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THEORETICAL CONCEPT OF A MYOELECTRIC CONTROLLED PROSTHETIC HAND

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Abstract

According to user feedback the current models of myoelectric mechanically actuated prosthetic hands are not functional enough for the user, and many users choose to use a passive prosthetic instead even if they own a mechanically actuated one due to the low functionality. The price of these advanced prosthetics is also an issue, especially in third world countries where the need is larger, and the economy is lower.

Keywords: prosthetics, medical chain, bionics, hand geometry, additive manufacturing.

Introduction

The development of prosthetics is needed since users are not fully satisfied regarding current mechanical prosthetic hands according to our user needs study, and this project is attempting to improve user satisfaction. There are many people in the western world that are dissatisfied or cannot afford functional prosthetics, and many more in third world countries that cannot afford prosthetics at all.

Hand prosthetics

Current prosthetics that are readily available are body powered or electric. As the name implies body powered prosthetics rely solely on the user’s strength to grip or interact with objects, the force required to use the prosthetic is harnessed from the user by means of a mechanical nature such as strings, springs or other harnesses.

The electrical prosthetics are powered by electric motors with an external power source (it can be internally implemented via a battery). And the motion of these prosthetics is driven by a processed electrical signal from the muscles in the residual limb by means of electromyography. Other electrical prosthetics are in development such as the EEG-based (electroencephalography) brain controlled prosthetic arm.

Safety and position in medical chain

Safety is of paramount concern, so we must ensure that the hand can be opened voluntarily when fully closed and introduction of a failsafe switch could be considered in the finalized design. Opening and closing times of the prosthetic should correspond or ideally be less than the competition as observed in the benchmarking table.

All non-invasive medical devices fall under CLASS 1 and must adhere to the regulations provided by the guidelines. To market and sell the device must undergo clinical trials to verify safety under normal use conditions to reveal or confirm side effects of use which must be less than the benefits of the device´s function.

The duration of use is classified as;

- Transient for continuous use less than 60 minutes
- Short term for continuous use less than 30 days
- Long term for continuous use more than 30 days

Which indicates that our product would fall under the short-term category.
Materials used for production must be screened for toxicity and flammability, compatibility with skin contact (in our case), must be safe to use with materials, substances and gases in the environments the product is normally assigned to.
Care must be taken to minimize the possibility of exposure of the user to harmful substances i.e., battery acid or hydraulic oils if used.
Our device must undergo a specific testing and verification period which requires, complete technical data on the device, specific characteristics, statement of conformity, and an overview of possible malfunctions and safety features, instructional manuals and others extensive and detailed analyses of the device itself and the production facility.

Human machine interfacing

The human machine interface can be defined as any input source which can be used by the machine and interpreted as a signal in a machine process. In the context of this project this interface is technically solved by surface electromyography (sEMG) sensors which detect electrical activity of muscles.
In our case the electrical activity present with muscle constriction as well as the replacement of a limb or body part by and artificial limb that is electronically or mechanically powered.
The term “bionics” is synonymous with “biomimetics - biomimicry” and in this context, it refers to the integration of human – engineered devices to take advantage of functional mechanisms / structures resident in nature.

Sensory Systems

sEMG surface electromyography is the method of control over the system, there is a plethora of available products that preform the same task, our selection of the Myoband was made due to the fact of the open-source software platform and the ability of outputting the signals to an Arduino board which in turn could use the Myoband signals to actuate the electrical engines within the prosthetic.
This system provides numerous benefits but also has its downsides in training time with the adjustment of sensor placement, signal “pickup” and calibration. One of the benefits is its low weight, compactness and real-time interpretation and output of detected signals which can

provide the user with near immediate reaction from the prosthetics leading to greater levels of satisfaction.

As the elected signal input system for the prosthesis, electrical impulses from the forearm muscle (sEMG) contractions will be detected and serve as signals for the actuation of the electrical engines via an Arduino board. The Myoband also has tactile feedback in the form of vibration where it signals the user that it is detecting and processing signals from the forearm. The accuracy of the signal pickup rate according to is in the range of 93.6% accuracy.

The amplitude of the signal can range from 0 to 10 mV (peak-to-peak) or 0 to 1.5 mV (rms). The usable energy of the signal is limited to the 0 to 500 Hz frequency range, with the dominant energy being in the 50-150 Hz range. Usable signals are those with energy above the electrical noise level.

Several articles in our study show that the Myo-band is a proven method of control.

Feedback systems, proprioceptive feedback loops, tactile vibration and constriction

Proprioceptors are sensors which provide information about the orientation of the body in respect to gravity, movement of the body relative to the external medium and movements and forces in localized regions of the body. Proprioceptive feedback is essential for accurate execution of movement. The lack of proprioceptive sensors due to the loss of limb would indicate impaired spatial and movement coordination in the affected part of the body.

According to article studies haptic feedback systems in prosthetics can increase acceptance of the prosthetic, lack of such systems is in fact a reason for rejection of prosthetics in some cases. As such haptic feedback systems can relieve current issues user have with the need for increased visual attention when using the prosthetic and as noted in can assist users in object size recognition.

Actuating Systems

Current prosthetics and prototypes are utilizing a variety of systems to achieve actuation, some of those systems are described below to provide an overview of the solutions already present.

Shape memory alloy (SMA) string actuation is a novel approach to a well- established and common method of using strings. The metallic string is used as a tendon which is attached to the end of the finger, when tensioned the finger will flex. Tensioning is achieved by another SMA string or other mechanical means. Introducing a current in the string causes it to heat up and return to its original state.

Electric engine actuation is commonplace in nearly all market upper limb prosthetics, where motion is achieved by means of converting electrical power, usually from a battery into mechanical motion via a mechanical system of linkages.

Pneumatic systems have been developed and tested as a means of actuation where pressurised CO_2 was used to power the prosthetic which was obtained from commercially available disposable cartridges which were connected to pressure reducing valves and subsequently to piston like actuators.

Hydraulic actuation systems have been designed which are miniaturised versions of larger systems that include a pump, fluid reservoirs, valves and fluidic actuators. Batteries where used to power the pump which generated a flow of synthetic oil and in turn the flexible actuator would expand.

Hand Geometry

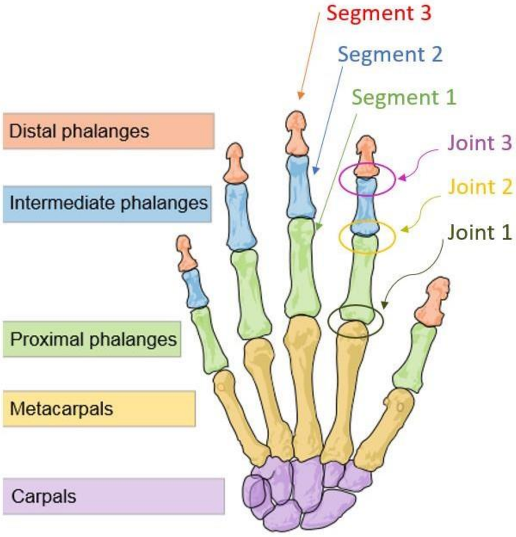
For the simplification of referencing and better understanding of the elements discussed numerical designations have been assigned to the phalanges are their interconnecting joints.

The distal phalange is referenced to as segment 3

The intermediate phalange is referenced to as segment 2

The proximal phalange is referred to as segment 1,

The metacarpals of the hand are referred to as the palm of the hand.



- Joint 3 is interconnecting the distal phalange and the intermediate phalanges, or segments 3-2
- Joint 2 is interconnecting the intermediate phalanges and proximal phalanges, or segments 2-1
- Joint 1 is interconnecting the proximal phalanges and the metacarpals, or segment 1 to the palm.

The metacarpals are referred to as the palm of the hand and house all major components of currently available market systems. refer to BeBionic, iLimb, Michelangelo etc. there are however technical solutions that house the actuation and other main components outside of the palm of the prosthetic as seen in article studies.

Selecting the proper geometry would influence many parameters such as the grasping area of the prosthetic, cosmesis, weight distribution etc.

To achieve a prosthetic hand similar the human hand in several factors should be considered; the number of fingers should be 5, in respects to pinky, ring, middle, index and thumb with their respective shapes and sizes and segment number. The width, length and height of the palm should relate to the average human male hand size.

Each finger has 3 distinct external segments (two for the thumb), of which two would house the pneumatic/hydraulic actuating mechanism. The actuation motion would mimic the gripping motion performed by the human hand. Regarding finger length the ratio between the fingers can be altered according to article studies to improve the gripping of the hand, as it is a natural development not exclusively for handling objects, this modification would not affect cosmesis as the overall hand form would remain untouched.

The thumb is an important point for the development of a successful prosthetic, according to article studies loss of thumb corresponds to 40% loss of hand function. As such the thumb should engineered in a way that could facilitate crucial grasping methods which would be used to interact with the environment and objects such as power grasp, precision grasp and key grasp. With the thumb being used in 90% of all gripping patterns and considering the motion range of the thumb, we have identified that the ability of thumb movement regarding the connecting part with the palm is critical to achieve grips rather than the general flexion range of the thumb.

The joints of the fingers should be used to assist in carrying loads to distribute the forces throughout the hand construction and to the socket. They should also act as a facilitator in generating a moment force on the fingertips to achieve a higher gripping force.

Natural hand Friction

It is observed that friction plays a role in the adjustment of force levels applied to an object while grasping, artificially induced impairment of localized areas of the finger yields diminished mechanoreceptive responses resulting in disproportionate force application.

Commercially available solutions to improve the overall performance and cosmesis of the prosthetic are available.

The base material of the skin natural gloves is silicone which has a Friction coefficient between 0.25 to over 0.75.

Fingertip design and contact surface

Modifications resulting in deviation from naturally occurring fingertips which provide with a greater surface area of interaction, mitigate the effects of an insufficient friction coefficient. The tribological properties of the contacting surface play a role in the adhesive bond occurring between the objects.

Testing

Testing of the prototype can be performed and compared to the gripping strength of the human hand; the forces expected can be compared and analyzed.

Measurements of grip forces should be conducted at 20%. 50% and full closure of the prosthetic to determine the force output of the prosthetic to ensure that it does not exceed normal gripping strength.

Electrical consumption should be evaluated to determine the operating lifetime to determine full product specifications.

Cyclical testing should be performed by fully actuating the prosthetic 25000 times and 50000 at which times the state of the mechanical and electrical systems should be inspected.

Joint system

Linkage system should be designed to enable a specific motion type resembling the flexion of the human hand. Such an approach is likely to lead to a “familiar” motion leading to reduced training times with the prosthetic. Its primary purpose is to facilitate motion and withstand incoming external forces acting upon the hand, as such it is robust and in a location that will not enable open element intersections leading to pinch spots.

Technologies used

Additive manufacturing

Additive manufacturing are production methods where layers of base material are stacked upon each other to produce the final product. The base material varies depending on the process used but the underlying principle for all materials is almost the same. The advantage of such a process is the versatility and easy adaptability of the product output regarding dimension

As a production technology it is highly suitable for prototyping and low production runs, which can easily accommodate the production of variously sized components required for addressing user needs regarding the product. These benefits can greatly assist in producing customized and dimensionally suitable prosthetic parts.

Electrical engines

For ease of use and standardization of elements within the hand, electrical engines are suggested as a solution to actuate the internal systems, storage of energy for these devices is widespread in use and consistently improving in quality resulting in a suitable choice for the prosthesis.

Depending on the size of the hand, multiple possible solutions are readily available for engine size and required power output.

Pneumatics

Pneumatically actuated muscles.

The force output of the pneumatically actuated muscles will equate to approximately 100N, and the actuation time if purely pneumatic will be approximately 0.2s at an operating pressure of 1.4Bars.

These characteristics are entirely achievable and an adequate solution for our system, the design of the actuator and the way of actuation will be altered to fit the project needs.

Hydraulics

Where initially considered due to their numerous advantages such as accuracy of control and movement, high degree of efficiency, high force output and simplicity. However, there are some critical issues which hinder our potential use such as weight due to the required cylinders, valves and storage of oil. Also, the presence of oils and difficulty of sealing in small sizes is a hazard for the user and the prosthesis itself. However, such oil can be replaced by water as a medium and sealing can be resolved by developing a fully enclosed system.

Materials

Previous studies have concluded that weight is important which naturally leads to lightweight materials as the primary choice for the main body of the prosthetic.

Suggested materials could include aluminum, titanium and composite materials.

Materials that are commonly used share attributes which relate to a high corrosion resistance and chemical stability. Polymer bases are widely used in the open source products which could provide adequate health and safety standards while actively fulfilling user requirements.

The glove is produced from a multi-layered, variable hardness, silicone-based material, lined with fabric mesh. To ensure minimal soiling, wear and puncture damage. Fabric was used to ensure that sliding was achieved over actuating joints which in turn evoked less loss of force output. A wide variety of cosmetic options is available.

BeBionic observations

Durable construction and advanced materials makes BeBionic strong enough to handle up to 45kg – so you can confidently use the hand to carry heavy objects and push yourself up from a seated position.

By the visual aspects, it uses titanium for the central palm and fingers, and a carbon fiber composite as the shell.

I-Limb observations

Aluminum load bearing structure with polymer over molded elements, joints can be aluminum or upgraded to titanium.

Results

During the development of the prosthesis the authors gathered information within many fields related to the development. The results from the findings will be presented under the topic for each field below. The results start with the user needs study which the development is based on. The second heading is the benchmarking that shows the most important specifications of current models of prosthetic hands to give perspective on the user requirements.

The third heading describes the results of what parts within biomimicry that had a major impact on the development and chosen mechanical solutions. While the fourth heading describes the results of the mechanical solutions themselves, the engineering specifications and how the prosthetic hand will function.

The fifth and sixth heading describes a proof of concept as in why the developed concept can satisfy the user requirements respectively information regarding safety regulations followed.

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