VOLUNTARY CLOSING PROSTHESES

An answer to user needs!

Dick H. Plettenburg, Gerwin Smit

Delft Institute of Prosthetics and Orthotics, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands
d.h.plettenburg@tudelft.nl; www.dipo.3me.tudelft.nl

INTRODUCTION

In order to meet the needs of a person with an arm defect, many, sometimes conflicting, requirements have to be fulfilled. These requirements can be summarized into three basic demands: cosmetics, comfort, and control [1, 2]. In the control domain natural, intuitive, subconscious control is strived for. To achieve this type of control proper feedback needs to be present [3]. This implies control according to the voluntary closing principle. In body-powered, body-controlled prostheses voluntary closing control enables proprioceptive feedback of position, velocity, and force to the user through the bodies own proprioceptive system, comparable to the way we use a tool, e.g. a tennis racket [4, 5].

The Delft Institute of Prosthetics and Orthotics (D IPO) has started several projects to develop body-powered, body-controlled voluntary closing hand prostheses. Current projects include a voluntary closing hand for toddlers, where the reduction of glove forces acting is the main challenge; a voluntary closing prehensor similar in looks to the already existing and successful appealing prehensor [6], where the main challenge is a variable advantage mechanism to promote fast sizing of powerful grasps; a wrist-operated voluntary closing prehensor, where the challenge is to incorporate novel hydraulics; and a study into the psychophysical properties of shoulder harnesses, where the main challenge is to identify the optimal force and excursion windows. Ultimately, we aim at voluntary closing hands that provide adaptive grasp patterns. Adaptivity enhances the natural appearance [cosmetics], and at the same time reduces the need for high pinch forces [comfort, control].

Each of the above mentioned projects is briefly described below.

VC HAND FOR TODDLERS

In active, toddler sized hand prostheses the cosmetic glove introduces a stiffness which causes the required operation forces to be too high to be generated by toddlers. Measurements on several cosmetic gloves of identical size and brand, showed different glove stiffness characteristics. The goal of this project is to design a voluntary closing toddler sized hand prosthesis using an adjustable glove compensation mechanism. A prototype of the glove compensated hand prosthesis was designed. The design is based upon the WILMER passive hand prosthesis for toddlers [7] and utilizes a spring mechanism with negative stiffness to compensate for the glove forces [8]. Future work should determine the feasibility of the design.

VC PREHENSOR

A relatively new project aims to convert the already existing and successful appealing prehensor [6], which operates in a voluntary opening fashion, into a voluntary closing device. Most likely, the design will incorporate a variable advantage mechanism to promote fast sizing of powerful grasps, similar to previous designs made within DIPO [9].

WRIST-OPERATED VC PREHENSOR

Currently, a person with an arm defect can choose between an electrically powered or a body-powered prosthesis. Both options have their own inherent advantages and disadvantages. The electronic prosthesis can be esthetical and easy to use, but is heavy, expensive and vulnerable. The body-powered prosthesis is cheap and reliable, but requires an uncomfortable shoulder harness to be operated.

Over a decade ago, a prototype of a new voluntary closing prosthesis was conceived [10]. It does not need external power or a shoulder harness to be operated, combining advantages of both types of prostheses. This is realized by using passive flexion of the prosthetic wrist to power the prosthesis. An integrated locking mechanism allows the user to hold an object without exerting any operating force.

A recent study [11] showed the feasibility of wrist flexion operation. Subsequently, a prototype of the new voluntary closing prosthesis was designed. It comprises a hydraulic system containing a pressure controlled pressure intensifier, an automatic locking system, and some novel hydraulic actuators. All components are built and tested. The results show the viability of the new concept [12].

PSYCHOPHYSICAL PROPERTIES OF SHOULDER HARNESSSES

High rejection rates indicate users are not satisfied with the performance of their arm prostheses. In theory, the advantage of shoulder controlled prostheses is that the user receives direct proprioceptive feedback about the opening width and pinch force of the terminal device. However, the operating forces of commercially available voluntary
closing prostheses are high, leading to discomfort and disturbing the direct proprioceptive feedback.

As a start, a pilot study was performed to find the optimal operation force, at which the user receives optimum force feedback during comfortable prosthesis operation [13, 14]. During experimental research, subjects were asked to reproduce a reference force, with and without visual representation of the forces produced. The subject’s performances of blind generated forces regarding the reproductibility, stability and repeatability were evaluated to find an optimal cable force. The performances of male and female subjects, with and without arm defects were compared.

The optimal operation force level is between 20 and 30N for male and female subjects without arm defects. No differences in stability and repeatability performance are found between subjects with and without an arm defect. Subjects with arm defects the reproductibility optimum is found between 10 and 20N as they have difficulties reproducing high force levels (> 30N).

Future work will extend the force measurements and combine them with measurements for the optimal cable excursion feedback. Hence, a proper understanding of the proprioceptive feedback capabilities of a prosthetic user is gained. From here, the optimal control forces and displacements can be determined. These will serve as the basis for the design of a new physiological control system.

VC HAND WITH ADAPTIVE FINGERS

When it comes to body powered prostheses, most users prefer a hook over a hand. Body powered hands require an uncomfortable high activation force [15, 16], produce a relatively low pinch force (<15 N) and have stiff fingers. Despite all its drawbacks, the design of body powered hand prostheses almost has not changed since the 1950’s.

The goal of this study was to design a new body-powered, voluntary closing hand prosthesis, which has articulating fingers. This hand should require an operation force within a comfortable level.

A new hand was designed and prototype [17]. The hand uses hydraulics, to enable an efficient transmission and to avoid the use of an inefficient Bowden-cable. The fingers have articulating MCP- and PIP-joints, enabling both precision and cylinder grasp. The fingers are actuated by individual hydraulic cylinders, which fit inside the fingers. The cylinders can be operated at a high pressure (>50 bar), which enables a high pinch load (>30 N). The user can operate the hand by activating a hydraulic master cylinder, attached to a shoulder strap. The hydraulic hand is fast and reliable, due to the use of body control. The hand provides feedback to the user, which enables accurate force and position control.

REFERENCES