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Smartphone supported upper limb prosthesis

Abstract: State of the art upper limb prostheses offer up to six active DoFs (degrees of freedom) and are controlled using different grip patterns. This low number of DoFs combined with a machine-human-interface which does not provide control over all DoFs separately result in a lack of usability for the patient. The aim of this novel upper limb prosthesis is both offering simplified control possibilities for changing grip patterns depending on the patients’ priorities and the improvement of grasp capability. Design development followed the design process requirements given by the European Medical Device Directive 93/42 ECC and was structured into the topics mechanics, software and drive technology. First user needs were identified by literature research and by patient feedback. Consequently, concepts were evaluated against technical and usability requirements. A first evaluation prototype with one active DoF per finger was manufactured. In a second step a test setup with two active DoF per finger was designed. The prototype is connected to an Android based smartphone application. Two main grip patterns can be preselected in the software application and afterwards changed and used by the EMG signal. Three different control algorithms can be selected: “all-day”, “fine” and “tired muscle”. Further parameters can be adjusted to customize the prosthesis to the patients’ needs. First patient feedback certified the prosthesis an improved level of handling compared to the existing devices. Using the two DoF test setup, the possibilities of finger control with a neural network are evaluated at the moment. In a first user feedback test, the smartphone based software application increased the device usability, e.g. the change within preselected grip patterns and the “tired muscle” algorithm. Although the overall software application was positively rated, the handling of the prosthesis itself needs to be proven within a patient study to be performed next. The capability of the neural network to control the hand has also to be proven in a next step.

Keywords: upper limb prosthetics; artificial hand; prosthesis; flexible hand; smartphone

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1 Introduction

In Europe, the number of amputations of the upper limb has been decreasing for several years. Although standards of patient-centred care in orthopaedics have improved in the last decade, the loss of an upper limb is still a huge constraint to patients. In Germany, thirty-five amputations of the upper limb [1] were carried out in 2013, while more than 5,000 patients are living with this diagnosis [2].

The human hand offers 22 DoFs and an efficient feedback system, being one of the most difficult parts of the body to replace. Today’s prostheses offer six active driven axes serving twelve DoFs coupled in pairs [3]. Motors are located inside the fingers or the mid-hand with one or two joints realized per finger. They are controlled with EMG signals allowing a limited level of control [4–6]. The patient is restricted to send close and open signals, while further control needs to be carried out by pre-defined grip patterns [3]. Those have to be generated by special control signals. Although existing prostheses are capable to perform different grips, they still do face two main challenges:

1. Poor usability due to complicated grip pattern change [6]
2. Less form fit due to kinematic coupled finger joints, less active axes and inflexible structure [3, 6, 7]

Mentioned constraints lead to higher energy consumption and a decreased ability to grasp and handle small objects.

Recent developments, such as the smarthand project [5, 7] as well as the modular prosthetic limb at the Johns Hopkins University [8, 9], improved the control of artificial limbs by implanting different kinds of sensors in the nerves or into the brain. The DLR hand [10] of the German Aerospace Centre increased the number of active driven axes. However, these improvements led to an oversized prosthesis or robotic hand compared to the human hand [7].

In order to avoid mentioned constraints, a novel concept of a prosthetic limb was developed, offering an elastic and flexible hand, a high form closure and a natural behaviour without loss of speed or grip force. A higher number of active DoFs combined with torsionable hinge joints, a passive distal finger joint are used. A smartphone based control unit offers a state of the art level of usability.
2 Methods

Design development followed the design process requirements according to the European Medical Device Directive 93/42 ECC and was structured into the topics mechanics, software and drive technology. User needs were identified by literature research and patient survey. Already marketed prostheses were evaluated. Finally, design input results were used to develop concepts of the novel prosthesis.

2.1 Patients’ needs

Main user needs identified can be structured as followed:

– capability of grasping and handling small objects
– simplicity of prosthesis control
– moving single fingers independently
– grasp force feedback

Performed patient survey showed that two grip patterns are used on a regular basis in everyday live. This is due to the complex methods of changing the grip patterns and the lack of the prosthesis’ mechanical capability to grasp and manipulate small objects. These circumstances lead to a poor level of usability and reduced acceptance of the prosthesis.

2.2 Benchmark of marketed prostheses

Most commercially available upper limb prostheses are in their dimension comparable to their human model. They are equipped with only one motor per finger which directly moves the metacarpophalangeal and the peripheral interphalangeal joint. No prostheses have been found with a distal joint implemented. All prosthetic hands available have an inflexible, adamant structure [3] made of hard plastic or aluminium with hinge joints consisting of steel axes. Even most prototypes of robotic hands and prostheses use this concept resulting in a largely unnatural movement and passive behaviour of these hands [7, 8]. Summarized, the mechanical hand can realize a punctual contact to grasped objects’ shape only, which is noticeable especially with small and flat objects.

Using EMG signals does not allow the transmission of enough different signals to control all DoFs of the prostheses directly and independently. To move all fingers anyway, predefined grip patterns are used. The patient has to select these grip patterns with special switch signals which can be used with control signals afterwards. Therefore it is necessary to be able to separate the signals from each other. Switching signals demands a high level of patients’ concentration. In addition, the separation between switch and control signal does not always work faultless.

Summarized, the following requirements identified need to be fulfilled by a novel prosthesis concept:

1. simplified and intuitively usable control offering a fast change between two favourite grip patterns
2. improved form-fit grasp capability

3 Results

The hardware manufactured consists of five force-controlled motors, a flexible mid-hand and fingers each equipped with two joints, allowing flexion, extension and torsion. The thumb can be manually brought into opposite position by the user. Communication between hardware and smartphone application is realized with Bluetooth technology.

Figure 1: Prototype of the hand.

For economic reasons, the hand (Figure 1) and its electronic unit are designed modular and scalable. This allows to build different hands, e.g. more or less complex, with a minimum number of parts and the appropriate software package. The hand and its different subsystems (hardware control, signal processing, Bluetooth, etc.) are connected with a bus system regulated by the main control.

3.1 Smartphone supported control

The prosthesis control can store two favourite grip patterns, allowing the patient to select among them by using a short co-contraction. The preselected patterns can
be chosen via smartphone application, e.g. lateral pinch and power grasp (Figure 2). In addition, the patient can adapt the control of the hand to his needs by modifying the control-mode (all-day, fine, tired muscle), the sensitivity of the signal detection and other important features without connecting the prosthesis to a computer or consulting an orthopaedic technician.

Figure 2: Smartphone app "grip pattern change".

3.2 Form fit

The hand consists of multiple parts connected with flexible and compliant structures offering an improved form fit. The peripheral interphalangeal joint consists of a flexible element allowing flexion and extension as well as, in a limited range, torsion of the finger. This enables the fingers to have a better adaption to uneven surfaces compared to fingers with a classic hinge joint. The distal phalanx is connected to the finger in full flexion and is able to (over) extend passively (Figure 3a). This enhances the finger’s form fit during grasping (Figure 4).

Figure 3: a) Movement of the passive finger tip b) Segmented mid-hand.

Figure 4: Grasping sequence of the distal phalanx.

The mid-hand is separated into three parts and is interconnected with flexible links made from silicone (Figure 3b). The segmented “metacarpal bones” interconnected with elastic elements offer a hand-vault like structure comparable to the human hand. The mid-hand is attached to a flexible wrist capable of passive extension, flexion and rotation of the whole hand and can be locked in neutral position if necessary.

4 Discussion

The approach of a modular and scalable prosthetic system is expected to be more complex in development, but
will offer an appropriate and patient individualized medical solution to a wider range of patients compared to existing competitive systems.

The overall mechanical stability may be reduced due to the high level of flexibility and number of joints. However, the elastic connections made from silicone do dampen impacts which results in an increased durability of the structure against external peak loads. If necessary, enhanced shock absorbing elements need to be implemented. As a side effect the flexibility offers a more natural haptic.

Patients certified the prosthesis concept a high usability due to the “two grip pattern mode” and rated the smartphone based application control as an improvement. Although the overall system was rated positive within a first user feedback survey, a detailed user study over a prolonged time needs to be carried out.

5 Conclusion and outlook

The proposed concept shows promising solutions to the points “size”, “weight”, “number of DoFs” and in particular usability. In order to transfer the system into the next stage, the following design work needs to be continued:

i integration of tactile sensors into the fingers providing grasp force distribution
ii implementation of miniaturized brushless motors
iii test set-up of a neural network
iv active opposition of the thumb

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