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THE DESIGN OF A MYOELECTRICALLY CONTROLLED HAND WITH MULTIPLE ACTUATORS FOR FIVE-YEAR OLD CHILDREN

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ABSTRACT

Myoelectric prosthetics are complex functional devices that can improve significantly a person's quality of life. This paper describes the development of a myoelectrically controlled prosthetic hand for a five-year old child. A key consideration in the design of upper-body prostheses is to use information from studies highlighting the main causes of rejection. These studies emphasize that in order to reduce rejection, it is necessary to include the opinions of the users in the design process. Additional constraints are introduced due to the small size and mass of a five-year old child's hand compared to that of an adult. The main points of the final design are detailed, including the areas where these constraints were overcome. Modularity was used throughout the design; it allows the hand to be configured for the individual user, and also helps to reduce the potential cost of the hand. The final design has three actuators controlled individually through the use of a master-slave microchip combination. This design has a final mass of 105.8g and produces a pinching force of 4.35 N.

INTRODUCTION

There have been greater advances in the design of prosthetic hands for adults compared to those for children. Although there have been developments to child prostheses, they have not always been in line with those made to adult prostheses. Acceptance of the user is a key consideration in the design of upper-body prosthetics. It is generally recognised that the younger a user is introduced to a myoelectrically controlled prosthesis, the greater their acceptance of the technology [1]; this is encouraging the fitment of functional and adaptable prosthetic limbs to young children. To provide choice, hands designed specifically for the needs of children are required. Currently there are two commercially available upper-limb prostheses specifically designed for children: the Otto Bock 2000 Electric Hand, and the RSL Steeper Scamp Myo Electric Hand. Both of these hands are single degrees of freedom devices that are available in various sizes, and driven by a single actuator that closes the first and second fingers onto the thumb. Improvements in child prosthetics could be made with improved adaptability and an increased number of individually driven axes. To address this, the development of prostheses for children that are produced in conjunction with research into the acceptance and needs of children is needed. This paper describes how a prostheses for young children was designed with multiple degrees of freedom, modularity and functionality, taking into account considerations from both a user's perspective and from technical constraints. (A final prototype can be seen in figure 1.)

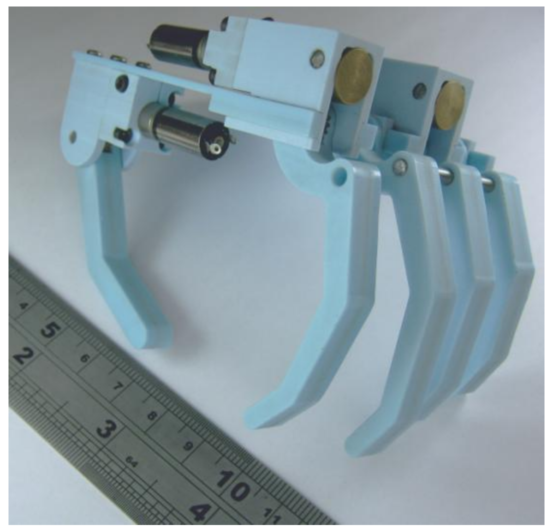

Figure 1 – A Prototype Myoelectric Hand.

USER CONSIDERATIONS

Rejection rates of upper limb prostheses amongst children have been reported to be as high as 50% [2]; indicating that upper limb prostheses that are currently being prescribed are not meeting the needs of young people [3]. Research into rejection of prostheses amongst adult users found dissatisfaction with the prosthesis to be linked to rejection [4], therefore highlights the importance of including the views of users when developing new prosthetic devices. This is supported by Bidiss & Chau's [3] historical review of upper limb prosthetic use and abandonment, which concluded that "increased emphasis on participatory research and consumer satisfaction is needed"

Bidiss et al [5] involved prosthetic wearers of all ages to inform prosthetic design by identifying their key development priorities. These were reduced weight, lower cost, life-like appearance, improved comfort, enhanced wrist movement and better grip control/strength. The design priorities varied substantially across age groups, suggesting that upper limb prostheses designed from the users' perspective would be different for children compared to those designed for an adult. This supports the need for prosthetic hands for children designed alongside studies into the views of the users. Before this user-led design, it is necessary to explore the technical feasibility of designing a hand of this size and mass.

At Southampton University a study (Our Bodies Our Views) used questionnaires and interviews to examine satisfaction with prostheses and reasons for prosthesis rejection in young people with upper limb loss aged 5-18 years. Three factors were identified as important amongst the participants. They were: the look of the prosthesis; the functional ability, and being involved in the selection of the prosthesis. Reasons identified for not wearing the prosthesis were: it was uncomfortable (including being too hot and too heavy); that it is only useful for specific tasks; the artificial appearance of the prosthesis (attracting unwanted attention), and wear and staining. This study also highlighted the importance of communicating with children when designing prosthetic devices.

TECHNICAL DESIGN CONSTRAINTS

			5yr	16yr	% Dif
A	Hand length	mm	125	187	66.8
B	Middle finger length	mm	52.5	80	65.6
C	Palm length	mm	72	107	67.3
D	Palm width	mm	57	82.5	69.1
E	Ratio of palm length to middle finger length	%	42.35	42.75	99.1
F	Ratio of palm width and length	%	82.5	80	103.1

Table 1: Hand Measurements of 5 and 16 Year Olds [6].

When designing prostheses for children there are issues introduced due to the differing size and mass requirements. Table 1, for example, shows average hand measurements for 5 and 16 year olds [6]. The data in rows E & F, shows that irrespective of age, certain proportions of the hand are virtually unchanged. However, the natural hand of a five year old child is two thirds smaller than that of the average 16 year old (approximately equivalent to an adults hand); suggesting a similar difference in the overall mass. The effect of this constraint is most prevalent in the design of the drive system, where the consideration of output power and speed are equally important. However larger actuators are typically heavier. Including multiple functional axes means that multiple drive systems are required; as a result there is a summing effect of the significance of the drive system weight.

DESIGN OF A PROTOTYPE HAND

To realise a design that is both cheap and flexible, the decision was made to include a high level of modularity. This would be split into two levels. The first level would be in the manufacture to aid in reducing the number of different parts and construction processes, therefore, reducing the cost of manufacture. The second is to provide technician level reconfiguration; to provide the user with flexibility and choice when choosing their exact specification. This permits easy setup, reconfiguration and maintenance of the hand; possibly allowing for reduced post-fitment costs.

An electric motor and gearbox was used to actuate the hand since it is the common method of actuating myoelectric prosthetic hands. The design of the gearbox arrangement is based on a scaled version of the Southampton Hand's gearbox [7]. It uses Faulhaber DC-Micromotors (0816 with a 64:1 gearbox) to drive the fingers and thumb through a worm-wheel combination. The defining characteristics of a drive system are the output speed and torque. Both of these values are determined by the characteristics of the motor and gear chain. Equation B (Appendix A) shows that the gears have a linear effect on the output torque and an inverse relationship with the output speed.

The motor selected for this project produces 0.15 mNm and rotates at 15,800 rpm (263.3 rps). There are two gear combinations in the drive chain, the first has a ratio of 64:1 and the second has a ratio of 20:1, with respective efficiencies of 60% and 89%. The torque across a gear system increases proportionally by the ratio of the number of teeth on the gears in the system, the speed through the system decreases with the same relationship. This determines the output characteristics, of 0.12 N maximum force and a maximum speed of 0.13 rps.

Two essential considerations were identified for the design of the prosthesis: the speed for 90^{o} closure of the hand and the force produced at the fingertip. It is assumed that the fingers only rotate through 90^{o}.

Equations C and D were used to convert the drive system output characteristics into prosthetic output characteristics. Equation C gives a closure time of 1.95 s. Equation D shows that to calculate the force at the fingertip, the length of the finger from the rotating axis is needed. This design has a middle finger measuring 55 mm which gives an output force of 2.17 N. This produces a theoretical combined finger closure force of 4.35 N. These

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characteristics are not optimal and improvements do need to be made in the speed and force generation. However, it was decided since the hand was for a preliminary study these characteristics would be acceptable.

The artificial metacarpophalangeal (MCP) joint is defined as the key component in the design, as it houses all of the driven components of the hand. As mentioned previously, the design is based on the Southampton Hand [7]. However scaling the design needed careful consideration to ensure adequate strength of the components. The design incorporates the axle for the motor and is split to allow the worm to be placed into the MCP joint. A key feature in this design is the connection slot to allow the MCP to fit into any of the four MCP locations on the palm.

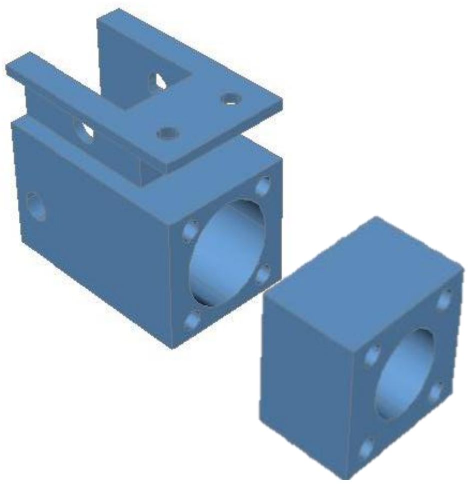

Figure 2 - Prosthetic Metacarpophalangeal (MCP) Joint

The shape of the fingers and thumb was chosen to mimic that of a human hand and to allow the first finger and the thumb to form an effective pinch. The base of the finger has a slot to allow for a strong and effective coupling to the wheel gear. The curved base of the finger is aligned with the MCP joint when straight; this allows the fingers to lie flat when fully extended.

The hand uses a microchip-based control system in a master and slave configuration. This design increases the modularity of the system; allowing for easy reconfiguration and motor addition. It uses an overcurrent device to regulate the force at the fingertips but has the availability to incorporate embedded force sensors into the fingertips. The current system though functional, does not provide closed feedback required for fine touch.

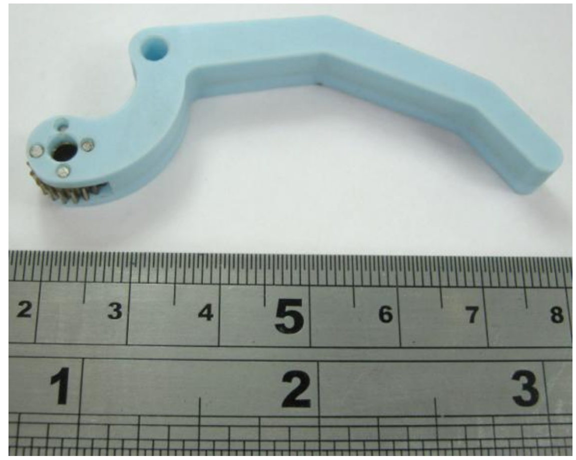

Figure 3: A Prosthetic First Finger.

DISCUSSION

This study shows that it is possible to build a prosthetic hand that incorporates multiple actuators for children aged five-years. The final prototype is 127 mm long and 60 mm wide; these values are comparable to the size of a five-year old human hand. The mass of this design is 105.8g; this value is similar to that of existing prosthetic hands for children. However, the mass can be reduced through material changes and design alterations. All of the components of the drive are interchangeable throughout the system; including the motors, gears and all drive shafts. The hand has only 22 different mechanical parts; including 7 drive shafts, screws and pins that all require minimal manufacturing. The second level of modularity allows for the hand to be reconfigured to fulfil the exact requirements of individual users without any adjustment to the design. An example of this is that the middle finger for one user may be the index finger for another. This would reduce the total amount of components that a fitment centre stocked, therefore, potentially reducing the costs.

CONCLUSION

This novel, child prosthetic hand is fully adaptable, whilst, still providing a high level of functionality. The design confirms that it is feasible to provide hands for children that are able to deliver choice, without compromising on the size or mass. The power of the drive system may be increased without affecting the target age and functionality and can be achieved by changing the motor and the design of the MCP joint. The modularity in the design added significant functionality and showed that it could increase the choice given to the users, whilst reducing pre- and post-fitment costs. This area of research calls for further development.

FUTURE WORK

This study highlights several areas for possible improvements, the first of which would be to increase the speed and force characteristics. Further studies will be undertaken to improve the control system by including force and position sensors allowing for the development of a hybrid force-position control system. This could be implemented with the use of encoders on the motor shafts to infer position of the fingers. During a redesign, the mass of the hand could be reduced further with the use of different materials and an altered drive system. The modularity incorporated into the design could be adapted to provide in-service reconfiguration. This would further increase the functionality and could reduce the need to service the entire hand.

Having confirmed the feasibility of producing a hand with suitable size and mass characteristics, research focusing on the users' views is needed. Although this study begins to address user considerations and reasons for rejection this was not extensive. Therefore further research will be conducted to investigate the aspects of prostheses that are important to children, and to explore their views on new designs for future devices.

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APPENDIX A

Gear ratio equations:

$$\mathrm{gr} = \frac{\text{(Teeth on Input)}}{\text{(Teeth on Output)}} = \frac{n_{\mathrm{in}}}{n_{\mathrm{out}}} \tag{A}$$

$$gr = \frac{n_{\mathrm{in}}}{n_{\mathrm{out}}} = \frac{\tau_{in}}{\tau_{out}} = \frac{\omega_{out}}{\omega_{in}} \tag{B}$$

Where,

n_{in} or n_{out} = Number of teeth on input or output shaft

τ_{in} or τ_{out} = Torque on input or output shaft

ω_{in} or ω_{out} = Rotational velocity of the input or output shaft

APPENDIX B

Time for 90^0 rotation:

$$t_{90} = \frac{1}{4\,\omega_{out}} \tag{C}$$

$$t_{90} = \frac{1}{4 \times 0.13} = 1.95s$$

Where,

t_{90} = Time for 90^0 rotation

ω_{out} = Drive shaft rotational velocity

APPENDIX C

Equation of moments:

$$F = \frac{\tau}{r_f} \tag{D}$$

$$F = \frac{0.1}{5.5 \times 10^{-2}} = 1.86\,N$$

Where,

r_f = length of finger from rotating axis.

τ = Torque

F = Force