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DESIGN OF HUMAN PROSTHETIC HAND

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Abstract: this research work seeks to develop a cosmetically appealing, functional and low-cost a first generation of prosthetic hand having a multi degree of freedom (DOF) to trigger finger movement by using standard on shelves parts. The design combination and integration of fingers tries to produce a prosthetic hand which is approximately the size of a human hand, and mimics the natural movements of it. In the design the space is a very important constraint to fit the electrical and mechanical parts without changing the shape nor the size. The design comprised of servo motors located at the palm to drive the gears and links mechanism connected to each of the finger joints enabling independent flexion finger link movement. Lightweight electric motors are positioned at the palm. The hand model was developed using Computer Aided Design software's (Auto CAD and SolidWorks). The link parameter analysis to determine the end tip position of the prosthesis finger at certain rotation angle was computed.
Keywords: hand prosthesis, biomechanics.

I. INTRODUCTION

Hand is one of the important parts of our body lend by ALLAH to us. It plays major roles in our daily life with its wide variety of functions. These include grasping, holding, touching, caressing, manipulating, and a lot more. However, there are some people who were born with no hand, or often in some cases, lost their hand due to a sudden and traumatic event. 67% of the events of upper limb amputees were male shows that men are significant more likely than women to lose their hands, where the cases most commonly take place during the productive working years with 60% between the ages of 16 and 54. Statistical studies estimated that 1.6 million United States civilians were living with the loss of a limb. They predicted that this numbers will increase and probably double to 3.6 million by the year 2050. Congenital or sensory and motor function loss may associate with disability. What is more, they might not only suffer for devastating trauma, but face limitation in activities, restriction in participation, discontent with daily live, employment difficulties, and affected the experience of health-related quality of life. Artificial extensions of the body which replace absent biological limbs are known as prosthetic limbs. The word "prosthesis" is derived from the Greek "to place before". Ancient literature used it to denote a separate word as opposed to "prefix". In surgery, it defines an artificial device recruited to replace a body imperfection. Although the prostheses do not come even near to compensate hand losses, they do offer a new hope and improvement in life of the amputees. A notable number of individuals around the world live without limb and use prosthetic technologies to aid and help them in diverse ways about their lives. 100,000 upper extremity amputees are estimate presently living in United States alone. A simple powered prosthesis could benefit them from the psychological gains and physical usefulness. It is a despondent fact that people who are seen as different in the community stand out, but those people simply want to match and be treated normally, and be able to lead ordinary high functioning lives. Amputees are strong and skilled people, who make do with what they have, and are able to overcome difficulty. An early prosthetic hook and socket created during the Civil War is shown in Figure 1, [2].

Figure 1: Civil War Prosthetic Hook.

A few centuries ago, a hand amputee would have been condemned to a hook prosthesis that had restricted function and brought significant social stigma. However in today‘s community, a hand amputee can expect a replacement hand that imitates a whole host of normal hand functions and looks astonishing life like. In spite of the fact that the bionic hand was recently hailed as a triumph of engineering excellence, it stays an inferior replacement to the genuine thing. As an effect, there are a number of hurdles to its uptake amongst the upper limb amputee population. These foil the prosthetic hand from achieving the ultimate goal of any prosthesis that is 100% acceptance by its users. Functional prosthesis acts as a device that allows the users to perform task or specific work, and may or may not serve for cosmetic purpose. It can be used as an aid tool to work on the basic hand function such as holding and grasping for the needs. The functional prosthesis may be in the form of hook prehensor, i.e. devices that consist of a thumb like component and a finger component and that may resemble lobster claws, pliers or a bird‘s beaker; or hand. As time passes, emerge of technologies has led to smaller, stronger and more natural designs for the functional prosthetic hand whether it is body-powered (i.e., mechanical) or electrically powered (i.e., myoelectric). Mechanism design for body-powered type does not rely on outer power source. In fact, it operates by using cable and harness systems that rely for the patient‘s body movements, e.g. moving the shoulders or the arm to pull the cable and make the terminal device, i.e., a hand, to open or close, Figure 2. This is similar to the working system of bicycle handbrake. In the other word, use cable-operated system to generate forces and move prosthetic joints. It also helps to restore basic grasping capability to people who have lost multiple fingers. [1]

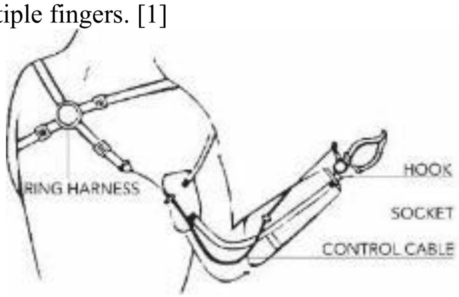

Figure 2: Prosthetic Hook and Harness.

On the other hand, electrical or myoelectric prosthetic hand is powered by external artificial limb which is control by the electrical signals generated by the patient ‘s muscles. A myoelectric-controlled prosthesis can be understood as an externally powered artificial limb that you control with the electrical signals generated naturally by your own muscles. Numbers of studies have been done on myoelectric hand prostheses.

It is a very challenging task to design and control of versatile upper limb prostheses. While many breakthroughs have been made over the last several decades, the contrasting in performance and quality between human hands and artificial hands is rather considerable. A latest survey of amputees confirmed this observation which proves that they still wish that their prostheses can function in a life-like manner. Moreover, another amputee ‘survey indicates that they desire their prostheses to be more intuitively controlled.

Upper limb amputees reject use of their prostheses because of low functionality, among other reasons are quite prevalent. In order to help refine these problems, E. D. Engeberg has made a novel contribution to develop a biologically inspired application of sliding mode control and EMG signal interpretation algorithms that make prosthetic hands may be controlled in a more intuitively feeling and physiologically expected manner. In the past, sliding mode control of prosthetic hands has been described in a few literatures.

In today‘s world, there are many innovative and unique design of upper limp prostheses can be found. Best prostheses are chosen by upper extremity amputees and people with congenital limb differences based on range of consideration. This includes the status of amputation, the state of the remaining portion of the hand, the desired appearance of the prosthesis, the goal of individual, and any activity or work-related needs. Some of the prosthetic options are passive cosmetic, i.e., which is for the sake of appearance; and functional prosthesis. As for the body-powered devices, it is lower in cost, easier to be repair, lighter, and offer better tension feedback to the body. [3]

II. Concept of Designs

It is about forming, modeling, shaping a new idea, approach, abstraction of an implementation.

(a) Engineering Design

Most engineering designs can be classified as inventions devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems. Inventions, or designs, do not suddenly appear from nowhere. They are the result of bringing together technologies to meet human needs or to solve problems. Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step by step methodology [5].

Engineers were described primarily as problem solvers. What distinguishes design from other types of problem solving is the nature of both the problem and the solution. Design problems are open ended in nature, which means they have more than one correct solution. The result or solution to a design problem is a system that possesses specified properties [18].

(b) The Design Process

The basic five-step process usually used in a problem-solving works for design problems as well. Since design problems are usually defined more vaguely and have a multitude of correct answers, the process may require backtracking and iteration. Solving a design problem is a contingent process and the solution is subject to unforeseen complications and changes as it develops [7].

The five steps used for solving design problems are:

1. Define the problem
2. Gather pertinent information
3. Generate multiple solutions

4. Analyze and select a solution
5. Test and implement the solution

The first step in the design process is the problem definition. This definition usually contains a listing of the product or customer requirements and specially information about product functions and features among other things. In the next step, relevant information for the design of the product and its functional specifications is obtained. A survey regarding the availability of similar products in the market should be performed at this stage. Once the details of the design are clearly identified, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives to achieve the goals and the requirements of the design. Considering cost, safety, and other criteria for selection, the more promising alternatives are selected for further analysis. Detail design and analysis step enables a complete study of the solutions and result in identification of the final design that best fits the product requirements [8].

When solving a design problem, designer may find at any point in the process to go back to a previous step. The chosen solution may prove unworkable for any number of reasons and may require redefining the problem, collecting more information, or generating different solutions. This continuous iterative process is represented in the following Flowchart [9], Figure 3.

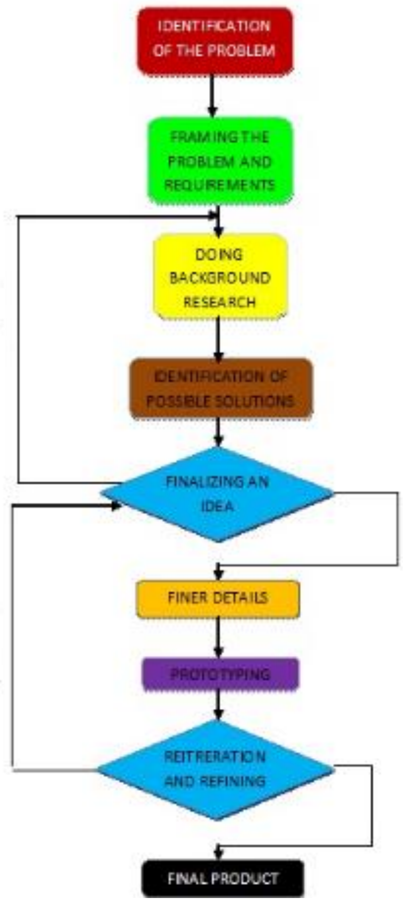

Figure 3: Engineering Design Flowchart.

(c) DEFINE THE PROBLEM

The designed prosthetic hand is defined as a hand that mimics the natural movements of the human hand, the most important point is to study the movements. Once the natural motions on the human hand are defined, the design of a prosthetic that can imitate them can occur. In the design of this prosthetic, space is a very important constraint. The size of the prosthetic must also resemble that of the average human hand. This means that there is not much space to fit motors. The fingers themselves are very small and there will not be any room for actuators that are powerful enough to accomplish everyday tasks. From another hand, the design should be flexible to serve the people in a very close period by providing the needed prosthesis according to the needed specification that built on the assembly of on shelf parts. So this design will be very helpful especially in the crises.

(d) GATHER PERTINENT INFORMATION

Before getting started in the design, collecting all the information available that relates to the problem. That effort spent searching for information about the relevant problem will pay big dividends later in the design process. Gathering pertinent information can reveal facts about the problem that result in a redefinition of the problem. Through this, mistakes will be discovered and false starts made by other designers [10].

It is very necessary to start the design job by collecting all the information available that relates to the problem. That will help in avoiding the previous mistakes and go through the positive points of the others, so many books, papers and researches were collected in concern to study.

Based on what have been mentioned above, the collected information was classified into groups as following:

6. Human hand prosthesis designs.
7. Human hand dimensions, volume and weight that related to the age and sex.
8. Material selection that can fulfil the needed design.
9. Human hand movements and dynamics.

(e) Generate Multiple Solutions

The next step in the design process begins with creativity in generating new ideas that may solve the problem. Creativity is much more than just a systematic application of rules and theory to solve a technical problem [11].

There are some general design considerations that need to take care as following:

- **Form versus Function:** The role of form, or cosmesis, in prosthetics cannot be overstated. Often the designers sacrifice cosmetic appeal to achieve increased prehensile function. However, the relative importance of appearance versus function is highly dependent on the person with the amputation. Some people may be solely concerned with visual presentation and reject a highly functional body-powered, cable-operated prosthesis because of the unacceptable appearance of the control harness or of a hook shaped terminal device. Others might find the function provided by these devices sufficient to outweigh their concerns about their appearance. Still others prefer a more tool like appearance believing a prosthesis that looks like a natural arm or hand but is not is a deception.

  It is not uncommon for a person with an amputation to have two prostheses, one that emphasizes mechanical function, one for work, and an interchangeable one with a more humanlike appearance for social occasion. Choice of prosthesis is ultimately based on many psychological, cultural and practical factors. Other factors affecting the issue are age, gender, occupation and degree of physical activity.

  Dynamic cosmesis is frequently the more important of the two form of cosmesis, but it is frequently overlooked because it is difficult to achieve. Dynamic cosmoses can be enhanced by preserving as much of the person's residual motion as possible, Figure 4.

Figure 4: Prosthetic Hand Hook.

- **Weight:** Final weight of a prosthesis is critical to the success of any prosthetic fitting. Prosthesis need to be as light as possible or else they will end up in a closet.

- **Power Sources:** As is the case of all portable devices, power is a scarce. Choice of power source defines a prosthesis, in that it determines the choice of actuator. If the power source is to be the person, i.e., body power, then the actuator is the person's own musculature and the prosthesis should not require excessive effort to use. Mechanical mechanisms need to be efficient and frictional losses need to be minimized to avoid tiring the user over the course of a day. If the artificial limb is externally powered, the limb should be able to run for a day from the same power source without needing to be replaced or recharged. In addition, it is desirable for the power source to be contained within the prosthesis.

  Electrochemical batteries are the main source of energy for modern externally powered prosthetic arms, although pneumatic gas cylinders have been used in the past. There are a number of other technologies that could replace batteries as portable sources of electricity in the future.

  The problem of portable prosthesis power is analogous to the power issue in the laptop computer and cellular phone industry, where a major contributor to the weight and space of these portable devices is the power source, which for the moment is the battery. In addition, prosthesis need high power density as well as high energy density.

  In addition to the general specifications mentioned above, some specific requirements are defined for the multifunctional hand prosthesis:

1. The palm and fingers segments resemble the human model in both configuration and proportion.
2. The fingers and thumb are powered by a single self-contained electric motor located in the palm.
3. The motor gearbox unit is self-locking and free of objectionable noise.
4. The flexibility of design that can be apply for any age and gender.
5. The dependency of the design on the on shelf ready-made spare parts, that helps on crises or any accidents to find a fast solution.
6. The minimum weight or much closer to the real one.
7. Moving and controlling the four finger and the thumb.
8. Keeping the same real dimensions and angels of the fingers, thumb and the palm.

9. Minimizing costs.
10. Minimizing the needed maintenance.

(f) Analyze and Select a Solution

Once getting the conceived alternative solutions to the design problem, analyzing those solutions and then deciding which solution is best suited for implementation. Analysis is the evaluation of the proposed designs. By applying the technical knowledge to the proposed solutions and use the results to decide which solution to carry out. design analysis will be covered in more depth when getting into upper-level engineering courses [6].

The overall design for this prosthetic hand was treated as an investigation of feasibility. After performing the necessary background research and studying the available products with its advantages and disadvantages. The process for designing this new product focused first on what needs of the user would be. The selections of the new design were clear to go through. But modification and renewing ways were needed for the new design to get much compatible one that can work easily with less problems than the previous, most applicable, easy, safe, economic and fulfills the needs. The prosthetic hand that designed in this project comprises of palm and phalanges or fingers.

The main idea of the design in this project is depending on the linkage connection, so the design will start with the selecting the motor with gearbox with the needed speed then designing the worm gear system that to change the feeding torque direction and its frame, designing the phalanges and how they connected to each other with the needed dimensions according to the natural dimensions, designing the link that gives the related movements needed for griping, designing the thumb that moves two different types of movements with different angles, designing the hand palm that can hold all the fingers with its system within the standard dimensions.

Detailed mechanical design was accomplished through the use of AutoCAD software and SolidWorks CAD. Backup data and part files were kept throughout the design process and can be made available upon request. Individual parts were carefully modeled with as much detailed information and accurate dimensions as possible. When working with such limited space and small components, accuracy was a priority.

(g) Test And Implement The Solution

The final phase of the design process is implementation, which refers to the testing, construction, and manufacturing of the solution to the design problem. Considering several methods of implementation is very important, such as prototyping and concurrent engineering, as well as distinct activities that occur during implementation, such as documenting the design solution and applying for patents. [10]

After The design done, the compatibility of the parts and the mechanism should be tested, that will be through prototyping the system in real or using CAD system. The 3-D computer modeling software Solid works allows the drafting of the hand model as well as the construction of all components in an assembly. Modeling the parts allows the user to see possible problems in the design as well as visualize changes in dimensions or other changes to the design. Then after completing this stage, the final drawings should be collected and numbered in groups for documentation in the future.

The hand components design was done supported with the drawings in 2-D and 3-D to show the part reality. Also, the assembly drawings for the designed components. All that showing in the Appendix.

Also (if required), testing the system for compatibility and the stability of parts is done according to the needs of the system. The results will be collected and documented in the report.

III. The Proposed Prototype Design

(a) General Description of the Proposed Prosthesis

After making reviews on the design previous studies, the designed artificial hand is intended to have precise specifications in order to fulfilling its purpose for high performance. The aimed prosthesis is a below-elbow prosthetic hand designed to fulfil most of the needed daily required tasks as does the real hand for light jobs like griping, holding, lifting, pushing,.etc. In addition, its weight should be convenient to the patient, therefore, it should be as light as possible. Also, cosmetically and functionally, it should be resembling to natural one, thus the whole fingers were designed to be full-opened and tight-closed during one cyclic operation. This type of figures movements requires special electrical and electronic parts to drive the mechanical parts of the aimed prostheses. Therefore, this design composes mechanical parts such as gears, links, bearings and gearboxes, and electrical parts such as electrical motors, micro controller that controls the fingers movement.

And finally, it ought to be of reasonable cost that to allow those who lacking stable financial support to own.

Engineering perspective strategy of design was based partly on ready made parts to get the benefits of shortening the required time of manufacturing, and lowering the gross cost of final product.

This flexible design allows to build any hand for any gender in a very close time, just having the standard dimensions of the fingers and rest from standard parts

(b) Design Requirements

The following requirements need to be taken into considerations, which are:

- **HUMAN HAND MEASUREMENTS:** As there are many studies for determining and finding the technical dimensions of the human hand, studies titled " Weight, Volume, and Center of mass of segments of the human body" [4] and "The Measure of Man; Human Factors in Design" [12] were issued to find all the dimensions of each part of human body through studying of number of cadaver's. The collected information related to the human hand is presented in Tables 1 and 2.

Table 1: Mass, Volume and Specific Gravity of the Right Hand [4].

Sex	Age (years)	Weight (gm)	Volume (cc)	Specific Gravity
M	68	447.7	403.5	1.1093
M	40	525.1	471.6	1.1134
F	20	316.8	283.7	1.1163
M	30	393.2	354.3	1.1191

Table 2: Hand Measurements of Men, Women and Children [12].

Hand Data	Men			Women			Children			
	2.5% tile	50% tile	97.5% tile	2.5% tile	50% tile	97.5% tile	6 years	8 years	11 years	14 years
Hand length	6.8	7.5	8.2	6.2	6.9	7.5	5.1	5.6	6.3	7.0
Hand breadth	3.2	3.5	3.8	2.6	2.9	3.1	2.3	2.5	2.8	-
3rd finger lg.	4.0	4.5	5.0	3.6	4.0	4.4	2.9	3.2	3.5	4.0
Dorsum lg.	2.8	3.0	3.2	2.6	2.9	3.1	2.2	2.4	2.8	3.0
Thumb length	2.4	2.7	3.0	2.2	2.4	2.6	1.8	2.0	2.2	2.4

The present study concentrates on the male right hand, and by having the average readings from the Table 2, the results were:

Right hand average weight = 455.34 gm
Right hand average volume = 409.8 cc
Right hand average specific gravity = 1.11394

The human hand mass can be calculated by using the following formula, [4,13]:

$$Hand\ Mass\ = 0.01\ \times Body\ Weight\ + 0.7\ \pm 0.4$$

Or

$$Hand\ Mass\ = 0.6\ percent\ of\ the\ total\ body\ weight\ for\ men$$

On another hand, the following Figure 5 shows the whole measurements of human hand [13], that helps to put the real dimensions for the prosthetic hand:

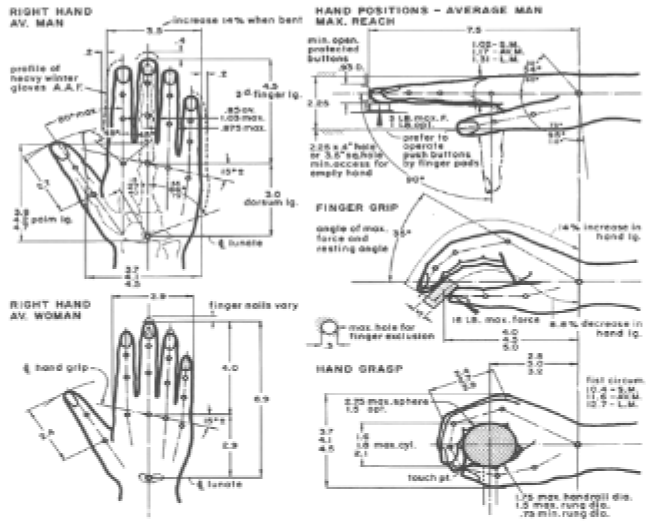

Figure 5: Hand measurements of men, women and children.

The main part in the hand design is the finger. The human finger is an amazing piece of engineering consisting of three individual pivot joints which can almost be individually actuated through muscular tendons. The finger design process began by determining the required motion needed for each finger. The location of all joints was measured and translated to drawings.

Therefore, the first opportunity for simplification comes from treating the fingertip as one fixed link as opposed to two separate links joined by a knuckle. The fingertip was treated as one link with the final knuckle fixed slightly bent.

The human finger when viewed from the side is convenient in that it rotates approximately 90^o from full extension to full closure. Similarly, the second knuckle joint also rotates approximately 90^o at this time. As one slowly flexes their hand from fully opened to fully closed, it becomes clear that the two joints move at approximately the same in a 1:1 ratio. That realization opened up many mechanical possibilities for example linkages which would allow for the base finger to be rotated actively while at the same time passively linked to the first joint. Figure 6 shows how the linkage system works in griping the fingers.

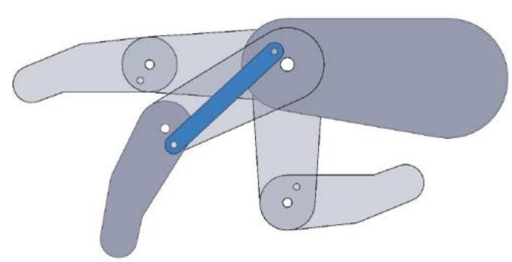

Figure 6: The mechanism of linkage system.

- **MATERIAL SELECTION:** According to the needed material specification required which insures toughness and the lowest cost, the proposed hand was recommended to be made of Polyoxymethylene (POM), CH2O, also it is known as acetal, polyacetal and polyformaldehyde. POM is an engineering thermoplastic used in precision parts required high stiffness, low friction and excellent dimensional stability. Its most advantageous specifications are [14]:

  - High abrasion resistance.
  - Low coefficient of friction.
  - High heat resistance.
  - Good electrical and dielectric properties.
  - Low water absorption.

POM is characterized by its high strength, hardness and rigidity to -40 oC. This material is intrinsically opaque white, due to its high crystalline composition, but it is available in all colors. Its density is about 1.410 – 1.420 gm/cm3, and its melting point is 175ºC [15].

POM supplied as extruded bar or sheet, it may be machined using traditional methods such as turning, milling, drilling. etc. These techniques are best employed where production economics do not merit the expense of melt processing [14].

- **MOTION STUDY:** According to previous studies that measured the finger flexion / extension speeds about the MCP joint using an externally mounted potentiometer. The full hand finger speed data correspond with the speed of the fingers when all fingers are flexed or extended simultaneously in free air. Table 3 shows the individual finger speeds for the six types of hands [13]:

Table 3: Finger flexion/extension speed.

Finger	Average (°/sec)	Number Trials	Standard Deviation
Vincent Large (ring, middle, and index)	103.3	2	3.0
Vincent Small (little)	87.9	2	5.1
iLimb Large (middle)	81.8	4	3.3
iLimb Med (index/ring)	95.3	2	3.4
iLimb Small (little)	95.4	2	2.6
iLimb Pulse Thumb	110.6	4	4.1
iLimb Pulse Large (index, middle)	60.5	4	1.8
iLimb Pulse Med (ring)	74.3	4	2.8
iLimb Pulse Small (little)	82.2	4	4.0
Bebionic Thumb	36.6	16	7.7
Bebionic Large (ring, middle, and index)	45.8	8	2.2
Bebionic Small (little)	37.8	8	5.2
Bebionic v2 Large (ring, middle, and index)	96.4	2	0.4
Michelangelo (index)	86.9	4	2.8

med = medium.

Then, by having the average reading from the mentioned above speeds:

The average speed = 74.328^{o}. sec^{-1} = 0.206 r.p.s

When looking at the finger motion in the SolidWorks assembly, a link was added to join the palm to the final fingertip. As the first joint of the finger was rotates, a linked motion of the fingertip could be achieved.

- **MOTOR SELECTION:** Power motor selection was an important aspect of this design because all 6 degrees of freedom could be powered by the same type of motor, Figure 7. According to the selected average speed, and depending on the available catalogues from several motor producers such as MOTIONCO and POLOLU companies, the most suitable selected motor for our design is:

  Manufacturer: POLOLU Robotics & Electronics [16]
  Type: 250: 1 Micro Metal Gear motor HP with Gearbox
  Size: 10×12×26 mm^2
  Weight: 9.5 gm
  Shaft diameter: 3 mm
  Gear Ratio: 248.98: 1
  Free-run speed@6V: 120 r.p.m
  Stall torque@6V: 60 oz.in = 0.424 N.m

Figure 7: Motor type POLOLU

- **GEARS SELECTION:** The aim of this stage is to choose how to power the finger joints, the proper mechanical drivetrain would include some type of active braking or force holding aspect which would somehow allow the motor to be turned off without having the fingers move when force is applied. Worm gears stood out as a clear option for a system of this nature. Work gears provide very high reductions in small spaces, and they also have non-back driving tendencies.

  According to the selected average speed, and depending on the reduction ratio to get the needed speed, the reduction ratio found 12: 1. Also depending to HPC Gears catalogue [5], the selected worm gear was having the following specifications:

- Plastic material.
- No. of starts = 1
- Part No. ZSW0.8-1
- Lead angle = 3º48'
- Shaft type.

Concerning to wheels selection (straight gears) were having the following specifications:

1) Type 1:
- Part No. ZM 0.8-12
- No. of teeth = 12
- Plastic material.

2) Type 2:
- Part No. ZM 0.8-20
- No. of teeth = 20
- Plastic material.

- **BEARING SELECTION:** Depending on the designed diameters of the worm gear and the wheel shaft, the selected bearings were as following (According to SKF Rolling Bearing Catalogue) [6]:

(a) Worm wheel bearings: Type W617/8, Weight = 0.7gm
(b) Wheel bearings: Type W617/5, Weight = 0.3gm

(c) GENERAL DESIGN METHODOLOGY

The general methodology used to design the fingers and total hand prosthesis was based on the following sequences:

- The average r.p.m speed for the fingers was calculated (in section of motion study), that is important for selecting the electrical motor and gears assembly. This assembly is represented in worm gear and straight gear. The selection of the worm gear which is the main part of the gearbox will be depending upon the final required speed of the finger. The straight gear which is indirect contact to the worm gear has been selected according to the standard parts catalogue available, Figure 8.

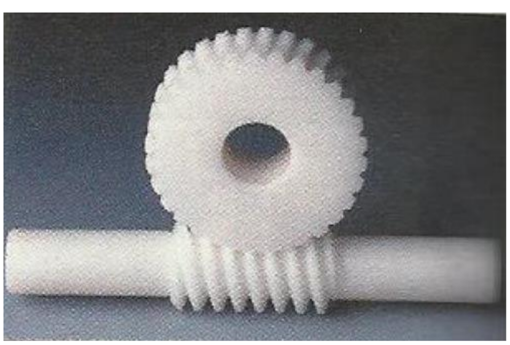

Figure 8: Worm Gear with Straight Gear.

- The design of the gearbox body, Figure 9, was intipated according to the dimensions of the worm gear, supporting bearings, straight gear and the connected motor. In order to reduce the total weight of the gearbox body, all the body wall sides were hollowed. To prevent sliding of the straight gear on the shaft, a key was fitted in the design between the shaft and the straight gear to keep them rotate together. The purpose of four tapped holes located in the top surface of the gearbox was to fix the gearbox to the main plate of the hand.

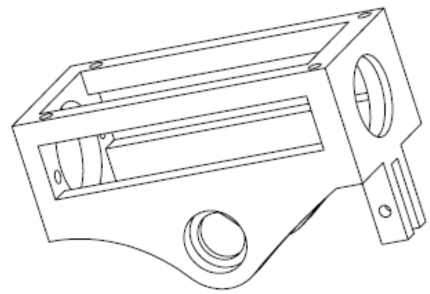

Figure 9: Index, Middle and Little Fingers Gearbox Body.

- Because the motor fixation holes were not alike to the corresponding holes in the gearbox body, an adapter metal plate was designed to join it with the designed site in the gearbox body, Figure 10.

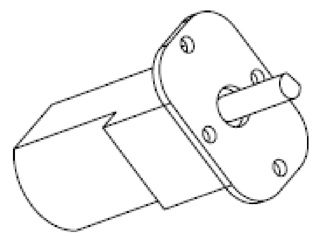

Figure 10: Motor with Motor Fixing Plate.

- The main target of the hand design is to move the fingers from fully opened to fully closed position, that will happen using an electrical motor which gives the torque to the worm gear that transmitted to the straight gear, then moves first knuckle joint through angular movement, finally the last knuckle (finger tip) will be followed the rotation by a link to give the needed grasping movement as well. According to the standard dimensions of the fingers (as mentioned above), the design of the knuckles for index, middle and little fingers was done. The knuckle was fixed to the straight gear through the shaft but the finger tip was connected to the end of knuckle and supported by a pin. The linkage was fixed from both sides with the gearbox and the finger tip. As much as the straight gear rotates clockwise towards the fully closed position, the linkage will rotate as well to reduce the distance between the gearbox and the finger tip which results a griping of the finger tip. The finger tip was designed as well with the needed pins for fixing, Figure 11.

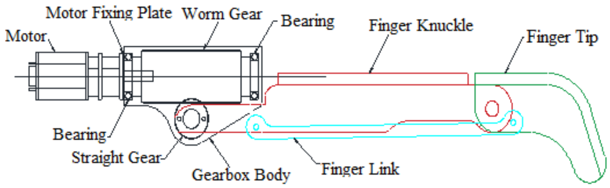

Figure 11: Finger Design with Gearbox and Motor.

As there are different dimensions for the finger knuckle according to the type of the finger, the design of the finger link that connecting between the finger tip and the finger gearbox to control the finger tip movement changes according to the distance between the two junction points, that was done for each finger but only the thumb as shown in Figure 11.

- The torque transmitted from the straight gear to the finger knuckle through two drilled holes passes from the both sides of the knuckle base through the straight gear. Two pins were inserted into these holes to make the two parts unity.
- The design of the thumb was the most complicated step, the thumb movements were completely different than the others, it has to move into two axis therefore two gearboxes were designed for each axis. It has two movements, one is for gripping the thumb and the another one is rotating around its base axis, also it should close in between the index and middle fingers to provide additional clamping force and support on the grasped subject. These movements need to design a compound thumb gearbox to get the required movements. The two gear boxes should be in a very limited space and each one has its own motor to generate its movement. The normal position of the thumb required an angle with the hand palm, so the gearbox was designed inclined with an angle. The two gearboxes were designed to be fitted on each other to get the needed movements and to reduce the space on the hand palm.

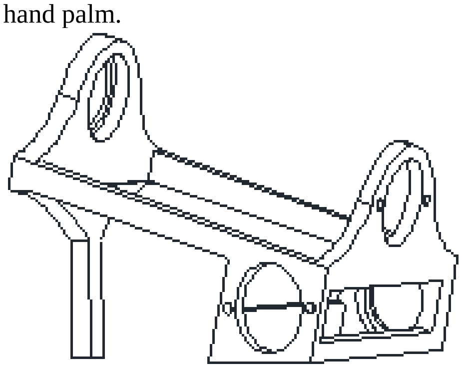

Figure 12: Thumb Gearbox Body 1.

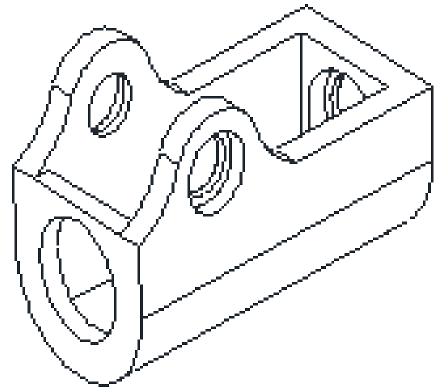

Figure 13: Thumb Gearbox Body 2.

- The last stage in the design procedure was the main chassis plate (hand palm) that holding all the fingers and the axillary components which bolted to it. It consists of a drilled plate with many threaded holes to fix the backside of fingers gearboxes on it. It has the special dimensions and spaces with angles for the fingers. Designing the hand palm was based on the real dimensions of the human hand, Figure 14.

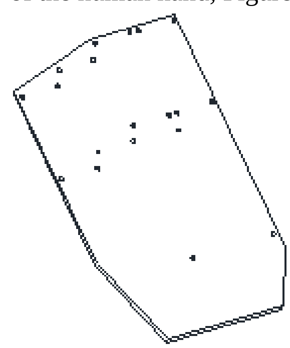

Figure 14: Hand Main Plate (Palm).

IV. Conclusion

The goal was successfully met. This design is the only known prosthetic design which is parametric. The advantages of a parametric design are that it can perfectly match the sound hand size and it is easily adjustable for different ages and hand shapes. Also, the fingers can move with the needed speed and needed movements, the hand shape and final weight were very close to the real one. The present design managed to provide a prosthetic hand with light weight of about 234.24 grams, as illustrated in Appendix A-1, and this will effect on the total hand weight, final hand shape and the complication of the hand.

The thesis study can further be projected with the designing of five fingers and the hand palm. The hand parts and assembly design were done using the Solid Works software and AutoCAD software that to result the whole hand aggregate design.

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