servo assist/resist motor, a variable speed motor, an actuator, and/or a subject sensor. The resistance system is adaptable to multiple configurations to provide different types of training, as described infra.

[0050] The resistance system significantly advances neuromuscular function as it is adaptable to a level of resistance or applied force. For example, the system optionally uses:

- **[0051]** biomechanical feedback
- **[0052]** motorized strength training;
- **[0053]** motorized physical conditioning; and/or
- **[0054]** a computer programmed workout.

[0055] For example, a system is provided that overcomes the limitations of the existing robotic rehabilitation, weight training, and cardiovascular training systems by providing a training and/or rehabilitation system that adapts a resistance or force applied to a user interactive element in response to:

- **[0056]** the user's interaction with the training system;
- **[0057]** a physiological strength curve;
- **[0058]** sensor feedback; and/or
- **[0059]** observations of the system.

[0060] For instance, the system optionally provides for an automatic reconfiguration and/or adaptive load adjustment based upon real time measurement of a user's interaction with the system or sensor based observation by the exercise system as it is operated by the subject **110**.

DEFINITIONS

[0061] Herein, the human or operator using the resistance system is referred to as a subject. The subject is any of: a trainer, a trainee, a lifter, and/or a patient.

[0062] Herein, a computer refers to a system that transforms information in any way. The computer or electronic device, such as an embedded computer, a controller, and/or a programmable machine, is used in control of the exercise equipment.

[0063] Herein, an x-axis and a y-axis form a plane parallel to a support surface, such as a floor, and a z-axis runs normal to the x/y-plane, such as along an axis aligned with gravity. In embodiments used in low gravity space, the axes are relative to a support surface and/or to the subject **110**.

Motor Assisted Resistance System

[0064] Referring now to FIG. **1**, a block diagram of a motor equipped exercise system **100** is provided. As the exercise system **100** optionally provides resistance and/or assistance to a motion of user interface, such as a weightlifting bar or crank system, the motor equipped exercise system **100** is also referred to as a motor equipped resistance system, a resistance system, a motor equipped assistance system, and/or an assistance system. For clarity of presentation, examples provided herein refer to a resistance provided by a motor of the exercise system **100**. However, the motor of the exercise system **100** is alternatively configured to provide assistance. Hence, examples referring to motor supplied resistance are non-limiting and in many cases the system is alternatively reconfigured to use motor supplied assistance in the range of motion of a particular exercise.

[0065] Still referring to FIG. **1**, the exercise system **100** includes one or more of: a computer configured with a program **120**, a controller **130**, an exercise element **140**, and/or a sensor **150**. The exercise system **100** is configured for use by a subject **110**.

[0066] Still referring to FIG. **1**, the subject **110**:

- **[0067]** enters a program **120** to the resistance system **100**;
- **[0068]** alters the resistance of the exercise system within a repetition;
- **[0069]** alters the resistance of the exercise system between repetitions;
- **[0070]** is sensed by sensors **150** in the resistance system; and/or
- **[0071]** is recognized by the resistance system, such as through wireless means described infra.

[0072] The program **120** is optionally predetermined, has preset options, is configurable to a specific subject, changes resistance dynamically based on sensor input, and/or changes resistance based on subject input, described infra. The program **120** provides input to a controller **130** and/or a set of controllers, which controls one or more actuators and/or one or more motors of an exercise element **140** of the exercise system **100**. Optional sensors provide feedback information about the subject **110** and/or the state of a current exercise movement, such as a position of a moveable element of the resistance system, a force applied to a portion of the exercise system **100**, the subject's heart rate, and/or the subject's blood pressure. Signal from the sensors **150** are optionally fed in a feedback system or loop to the program **120** and/or directly to the controller **130**.

[0073] Optionally, active computer control is coupled with motorized resistance in the exercise system **100**. The computer controlled motor allows for incorporation of progressive and reconfigurable procedures in strength training, physical conditioning, and/or cardiovascular exercise. For example, computer control of the motor additionally optionally provides resistance curves overcoming the traditional limits of gravity based freestyle weightlifting, described infra.

Linear Movement

[0074] Referring now to FIG. **2**, a linear movement system **200** is illustrated, which is a species of the exercise system **100**. The linear movement system **200** is illustrative in nature and is used for facilitating disclosure of the system. Further, the species of the linear movement system **200** is to a specific form of the exercise system **100**. However, the illustrated linear movement system **200** is only one of many possible forms of the exercise system **100** and is not limiting in scope. Herein the linear movement system refers to a linear, about linear, or non-rotational movement of the user interface exercise equipment, such as a weightlifting bar, or to movement of a resistance cable.

[0075] Still referring still to FIG. **2**, an exemplary computer and motorized aided linear movement system **200** is provided. Generally, FIG. **2** illustrates examples of the structural elements **140** of the exercise system **100**. In the illustrated system, the linear movement system **200** includes:

- **[0076]** a base **210**, such as an aluminum extrusion or suitable material
- **[0077]** an upright support member **212** affixed to the base;
- **[0078]** a removable weightlifting bar **220** placeable into a guide element of the upright support member **212**, or other geometry suitable for interfacing with the subject, such as a D-handle;
- **[0079]** a first end of a resistance cable **230** affixed to the weightlifting bar **220**;
- **[0080]** a cable spool **242** affixed to a second end of the resistance cable **230**;
- **[0081]** a resistance cable, such as flexible metallic cable, a fibrous cord, an about 0.053" sheathed Kevlar cord, or an about 3/32" T-100 cord; and/or
- **[0082]** an electric motor configured to provide resistance to movement of the weightlifting bar **220** through the resistance cable **230**.

[0083] As configured, the subject **110** straddles the electric motor **240** and stands on the floor, base **210**, and/or a foot support or cross-member **214** of the base **210**. The subject **110** pulls on the removable weightlifting bar **220** and/or on hand grips **222** affixed or attached to the weightlifting bar **220**. Movement of the weightlifting bar **220** is continuous in motion, but is illustrated at a first point in time, t_1, and at a second point in time, t_2, for clarity. The subject pulls the weightlifting bar **220**, such as along the z-axis. Movement of the weightlifting bar **220** is resisted by the electric motor **240**. For example, the electric motor **240** provides a resistive force to rotation of the cable spool **242**, which transfers the resistive force to the resistance cable **230** and to the weightlifting bar **220** pulled on by the subject **110**. In one example, the electric motor **240** includes a 10:1 or low lash gearbox and/or a

MicroFlex drive to control motor torque. The torque produced by the motor is optionally made proportional to an analog voltage signal applied to one of the drive's analog inputs or is controlled by sending commands to set the torque value using a digital communications protocol.

Orientations

[0084] The linear movement system **200** is illustrated with the resistive cable **230** running in the z-axis. However, the resistive cable **230** optionally runs along the x-axis or any combination of the x-, y-, and z-axes. Similarly, the linear movement system **200** is illustrated for the user subject **110** standing on the floor. However, the exercise system **100** is optionally configured for use by the subject **110** in a sitting position or any user orientation. Further, the linear movement system **200** is illustrated with the subject **110** pulling up against a resistance. However, the subject is optionally pushing against a resistance, such as through use of a force direction changing pulley redirecting the resistance cable **230**. Still further, the linear movement system **200** is illustrated for use by the subject's hands. However, the system is optionally configured for an interface to any part of the subject, such as a foot or a torso.

Resistance/Assistance Profiles

[0085] Traditional weight training pulls a force against gravity, which is constant, and requires the inertia of the mass to be overcome. Particularly, a force, F, is related to the mass, m, moved and the acceleration, g, of gravity, and the acceleration of the mass, a, through equation 1,

$$F=mg+ma \qquad \text{(eq. 1)}$$

where the acceleration of gravity, g, is

$$9.81\frac{\text{m}}{\text{sec}^2}.$$

Hence, the resistance to movement of the weight is non-linear as a function of time or as a function of movement of the user interactive element.

[0086] Referring now to FIG. **3**, resistance profiles **300** are illustrated, where both the resistance and distance are in arbitrary units. For traditional free weight strength training, the external resistance profile is flat **310** as a function of distance. For example, on a bench press a loaded weight of 315 pounds is the resistance at the bottom of the movement and at the top of the movement where acceleration is zero. At positions in between the external force required to accelerate the mass is dependent on the acceleration and deceleration of the bar. In stark contrast, the exercise system **100** described herein allows for changes in the resistance as a function of position within a single repetition of movement. Returning to the bench press example, it is well known that the biomechanics of the bench press result in an ascending strength curve such that one can exert greater force at the end of the range of motion than at the beginning. Hence, when the lifter successfully lifts, pushes, or benches through the "sticking point" of the bench press movement, the person has greater strength at the same time the least amount of force needs to exerted as the mass is deceleration resulting in the musculature of the chest being sub-optimally loaded. Accordingly, a variable resistance profile starting with a lower resistance and then increasing to a peak resistance is more optimal for a bench press.

[0087] Still referring to FIG. **3**, still an additional profile **350** is a profile where the force at the beginning of the lift (in a given direction) is about equal to the force at the end of the lift, such as a weight of mass times gravity. At points or time periods between the beginning of the lift and the end of the lift (in a given direction) the force applied by the electric motor optionally depends on whether the bar is accelerating or decelerating. For example, additional force is applied by the motor during acceleration and no additional force is applied by the motor during deceleration versus a starting weight. For example, the applied force profile is higher than a starting weight or initial force as the load is accelerated and less than or equal to the initial load as it movement of the repetition decelerates.

[0088] Still referring to FIG. **3**, more generally the resistance profile **300** is optionally set:

- **[0089]** according to predetermined average physiological human parameters;
- **[0090]** to facilitate therapy of a weak point in a range of motion;
- **[0091]** to accommodate restricted range of motion, such as with a handicap;
- **[0092]** to fit a particular individual's physiology;
- **[0093]** to fit a particular individual's preference;
- **[0094]** in a pre-programmed fashion;
- **[0095]** in a modified and/or configurable manner; and/or
- **[0096]** dynamically based on
  - **[0097]** sensed values from the sensor **150**; and/or
  - **[0098]** through real-time operator **110** input.

[0099] Several optional resistance profiles are illustrated, including: a step-down function resistance profile **320**, an increasing resistance profile **330**, and a peak resistance profile **340**. Physics based profiles include:

- **[0100]** accurate solution of F=mg+ma;
- **[0101]** accurate solution of

$$F=\text{mg}+\left\{\begin{matrix} ma,\ (a>0) \\ 0,\ (a\le 0)\end{matrix}\right\},$$

- **[0102]** which prevents the resistance from dropping below the baseline, static resistance; and/or
- **[0103]** accurate solution of F=mg+maximum, which maintains the maximum resistance developed when accelerating the load through the remainder of the lift.

[0104] Additional profiles include a step-up profile, a decreasing resistance profile, a minimum resistance profile, a flat profile, a complex profile, and/or any permutation and/or combination of all or parts of the listed profiles. Examples of complex profiles include a first profile of sequentially increasing, decreasing, and increasing resistance or a second profile of decreasing, increasing, and decreasing resistance.

[0105] In one example, the resistance force to movement of the subject interface varies by at least 1, 5, 10, 15, 20, 25, 50, or 100 percent within a repetition or between repetitions in a single set.

Reverse Movement

[0106] For the linear movement system **200**, resistance profiles were provided for a given direction of movement, such as an upward push on bench press. Through appropriate mounts, pulleys, and the like, the resistance profile of the return movement, such as the downward movement of negative of the bench press, is also set to any profile. The increased load is optionally set as a percentage of the initial, static load. For example, the downward force profile of the bench press are optionally set to match the upward resistance profile, to increase weight, such as with a an increased weight "negative" bench press, or to have a profile of any permutation and/or combination of all or parts of the listed profiles.

Time/Range of Motion

[0107] One or more sensors are optionally used to control rate of movement of the resistive cable. For example, the electric motor **240** is optionally configured with an encoder that allows for determination of how far the cable has moved. The encoder optionally provides input to the controller **130** which controls further movement of the actuator and/or motor turn, thereby controlling in a time controlled manner movement or position of the resistive cable.

[0108] In one example, the exercise system **100** senses acceleration and/or deceleration of movement of the movable exercise equipment, such as the weightlifting bar **220**. Acceleration and/or deceleration is measured using any of:

- **[0109]** an encoder associated with rotation of the electric motor;
- **[0110]** an accelerometer sensor configured to provide an acceleration signal; and/or
- **[0111]** a-priori knowledge of a range or motion of a given exercise type coupled with knowledge of:
  - **[0112]** a start position of a repetition;
  - **[0113]** a physical metric of the operator, such as arm length, leg length, chest size, and/or height.

[0114] Since putting an object into motion takes an effort beyond the force needed to continue the motion, such as through a raising period of a bench press, the forces applied by the motor are optionally used to increase or decrease the applied force based on position of movement of the repetition. The encoder, a-priori knowledge, physical metrics, and/or direct measurement with a load cell, force transducer, or strain gage are optionally used in formulation of the appropriate resistance force applied by the electric motor **240** as a function of time.

Exercise Types

[0115] Thus far, concentric and eccentric exercises configurable with the exercise system **100** have been described. Optionally, isometric exercises are configurable with the exercise system **100**. An isometric exercise is a type of strength training where a joint angle and a muscle length do not vary during contraction. Hence, isometric exercises are performed in static positions, rather than being dynamic through a range of motion. Resistance by the electric motor **240** transferred through the resistive cable **230** to the weightlifting bar **220** allows for isometric exercise, such as with a lock on the motor or cable, and/or through use of a sensor, such as the encoder.

Rotational Movement

[0116] Thus far, the linear movement system **200** species of the exercise system **100** has been described. Generally, elements of the linear movement system **200** apply to a rotational movement system **400** species of the exercise system **100** genus. In a rotary movement system, the electric motor **240** provides resistance to rotational force.

[0117] Referring now to FIG. **4**, a rotational movement system **400** is illustrated, which is a species of the exercise system **100**. The rotational movement system **400** is illustrative in nature and is used for facilitating disclosure of the system. Further, the species of the rotational movement system **400** is to a specific form of the exercise system **100**. However, the illustrated rotational movement system **400** is only one of many possible forms of the exercise system **100** and is not limiting in scope.

[0118] Still referring still to FIG. **4**, an exemplary computer and motorized aided rotational movement system **400** is provided. Generally, FIG. **4** illustrates examples of the structural elements **140** of the exercise system **100**. In the illustrated system, the rotational movement system **400** includes:

- **[0119]** a support base **410**;
- **[0120]** an upright support member **422** affixed to the base;
- **[0121]** an operator support **420**, such as a seat, affixed to the upright support member **422**;
- **[0122]** a hand support **430** affixed to the upright support member **422**;
- **[0123]** a crank assembly **440** supported directly and/or indirectly by the support base **410** or a support member;
- **[0124]** pedals **450** attached to the crank assembly **440**;
- **[0125]** an electric motor **240**;
- **[0126]** a rotational cable **442** affixed to the crank assembly **440** and to the motor **240**;
- **[0127]** control electronics **246** electrically connected to at least one of the electric motor **240** and controller **130**;
- **[0128]** a display screen **492** attached to a display support **492**, which is directly and or indirectly attached to the support base **410**; and/or
- **[0129]** an aesthetic housing **480**, which is optionally attached, hinged, or detachable from the support base **410**.

[0130] In stark contrast with a power generation system where a user pedals a crank and generates power, the system herein described optionally uses an electric motor to provide a resistance against which the person exercising needs to exert force.

Orientations

[0131] As with the with linear movement system **200**, the orientations of the rotational movement system **400** are optionally configurable in any orientation and/or with alternative body parts, such as with the hands and arms instead of with feet and legs.

Resistance/Assistance Profiles

[0132] As described, supra, with respect to the linear movement system **200**, traditional rotary systems have a preset resistance, which is either flat or based upon a fixed cam or set of fixed cams. Referring now to FIG. **5**, resistance profiles **500** are illustrated, where the resistance is in arbitrary units as a function of rotation angle theta. For traditional rotation systems, the resistance profile is flat **510** as a function of rotation. In stark contrast, the exercise system **100** described herein allows for changes in the resistance as a function of rotation within a single revolution of movement and/or with successive revolutions of the rotating element. Typically, resistance variation is a result of changes in the electric motor supplied resistance.

[0133] An example of rotation of a bicycle crank illustrates differences between traditional systems and resistance profiles available using the rotational movement system **500**. A flat resistance profile versus rotation **510** is typical. However, the physiology of the body allows for maximum exerted forces with the right leg at about 45 degrees of rotation of the crank (zero degrees being the 12 o'clock position with a vertical rotor) and maximum exerted forces by the left leg at about 225 degrees of rotation of the crank. The computer controlled electric motor **240** allows variation of the resistance profile as a function of rotational angle **520**. Unlike a cam system or a bicycle equipped with an elliptical crank, the resistance profile is alterable between successive revolutions of the crank via software and/or without a mechanical change.

[0134] Still referring to FIG. **5**, more generally the resistance profile **500** of the rotational exercise system **400** is optionally set:

- **[0135]** according to predetermined average physiological human parameters;
- **[0136]** to facilitate therapy of a weak point in a range of motion;
- **[0137]** to accommodate restricted range of motion, such as with a handicap;
- **[0138]** to fit a particular individual's physiology;
- **[0139]** to fit a particular individual's preference;
- **[0140]** in a pre-programmed fashion;
- **[0141]** in a modified and/or configurable manner; and/or
- **[0142]** dynamically based on
  - **[0143]** sensed values from the sensor **150**; and/or
  - **[0144]** through real-time operator **110** input.

[0145] Several optional rotational resistance profiles are possible, including: a step function resistance profile, a changing resistance profile within a rotation and/or between rotations, a range or programs of resistance profiles. Additional profiles include any permutation and/or combination of all or parts of the profiles listed herein for the linear movement system **200** and/or the rotational movement system **400**.

Combinatorial Linear and Rotation Systems

[0146] Referring now to FIG. **6**, a combinatorial movement system **200** is illustrated. In the illustrated example, a single electric motor **240** is used for control of two or more pieces of exercise equipment, such as:

- **[0147]** an isometric station;
- **[0148]** a linear movement system **200**; and
- **[0149]** a rotational movement system **400**.

[0150] Generally, the single electric motor **240** optionally provides resistance to 1, 2, 3, 4, 5, or more workout stations of any type.

[0151] Still referring to FIG. **6**, an exercise system is figuratively illustrated showing interfaces for each of: (1) a linear movement system **200** and (2) a rotational movement system **200** with a motor **240** and/or motor controlled wheel **462**. The combinatorial movement system **600** is illustrative in nature and is used for facilitating disclosure of the system. However, the illustrated combinatorial movement system **600** is only one of many possible forms of the exercise system **100** and is not limiting in scope.

Sensors

[0152] Optionally, various sensors **150** are integrated into and/or are used in conjunction with the exercise system **100**.

Operator Input

[0153] A first type of sensor includes input sources to the computer from the operator **110**. For example, the hand support **430** of the rotational movement system **400** is optionally configured with one or more hand control **432** buttons, switches, or control elements allowing the operator **110** to adjust resistance and/or speed of the electric motor **240** within a repetition and/or between repetitions. For example, an increase weight button is optionally repeatedly depressed during raising of a weight, which incrementally increases the load applied by the electric motor **240**. A similar button is optionally used to decrease the weight. Similarly foot control buttons **452** are optionally used to achieve the same tasks, such as when the hands are tightly gripped on a weightlifting bar.

Instrumentation Sensor

[0154] A second type of sensor **150** delivers information to the computer of the exercise system **100**. In a first example, the pedals **450** of the bicycle assembly are optionally equipped with sensors **150** as a means for measuring the force applied by a operator **110** to the pedals. As a second example, the linear motion system **200** and/or rotational motion system **400** optionally contains sensors **150** for measuring load, position, velocity, and/or acceleration of any movable element, such as the pedals **450** or the weightlifting bar **200**.

[0155] For example, muscle loading is controlled using the resistance force exerted on the bar by the electric motor. Position, velocity, and acceleration data are provided by an encoder on the motor and are used as feedback in the control system. For additional muscular overload, often more weight is lowered than can be raised. The lowering or eccentric phase of the exercise can be controlled in real-time for eccentric overload. Muscle loading control and data acquisition is optionally performed, for example, in a dataflow programming language where execution is determined by the structure of a graphical block diagram which the programmer connects different function-nodes by drawing wires, such as LabView® or other suitable software.

Radio-Frequency Identification

[0156] A third type of sensor **150** delivers information to the computer of the exercise system **100** from the operator. For example, the operator wears a radio-frequency identification (RFID) tag, such as in a belt, shoe, wallet, cell phone, article of clothing, or an embedded device. The radio frequency identification identifies the operator to the exercise system **100** along with information, such as any of:

- **[0157]** an operator name;
- **[0158]** an operator gender;
- **[0159]** an operator age;
- **[0160]** an operator height;
- **[0161]** an operator weight;

[0162] an operator physical characteristic, such as arm length, leg length, chest size for an exercise like a bench press;

[0163] an operator workout preference;

[0164] an operator workout history; and

[0165] an operator goal.

[0166] The radio-frequency identification tag is of any type, such as active or battery powered, passive, and battery assisted passive. Generally, wireless signal is received by the exercise equipment **100** from a broadcast source, such as from a global positioning system or RFID tag.

Computer

[0167] The motor drive controller **130** is optionally connected to a microprocessor or computer and power electronics that are used to control the electric motor **240**. The power electronics are connected to a power supply such as a battery or power outlet. The computer, the electric drive unit, and the sensors **150** optionally communicate with one another to form feedback control loops allowing the profile of the force and/or resistance applied to the operator **110**. The computer optionally provides: a user interface, data storage and processing, and/or communication with other computers and/or a network.

[0168] A visual feedback system **492** is also optionally used to provide the user with immediate feedback on velocity tracking ability and/or other exercise related parameters. Velocity tracking is particularly useful for systems designed for patients in rehabilitation settings.

Microgravity

[0169] In yet another embodiment, the exercise system **100** described herein is designed for use in a microgravity environment. Variations include use of lightweight materials, straps for holding an astronaut relative to the exercise system, and an emphasis on foldable and/or collapsible parts.

Compact/Reconfigurable System

[0170] As described in U.S. patent application Ser. No. 12/545,324, which is incorporated herein, the system **100** is optionally configured as a compact strength training system that provides the benefits associated with free weight lifting and/or aerobic training. Optionally, structure of the exercise system **100** is optionally manually or robotically reconfigurable into different positions, such as a folded position for storage. For example, the weightlifting bar **220** folds, the operator support **420** folds, and/or the support base **410** folds or telescopes.

[0171] Although the invention has been described herein with reference to certain preferred embodiments, one skilled in the art will readily appreciate that other applications may be substituted for those set forth herein without departing from the spirit and scope of the present invention. Accordingly, the invention should only be limited by the Claims included below.

1. An exercise apparatus for operation by a user, comprising:

a rotatable crank; and

means for varying resistance of rotation of said rotatable crank, wherein said means for varying resistance comprises use of an electric motor.

2. The apparatus of claim **1**, wherein said resistance of rotation varies by at least ten percent during a single revolution of said crank.

3. The apparatus of claim **1**, said means for varying resistance further comprising:

a controller, said controller configured to control the resistance of rotation provided by said electric motor.

4. The apparatus of claim **3**, wherein said controller comprises use of a computer implemented function relating human physiological strength to angle of rotation of said rotatable crank.

5. The apparatus of claim **3**, said means for varying resistance comprising use of data output from a pressure pad, the data used by said controller to control the varying resistance generated by said electric motor.

6. The apparatus of claim **1**, wherein said means for varying resistance of rotation further comprises use of an encoder to determine an angular position of said rotatable crank.

7. The apparatus of claim **1**, said means for varying resistance further comprising use of an accelerometer sensor configured to measure acceleration associated with rotation of a shaft of said electric motor.

8. The apparatus of claim **1**, wherein said electric motor changes level of said resistance of rotation to at least fifteen separate levels during use of a single program in an exercise period of the user.

9. The apparatus of claim **1**, said electric motor configured to supply resistance to movement of at least two workout station user interfaces.

10. The apparatus of claim **1**, further comprising:

a linear movement system, wherein said linear movement system comprises:

a subject interface element;

a resistance cable comprising:

a first cable end attached directly or indirectly to said electric motor;

a second cable end attached to said subject interface; and

a controller, said controller configured to control movement of said electric motor, movement of said electric motor configured to provide a force transferred by said cable to said subject interface.

11. The apparatus of claim **1**, further comprising:

a user interface;

a cable linked to said user interface;

said electric motor configured to supply a resistive force to movement of said cable;

a sensor configured to provide a feedback sensor reading; and

a controller electrically connected to said motor, said controller configured to use the feedback sensor reading in control of the resistive force to movement of at least one of:

said rotatable crank; and

said cable.

12. A method for exercising a user, comprising the steps of:

providing a rotatable crank; and

varying resistance of rotation of said rotatable crank using an electric motor.

13. The method of claim **12**, further comprising the step of:

using a controller electrically linked to said electric motor to vary the resistance of rotation.

14. The method of claim **12**, further comprising the step of:

controlling the resistance at least two user interface stations with said electric motor.

15. The method of claim **14**, wherein at least one of said two user interface stations comprises:

a handle grip; and

a cable linked to said handle grip, said electric motor configured to supply a resistive force to movement of said handle grip.

16. The method of claim **15**, further comprising the steps of:

generating a feedback signal with a sensor; and

using the feedback sensor reading in control of the resistive force applied to movement of at least one of:

said rotatable crank; and

said cable.

17. An exercise apparatus for operation by a user, comprising:

a user interface comprising at least one of:

a rotatable crank; and

a handgrip;

a cable or linkage connected to said user interface;

an electric motor configured to supply a resistive force to movement of said user interface;

a sensor configured to provide a feedback sensor reading; and

a controller electrically connected to said motor, said controller configured to use the feedback sensor reading in control of said motor generating the resistive force.

18. The apparatus of claim **17**, said sensor configured to generate said feedback sensor reading in response to interaction by the user.

19. The apparatus of claim **17**, said controller configured to automatically adapt the resistive force based upon an observation of a mechanical element, said mechanical element not touched by the user.

20. The apparatus of claim **17**, wherein said electric motor comprises an electric servo assist/resist motor.

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