PROSTHETIC, ORTHOTIC, AND OTHER REHABILITATIVE ROBOTIC ASSISTIVE DEVICES ACTUATED BY SMART MATERIALS

This application claims the benefit of U.S. Provisional Application No. 60/100,127, filed Sep. 14, 1998 and entitled "Robot Prostheses Actuated by Shape Memory Alloys".

FIELD OF THE INVENTION

The present invention relates to an assistive device, such as a prosthetic, orthotic, surgical or other rehabilitative device, which improves the freedom of movement capabilities of artificial limbs or dysfunctional body parts. More specifically, this invention is directed to an assistive device which is actuated by smart materials and which includes force and torque sensors to more accurately replicate the freedom of motion and sensory capabilities of human limbs.

BACKGROUND OF THE INVENTION

For the more than 43 million Americans with disabilities, and millions of other such patients worldwide, rehabilitation with orthotic and prosthetic (O&P) care subsequent to amputation or injury is a healthcare solution which addresses the problems of escalating healthcare costs and limited access to quality care. Studies have shown that for every dollar spent on rehabilitation, many more dollars are saved by enabling disabled patients to resume normal daily activities after an injury has occurred. When the costs of long-term care are compared to the savings realized by patient rehabilitation, long term care can include institutionalization, adult day care and custodial care at home. Rehabilitation generates revenue because rehabilitated people are more likely to return to work and resume paying taxes, thereby ending claims of wage compensation. Rehabilitation patients are also less likely to require consistent, long-term medical attention. Rehabilitative care and research is, therefore, essential if people with injuries and disabilities are to achieve and maintain independence. (Source: "About Orthotics and Prosthetics", www.adbiomech.com/oandpcare.html, 1999.)

Recently, the possibility of merging robotic and rehabilitative technologies has been expressed with great interest in rehabilitative applications. During the last fifteen years, multi-degree of freedom robot arms and dexterous robotic hands have been built to perform autonomously fine and delicate tasks. Based on this technology, researchers have started experimenting on the electromyographic (EMG) control of multi-fingered hands, tele-operation of complex robotic prosthetic hands, implementation of force sensory feedback on myoelectrically controlled forearm prostheses and design of multi-function robot prosthetic hand mechanisms.

Current actively controlled prostheses, however, have only one or two controlled degrees-of-freedom that are actuated by low power motors. Most extremity prostheses currently in use have a terminal device (such as a hand or hook) controlled either by movements of a shoulder girdle transmitted via a cable (i.e. body powered), or by myoelectric control (i.e., motors triggered by the contraction of muscles in the residual limb). In the latter control method, electrodes embedded in the socket of a prosthesis detect EMG signals generated by contraction of the residual muscles of an amputated limb. These signals provide a trigger for battery powered DC motors which move a hand, elbow and/or wrist of the prosthesis.

Such prostheses, however, provide limited ability to grasp and manipulate small objects. Control of the force of the grip is very gross, due to the lack of sensory feedback. In addition, the weight of the motors, their associated support structures and accompanying gearing systems increase the weight of the prosthesis. Furthermore, excessive system noise obviates the important aesthetic qualities of an assistive device. Improved control of multiple degrees of freedom, along with the provision of sensory feedback, would greatly refine the function of such prostheses.

Robotic systems have also been proposed to perform important tasks in non-medical applications where anthropometrical movement is preferred but human intervention presents inherent risks. Examples of such activities include removal of hazardous waste and decommissioning of nuclear sites. Since these tasks occur in a highly radioactive environment, robotic and other automated systems are required to reduce worker exposure to radiation. Robots operating in these remote and hazardous conditions must have a high weight lifting capability and be able to cover a large workspace. At the same time, they must be lightweight for easy transportation and dexterous enough to move in a cluttered environment. However, existing robotic systems for macro manipulation are characterized by poor payload to weight ratio and are often cumbersome and voluminous.

The conventional systems used to meet the above described robotic applications demonstrate a plethora of limitations. Weak, heavy and voluminous actuators are often incompatible with human anatomy. In addition, a lack of advanced sensory interfaces and the use of conventional control approaches impede interaction between human and artificial members. Human upper and lower limbs have tactile sensing, can perceive changes in temperature and sense when a force is exerted upon the limb as well as judge the appropriate application of a force. Current prosthetic and manipulative articulated devices do not offer these capabilities.

In an effort to reproduce the agility and sensory capabilities of human limbs, current research has sought to mechanically reproduce joint systems on a macro-mechanical scale analogous to the actual dimensions of human limbs. Such research not only includes the testing of mechanical joints themselves, but also the use of contracting materials, such as muscle wire, to imitate muscle motion as it occurs in the human anatomy. Previous macro-mechanical systems which have been created use complex and heavy linkage-type mechanisms that are mostly actuated by electrical motors (i.e., stepper motors, dc servo motors, etc.). These systems are highly dependent upon the unique range of capabilities of the particular device being tested and constructed. Such systems require extensive investments of time and resources that directly increase costs not only due to testing delays but also due to increased difficulty in manufacturing the resulting robotic device.

The present invention addresses the need for a new type of assistive device that is lightweight and provides a better sensory interface among the user, the device and the stimuli in the surrounding environment. Significant weight reduction is realized in a device that uses smart materials as artificial muscle actuators of system joints. The overall interface is improved by incorporating advanced sensors into the design, such as force/torque sensors which sense the weight of the artificial limb and monitor the interactive forces between the wearer and the surrounding environment. There are numerous applications for such devices in physical medicine as a replacement or support for joints, such as legs, hands, feet, knees and elbows. Additionally, these