THE EVOLUTION OF ACTIVE PROSTHETICS

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Abstract

In their long history the prostheses have progressed from simple wooden legs through complex and heavy active research devices to state of the art mind driven robotic limbs. Many hurdles have been cleared during the years of research but still many challenges remain to be solved.

This article provides a summary of the some of the active prosthetics projects, their advantages and disadvantages. This paper gives the reader some sense of perspective concerning the evolution of this field. The paper provides a discussion about the future of active prosthetics as well the problems still not solved.

1. INTRODUCTION

The origin of prosthetics dates back to the early civilizations of Egypt, Greece and Rome, when prosthetic limbs were made out of wood, iron, and bronze. Brutal war battles throughout world history have resulted in extraordinary mortality and morbidity, including grotesque injuries and the loss of limbs. During the 20th century world wars the number of amputees rose to unprecedented levels. The need for advancements in this filed had been recognized by many institutions any many researches began.

Before that all prostheses were passive. They had no synchronization with the patient intended movement. This had resulted altered gait for the patient, much more energy spent when walking and almost impossible hurdle passing (such as stairs). Also the unnatural gait that this prosthesis produces was the cause for many diseases to the remaining joints of the limb. This created the need for development of active prostheses, which had to provide more natural movement with less energy spent by the patient.

In this paper, we will present a review of the work done on some active prostheses projects.

The term ‘active prosthesis’ is typically used to describe a device intended to increase the ambulatory ability of a person suffering from a leg or hand pathology by providing some means of augmenting the power at one or more joints of the extremities.

Unlike passive prostheses, active orthotic devices have the potential of actively controlling the joints of the devices, rather than just simple mechanical coupling that exists with the most common commercial assistive devices. Architectures in which power or torque is added at appropriate phases of the gait cycle might be able to enable users to walk who otherwise could not with passive devices, or allow them to walk more naturally and/or efficiently. Additionally, portable devices such as these have the potential of providing both assistance and therapy at the same time, an extremely desirable property in rehabilitation.

Active prostheses are generally classified as - 1. Active prostheses with state based control via Intrinsic sensing. 2. Active prostheses with biofeedback control or myoelectric prostheses. 3. Myoelectric prostheses with surgical interventions.

The state based designs use the sensors on the prostheses which activates the responding movement (e.g. when the sensor detects pressure on the toe edge of the foot a walking cycle is started).

Myoelectric prostheses collect EMG signals from residual muscles and nerves, process them and generate control signals to the prostheses. It is usually combined with the state based designs to give better results.

Myoelectric prostheses with surgical interventions again uses EMG signals for control, but patients undergo a surgical procedure for either nerves rerouting or implantable sensor placement. This techniques provide much better reliability and functionality then simple myoelectric prostheses.

2. ACTIVE PROSTHESES WITH STATE BASED CONTROL VIA INTRINSIC SENSING

The first controllable active orthosis that could be found is a patent for a hydraulically-actuated device from 1942 for adding power at the hip and knee joints. However, due to the state of the art in controls technology at the time, the device was “controlled” by the physical opening and closing of the hydraulic valves by a cable and linkage system that activates at certain joint angles in the gait cycle. Another early patent from 1951 describes a similar passive device that uses spring-loaded pins for locking and unlocking the joints of the brace at various stages of the wearer’s gait [1].

2.1. Mihailo Pupin Exosceleton

The pioneering work done with exoskeletons by Miomir Vukobratovic and his associates at the Mihailo Pupin Institute in Belgrade in the late 1960s and 1970s is some of the most extensive to date. The work started with a passive device for measuring the kinematics of walking and then quickly progressed to the development of powered exoskeletons. The earliest of these, the ‘kinematic walker’, featured a single hydraulic actuator for driving the hip and knee, which were kinematically coupled. In 1970, the so-called ‘partial active exoskeleton’ was developed, which incorporated pneumatic actuators for flexion/extension of hip, knee, and ankle, as well as an actuated abduction/adduction joint in the hip for greater stability in the frontal plane. This concept was later slightly modified into the ‘complete exoskeleton’ by extending the attachment at the torso to enclose the entire chest of the patient, providing greater trunk support (Fig. 1). More than 100 clinical trials were performed with this device, and a number of patients with varying degrees of paralysis mastered walking using the complete exoskeleton with support from crutches. These devices interfaced with the wearer via shoe bindings, cuffs around the calves and thighs, and a ‘corset’ on the torso. This corset also holds the 14 solenoid valves for the control of the pneumatic pistons. The total weight of the ‘complete’ exoskeleton, after incorporation of lighter valves, was 12 kg. This value does not include the power source and control computer, which are not located on the device

During operation, all of the above exoskeleton devices were driven through a predetermined reciprocating motion via an ‘electronic diode’ function generator. However, a set of three piezo-ceramic force sensors were soon incorporated into the sole of the ‘complete’ exoskeleton foot for use in determining the location and magnitude of the ground reaction force, which in turn was used in the control of the device.

In order to begin to address the problem of being energetically autonomous, a version of the exoskeleton actuated by DC motors was developed. Although the state of motor, battery, and computer technology limited the true portability of the device, this new actuation scheme offered further improvements such as smoother motion and better tracking ability.

One of the most lasting contributions of their work with exoskeletons is in control methods for robotic bipeds. Indeed, Professor Vukobratovic along with Devor Juricic are credited with developing the concept of the ‘zero moment point’ and its role in the control of bipedal locomotion [1].

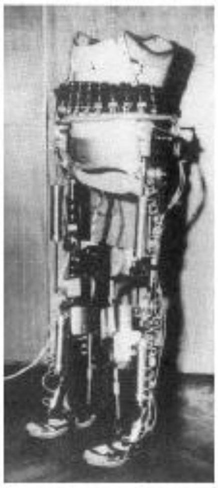

Fig.1 Pupin institute exoskeleton

This type of prostheses use sensors in the foot surface to determine the current state of the movement. Below is a typical state chart of an active prostheses with state based control. The movement start when a threshold weight is applied to the heel.

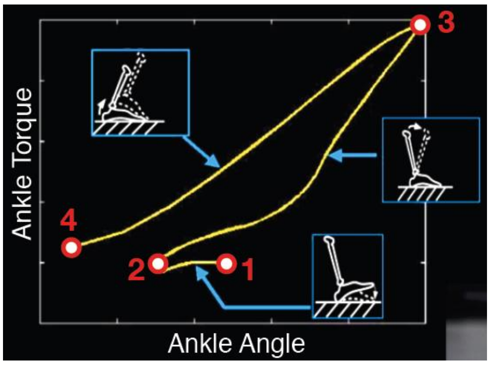

Fig.2. State chart of an active prosthesis with state based control

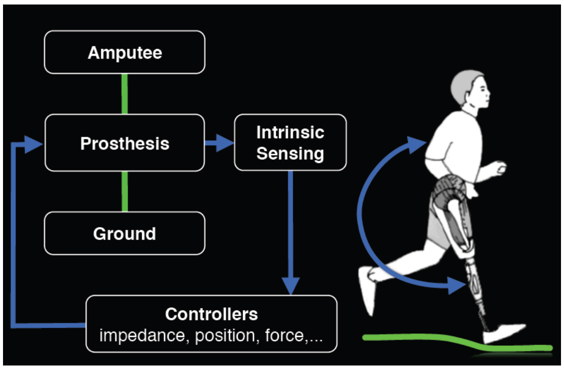

Fig.3. Block scheme of a typical active prosthesis

The advantages of this type of prostheses are the much lower price, the relatively secure interface with patient. They do not need extensive personalization from patient to patient and the process of patient learning is also short. The drawbacks are that this devices don not have any feedback of the actual patient intend, the few degrees of freedom and the absence of different modes of operation such as level walking, stairs climbing or descending. At best there is a manual control for these modes.

3. MYOELECTRIC PROSTHESES

The first myoelectric prosthesis was created in the period 1944-1948 by Reinhold Reiter, then a physics student at Munich University. Because the transistor had not been invented, Reiter was forced to use vacuum tubes for the electronic control system and it was not feasible to make the system portable. Instead this prosthesis was designed for use at a factory bench, powered from the nearest outlet. Even at this early date Reiter recognized the need to obtain maximum information from the myoelectric signal. His system controlled both opening and closing of an electronic hand from a single muscle [3].

There are many designs today that use myoelectric signal to control prosthesis.

The basic principle is to obtain a surface EMG from electrodes placed on the skin above a patient's residual muscles and use the signal from one muscle for flexion and from another for extension. When the muscle originally responsible for a given movement is not available, the myoelectric signal from another which is related also to the movement is used. In this case a more complex algorithm is needed.

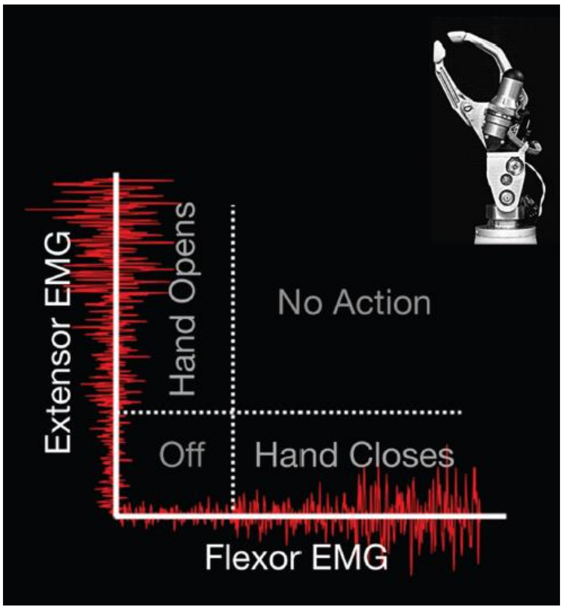

Fig. 4. Myoelectric prosthesis

The main advantages of myoelectric prosthesis are the voluntary movement of the artificial limb, the possibility to apply different force, depending on the strength of the EMG signal and also more degrees of freedom when extracting EMG signal from more muscles.

The disadvantages are that sometimes there are no residual muscles to extract the EMG signal for a given joint (e.g. when we have above the knee amputation we do not have the muscles responsible for the movement of the ankle). Other problems are the need for personalization and adaptation for every patient, since the levels of the EMG signals will be different. Another hurdle is the stability of the connection between the EMG electrode and the patient. If an electrode falls the prosthesis will become unusable. To meet some of this problems new surgical procedures were developed to improve the myoelectric prosthetics.

3.1. Targeted Muscle Reinnervation

In 2001 The Rehabilitation Institute of Chicago developed the targeted muscle reinnervation (TMR) prosthesis, which is an advancement of the myoelectric prostheses. In TMR the nerves from the amputated limb are rerouted to intact, healthy muscle in the body, such as chest muscles (when the prosthesis is for the upper limb), allowing for the movement of the prosthetic limb by thinking about the action to be performed. The nerve impulses generate a muscle contraction which generates EMG signal which in turn is sensed by surface electrodes attached to the surface of the muscle, where the nerves have been rerouted, and carried to the artificial limb to generate movement. The targeted muscle acts as a natural amplifier for the neuronal signals produced by the transferred residual nerves [2].

EMG signal are recorded, then a high-pass filter is used to remove the body movement artefacts. Additional filtering is needed to eliminate crosstalk from other muscles and in case the prosthesis is for upper limb and a chest muscle is used as target muscle, the ECG signal needs to be eliminated from the EMG signal [6].

In November 2012 Zac Vawter successfully used his TMR myoelectric leg to climb 103 floors of Chicago's Willis Tower. This was an exciting event that validated the success of TMR technology.

The obvious advantages of this technology are the voluntary control of the prosthesis and the possibility of adding many degrees of movement.

The disadvantages are the surgical procedure needed, which prove to be unsuccessful sometimes or with side effects experienced by patients. Also the link between the prosthesis and the patient is with electrodes on the surface of the skin which can compromise the functioning of the prosthesis in the event of a bad contact.

Fig. 5 Rehabilitation Institute of Chicago Bionic leg, used by Zac Vawter to climb 103 floors of Chicago's Willis Tower

3.2. Myoelectric prosthetics with implanted sensors

Max Ortiz Catalan from the Chalmers University of Technology in Sweden has developed a new type of myoelectric prosthesis. He and his team use the Osseointegrated Prosthesis for the Rehabilitation of Amputees (OPRA) method developed by Rickard Branemark at Sahlgrenska University Hospital in Gothenburg [5]. This is a new type of method for anchoring prosthesis directly to the bone of the amputee. The method uses the recently discovered property of the titanium to fuse with the bone tissue. The new prosthesis uses a titanium screw implant for anchoring with the body [7].

Then this titanium screw acts as a bidirectional interface with implanted sensors directly attached to the patient nerves. It is a truer replication of how the arm was designed to work, with information from existing nerves being transferred to the limb and to the implant, where algorithms can translate thought-controlled instructions into movement.

The advantages of this method are the secure connection between the patient and the prosthesis. The implanted sensors give signals with much higher amplitudes and less noise. The disadvantages are the need for a more complex surgery for the titanium screw and the sensor implants. Also it is possible that the body will deny the implants.

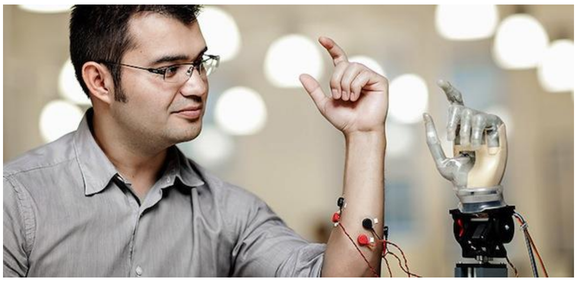

Fig. 6 Max Ortiz and his myoelectric prosthesis

4. DISCUSSION AND CONCLUSIONS

It is evident that the future belongs to the EMG driven prosthetics.

The main area for improvement, remain the development of a secure connection between the patient nerves and the active prosthesis. Also more complex algorithms are needed to process the signals, filter the noise and create the appropriate controls for the prosthesis. Multichannel signal processing will allow more degrees of freedom, hence more natural feeling for the patient. With the complexity however the weight of the prosthesis will become a factor.

There are research ideas to acquire signals directly in the brain of the patient with implantable electrodes.

The targeted muscle reinnervation and the Osseointegration also to stimulate the sensory nerves which can provide the patient with a sensitivity to the artificial limb.

The technologies being developed are not only restricted to the amputees, but they can also be used in the development of exosceletons that can restore mobility to patients with Parkinson disease, stroke or other disorders that disrupt motor behaviors.

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