UPPER LIMB PROSTHESES – FUTURE PERSPECTIVES FOR BODY-POWERED PROSTHESES

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ABSTRACT

Body powered upper-limb prostheses (bpp) have many advantages over EMG-controlled, electrically actuated ones (myo's), including mass, reliability, and proprioceptive feedback. Despite these advantages, bpp are rejected as often as myo's. Reasons mentioned include mass (despite being lower than myo's), and comfort (especially of the harness). In addition, recent research has shown the operating forces of bpp being too high. As a result the main advantage of bpp – feedback – is overshadowed, and the high operating forces negatively influence the comfort.

Current research at the Delft Institute of Prosthetics and Orthotics aims at improving the performance of upper-limb prostheses. First results show a promising future for prostheses controlled and/or powered by body movements, while satisfying the basic requirements for upper limb prostheses.

INTRODUCTION

For centuries mankind has tried to provide people with an arm defect with some kind of a replacement for the limb parts missing [1]. One of the oldest examples known, dating back to 330 B.C, is a prosthetic hand found on an Egyptian mummy. This device is a cosmetic hand prosthesis, i.e. without moving parts, primarily aiming at the restoration of the wearer's outward appearance. Dating from mediaeval times and some later ages, several examples of passive hands remain. Some of them with a moveable thumb only, some with the four fingers moving together in one finger block, and others with passive, individually adaptable, fingers. In these hands the thumb and finger configuration can be locked in a chosen position by the activation of a knob. A few examples are the famous hands of Götz von Berlichingen [2, 3] and the hands made by Ambroise Paré [1].

The beginning of the 19th century brings about a tentative start with actively operated prostheses. Harnessing gross movements of other body segments operates these prostheses. Hence, this type of prostheses is called body-powered (bpp). Examples include prostheses designed by Ballif in 1818 [2], by Van Peetersen in 1844 [2], and by the Count de Beaufort in 1860 [1], Figure 1.

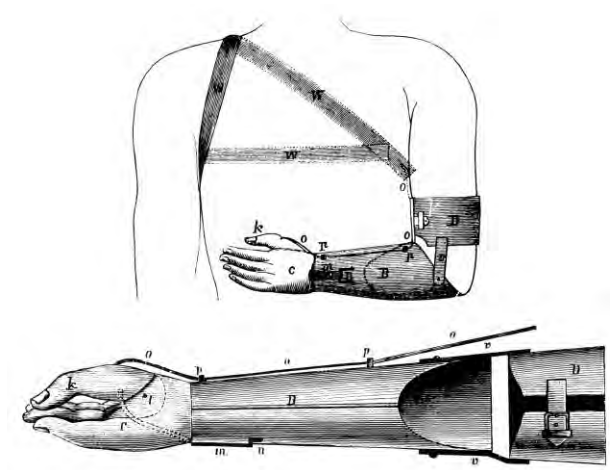

Figure 1 - Prosthetic forearm designed by Count De Beaufort in 1860. The hand is controlled by a cable, indicated by O, which is attached to a shoulder harness.

Around 1900 the first attempts to power prostheses from an external energy source, most likely to relieve the user from the relatively high operating forces in body powered prostheses, can be seen. Examples include electrically powered prostheses [2, 4], or pneumatically powered ones [2, 5].

During WWII the idea of using myo-electric signals for the control of prostheses was conceived [6]. After extensive research and development myo-control evolved into the present day EMG-controlled, electrically actuated prostheses (myo's) and is still the subject for many researches to try and improve this control method.

At the Delft Institute of Prosthetics and Orthotics [DIPO] three basic requirements for upper limb prostheses were established: cosmesis, comfort, and control [7]. Judging bpp and myo's against these requirements it can be seen that bpp have many advantages over myo's, including mass, reliability, and proprioceptive feedback. Despite these

advantages, bpp are rejected as often as myo's. Reasons mentioned include mass (despite being lower than myo's), and comfort (especially of the harness) [8]. Moreover, the functionality of myo's still lacks behind bpp (with the result of the Cybathlon 2016 and 2020 as an example).
Recent research has shed even more light into why bpp are rejected: the operating forces are too high [9-11]. As a result the main advantage of bpp – feedback – is secluded, and the high operating forces negatively influence the comfort.

At the Delft Institute of Prosthetics and Orthotics (DIPO) current research aims at improving the performance of upper-limb prostheses.

METHODS

Within several ongoing projects DIPO tries to improve different aspects of upper-limb prostheses. Four of these projects will be highlighted here:

• Natural grasping
Within this project a body-powered voluntary closing hand prosthesis with adaptive fingers, a high pinch force to operating force ratio, and a low mass will be designed.

• Self-grasping hand
The goal of this study is to design a next generation adjustable prosthetic hand. This prosthetic hand must be able to grasp objects without the help of the sound hand, and without the need of a harness or batteries.

• Haptic interface for prostheses control
This project aims to combine the advantages of externally powered prostheses (low operating effort, high pinch force) with the advantages of body-control (feedback). The idea is to measure movements of the body to control the aperture of the terminal device, and to measure pinch forces in the terminal device and feed them back to the body.

• Servo mechanisms
This project aims to enable prosthesis operation with low operating efforts. The envisioned servo mechanism uses pneumatic energy, as electro-mechanical servo mechanisms suffer from a high mass, and are sensitive for water and dirt.

RESULTS

The current status of the above mentioned project is discussed below.

• Natural grasping
A prototype hand was developed [12]. It has four adaptive, under-actuated fingers and a stationary thumb, Figure 2. The hand requires less energy (50-160%) of the user compared to current bpp-hands, while its mass is only 152 grams. Clinical test are ongoing.

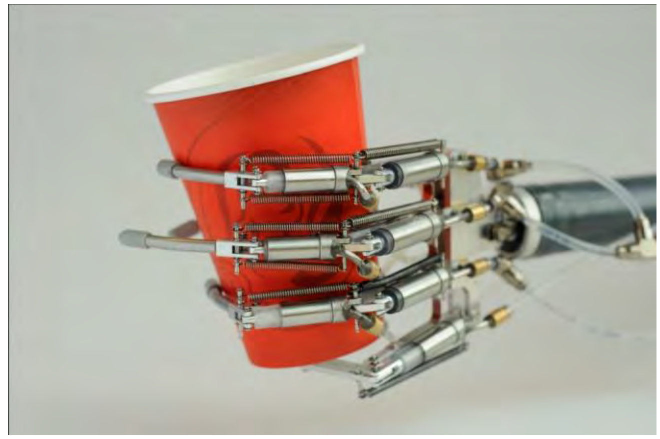

Figure 2 - The prototype of the Delft Cylinder Hand. It has four adaptive fingers actuated with two hydraulic cylinders in each finger, except for the little finger which has only one hydraulic actuator. The springs return the fingers to the open position at rest, and partly compensate for the counteracting forces of the cosmetic glove (not shown in the picture) as well. The cylinders in the hand receive the pressurized hydraulic fluid from a master cylinder incorporated in a shoulder harness.

• Self-grasping hand
Among the users of a hand prosthesis, about one-third uses a passive device. Nonetheless, little research is performed on improving passive hand prostheses [13]. At DIPO an innovative passive hand mechanism was designed. This hand has articulating fingers and can perform the hook grip, power grip and pinch grip. The gripping function is controlled indirectly by pushing an object to the hand, or directly by pushing the prosthetic thumb against a fixed object. The grip force is proportional to the applied push force. By releasing the push force, the grip force is locked and the object is being held. In order to release the object, a button has to be pushed after which the object can be released by pushing the object slightly into the hand. The hand, Figure 3, has a mass of 130 grams. A commercial version of this hand is almost ready for release.

Figure 3 – The Self-grasping hand, shown without the cosmetic glove. In the right picture, the button to unlock the hand is visible on the dorsal side of the hand [www.moveable.nl].

• Haptic interface for prostheses control
The designed interface utilizes skin anchors [14], Figure 4, connected by sensors and an actuator to record force/displacement and to provide feedback from sensors in the terminal device.

Figure 4 – The skin anchors placed on the body of a test subject. The cables are connected to the experimental set-up used verify the idea behind the haptic interface.

An experimental set-up, Figure 5, showed that the system indeed is able to provide input to the terminal device and gives proper feedback to the user [15]. Current activities include the design of a wearable actuator system.

Figure 5 – The experimental set-up. On the left the prosthetic simulator; in the middle and right part of the figure the master-slave unit is shown. Also visible are the cables and on the foreground, the skin anchors.

• Servo mechanisms
A hybrid system, Figure 6, was designed that closes a voluntary closing terminal device by a Bowden cable as usual, and automatically activates a pneumatic servo as soon as an object is grasped. The output of the servo is proportional to the cable force, with a three-fold amplification.

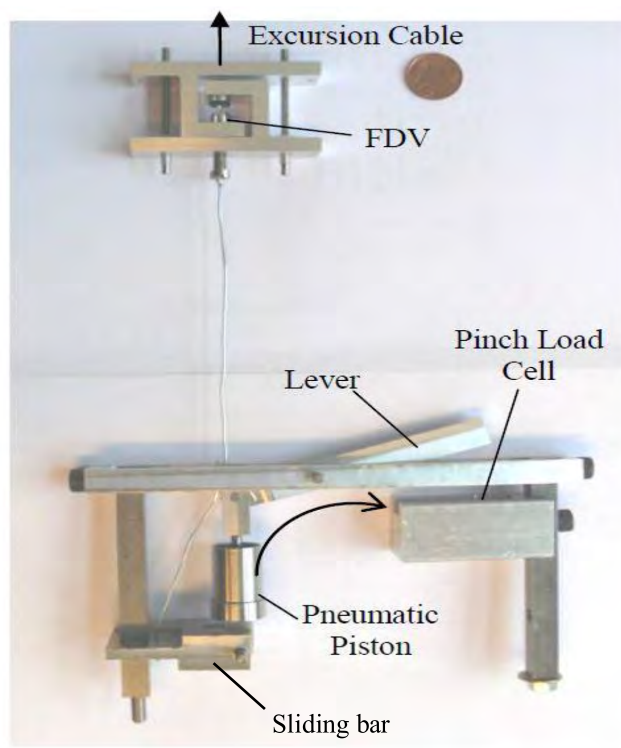

Figure 6 - An overview of the experimental setup. A cable (excursion cable) is connected to the force demand valve (FDV). The sliding bar will move when the excursion cable is pulled, this movement will cause the lever, which mimics a finger of the hand prosthesis, to rotate. Once the lever reaches the pinch load cell, representing the object to be grasped, the force in the excursion cable will rise. This increase in force will cause the FDV to start increasing its output pressure, which is connected to the pneumatic

piston. This will cause the pneumatic piston to start applying force on the lever. The same force locks the sliding bar.

DISCUSSION AND CONCLUSION

The current projects at DIPO all show the future promises for upper-limb prostheses. The Delft Cylinder Hand is the first hand prosthesis that fulfils most requirements of the user: low mass, low operating effort, and proprioceptive feedback. The haptic interface shows a promising way of avoiding the harness, while maintaining the proprioceptive feedback. In combination with the pneumatic servo mechanism a prosthesis that combines body-control with a low operating effort comes within reach.

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