PRELIMINARY EXPERIENCE WITH HYDRAULICALLY DRIVEN HAND PROSTHESSES

Christian Pylatiuk, Artem Kargov, Reinhold Oberle, Heinrich Klosek, Stefan Schulz
Forschungszentrum Karlsruhe GmbH, Institute for Applied Computer Science (IAI),
P.O. Box 3640, D-76021 Karlsruhe, Germany
phone: ++49-7247-82-2430, fax: ++49-7247-82-5786, E-Mail: pylatiuk@iai.fzk.de

INTRODUCTION
The need for further development of prosthetic hands with enhanced functionalities and better cosmetic appearance than conventional prosthetic hands became evident in many investigations of this topic [1-3]. Consequently, a new generation of multi-articulated hands for prosthetic application were designed in the past decade. Some of these hands are characterized by a multitude of miniature DC gear motors integrated into the hand [4-8], or by an underactuated mechanism driven by a single DC motor [4,9]. However, the transition from an experimental hand to a clinically viable hand is a crucial test for any new development. Different approaches using fluidic actuators were chosen by [10] and by our research group [11]. Unlike [10], we do not use a pneumatic drive system powered by pressurized CO₂ from disposable cartridges, but a compact electro-hydraulic system. Its components are micropump(s), microvalve(s), a reservoir, a controller, and small flexible fluidic actuators integrated into the finger joints. The flexible fluidic actuators expand during inflation, generating the flexion movement of the digits, whereas the extension movement is achieved by elastic elements [11]. Publications on standards for prosthetic hands and criteria to meet user requirements [1-3, 12] were analyzed and taken into consideration in designing new experimental hands. The results obtained in the first year with three hydraulically driven experimental hands are displayed and test experiences are presented.

FIRST PROTOTYPE
Designing the first hydraulically driven experimental prosthetic hand served these purposes: (1) Demonstrate the feasibility of a hydraulic mechanism as an alternative to DC motors. (2) Move the center of mass from the hand towards the residual limb by placing heavy components (valve and DC motor-driven micropump) on an external unit. (3) Design a multi-articulated hand able to grasp adaptively. Finally, the hand should have an anthropomorphic design and fit into a cosmetic glove.

Fig. 1: The first prototype with 14 dependant DOF’s.
The hand is divided into two parts connected by a pressure line and a conductor. The external power supply contains the micropump (Speed 300 from Behotec, Bergkirchen, Germany) of 69 mm x 32 mm, a valve (A321-OC2 from Camozzi, Italy), the microcontroller (Infineon C164CI), and high-current NiMH batteries (Varta VH4000 4/3A). Measurements of power consumption indicated the need for a battery capacity of 4000 mAh to allow the hand to be operated for 12 hours with one charge. The digits include a framework of carbon fiber reinforced plastic “bones,” and the joints are made of aluminium of high tensile strength. A total of 14 small flexible fluidic actuators are integrated in the digits at the metacarpophalangeal (mp) joint and at the interphalangeal (ip) joints which can be flexed up to 90° each. The thumb has only two joints, i.e. one base joint allowing a palmar abduction movement of the thumb, and one ip joint rotated by 30° in relation to the base joint, resulting in a thumb plane of motion of 60° in relation to the plane of the palm, which proved to be beneficial [9]. A 34 year old test person with congenital transradial limb deficiency appreciated the low weight of the hand mechanism (140 g) and the flexibility of the digits, but also said that he would not accept the lower weight if it meant wearing a separate pressure supply unit. All actuators were connected to each other in such a way that they were inflated at the same time, resulting in a tangential force of 4 N at each finger tip. Despite the low force, cylindrical objects with a maximum diameter of 120 mm and a weight of approx. 2 kg can be held, as the contact area between the object and the hand is increased by conforming to the shape of an object [13]. However, the maximum grasping force was rated by the test person to be too low. It was restricted largely by the maximum operating pressure of 4 bar. Also, the grasping speed of 3 s was found to be too slow, which can be explained by the quotient of the maximum pump flow rate of 400 ml/s and the volume needed to fill 14 actuators. Finally, the hand was covered with a latex glove which offered reasonable functionality. The cosmetic appearance was rated as unsatisfactory as that of PVC gloves.

SECOND PROTOTYPE

A new prototype design was to fulfill these criteria:

- Integration of the pressure supply unit into the socket of the hand.
- Five different prehension types possible: tripod prehension, cylindrical grasp, lateral prehension, hooks grasp, and index position.
- Increased grasping speed.
- Modularity of the skeletal framework and the joints to allow different hand sizes to be designed and reduce production costs.
- Reduced noise level of the micropump.
- Hardware and software for multifunctional control.

Fig. 2: The second prototype with six valves.
To increase grasping speed, the volume necessary to move the fingers was decreased by reducing the number of joints actively actuated to one ip joint and one mp joint in each finger, and another micropump was added. The metacarpus of the hand was redesigned such that it houses six customized microvalves. They are connected to one to three actuators so that different types of prehension can be performed. As the hand was only designed for lab testing, it does not have a cosmetic glove but elastic finger tips, as proposed by [12]. A simple, rugged two-step control scheme is used to operate the hand. First, depending on the first control signal, the digits move from a neutral state into a predefined preshape state, each representing one prehension pattern. The user receives feedback when the hand performs the desired prehension pattern. Grasping speed was between 1 and 2 seconds [11]. It turned out that the stability of this prototype had to be improved. Moreover, the power consumption of the system was too high. Furthermore, users with a distal transradial amputation cannot be fitted this prosthesis.

THIRD PROTOTYPE

A third prototype was designed to solve the drawbacks of earlier prototypes. One major challenge was the need to fit all requisite components into the small volume of the metacarpus by miniaturizing the components, thus allowing users with long transradial amputation to wear the device. Another consequence was the reduction of the power consumption of the micropump. Moreover, the maximum pressure of the micropump was increased to 6 bar by using a different DC motor and pump design, which resulted in higher holding forces of up to 110 N [14]. The noise level of 60-70 dB of the initial outer gear pump was reduced by 20 dB by using an optimized pump design and adding acoustic insulation. The mass of this hand complete with battery, socket and cosmetic glove is 860 grams.

![Fig. 3: The third prototype contains all components within the hand.](image)

Kinematic analysis showed that active ip joints can be replaced by passive ones in the ring finger and the little finger without significantly diminishing dexterity [11]. Control of the motor speed was also improved by the integration of a pulse width-modulated signal. The first custom-made cosmetic silicone rubber glove gave the hand a very realistic appearance. Initially, the first glove restricted grasping to objects with a diameter of \( \leq 45 \) mm; a redesigned glove model then allowed an active opening range of 90 mm and a passive range of 120 mm to be achieved. To increase the robustness of the new hand, test rigs for all components were developed, and mechanical loads were simulated by using CATIA-FEM simulation software. For software updating, the microcontroller can be connected to a PC via Bluetooth™ interface for wireless communication. A new real time control concept for grasp-type classification using on-line feature extraction from EMG-signals was developed [15].

Distributed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 United States License by UNB and the Institute of Biomedical Engineering, through a partnership with Duke University and the Open Prosthetics Project.
The teaching process is based on statistical classifiers, fuzzy rulebases, and artificial neural networks. It also incorporates a routine automatically generating source code for microcontroller implementation. The results obtained from seven upper limb deficient test persons showed that a switch signal can be generated after five minutes of training with a signal classification rate of > 91 percent. An optional sensory feedback system was developed for the prosthesis, which is based on mechanical vibration. It consists of a tactile sensor integrated into the fingertip of the thumb, a controller, and a coin-type DC motor with an integrated eccentric (VM14B-S1, JinLong Machinery Co. Ltd., Yueqing, China). First clinical trials with the feedback system indicated high acceptance and showed the force necessary to hold an object securely to be reduced significantly.

ACKNOWLEDGMENT
This work received major support from the limb fitting center of the Heidelberg Orthopaedic University Hospital, Pohlig Orthopädietechnik, Traunstein, Germany, and Brillinger Orthopädietechnik, Tübingen, Germany.

REFERENCES