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(54) **CONTROLLABLE TRAINING AND REHABILITATION DEVICE**

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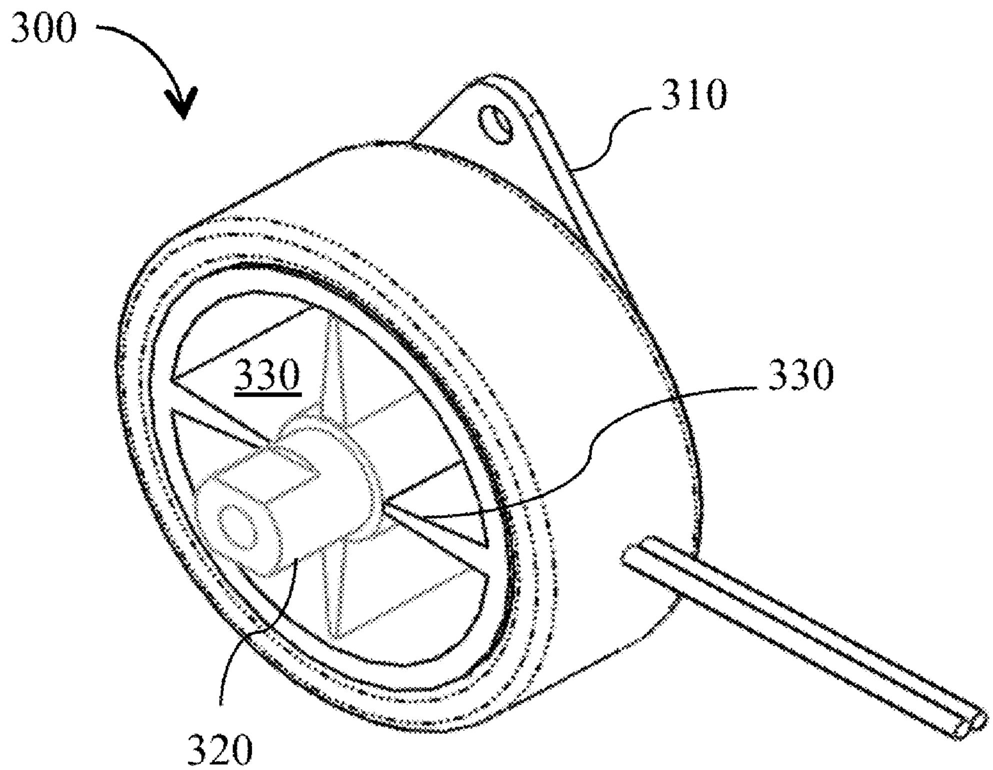
(57) **ABSTRACT**

A muscle training and physical rehabilitation device is disclosed. The device is controllable by liquid based resistive units. The liquid based resistive unit utilizes either smart magnetorheological (MR) liquid whose resistance to motion can be adjusted by electromagnetism or by proportional valves with various liquids whose resistance can be controlled by an electronic signal. The MR fluid resistive units comprises a rotor supported by a bearing inside a housing, a stator mounted together with the housing to the mounting plate, and the MR liquid that flows inside the cavity formed by the vane of the rotor and chamber of the stator. The MR liquid is controlled by the applied electromagnetic field to adjust the resistance according to the exerted toque.



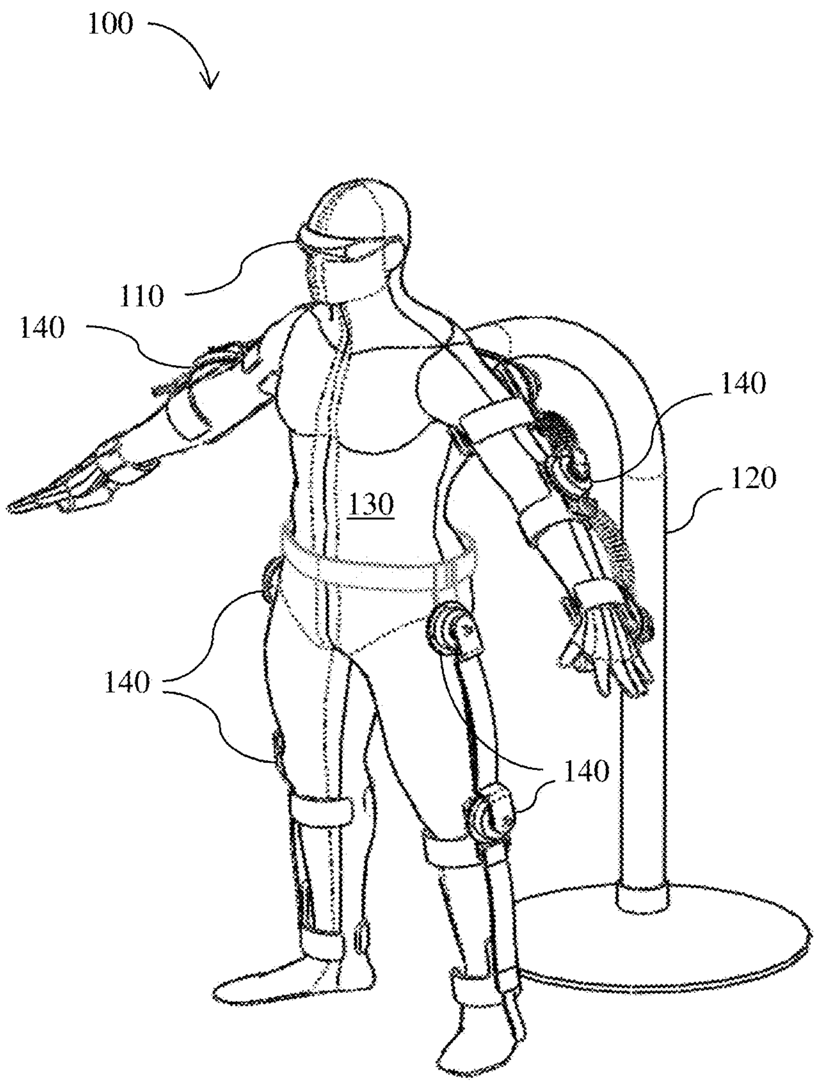



FIG. 1

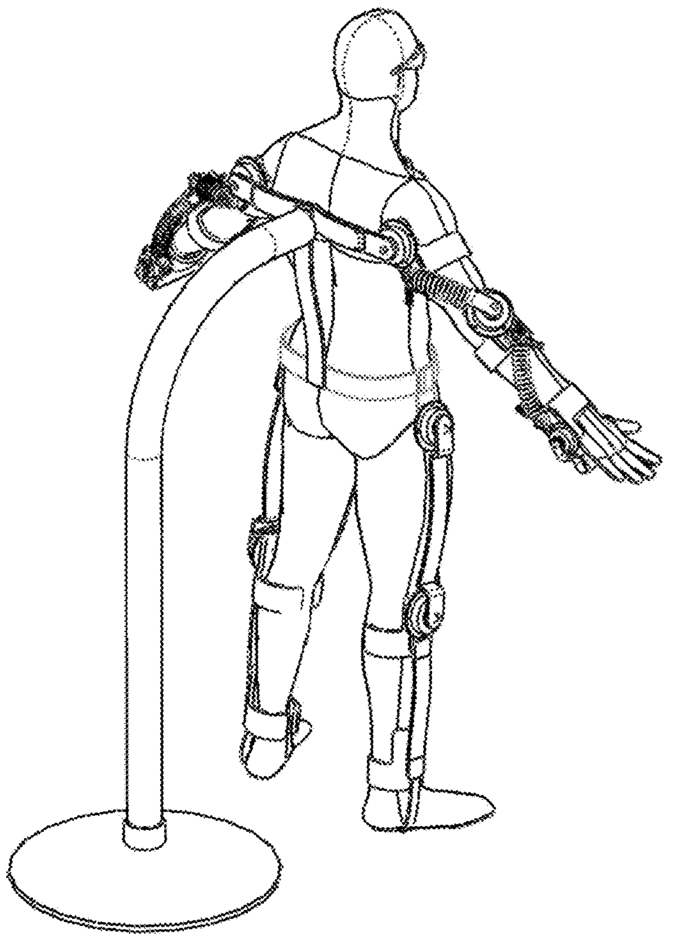


FIG. 2

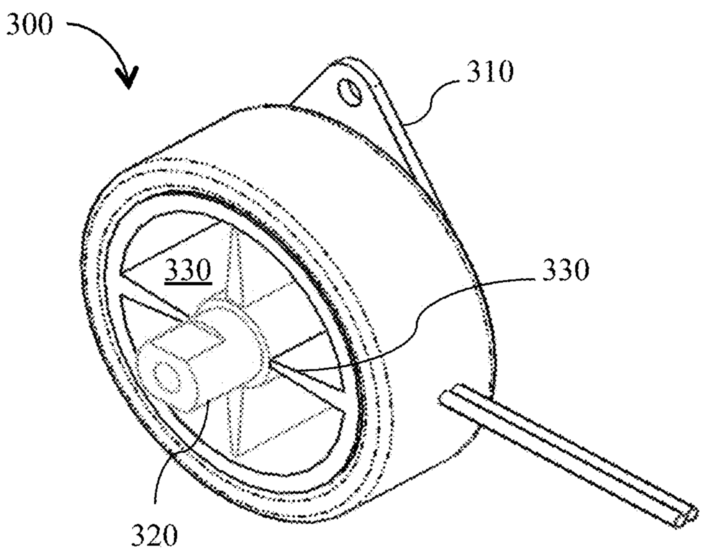



FIG. 3A

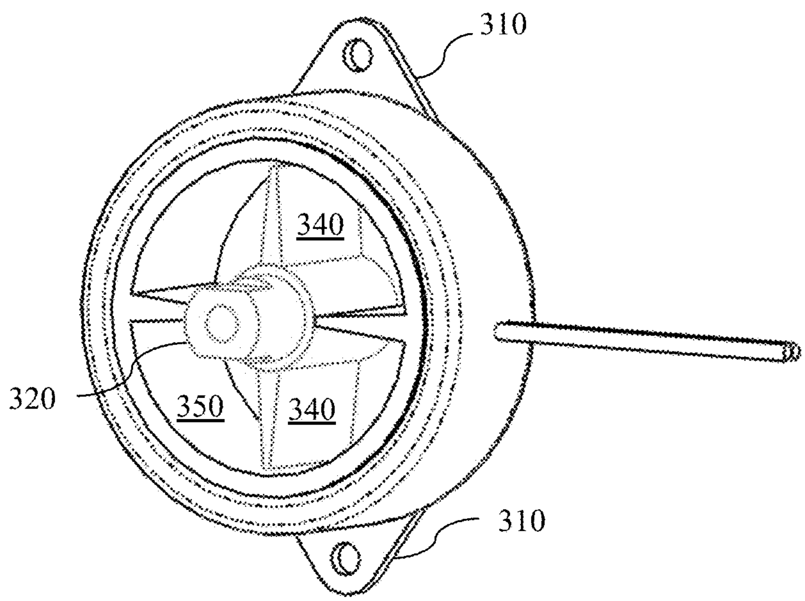



FIG. 3B

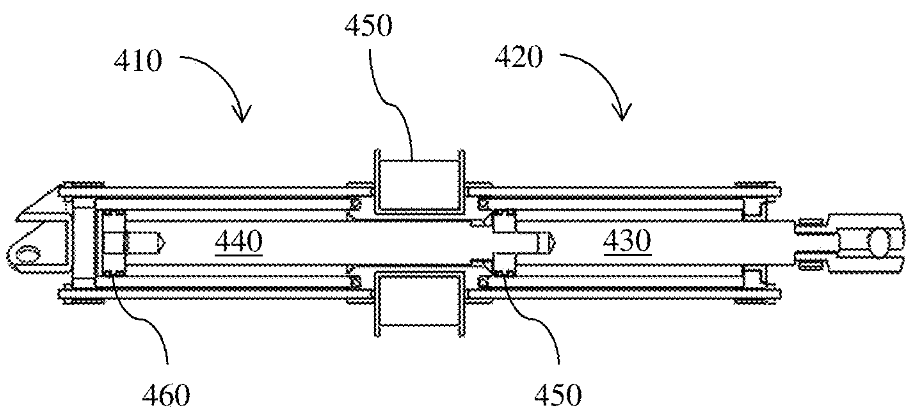



FIG. 4

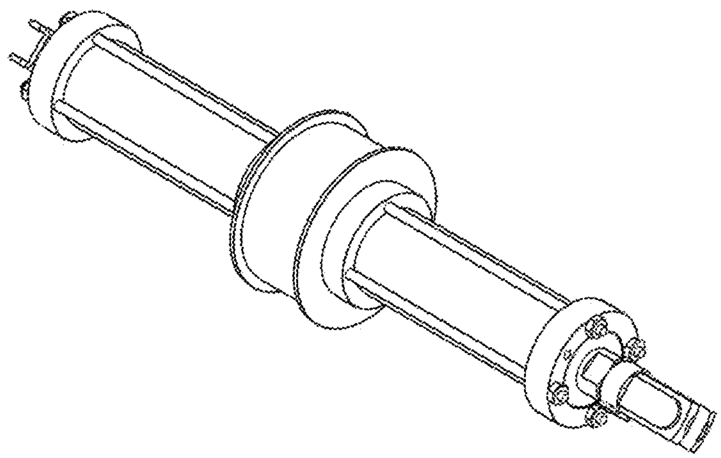


FIG. 5

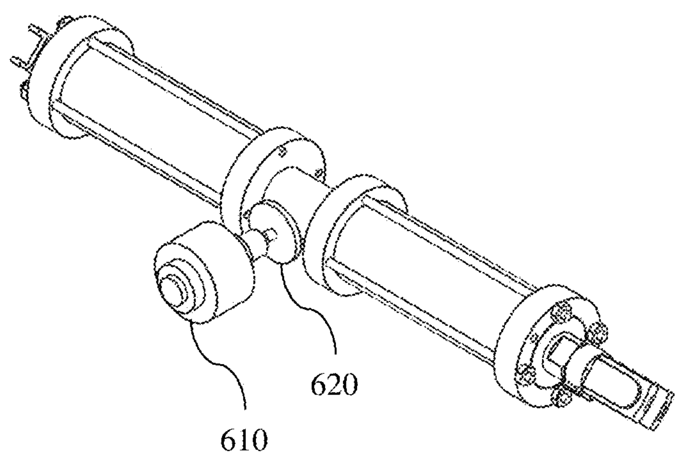



FIG. 6

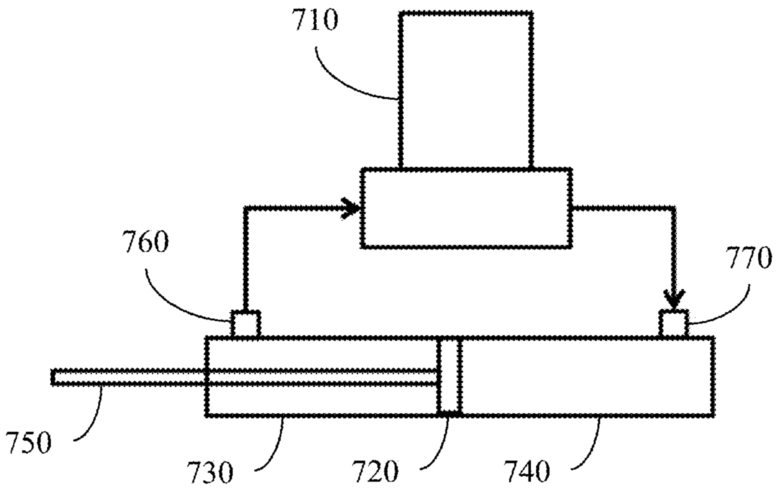



FIG. 7A

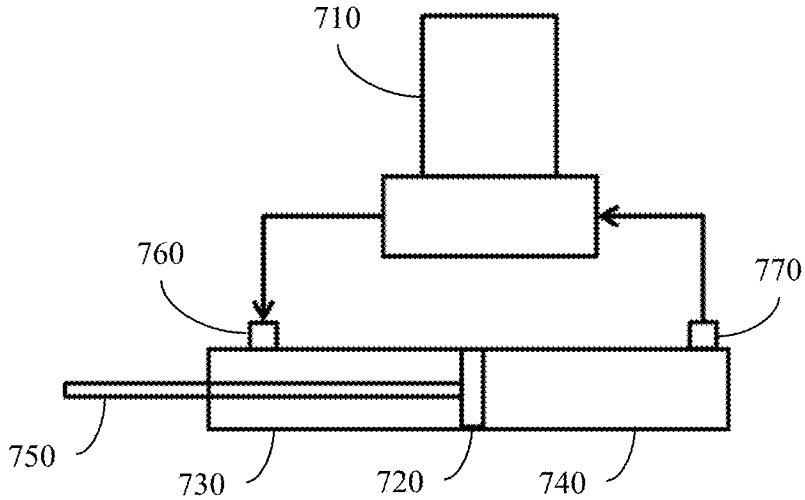



FIG. 7B

# CONTROLLABLE TRAINING AND REHABILITATION DEVICE

**[0001]** This patent application claims the benefit of, priority of, and incorporates by reference U.S. Provisional Patent Application Ser. No. 61616938, entitled "Full Body Controllable Training and Rehabilitation Device" by Alexandr Shkolnik filed on Mar. 28, 2012.

## BACKGROUND OF THE INVENTION

**[0002]** 1. Field of the Invention

**[0003]** The present invention relates generally to an exercise equipment, and more particularly, to a dynamic resistance exercise device.

**[0004]** 2. Description of the Related Art

**[0005]** Various training and rehabilitation devices are used by individuals at home or as public facilities in community. These devices are usually based on simple mechanical systems such as the gravity force from a stack of weights, elastic force from springs, etc, which provide the resistance subjecting to the movement of human body to strengthen the muscles. A lot of exercise machines are developed to train different portion of body, such as stationary bicycles, rowing machines, treadmills, ski trainers, stair stepping machines etc. However, these conventional exercise machines usually only provide fixed resistive force due to the fixed gravity and fixed elasticity. Also, most of these conventional exercise machines are not capable of changing resistance in real time. For example, the user can stack a number of weights before using the weight training device. In the middle of the training, the only way of changing the weight is stopping the training and changing the number of weights, the same situation is for the spring based devices, which is quite inconvenient for the users. Even worse, the conventional devices have limited range of forces. They cannot be used by a large population of users with different ages and different physical conditions. Moreover, most of the devices focus on training a specific portion of the human body. For example, the weight bench machine is mainly for working out the upper body while the stationary bicycle is mainly for working out the lower body. Even so, these devices are quite large and bulky. It is quite desirable to have a portable exercise device that can train the whole body. Other disadvantages of existing exercise machines include annoying noises generated by material deformation and friction, and possibly ill-smelling odor generated by the lubrication oil or rust. This noise and smell may dramatically reduce the enjoyment of the exercise and increase the boredom during the extended exercise period. In addition, gravity and friction based system may be worn out after a certain time period which shortens the lifetime of the device. These worn out exercise systems may injure users when they ultimately malfunction.

**[0006]** In some cases, the user may require feedback regarding the level of performance such as the current speed, force, torque, elapsed time, etc. For physical rehabilitation therapy purposes, the user may also need to know physiological and bio-mechanical information such as oxygen level, breathing rate and heart rate. According to this feedback, the resistance of the device can be adjusted accordingly.

## SUMMARY OF THE INVENTION

**[0007]** Considering the shortcomings of the previously mentioned conventional training devices, there is a desire to provide a portable and controllable machine based on smarter resistance. It is also desirable for the resistance to be adjusted on the fly based on various variables. The resistance may be adjusted by a programmed micro control system working together with various onboard sensors. This can vary the exercise and tune the workout to accommodate the response of the user.

**[0008]** Liquid based resistive units may be utilized for providing improved resistance for an exercise device. In a preferred embodiment, a device utilizes rotary and translational MR liquid based resistive units to provide variable resistance to the user. For a rotary MR liquid based resistive unit, a mounting plate may be utilized to mount the resistive unit to specific joint positions. A rotary resistive unit may be comprised of a rotor supported by bearing inside a housing unit, a stator mounted together with the housing to the mounting plate, and MR liquid that flows inside the cavity formed by the vane of the rotor and chamber of the stator. For a translational MR liquid based resistive unit, two universal junctions may be utilized to connect the resistive unit and two handles which may be grabbled by human hands or other joints that need to be trained. The resistive unit may be comprised of two cylinders, two rods, two pistons, and MR liquid. MR liquid is sealed inside the cylinders between two pistons. Two rods are connected to the universal junctions and move the pistons back and forth inside the cylinders. The MR liquid flows between the two chamber formed by the cylinders and pistons through the gap between the steel rod and steel orifice. The magnetic field created by electromagnets or permanent magnet with adjustable magnitude change the viscosity of the MR fluid and controls the resistance. The viscosity of MR fluid can be changed dramatically and instantly, thus, the device can achieve a large range of adjustable resistance very quickly.

**[0009]** In some embodiments, a set of MR damper units may be mounted at different positions of the body, and multiple resistive units are also used in different rotation directions for different degrees of freedom. The present invention is a true full body trainer including training of the hands, wrist, arm, shoulder, hip, legs, knees, ankle etc. The user can alternately wear the MR unit band for the specific joint training.

**[0010]** The resistance can be adjusted on the fly by the preprogrammed instructions in the micro controller. There is no need for the user to take off the device and manually change the exercise level. With different volume ratio of the magnetic particles in the MR liquid composite, the range of the force can be very large, which allows for the device to satisfy a larger base of users, with different ages and physical conditions.

**[0011]** In another embodiment, a MR liquid based system is substituted with one that is electronically controlled by proportional valves, and may utilize a simple liquid, such as water. Such a device combines a solenoid valve with an electronics package that digitally modulates the control signal to provide analog proportional control without the expensive or complexity of stepper motors, servo valves or other proportioning devices.

**[0012]** In some embodiments, several on board sensors may detect the user's performance as well as physical condition, and this information may be utilized to automatically control the resistance level.

**[0013]** In some embodiments, a VR system may be utilized to improve the enjoyment of exercising. The VR system may also be interconnected with the on board sensors and resistance levels of the various resistive units to determine what is displayed within the VR system.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** A more complete appreciation of the invention and many of the advantages thereof will be readily obtained as the same becomes better understood by reference to the detailed description when considered in connection with the accompanying drawings, wherein:

**[0015]** FIG. **1** is a perspective view of a full body exercise device.

**[0016]** FIG. **2** is a perspective view of a full body exercise device.

**[0017]** FIG. **3**A is a perspective view of a MR liquid based damper.

**[0018]** FIG. **3**B is a perspective view of a MR liquid based damper.

**[0019]** FIG. **4** is a cross section view of double chambered damper with MR liquid and electromagnet.

**[0020]** FIG. **5** is a perspective view of double chambered damper with MR liquid and electromagnet.

**[0021]** FIG. **6** is a perspective view of double chambered damper with MR liquid and permanent magnet with adjustable magnitude.

**[0022]** FIG. **7**A is a schematic drawing of double chambered damper with ordinary liquid and electronically controlled proportional valves.

**[0023]** FIG. **7**B is a schematic drawing of double chambered damper with ordinary liquid and electronically controlled proportional valves.

## DETAILED DESCRIPTION

**[0024]** In a preferred embodiment of the invention is a device that may be utilized for full body muscle training and physical rehabilitation. It may provide real-time controllable resistance by using smart liquid. Smart liquid refers to those materials whose properties can be changed or controlled by various stimuli. In a preferred embodiment a magnetorhelogical liquid (MR liquid) controlled by magnetic field is incorporated in the device.

**[0025]** MR liquid or MR fluid is magnetically polarizable particles suspended in viscous fluids. They have the ability to change their rheological properties under the effect of a magnetic field. They are usually suspensions of magnetizable particles in a carrier liquid. The magnetizable particles are metal or metal oxide particles with size on the order of a few microns. The carrier liquid is also referred to non-magnetic liquid, such as base oil. Additionally, surfactants are used to allow for high particle volume fractions to increase the fluid's stability. Normally, the magnetic particles are randomly distributed in the liquid while no magnetic field is applied, and the suspensions behave as regular liquid. If the suspensions are exposed to a magnetic field, its flow resistance increases. This is because the magnetic particles form chain-like structures parallel to the magnetic field as a result of the magnetic interaction. The rheological properties as shear modulus and viscosity reversibly can change in milliseconds. The chain-like structure can be deformed and destroyed due to external forces, but they will quickly re-form as the external force is decreased or removed.

**[0026]** The magnetic field created by electromagnets or permanent magnets with adjustable magnitude can change the viscosity of the MR fluid and controls the resistance. The viscosity of the MR fluid can be changed dramatically and instantly. Thus, it can achieve a large range of adjustable resistance very quickly.

**[0027]** Controlled by the electromagnet, even small amounts of MR fluid can generate a large and smooth resistive force when the magnetic field is strong. Thus, the unit can be quite small and compact, which allows the exercise device to be light-weight and portable.

**[0028]** MR fluid is not abrasive or toxic, and thusly, environmentally friendly and safe. It does not store energy like a spring or lifted weight, and is not prone to deformation or contacting friction. As such, it is much quieter than conventional exercise devices. In addition, unlike with a spring and weight, the MR unit applies the force in a passive mode. I.e, the human body can feel the resistance only while he/she exerts force, and the resistive force disappears immediately after the user force is released. Thus, it is physically much safer for the user.

**[0029]** Both a rotary resistive unit and a translational resistive unit can be devised using controllable resistance from a liquid, such as MR liquid. These resistive units can be utilized for various muscular exercise and can be the primary source of resistance in a full body exercise device, as depicted in FIG. **1** and FIG. **2**. The full body exercise device **100** is a preferred embodiment that utilizes multiple rotary resistive units **140** with MR liquid. The rotary resistive units **140** with MR liquid are positioned at major joints to control resistance when motion is applied by the user.

**[0030]** Despite prominent advantages of the MR liquid, several disadvantages may hinder its wide applications for different level of customers. Most high-quality MR liquids are quite expensive, and as such, may be cost prohibitive for many. In addition, MR liquid has much higher density, due to the presence of iron, making it heavy. Even though the operating volumes are small for one single resistive unit, the accumulated volume may dramatically increase as the number of resistive units increases, which finally result in cumbersome system.

**[0031]** To overcome aforementioned problem, in another embodiment, an option that utilizes electronically controlled proportional valves is proposed. The device combines a solenoid valve with an electronics package that digitally modulates the control signal to provide analog proportional control without the expensive or complexity of stepper motors, servo valves or other proportioning devices. When the valve is de-energized, pressure is sealed off by the force of the plunger assembly return spring and the seal in the plunger assembly. When the valve is energized, the plunger assembly moves upward, permitting flow through the valve. Higher current or control signal results in more plunger movement and more flow. Using proportional valve, the resistance can be accurately controlled, but the liquid is not necessarily expensive and heavy like MR fluid. The fluid could be a very cheap and light fluid such as water.

**[0032]** The full body exercise device **100**, in another embodiment, can utilize rotary resistive units controlled by proportional valves instead of MR liquid and magnetism. In other embodiments, the resistive units may be utilized for only specific joint positions, and not the entire body.

**[0033]** The preferred embodiment using a rotary MR liquid based unit is shown in FIGS. **3***a* and **3***b*. The rotary resistive unit **300** includes a rotor **320** supported by a bearing within a housing **350**, a stator **330** mounted together with the housing **350** to the mounting plate **310**, and strands of coils wrapped around the stators **330** for inducing electromagnetism. The MR liquid flows inside the cavity formed by the vane **340** of the rotor **320** and chamber of the stator **330**. The mounting plate **310** may be utilized to mount the resistive unit to specific joint positions. As the vane **340** on the rotor **320** rotates between fixed vanes on the stator **330**, MR fluid is displaced through clearances from one side of the vane **340** to the other. Magnetic fields created by electromagnets change the viscosity of the MR fluid and the damper resistance.

**[0034]** Similarly, the embodiment using a translational MR liquid based unit is shown in FIG. **4**, FIG. **5**, and FIG. **6**. FIG. **4** and FIG. **5** show a double chambered damper with MR liquid and electromagnet. In includes two rods **430 440** that drive two pistons **450 460** moving back and force inside two cylinders **410 420**. MR liquid is sealed inside the two chambers formed by the two pistons **450 460** and two cylinders **410 420**. As the pistons **450 460** move inside the cylinders **410 420**, the MR liquid flows though the gap between the steel rod and steel orifice. Strands of coils **450** are wrapped around the junction between two cylinders **410 420** for inducing electromagnet. Similar with the rotary unit, the adjustable electromagnet can precisely control the resistance of the MR liquid.

**[0035]** FIG. **6** shows another alternative embodiment of a double chambered damper with MR liquid. A permanent magnet **620** as opposed to electromagnet is utilized. The magnitude of the magnetic flux is controlled by adjusting the distance between the magnet and the junction. A linear actuator **610** such as solenoid based plunger, linear motor or lead screw with step motor mechanism can be used to drive the magnet unit.

**[0036]** With a translational MR liquid based resistive unit, two universal junctions may be utilized to connect the resistive unit and two handles which may be held by human hands or other joints that need to be trained. The resistance can be highly controlled through the magnetism of the MR liquid.

**[0037]** MR liquid based damper has the advantage of accurate resistance control, but compared with regular liquid, it is much heavier and more expensive. FIGS. **7***a* and **7***b* show an alternative, using a two chambered **730 740** damper based on electronically controlled proportional valves and regular liquid instead of magnet and MR liquid. The proportional valve is driven by a solenoid plunger which is controlled by digitally modulated signals. The system consists of one closed cylinder **730 740**, one rod **750** that drives a piston **720** moving inside the cylinder. The proportional valve **710** is connected to the cylinder **730 740** though two opening **760 770** at both ends. As the system is not energized, the valve is open **710** and liquid flows through the valve with low resistance. As the system is energized, the valve **710** changes the opening size and resistance changes accordingly. The magnitude of resistance is proportional to the input signal modulated by the driver which can be easily adjusted by users. One embodiment of electronically controlled proportional valves using solenoid technology is PACE Hf Miniature Proportional Valve from Parker Inc. (http://ph.parker.com/webapp/wcs/stores/servlet/Product2__1 0151__12051__12176_-1-1__14106__14097_ProductDisplayErrorView) The valve can deliver precise flow with low hysteresis, rapid response and highly repeatable pressure and flow control. In this system, no specific requirement is needed for the liquid, and very cheap and light water can fit the purpose.

**[0038]** A set of damper units are connected by linkages and mounted on different actuation joints of human body such as hands, wrist, arm, shoulder, hip, legs, knees, ankle etc, as shown in FIG. **1** and FIG. **2**. When the user moves the joints, the resistance force changes accordingly, in this way, the muscle can be trained. The device also includes a sensor system comprising a sensor assembly to measure angle, velocity, and acceleration of the movement as well as the elapsed time of training, the sensors along with the microcontroller provide a closed loop system that can adjust the magnetic-rheological fluid according to the user feedback.

**[0039]** The resistance can be adjusted on the fly by the preprogrammed instructions in the micro controller. There is no need for the user to take off the device and manually change the exercise level. With different volume ratio of the magnetic particles in the MR liquid composite, the range of the force can be very large, which allows for the device to satisfy a larger base of users, with different ages and physical conditions.

**[0040]** In some embodiments, several on board sensors are used to detect the signals of the user's performance such as speed, torque, force, training time etc and the signals of the user's physical conditions such as oxygen level, breathing rate and heart rate. The sensors, MR unit and micro-processor form a closed-loop system. The device may be programmed so that the resistive force of the MR unit is adjusted according to the sensor readout. The device may also allow for the user to modify variously settings, such as the level of difficulty, purpose of exercise (e.g. strength training, rehabilitation, etc.), and other variables that will allow the user to customize their workout. Microcontroller takes the customized setting as target and use PID control algorithm to adjust the resistance of MR liquid. The basic idea behind a PID controller is to read the sensor values, then compute the desired output by calculating proportional, integral, and derivative responses and summing those three components to compute the output. In this closed loop system, the resistive force is the system parameter to be controlled. The sensor reading provides the feedback to the control system. The customer setting is the desired set point. At any given moment, the difference between the sensor readout and the set point is used by the control system algorithm (compensator) to determine the desired output to drive the system. For instance, if the sensor readout is lower than the set point, then the output specified by the control algorithm might be to increase the resistance. This is called a closed loop control system, because the process of reading sensors to provide constant feedback and calculating the desired output is repeated continuously.

**[0041]** In some embodiments, to improve the enjoyment of the training process and encourage the user's performance, a virtual reality (VR) smart system is incorporated. The sophisticated micro controller system and 3D software convert the physical components of the device into fully virtual reality scene. The users can be immersed in a VR simulation with visual, auditory and even haptic feedback to the user's performance by wearing the VR 3D goggle. For example, the VR 3D goggle can read the information of user's current joint position through the position sensors, it then displays the scene according to current positions, therefore the user can see a 3D aviator perform exactly the same movement as he/she moves the joints. Another set of sensors are also used to provide the physiological and bio-mechanical information such as oxygen level, breathing rate and heart rate. They are used to drive the virtual environment and collect the performance data. I.e, they can be used to measure a user's level of exertion, which can be used as a means to control and modify the difficulty of VR activity. One embodiment of the VR system is utilizing oculus rift, which is an upcoming high field of view, low-latency, consumer-priced virtual reality head-mounted display. With an incredibly wide field of view, high resolution display, and ultra-low latency head tracking, the rift provides a truly immersive experience that allows user to step inside the virtual scene and explore new worlds like never before. The rift kit is open source and thus provides tremendous flexibility of software and firmware development and integration for the proposed system.

**[0042]** Although the present invention has been described in detail with respect to certain embodiments and examples, variations and modifications exist which are within the scope of the present invention as defined in the following claims.

What is claimed is:

**1**. An exercise device comprising:

a liquid based resistive unit.

* * * * *