Fabrication of Prosthetics for Upper Limb

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Abstract: This thesis demonstrates a design for an upper limb prosthetics is an artificially made substitute for a limb lost through a congenital defect (present at birth), accident, illness, or wartime injury. the last two decades, there have been great strides in the development of novel prosthetic hands and terminal devices that take advantage of the latest technological advances, moving toward more advanced bionic hands, however it leads higher in cost. This higher end prosthetic cannot be affordable by a common people as its difficulty in maintenance. These limitations lead research on the mechanical hand which would give better movement and affordable. The Current existing mechanical hands have limited functionality or it is made only as aesthetic. Hence this project is a focus on mechanical prosthetic which operated by physical strength of person so that all sensors and motors are eliminated. Current prosthetic hand has least degrees of freedom and it does not contain wrist movement hence it becomes less flexible for the person. This project gives multi-functional like finger movement, wrist movement, and arm movement. Hence person can do his least daily needs and become self-dependent. This hand is made with equal weight of other hand to make body balance. These hand uses aluminium and mild steel material for its parts construction. The movement can be achieved by stretching the cable which is connected to chest belt, which wore by disabled persons.

The thesis presents the results of a comprehensive literature analysis towards a development of an upper-limb prosthetic arm. In this study, the upper extremity prosthetic devices are classified based on the segment of application. Thus, they can be mainly classified into shoulder prosthetics, trans humeral and elbow prosthetics, trans radial and hand prosthetics. This study considers all the above categories of recent upper extremity prosthetics, and reviews their key technologies by taking state-of-the-art robots as examples.

Keywords: Robotic prosthetics, Trans humeral, Trans radial, upper-extremity.

1. INTRODUCTION

Prosthesis is defined as an artificial body part, to replace a limb which may be lost by the subject through an accident, congenital disorders or infections. Prosthetic rehabilitation is a huge task that involves both psychological and physical training that takes time and a huge team of health-care experts, not to mention the immense determination on the part of the subject. Anything to streamline this rehabilitation process is always encouraged and sought out for. A prosthetic design which is light weight, easy to use and replicates human hand motions as faithfully as possible is of vital importance in the rehabilitation process. This will help the subject to focus on overcoming the psychological barriers rather than worry about the learning curve that comes with a non intuitive design.

Recent improvements in body Armour, battlefield medicine, speed of evacuation, and surgical techniques have resulted in a high incidence of survival from blast wounds sustained during armed conflict. The mechanisms of injury include explosively formed projectiles, improvised explosive devices (IEDs), mobile IEDs, rocket-propelled grenades, suicide vehicle borne IEDs, and gunshot wounds. Those individuals who survive are frequently poly-traumatized and challenged with hearing or vision impairment, burns, traumatic brain injury (TBI), upper and lower extremity injuries, and/or amputations. Service members with well-irrigated, but open, wounds are rapidly transferred from the battlefield to a rehabilitation hospital, which requires an organized approach to prosthetic rehabilitation.

Types of prostheses:

An individual who has suffered an upper limb amputation who wants to get back to work which is labor intensive and someone who feels separated from the society due to cosmetic concerns and wants to get back into the social circles and mingle in parties and conferences will have different expectations from the prosthesis. The basic needs could be categorized into three groups as follows:

- Daily activities prostheses
- Recreational prostheses
- Cosmetic prostheses
- Body powered prosthesis
- Externally powered prosthesis

Upper limb disorders classification:

Over the years, there have been several suggested terminologies for upper limb deficiencies in order to facilitate scientific communication about these disorders. However, there is a lack of consensus as to the best way to classify limb disorders (Association of Children's Prosthetic - Orthotic Clinics, 1966; Day, 1991; Frantz & O'Rahilly, 1961; Gaebler-Spira & Lipschutz, 2010; Gold et al., 2011; McGuirk et al., 2001). The chosen terminology for this work was International Society for Prosthetic and Orthotics (ISPO) terminology. ISPO terminology describes skeletal limb deficiencies present at birth based on anatomical and radiological features. Nevertheless, it is important to notice that epidemiology issues are not reflected in the referred terminology (Day, 1991).

For this, upper limb disorders are split into two categories, the transverse and the longitudinal ones. A transverse disorder denotes absence of elements beyond a particular level even though digital buds (nubbins) may arise. In this way, a child who has a transverse deficiency has no distal remaining parts. This category is the most common among limb disorders, mostly caused by the early amnion rupture (Gold et al., 2011; Wilcox et al., 2015).

Transverse disorders description is made by naming the segment at which the limb ends and then describing the level within the segment beyond which there is no skeletal elements. Regarding phalangeal case, it is feasible to resort to 15 another descriptor in order to indicate a precise level of loss within the fingers (Gaebler-Spira & Lipschutz, 2010; Services & Hospital, 1991). Table (1) summarizes the designation of levels of transverse disabilities for the upper limbs.

Upper limb region	Disability designation
Shoulder	Total
Upper arm	Total Upper third Middle third Lower third
Forearm	Total Upper third Middle third Lower third
Carpal	Total Partial
Metacarpal	Total Partial
Phalangeal	Total Partial

Table 1:Designation of levels of transverse deficiencies of upper limbs.

Historical evolution of limb prostheses

The first concept of limb prosthesis emerged from the ancient pyramids. Egyptians conceived a device made of fiber to be worn for cosmetic purposes. However, scientists believe that this civilization was the pioneer of toe prosthesis with functional properties (Norton, 2007). A letter from Rome (218-210 B.C.) reported a roman general in the Second Punic War who had an upper limb prosthesis made of iron (Meier, 2004; Norton, 2007.

The mid-to late 1500s were denoted in prosthetics field by French Army barber/surgeon Ambroise Paré, who is considered by many as the father of modern amputation surgery and prosthetic design. Paré introduced modern amputation procedures in 1529, as well as innovative concepts for upper- and lower- limb prostheses (Meier, 2004; Norton, 2007). A famous Philadelphia surgeon named Samuel Gross wrote in the 19th century about the dilemma of when the limb should suffer an amputation or a limb salvage procedure. In fact, this is still one of the current problems in prosthetics (Meier, 2004). Adjustable harnesses, joint lock control and other features that are currently used were some of the prosthetic features created by Paré. Moreover, a colleague of him named Lorrain also offered an important contribute in the field by replacing iron prosthetic elements with leather, paper and glue (Norton, 2007).

U.S. Civil war led to a rising of limb amputations. For this, Americans join their efforts in the field of prosthetics (Meier, 2004; Norton, 2007). During World War I, men who suffered amputations were equipped with prosthetic devices in order to perform a mechanical aid. A great effort was made to return amputees to work. In this way, men were equipped with a socket and a universal terminal device, with the possibility of changing the device according to a certain task (Meier, 2004). In Great Britain, a "dummy" hand was also used as terminal device. Moreover, the United States (US) developed a split hook with a closing system triggered by rubber bands (Meier, 2004). The first patented externally powered prosthesis was a pneumatic hand created in Germany in 1915 (Kutz, 2004). The advances in the field prompt by World War I led to the formation of the American Orthotic & Prosthetic Association, AOPA (Norton, 2007).

During the 80's, the development of robotics led to an improvement of electric arm prosthesis (Meier, 2004). Since those years, the field has undergone to a wide evolution. Today's prostheses are more realistic and able to mimic better the 21 function of a natural limb. The market currently offers cosmetic, body powered, myo electric and bionic prosthetic devices. Otto bock owns several upper limb devices, ranging from cosmetic prosthesis to myo electric components (Virtual Expo Group, 2017j). Fillauer sells 20 clamp devices for adults and children, as shown in Figure 1 (Virtual Expo Group, 2017b). Steeper owns multi articulated (which is, with multiple grip patterns) myo electric hand devices for adults with the possibility of using a cosmetic glove (Virtua lExpo Group, 2017f). Furthermore, this company sells an electrically operated hand with nine control modes. This device also includes an electronic "gear change" allowing to store power and to release it on a demand (Virtual Expo Group, 2017e). It also sells cosmetic gloves for adults and children, as presented in Figure 2.

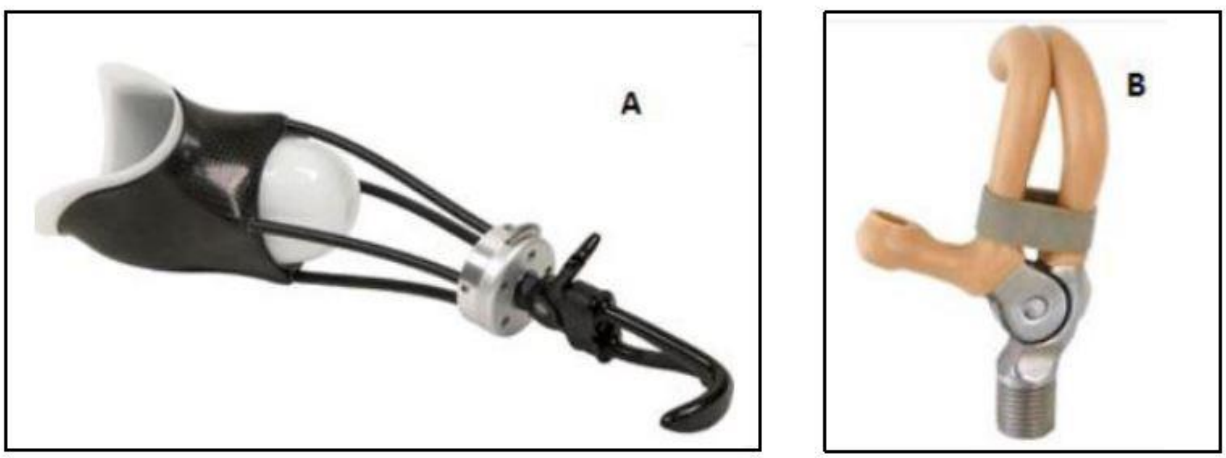

Figure 1: Clamper devices: A for adults (Virtual Expo Group, 2017 c; B for children.

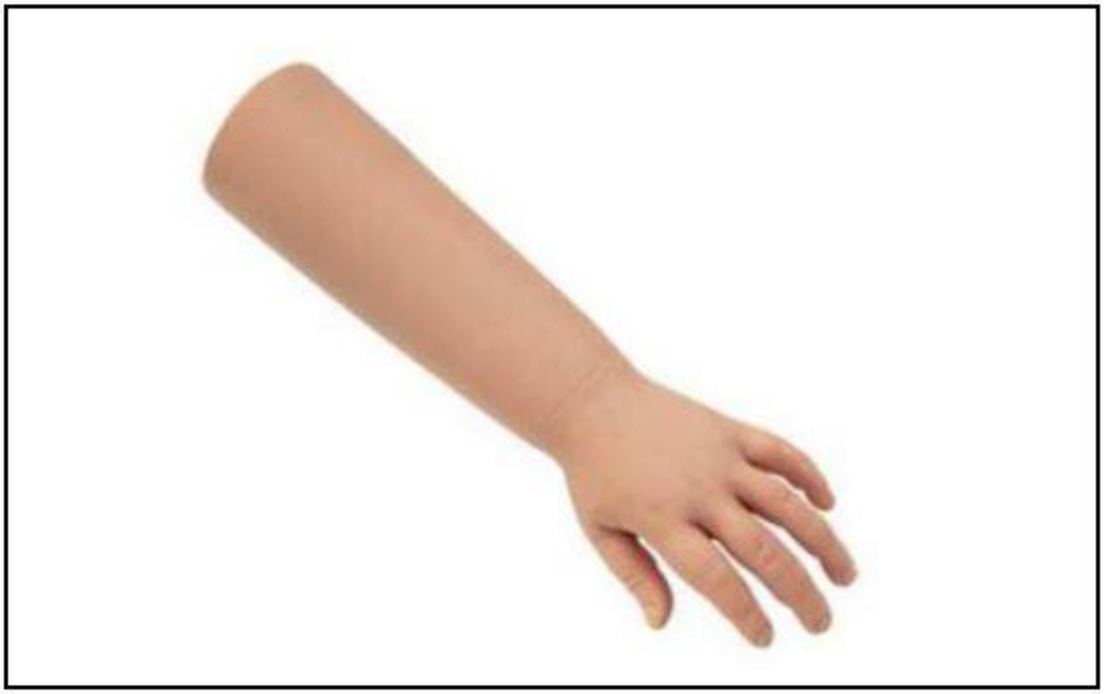

Figure 2: Cosmetic hand glove for children.

Literature review

In this chapter the related work in the field of upper limb prostheses, focusing on the wrist mechanisms, is discussed.

Usually, the designs for the prosthetic wrists only have one Degree of Freedom (DOF), usually forearm rotation, be it driven or passive. Multiple-DOF wrists helps in positioning the hand, reduces the need for extra arm motions and in return, makes day to day activities easier. There are a few multi-DOF wrists that are available, either for purchase or in the research phase and this chapter will shed light on some of the popular ones.

Touch bionics sells partial and total multiarticulated myoelectric hand devices for adults. These devices require simple gestures to change grips and present adjustable operating speeds (VirtualExpo Group, 2017i). This company also sells cosmetic gloves and cosmetic hand prosthesis. DEKA sells the DEKA arm (Figure 3), a multiarticulated myoelectric arm, apparently suitable for transhumeral disorders (VirtualExpo Group, 2017a). Exii owns a myoelectric hand with a homogeneous design, as shown in Figure 4), however with an expensive cost (VirtualExpo Group, 2017g). Aesthetic prosthetics inc. sells a myoelectric clamp/hook device for adults with an optional cosmetic glove (Figure 5)) (VirtualExpo Group, 2017h).

Figure 3: Mioelectric upper limb device.

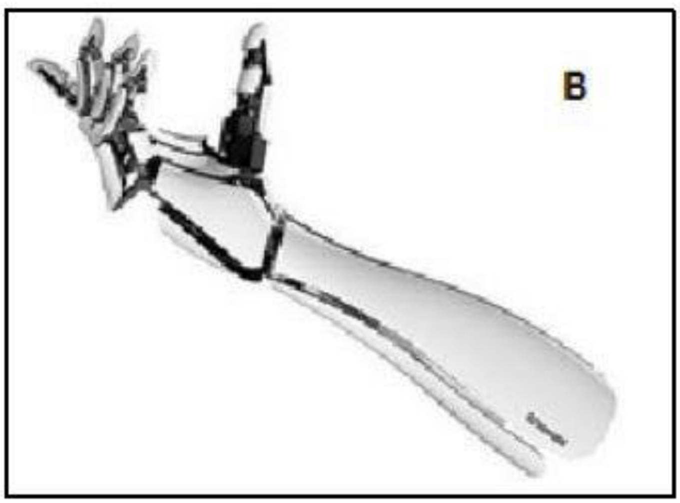

Figure 4:Mioelectric multiarticulate hand prosthesis for adults.

Objectives

The main aim of this project is to overcome the handicapped situation and to make a person Self-dependent. In this work the objective is to achieve the prosthetics for upper limb with low cost so that it can be affordable by common people. This work aims to have the movements of finger, wrist and arm. This prosthetics hand is to be operated by means of spring action through the cable. And also, the objective is to avoid the sensors and motors for the operation so that the handicapped person free from frequent maintenance and carrying the battery.

Methodology

To Developed this low cost mechanically operated prosthetic requires the appropriate study of the past prosthetic and the present prosthetic hand. The study revealed that there was no appropriate wrist movement in the simple prosthetic hand whereas the presence of the wrist movement in bionic hand makes it more expenses. Taking all these into account, appropriate design and dimensions of the various parts like fingers, links, palms, etc have been done to the requirement. The aluminum material is used to develop the fingers, palm and links which connects all parts of hand.

The above components are assembled together to obtain the proper structure of the required prosthetic. The fingers, shaft, and palm dimensions are taken according to the literature survey and it is drawn in the 3D modeling software. The different parts have to be done according to required dimension given in the drawing. The fingers are made to connect with the shaft and the finger movement is obtained by using specific extension spring. The finger and arm movement are obtained by using the cables which are connected to the chest belt of the person.

The cable length can be varied by stretching the chest of a person who fitted with this prosthetics. When the cable stretches out, the fingers are made to move outward and things can be picked up. The wrist movement is achieved by folding the arm towards the person this assembly is mounted on the base plate which is of mild steel to have enough strength on the wrist movement. This plate is connected to the other plate which bridges the gap between the upper fist and the 40 forearm. The forearm is structured with wood and it turned to make it taper. Again, by using spring which is connected between the two plates which enables the wrist movement of appropriate angle. The strip is passed in such a way that when the motion is given to the arm, the tension is produced in the spring, thereby providing the wrist movement.

Design of the Wrist Mechanisms

This section will concentrate on the flexion and extension of the wrist and how this mechanism can be adapted for prosthesis.

To understand how to design any mechanism to mimic a body part, it is important to understand how the mechanism works in the human body. The following section gives information about the muscles and bones involved in Flexion - Extension and how they work together to achieve this mechanism.

Hand geometry:

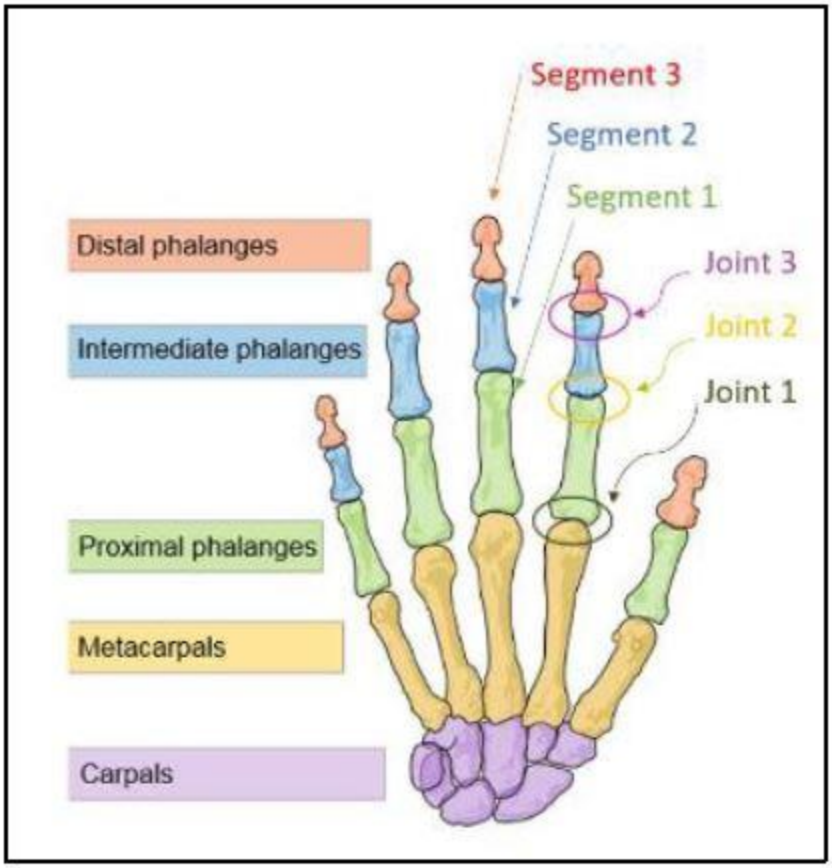

Figure: - 5 Hand Geometry

The Designing of the Mechanism

The design can be modified to provide a firmer lock which distributes the stresses evenly. This current design is selected for easy 3D printing and 3D modelling Software such as SolidWorks. 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 aluminium, 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 make 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.

Limb observations

Aluminium load bearing structure with polymer over melded elements, joints can be aluminium or upgraded to titanium.

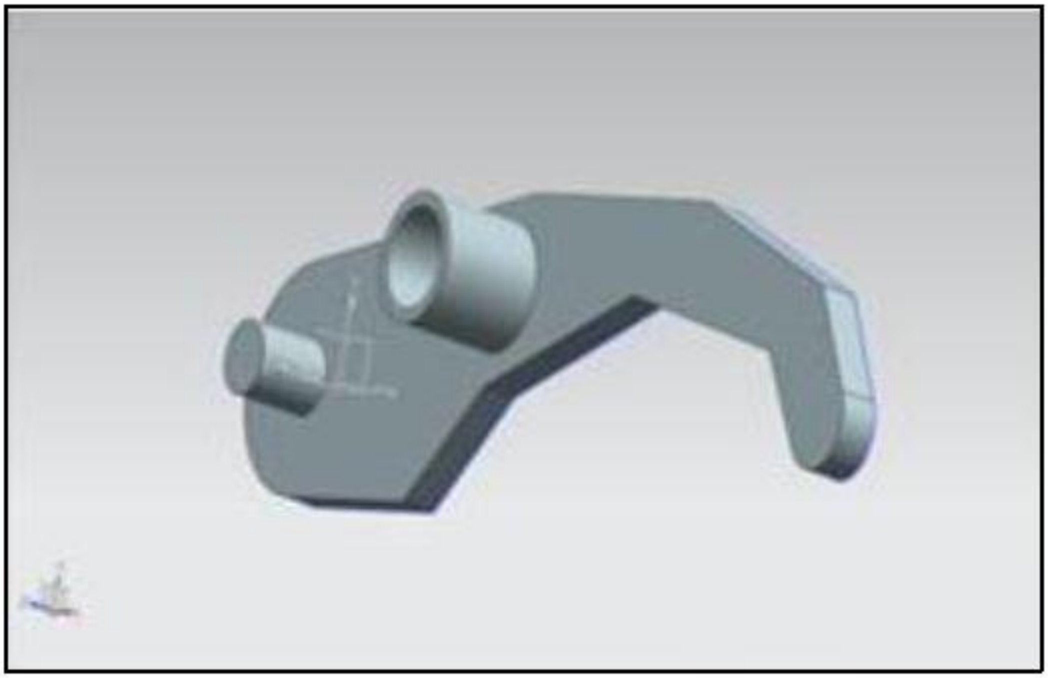

Figure: 6 Design of Finger

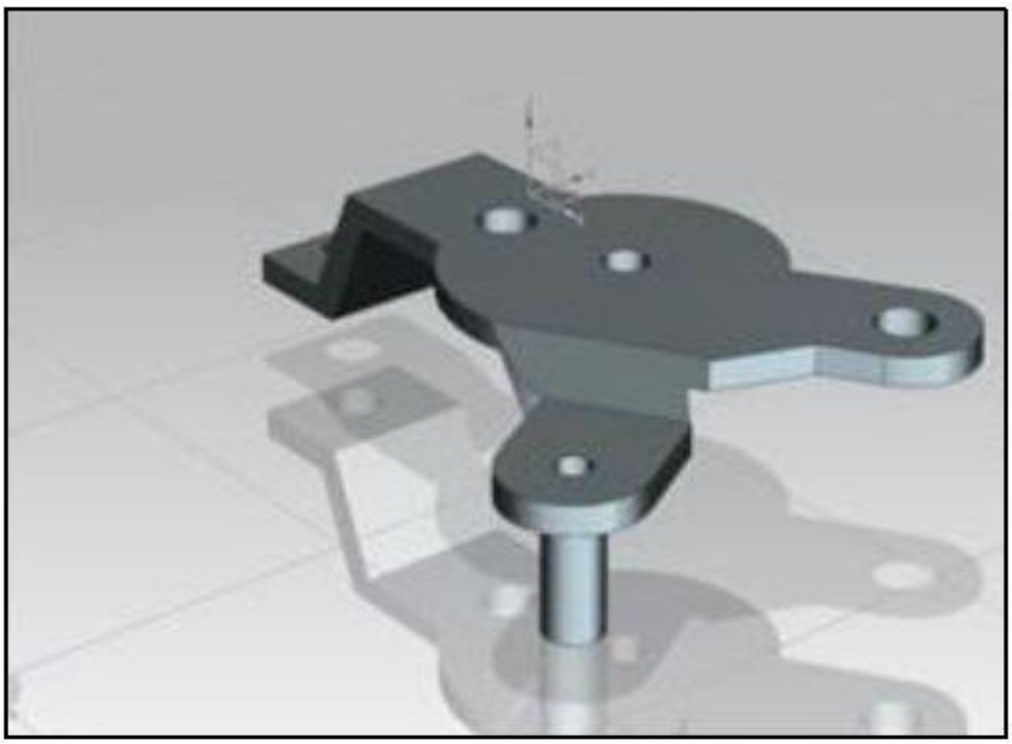

Figure: 7 Design of Palm

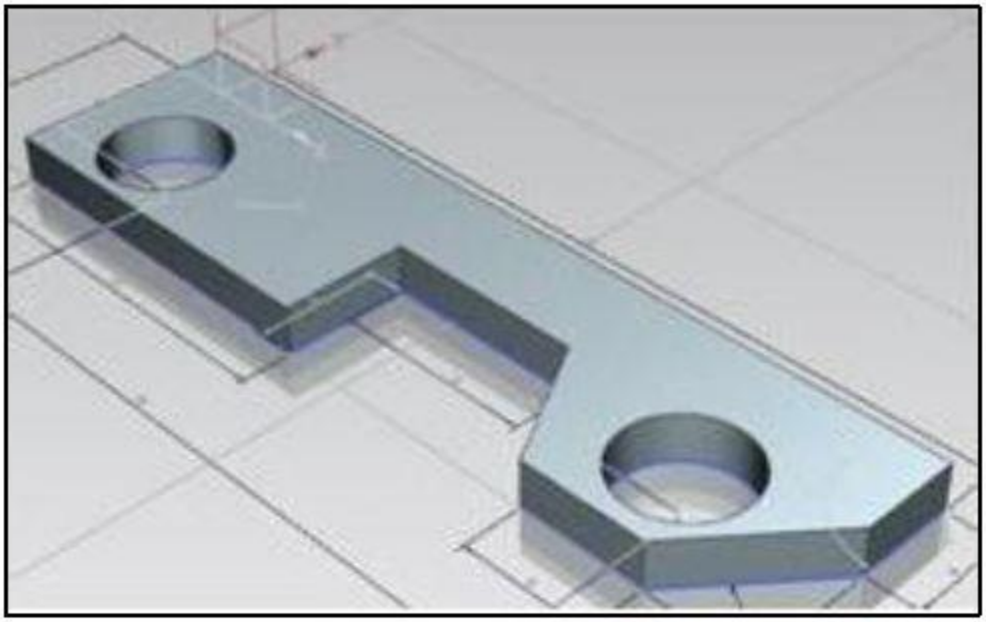

Figure 8 Design of Link

Results

The result of this fabrication process is expected that, the cost of this prosthetic hand is less compared to that of bionic hand and it is more flexible and reliable since it contains wrist movement. Since no battery or motors are used the maintenance is easy and costs less.

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.

Article study

The results from the user needs study reveal the level of user satisfaction for current models of prosthetic hands. The results are the base of the customer requirements presented later. The tables below contain a summary of the findings from three surveys related to user needs.
Table (2) X Biddiss et al., (-2007) is an open-ended question where prosthetic users openly suggested what should be prioritized when designing a myo electric prosthetic hand. The survey highlights the importance of; weight, glove durability, cost, sensory feedback, fine motor skills/dexterity, heat, appearance and reliability

Table (2) McFarland, Hubbard, Winkler, Heinemann, Jones, Esquenazi. -2010) shows rejection rates for myoelectric hand prosthetics based on answers from war veterans. The survey highlights the importance of; functionality, comfort and weight.

Table (3) User satisfaction -X (2007). shows the users satisfaction levels from a survey which highlights the importance of; weight and grasping speed. The survey had answers for children, women and men. The authors show answers for questions related to this project for women and men only, and an average will be calculated when the data is used for deciding the customer requirements.

Design priorities (open end question)	Rejection rates
1 Weight	8% Not functional
2 Glove durability	14% Uncomfortable
3 Cost	17% Too heavy
4 Sensory feedbacks	
5 Fine motor skills/dexterity	
6 Heat	
7 Appearance	
8 Reliability	

Table 2:Survey results from prosthetic user suggestions. R. Rejection rates study)

Satisfaction survey

Weight	Females 50% acceptable 25% a little too heavy 25% much to heavy Males 23% acceptable 50% a little too heavy 27% much to heavy
Grasping speed	Females 100% too slow Males 15% acceptable 67% too slow 18% too fast

Table 3:Survey results, user satisfaction.

User requirements

The user needs study led to defined user requirements and user wishes (table 4). The users want a prosthetic hand that is lighter, more durable and that has better functionality for a lower price than the current top models

User requirements	User wishes
Low weight / comfort Higher durability Lower cost Better functionality (response) Resistance to water Appearance	Sensory feedback Less object slipping Adaptable grip strength Reduction of noise Anthropomorphism Increased movement speed

Table 4:Customer requirements.

Mechanical solutions

The mechanical solutions are based on the technical specifications (table 5). The technical specifications were decided by the user requirements, benchmarking and biomimicry study. The mechanical solutions also consider the user wishes in table 5.

User requirements	Engineering specifications
Low weight / comfort	Low weight, <450g
Higher durability	Can take outer forces up to 200N
Lower cost	N/A
Better functionality (response)	Gripping speed, power grasp <1.5s
Resistance to water	Waterproof, up to 1 meter of water
Appearance	Mimic the human hand with skin-like glove

Table 5:User requirements and the related engineering specifications.

Mechanical solutions for the prosthetic that theoretically can satisfy all of the technical and customer requirements. But preliminary calculations and testing of the actuation system indicate a proclivity for a solution. The final design is not determined, but the concept includes fingers, joints, linkages, the actuation system and the internal component layout.

Proof of concept:

Weight:

Lightweight materials would be used for all parts of the prosthesis, this is however also used by the benchmarked models and wouldn't make a big difference. will consider most structural parts of the prosthesis to be similar in weight as current models.

Durability:

The developed concept is meant to improve this by having no linkages between the finger segments that can break and lead to non-functional flexing. Also, the hydraulic bellow actuation system is meant to leave room for a very strong design of the finger segments which gives opportunity to make the fingers less fragile than the benchmarked models.

Cost:

The cost cannot be determined. The concept is meant to reduce the cost compared to current models while still achieve at least the same functionality. The concept would achieve this by having fewer parts and being less complex in general. The electronics and programming will be less advanced since there won't be as many engines or as advanced actuation system. This leads to less development costs as well as material costs. The lower complexity is meant to remove the excess functions of the benchmarked models and not the functions that users actually ask.

Functionality:

The functionality of the concept is not greatly improved compared to the benchmarked models. Only the final design can determine how the functionality actually, will be. But the concept is built in a similar way which makes it at least as functional as the benchmarked models. And a future continued development together with users gives opportunity to also improving the functionality compared to current models.

The suggested introduction of a force feedback system which would give the user a signal in the form of an armband that contracts as the prosthetic grip force increases would increase the functionality according to the user needs study.

Water resistance:

The concept is meant to have a coating of silicone or a silicone glove making it fully water resistant and easy to wash. This was asked for in different grade in all the sources of data in the user needs study. Making is water resistant increases the functionality in many applications for the user ranging from cooking to personal hygiene.

Appearance:

The concept is only on a mechanical development so far. However, appearance has been considered greatly by studying the human hand geometry and gripping patters to make the prosthesis “human like”. The authors also suggest for the final design that a custom-made glove should be made available for the user in the user's own skin tone since it was suggested by a user in an open-ended question.

Scope for Future Work

Prosthetics is an artificial device that replaces the missing body part, which may be lost through trauma diseases or congenital condition, so to overcome such problems prosthetic limbs came into use to make an individual self-dependent. Despite many advances of bionic hand, mechanical operated prosthetic will have ease in construction and also will have less maintenance charges. As we know that advanced and highly technical and well-versed bionic hand are available, but the current cost and maintenance almost make it impossible for common man to afford.

So, the prosthetic operated by simple mechanism might have great scope, since it is simple in construction and easily affordable for common people. On the basis of operative mechanism point of view, it becomes great medium for normal people. In this project, the arm can be made by using plastic/fibre materials so that it can be light weight can improve the aesthetics looks. The movement of wrist can be operated by dc-motors, with pulling arrangement so that the physical stress on the person can be avoided but once again it leads higher cost and also person should knowledge to operate it.

Conclusions

Prosthetics is a tool to lead life for the person who lost their hands/legs through congenital defect develops more advanced prosthetics but the main concern is the cost. If the cost is less, then it will be affordable for middle class/ common people so they can work independently. Hence the main aim is developing prosthetics with minimum cost.

As for arm prosthetics, the extent of work can be performed by prosthetics largely depends on the interaction of physicians, surgeons, prosthetics and engineers if meaning full multi-functional control prosthetics are developed then surgeons and physicians need to perform innovative procedure during medical treatment for the patients. In this project, a mechanical hand physically operated prosthetics is developed which leads less maintenance and repairing cost. As compare to bionic or motorized prosthetics the Bionic hand is costlier as it contains sensors and precision motors for its operations and its maintenance may take long process which makes the patient inconvenience due to lack of prosthetics during repairing works.

Hence this project is adoptable for common people who lost their hand and repairable at lower cost. This project is simple in design and operated mechanically by physical strength of disabled person. By stretching his/her chest the finger movement can be performed and can hold the items as His/her wish. The wrist movement is achieved by holding his/her arm towards is body so that he can fill the object according to arm folding angle, which gives great advantages to the disabled person.

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