1 revolution per 2 seconds (30 rpm). So, for moving the knee slowly at the required torque, a typical DC motor may have to run at speeds greater than 10,000 rpm and require a large gear ratio, e.g., more than 380:1. Then, when the actuator is not powered, the large gear ratio of the DC motor would amplify the frictional drag and greatly impede free movement of the knee. Another reason for preferring electrostatic actuators over standard DC motors is their weight. Motors are based on magnetic fields that are produced by heavy components such as high-current copper windings and iron cores. Conversely, electrostatic actuators can be constructed from lightweight polymers and thin, low current conducting layers, substantially reducing their weight.

[**0058**] In the assist mode **508**, the actuator is programmed to assist movements initiated by the muscle. This mode augments the muscle, supplying extra strength and stamina to the user.

[**0059**] In the resist mode **514**, the device is operating as an exercise device. Any attempted movement is resisted by the actuator. Resistance intensity controls on the control panel determine the amount of added resistance.

[**0060**] In the rehabilitate mode **512**, the device provides a combination of assistance and resistance in order to speed recovery or muscle strength while minimizing the chance of injury. Assistance is provided whenever the joint is under severe external stress, and resistance is provided whenever there is movement while the muscle is under little stress. This mode levels out the muscle usage by reducing the maximum muscle force and increasing the minimum muscle force while moving. The average can be set to give a net increase in muscle exertion to promote strength training. A front panel control provides the means for setting the amplitude of the assistance and resistance.

[**0061**] Then, assuming that the rehabilitate mode **510** is selected, a determination is made as to whether the muscle is under stress. The indicia of a muscle under stress is provided as the output of the muscle stress sensor reaching a predetermined minimum threshold. That threshold is set by the microcontroller in response to front panel functions.

[**0062**] If the muscle is not under stress or if the resist mode **514** is selected, a further determination is made as to whether the joint is moving **522**. The output of the joint position sensor, together with its previous values, indicate whether the joint is currently in motion. If it is, and the mode is either rehabilitate or resist, the actuator is driven to apply force opposing the joint movement **524**. The amount of resistance is set by the microcontroller in response to front panel settings. The resistance may be non-uniform with respect to joint position. The resistance may be customized to provide optimal training for a particular individual or for a class of rehabilitation.

[**0063**] If the joint is not is motion **522** or the monitor mode **510** is selected, the actuator is de- energized to allow free movement of the joint **526**. This is preferably accomplished by using an actuator that has an unpowered clutch mode.

[**0064**] Additionally, if the muscle is under stress **520** or **522** and either the rehabilitate or the assist modes are selected, the actuator is energized to apply force for assisting the muscle **528**. The actuator force directed to reduce the muscle stress. The amount of assistance may depend on the amount of muscle stress, the joint angle, and the front panel input from the user. Typically, when there is stress on the muscle and the joint is flexed at a sharp angle, the largest assistance is required. In the case of knee assistance, this situation would be encountered when rising from a chair or other stressful activities.

[**0065**] As mentioned before, when the device is in monitor mode **510**, measurements are recorded to a non-volatile memory such as the flash memory of the microcontroller (item **420** in **FIG. 4**). Measurements may include the state of all sensors, count of number of steps, time of each use, user panel settings, and battery condition. This and the step of uploading and analyzing the stored information are not shown in the diagram.

[**0066**] **FIG. 6** is a flow diagram specific to an active knee assistance device. This diagram assumes a specific type of muscle stress sensor that measures the weight on the foot. Relative to the diagram of **FIG. 5**, this diagram also shows a step (**620**) to determine whether the knee is bent or straight (within some variation). If the knee is straight, no bending force is needed **624** and power can be saved by putting the actuator in free-movement mode **630**. To prevent problems such as buckling of the knee, the transitions, i.e., de-energizing the actuator, in both **FIGS. 5 and 6** may be dampened to assure that they are smooth and continuous.

[**0067**] Software

[**0068**] The software running on the microcontroller may be architected in many different ways. A preferred architecture is to structure the embedded program code into subroutines or modules that communicate with each other and receive external interrupts (see item **424** in **FIG. 4**). In one implementation the primary modules include control panel, data acquisition, supervisor, actuator control, and monitor modules. A brief description of these modules is outlined below.

[**0069**] The control panel responds to changes in switch settings or remote communications to change the mode of operation. Settings are saved in a nonvolatile memory, such as a bank of flash memory.

[**0070**] The data acquisition module reads the sensors and processes data into a format useful to the supervisor. For instance, reading position from a capacitive position sensor requires reading the current voltage, driving a new voltage through a resistance, then determining the RC time constant by reading back the capacitor voltage at a later time.

[**0071**] The supervisor module is a state machine for keeping track of high-level mode of operation, joint angle, and movement direction. States are changed based on user input and sensor position information. The desired torque, direction and speed to the actuator control the functioning of this module. The supervisor module may also include training, assistance, or rehabilitation profiles customized to the individual.

[**0072**] The actuator control module is operative to control the actuator (low level control) and includes a control loop to read fine position of the actuator and then drive phases to move the actuator in the desired direction with requested speed and torque. Torque is proportional to the square of the driving voltage in an electrostatic actuator.

[**0073**] The monitor module monitors the battery voltage and other parameters such as position, repetition rates, and