Improved Prosthetic Functionality Through Advanced Hydraulic Design

Bjørn Olav Bakka[1], MSc and MBA, Norway, bb@hy5.no
Christian Fredrik Stray[1], BSc and MBA, cf@hy5.no
Jos Poirters[1], jp@hy5.no
Ole Olsen[1], MSc, ole@hy5.no
[1]Hy5 Pro AS, Bygning 100, Raufoss Industripark, 2830 Raufoss, Norway

ABSTRACT

Hy5 met its research objective of designing a hand prosthesis to fill the gap between standard myoelectric grippers and premium, bionic-like hand prostheses. Our approach applied state-of-the-art hydraulic actuator technology with functionality embedded in advanced 3D printing of titanium and plastics. As a result, the opening and closing of the hand is myo-electrically controlled and compatible with industry standards while the hydraulics enable an adaptive and independent pressure build-up on the fingers as they grasp an object. This design mimicking realistic hand gripping without requiring one motor per finger as in bionic-like prosthesis.

Testing concluded that the MyHand prosthetic hand manages all grips (pinch, power, fist, tripod and point) as intended and works as a substitute for a missing hand. Users also responded very favourably to the innovative emergency release button, an added safety feature. The users were attracted by the simplicity and sturdiness of Hy5, which promises a reliable product with low life-cycle cost.

INTRODUCTION

Advancements in technology can result in overly complex designs leading to underutilized features. Advanced prosthetic devices are no different, specifically with overly complex hand prostheses where highly technical designs may lead to increased weight and cost, along with reduced reliability and usability. Additionally, when a person experiences an amputation, they face staggering emotional, practical, and financial lifestyle changes.[1] Following such an event, the person typically requires a lifetime of costly prosthetic device(s) and services, reduced physical activity, and difficulty with community reintegration and full participation in social life. Losing a limb has been found to dramatically change a person's sense of body image and consequently self-image, which has, in turn, been associated with a person's satisfaction with life.[2] An upper-extremity (UE) prosthesis is considered among the most challenging prosthetics devices to use, both from a functional and a control perspective.

Compared to the typical UE prosthesis, the biological human hand is complex device. With 38 muscles[3], 27 bones[4], 21 Degrees of Freedom (DOFs), thousands of touch sensors, a human hand is direct skeletally-attached and weight-bearing, capable of swift movements, and designed for life. Alternatively, a typical prosthetic hand has few DOFs, no sensors, its distal weight is supported only through a socket, it is much slower and imprecise than a biological human hand and is regularly in need of service and repair. The biological human hand is controlled naturally through afferent sensory input and efferent motor output signals of the Somatic Nervous System, while a myoelectric prosthetic hand is controlled through learned intentional, yet often unintuitive muscle contraction.

The human hand is used as an indispensable tool in daily life. There are several reasons why the human hand should not or cannot be copied in order to produce effective end effectors and terminal devices[2] as current state of the art in engineered systems cannot achieve a comparable level of complexity and performance in the same size package. Due to the many reasons the full spectrum of human hand capabilities cannot be practically achieved in a prosthetic hand, some smaller subset of those must be chosen. Several studies have concluded that a small number of grasp types comprise the majority of those used.[2] Other studies have shown that weight, cost and reliability is a concern with higher preference by users over independently moving fingers.[5]

First demonstrated in the 1940s, myoelectric prosthetic hands rely on electrodes applied to the skin to detect and translate muscle pulses drive a device actuator. The actuator can be hydraulic (i.e. pump and cylinders), electromechanical (i.e. motor and gears) or pneumatic (i.e. compressed gas). The DOF is usually limited to only one – open or close hand. The 1940s myoelectric control technology is still the most widely-used control method, while technology achievements have made the components lighter, cheaper and more reliable.

Several anthropomorphic multiarticulate prosthetic hands have been developed and introduced onto the international market in the previous two decades.[6] Common to all of them is a complex design with high number of DOF and actuators that still rely on two-sensor myoelectric control with the basic "open" and "close" commands. This is a clear example of overdesign by applying new technology indiscriminately, and often requiring the user to switch between hand operation modes by means of buttons, apps or muscle co-contractions. This complicates operation by increasing cognitive stress and training needs and results in underutilization of the capabilities of the prosthetic hand. Additionally, most of these advanced prosthetic hands still bear the cost of increased weight, reduced reliability, and reduced affordability.

The situation is that the current prosthetic technology provides limited options for amputees: patients are provided with either standard utilitarian myoelectric grippers with limited functionality, or advanced and expensive bionic-like hand prostheses. Each of these choices results in underutilization or inadequate functionality, or both.

Hy5 has integrated a simple design with lightweight materials and advanced motion control and flexibility, resulting in a prosthetic hand that improves utilization and functionality for daily life. The MyHand design addresses the critical functional and economic gap that exists between body-powered and relatively simple myoelectric devices, and high-cost anthropomorphic multiarticulate prosthetic hands.

METHODS

The technology that led to Hy5's "Improved Prosthetic Functionality Through Advanced Hydraulic Design" was initiated more than 15 years ago. Our development path began with the idea to replace error-prone electric motor actuators with hydraulic actuators in dolls in an amusement park. Since then, the work has evolved, inspiring us to make a better life for people living with upper extremity amputation, with the vision of "Giving the World a Helping Hand".

Figure 1: Hy5's vision of "Giving the World a Helping Hand" - MyHand testing with newly amputee.

Hy5's design employs a hydraulic actuator, which is one of several possible actuators, or "muscles", that can be used in prosthetic limbs. In 1985 it was stated that "electro-hydraulic systems may be used in the future because they have the potential advantage of developing high torque in small actuators" [7]. Hydraulics is well-proven technology with documented benefits for prosthetic lower-limbs. Several research projects have resulted in hydraulic actuated prosthetic hand prototypes. Examples include the "Fluidhand" developed in Karlsruhe, Germany and a mesofluidic hand developed in Oak Ridge, USA.[8] However, Hy5 is the first company that is designing, producing, and selling a hydraulic prosthetic hand.

The MyHand prosthetic hand integrates several innovative features, some of which are patented. The palm unit integrates the electrical motor, hydraulic pump,[9] cylinders and piping and is 3D printed for low weight, low cost, high flexibility and high complexity. The hydraulic pump is a single high-volume and high-pressure integrated pump.[10] The high-volume pump provides the high non-resistance opening and closing speed, while the high-pressure pump provides the high gripping force. The digits are closed by wires being actuated by the palm cylinders. The digit mechanism is a force balancing mechanism[11] enabling the digits to close on objects regardless of their shape. Major parts of the digits are 3D printed in titanium for low weight and high durability.

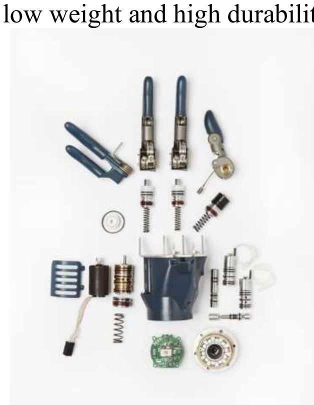

Figure 2: MyHand Advanced Hydraulic Design

The opening and closing functions of the MyHand prosthesis are myoelectrically controlled. The prosthesis uses a single motor to control three hydraulic cylinders. Each hydraulic cylinder controls the digits of the thumb, index, and middle finger by means of the mechanical wire solution in their respective knuckle joints. This enables an adaptive and independent pressure build-up on the thumb, index and middle fingers while the ring and pinkie fingers move together with middle finger as they grasp an object, thus mimicking realistic hand gripping without requiring one motor per finger.

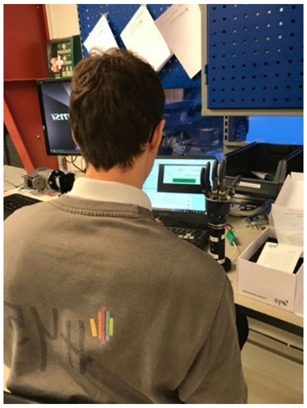

Figure 3: MyHand Production Testing

The MyHand device design specifications demonstrate its impressive performance: a maximum power grip of 120N, maximum tripod grip of 60N, maximum static load of 40kg, the maximum time to close is 1.2 seconds and weight is 580g.

Table 1: MyHand Specifications

Performance specification	
Maximum power grip	120 N
Maximum tripod grip	60 N
Minimum time to open/close: power grip	1,5 Sec
Minimum time to open/close: tripod grip	1,5 Sec
Maximum static load: hook grip	40 Kg
Maximum load individual finger – hook grip	20 Kg
Fingertip extension load	8 Kg
Weight	580 g
Size	7 ¾

RESULTS

The Southampton Hand Assessment Procedure (SHAP)[12] is designed to measure a hand's functional range. The procedure was developed in 2002 at the University of Southampton to assess the effectiveness of upper limb prostheses. The SHAP test consists of a series of manipulations of both lightweight and heavyweight abstract objects intended to directly reflect specific grip patterns while also assessing the strength and compliance of the grip, followed by 14 Average Daily Life (ADL) tasks.

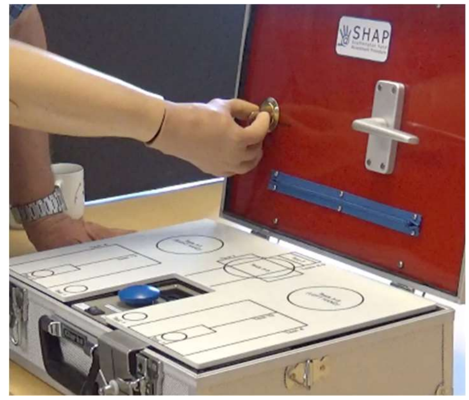

Figure 4: SHAP briefcase with gloved MyHand

In late 2017 the SHAP was conducted internally with the MyHand prosthetic hand used by 21 subjects comprising 20 males, and 1 female users, ages 27 to 65[13,14]. The testing revealed some variations in how the users managed to control the device. Users with limb-difference from birth generally have longer experience with handling a prosthesis and managed to control the MyHand hand quicker than users amputated later in life. Some managed to control MyHand instantly, others needed more time to get accustomed to it. An orthopedic specialist observed the testing together with Hy5 employees. Both the orthopedic specialist and the user were interviewed after testing.

Figure 5: MyHand SHAP testing

The SHAP testing concluded that the MyHand device manages all grips (pinch, power, fist, tripod and point) as intended and works as a substitute for a missing hand. General user feedback and specific results from the SHAP testing have been positive.

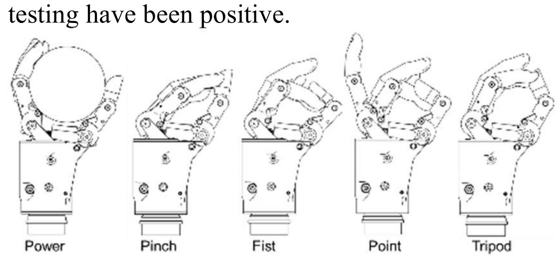

Figure 6: MyHand Grip Patterns

The users expressed specific satisfaction about the ability of the MyHand to adopt to and grip complex objects. All users were very positive to the extra safety, accomplished with the emergency release button on the Hy5. The emergency release button releases all hydraulic pressure on the fingers, which will then open by themselves or may easily be forced open. The emergency button may prevent the hand from breaking when the locked around an object, or the battery is empty, and the hand is forced open by breaking it. None of the users have seen this feature on any other hand prosthesis today. The users were attracted by the simplicity and sturdiness of MyHand promising a reliable product.

DISCUSSION

Analysis of the SHAP testing shows that the grip patterns of the MyHand prosthesis allow recovery of up to 30% of total gripping functionality required for activities of daily life (ADL's) compared to standard grippers. This is an important part of the MyHand value proposition.

Figure 7: MyHand Power Grip and Fist Grip

Further analysis showed that user functionality achieved with the MyHand prosthesis is comparable to that of most advanced bionic-like prosthesis users. Functionality in the advanced bionic-like hand requires significant training, cognitive attention and risk of faulty functionality. Access to MyHand gripping patterns is intuitive with less training and cognitive attention.

One benefit of the MyHand is the simplicity and sturdiness of the hand which supports a reliable product resulting in low life-cycle costs. For users this translates into less time lost to breakage or servicing, minimizing time spent without the use of the hand. Being rugged, the MyHand hand can be employed in activities and environments where other hands will break, improving quality of life by enabling new lifestyles. Whether the user pays for the device personally, or with the use of insurance, low life-cycle cost simply means fewer budget restraints and the ability to service more people.

The MyHand prosthetic hand has received regulatory approval in Europe, US, Australia and Canada.

CONCLUSIONS

Hy5 has designed a prosthesis to fill the gap between standard myoelectric grippers, and premium, bionic-like hand prostheses. This technology offers cost-effective advanced motion control and flexibility with critical functionality. Hy5 will break critical barriers for user comfort, directly addressing the existing needs for lighter and faster hand prostheses. Providing the general public with a wider variety of options allows individuals the best fit to their lifestyle, and an improving quality of life.

REFERENCES

[1] Dr. Grant McGimpsey, Terry C. Bradford: Limb Prosthetics Services and Devices; Critical Unmet Need: Market Analysis.

[2] Nellie Njambi Mugo: The effects of amputation on body image and well-being. A systematic literature review.

[3] Joshua Z. Zheng, Sara De La Rosa, Aason M. Dollar: An Investigation of Grasp Type and Frequency in Daily Household and Machine Shop Tasks.

[4] Qiang Zhan, Chao Zhang,a and Qinhuan Xu: Measurement and Description of Human Hand Movement.

[5] Elaine Biddiss, Dorcas Beaton and Tom Chau: Consumer design priorities for upper limb prosthetics. Disabil. Rehabil. Assist. Technol. 2 pp346-357 doi:10.1080/17483100701714733.

[6] Joseph T. Belter, Jacob L. Segil, Aaron M. Dollar, Richard F. Weir: Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review.

[7] Dudley S. Childress: Historical Aspects of Powered Limp Prostheses.

[8] Josephus M. M. Poirters: A hand-prosthetic. Available at https://patents.google.com/patent/WO2011072750A1/en

[9] Josephus M. M. Poirters: Palm Unit for Artificial Hand. Available at https://patents.google.com/patent/US20180133028A1/en

[10] Josephus M. M. Poirters: Hydraulic Pump Assembly for Artificial Hand. Available at https://patents.google.com/patent/US20180133032A1/en

[11] Josephus M. M. Poirters: Control of Digits for Artificial Hand. Available at https://patents.google.com/patent/US20180140441A1/en

[12] Southampton Hand Assessment Procedure (SHAP). Available at http://www.shap.ecs.soton.ac.uk/;

[13] Ole Lerstøl-Olsen: Hy5 DOC-11030-03-Usability_Results_and_Raw_Data. Company confidential

[14] Ole Lerstøl-Olsen: Hy5 DOC-11031-03-Usability_Engineering_Report. Company confidential