When the two parts are joined again, head support **402** comfortably cradles the user's head and pivots about an axis **412** that corresponds to the natural tilt of the human head (the "Azimuth Pivot"). SM actuators **410** connected to neck support **404** and axis **412** provide power to tilt the head.

Rotation of the user's neck with respect to the torso is accomplished by a cervical rotation transport mechanism **408** (CRTM). This mechanism translates in a circular path whose center of curvature corresponds to the anatomical rotation axis of the neck. The entire orthosis is supported by a comfortable torso brace **406** similar to that of modem stationary cervical orthoses.

The basic operation of smart cervical orthosis **400** is similar to that of smart arm orthosis **300**. The individual can communicate with the orthosis using an input device that is best suited to the individual's ability. Appropriate command circuitry will process the user's input and then issue control signals to the Azimuth SM actuator and the CRTM for the desired positioning of the head.

All of the above described assistive devices (prostheses and orthoses) are equipped with very small linear transducers (not shown) that will provide real time measurement of the muscle displacements. These measurements will aid in the calculation of the joint positions necessary for closed loop control schemes.

The system electronics that are-used to control the motion of devices constructed in accordance with the present invention include a computer system, a digital to analog converter, amplifiers and a power supply. The system can operate in open loop mode where no feedback of the joint motion is obtained, or in closed loop mode. In closed loop mode, the joint's position and orientation can be either estimated by models by measuring the voltage applied to the muscles or by using small linear encoders to measure accurately the length of the muscle wire. The latter is considered to be the most efficient method to control these systems.

## Personal Portable Control of Smart Material Actuated Assistive Devices

The assistive devices described and shown herein are preferably controlled using electromyographic (EMG) signals obtained from the patient's residual muscles along with a system of sensors that detect environmental stimulation on the device and provide corresponding feedback signals to the command circuitry. Low level command interface is performed using the EMG signals. Higher level control of the arm, i.e., decision making, is accomplished by the patient's cognitive skills using sensory feedback obtained from the system sensors. The patient's own visual capabilities will be used to supervise the position control of the arm and generate the necessary EMG signals. It is expected that adaptive control gains based on environmental and payload changes will permit the patient to better perform a large variety of tasks, vastly increasing the feeling of physical and psychological comfort in the patient.

As illustrated in FIG. **39**, the control electronics and power are preferably installed on a lightweight portable device worn by the patient. An example of such a portable device is belt **500** as shown in FIG. **39**. Belt **500** is a self-contained system for control of and detection of environmental stimuli on robotic arm **502**.

Belt **500** includes a micro-controller board along with an analog-to-digital (A/D) board and a digital-to-analog (D/A) board. The micro-controller processes software operations such as the control of analog signals to arm **502** and the detection and processing of sensory signals therefrom. The A/D portion of the circuitry converts sensory inputs from a plurality of system sensors such as proximity detectors, tactile sensors (i.e. vibro-tactile array **52** as shown in FIG. **39** and described hereinabove with respect to FIG. **12**), accelerometers and linear encoders integrated into the prosthetic arm. The D/A portion of the circuitry serves as the control output to drive the operational amplifiers that will actuate the muscles within the arm.

Belt **500** further includes components such as a double latch safety shut-off switch (which, when engaged, will shut off all power to the arm), a number pad and a plurality of status indicators (such as LEDs) that provide the patient with the current operational status of the arm. Additionally the batteries which power the entire system, are also located here.

## Conclusion

The examples provided in this disclosure emulate human skeletal structures via actuation with smart material artificial muscles. SM artificial muscle actuators decrease overall weight since they weigh even less than the power connection wires of a servo motor itself, and they perform with the same capability as the servo does. It is shown that these systems can exhibit relatively large motions and their use is possible for artificial limbs. The methods and prototypes presented in this disclosure show that smart material muscles can be used as actuators in artificial human limbs. However, a multitude of design and applications, both medical and non-medical, can be realized with the teachings of the present invention.

The reaction time of some smart materials is not the same when the wire contracts as when it extends, due to the inherent non-linear behavior of the material. Placement of antagonistic smart material in the design of the artificial members will resolve this problem. This antagonistic smart material feature emulates human anatomy, so that smart materials work together to provide a member having the same behavior during extension as during contraction. To avoid overloading and breaking of the smart materials, assistive devices can be equipped with smart material wire arrangements which coordinate the synergies of smart materials. In addition, springs can be added to increase the smart material compliance. Some smart materials have limited life cycles. In these cases, use of a modular smart material design system allows quick and easy replacement in the assistive device.

The present invention will have a wide impact on the biomedical, biomechanical, rehabilitative, prosthetic and orthotic engineering fields. It will lead to new devices, methods, and techniques to help disabled persons perform dexterous and fine tasks and assist medical specialists in accomplishing fast and successful treatments. Robotic systems will be implemented to perform surgical procedures such as knee arthroplasty, neurosurgery, eye surgery, and endoscopic diagnostic and surgical interventions. In addition, robotic and mechatronic technologies will be further implemented to design and control rehabilitation systems as assistive devices for people with disabilities and to develop automated home health care systems.

Various changes to the foregoing described and shown methods and corresponding structures would now be evident to those skilled in the art. Accordingly, the particularly disclosed scope of the invention is set forth in the following claims.

What is claimed is:

**1**. A kinetic prosthesis actuated by artificial muscles providing increased dexterity and agility of an artificial limb, said prosthesis comprising: