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Modelling of A User-Driven Prosthetic Robotic Arm for Patients with Forearm Amputation

Muhammad Hazim Mohd Hanifah[1], **Amirul Syafiq Sadun**[1]*

[1]Department of Mechanical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: With the growth of advanced technology and manufacturing, the design of prosthetic forearm has evolved. For example, in the past decades, numerous researchs have been conducted to improve the comfortability and effectiveness of prosthetic limbs such as by applying electromyographic (EMG) technique where the signal from muscle movement was processed to control the prosthetic forearm movements instead of using earlier design with fixed movement. This research was conducted to draw a design of a 3D model of prosthetic forearm that able to perform grasping operation. The sketching and drawing design were conducted via CAD/CAM design software to realise a 3D model design based on design data and idea obtained in previous study. The concept idea for this design were biologically inspired by the construction of human forearm. This paper presents the design outcome that able to satisfy the objectives stated. However, compare to the previous study, the design is still lacking to mimic an actual human forearm and can still be improved to rival the design from previous study.

Keywords: Prosthetics Forearm, Electromyographic, 3D model, CAD/CAM, Grasping

1. Introduction

Prosthesis is an artificial tool that substitutes for a body part or an organ. A prosthetic arm replaces an upper limb that may have been amputated due to trauma or disease. Generally, for an amputee, their remaining part of the muscle function normally by emitting Electromyogram (EMG) signal. This signal can be exploited as a system to improve prosthetic limb movements. Those myoelectric signals are recorded by two invasive and non-invasive methods. But non-invasive is mostly the preferred method since it is mounted directly above the surface of the skin without defects, misplacement of the electrodes and interpolation of noise [1].

The advancement and the availability of digitizing and rapid prototyping technologies has enabled the transition between physical and digital media domains of design. The successful implementation

**Corresponding author: amirul@uthm.edu.my*

within feasible time and budget limits of complex-shaped product has drawn attention to the potential of computer-aided design and development technologies (CAD/CAM) and the need for integrated practice [2]. For example, the widely popular designing software is SolidWorks [3]–[5] and the recent online designing software called Onshape [6].

The inspirations for the idea of the concept design were taken from the structure of human skeletal forearm. Many past researches has manage to influence the design of this project such as the anatomically correct testbeds (ACT) researches by Matsuoka [7]–[9]. Referring to the mentioned research, the goals of ACT is to evaluate surgical reconstruction procedures for injured hands as a functional physical model of a human hand for neuro- and plastic-surgeons, as an experimental test for the study of the human hand's complex neuromuscular control, and as a remote manipulator for precision teleoperation and prosthetics that mimics both the passive and active properties of a human hand.

Throughout this project, two objectives were listed as a target to be achieve. The first objective is to design a 3D model of a prosthetic forearm. The second objective is for the design of the prosthetic hand able to perform grasping operation.

To avoid being astray during conducting this study, a boundary needed to be stated. Below are several scopes that were listed and identified as a guideline: the concept design for the prosthetic hand design were referred from human skeletal structure to achieve a biologically accurate design. Since the purpose of prosthetic forearm is to support amputee in daily activity, the design of the prosthetic forearm will be extrinsic. Hence, the material to be used during load test simulation will be Polyethylene Terephthalate Glycol (PETG). With an extrinsic characteristic, the design of 3D model prosthetic forearm able to support EMG technique with non-invasive method for acquiring the muscle signal as one of the control mechanisms.

2. Methodology

The project started with determining the concept of the design by researching any latest design of the prosthetic arm available in any open sources. With the idea from researching past design, the draft of the prosthetic forearm was translated into possible drawing. The next process after the draft of the drawing was accepted is to measure the actual hand model. With the data from measuring process, the 3D drawing of the prosthetic forearm model can be realised. Load test simulation was conducted after the realisation of the 3D model. Figure 1 illustrated the workflow of this project.

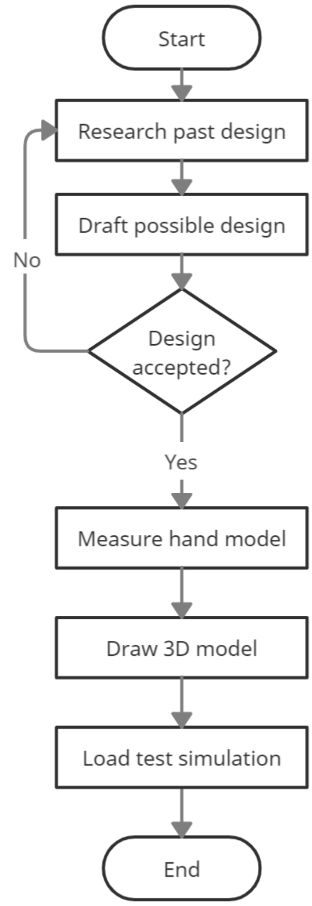

Figure 1: Workflow of the project

2.1 Gathering data to realize the 3D drawing.

The design of the drawing was inspired by the structure of human skeletal design. By studying the structure of bones involve in the making of human hand, the initial draft of the design was sketched to gain a visual idea on how to start an actual drawing. With a clear visual on the design, the next process can be proceeded by measuring an actual hand model using plastic ruler.

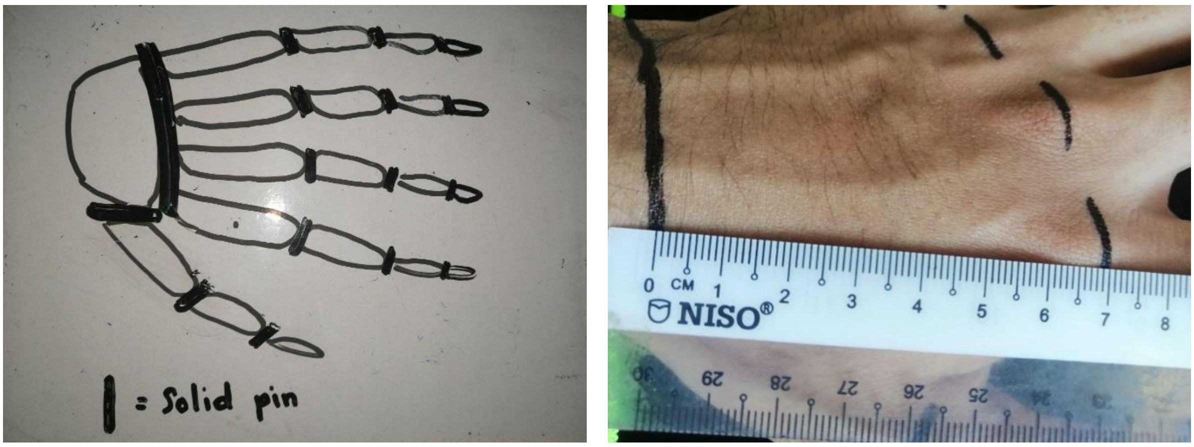

Figure 2: Initial draft of the design (left) and measuring the finger structure (right)

The next process involves with the housing for the electrical components. With the number of the electrical components, the forearm part of the were designed to become the base for electrical system.

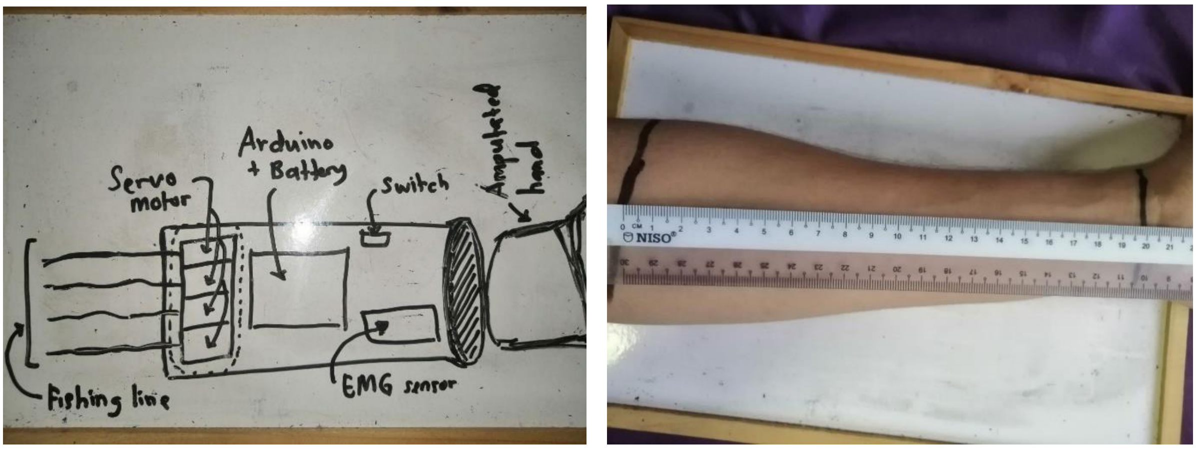

Figure 3: Initial draft of the electrical housing (left) and measuring the forearm sizes (right)

2.2 Drawing 3D model of the prosthetic forearm.

Using the online designing software, Onshape, the 3D drawing of the prosthetic forearm can be realized. The main reason of using Oshape is due to its easy and simple sharing system. With the data measured, the 3D drawing can be completed. After registered for Onshape, user will be brought to own home page and can begin drawing the design. Other than creating new drawing, the home page contains information regarding user's recent activity and project. New drawing can be created by clicking a blue coloured 'create' tab as illustrated in Figure 4.

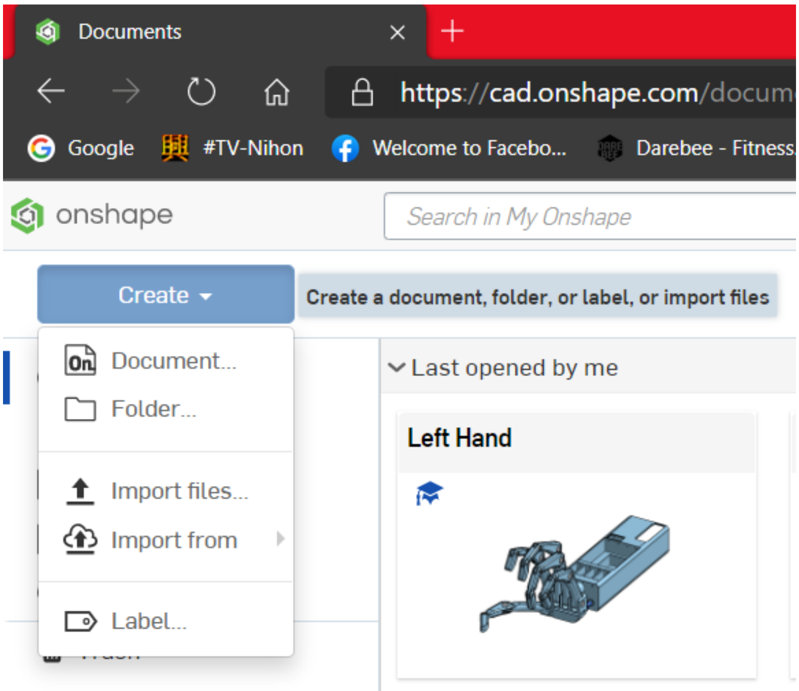

Figure 4: 'create' tab in Onshape home page

In Figure 5 shows the 3D drawing of the prosthetic forearm that were drawn in Onshape. The design of the hand was referred from actual human skeletal hand structure. The only parts that identical were the metacarpals and phalanxes. In Figure 6, carpal consist of 8 different bones but in this drawing all 8 bones in carpal were combined to become one part.

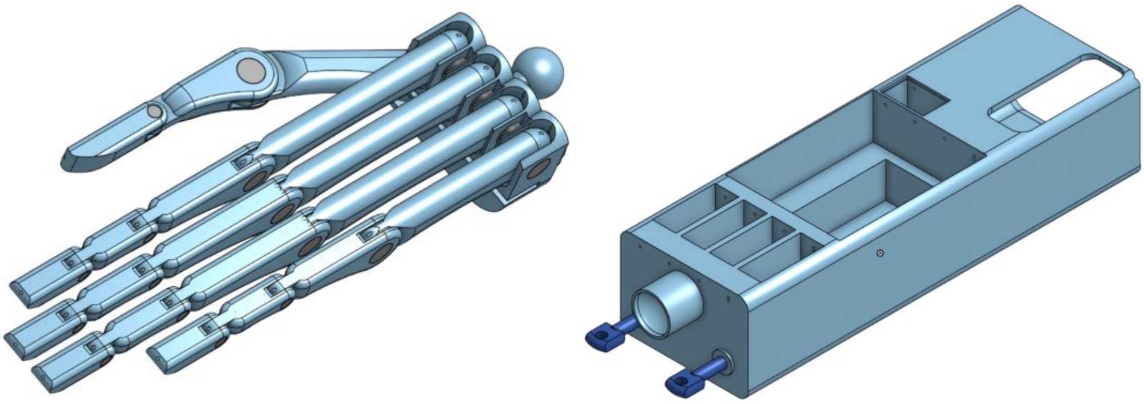

Figure 5: 3D model of the hand (left) and the forearm (right)

Table 1: Guide to parts involved excluding fasteners in figure 5

Item	Components name	Quantity
1	Carpal	1
2	Metacarpal	5
3	Proximal Phalanx	5
4	Middle Phalanx	4
5	Distal Phalanx	5
6	Forearm	1
7	Piston	2

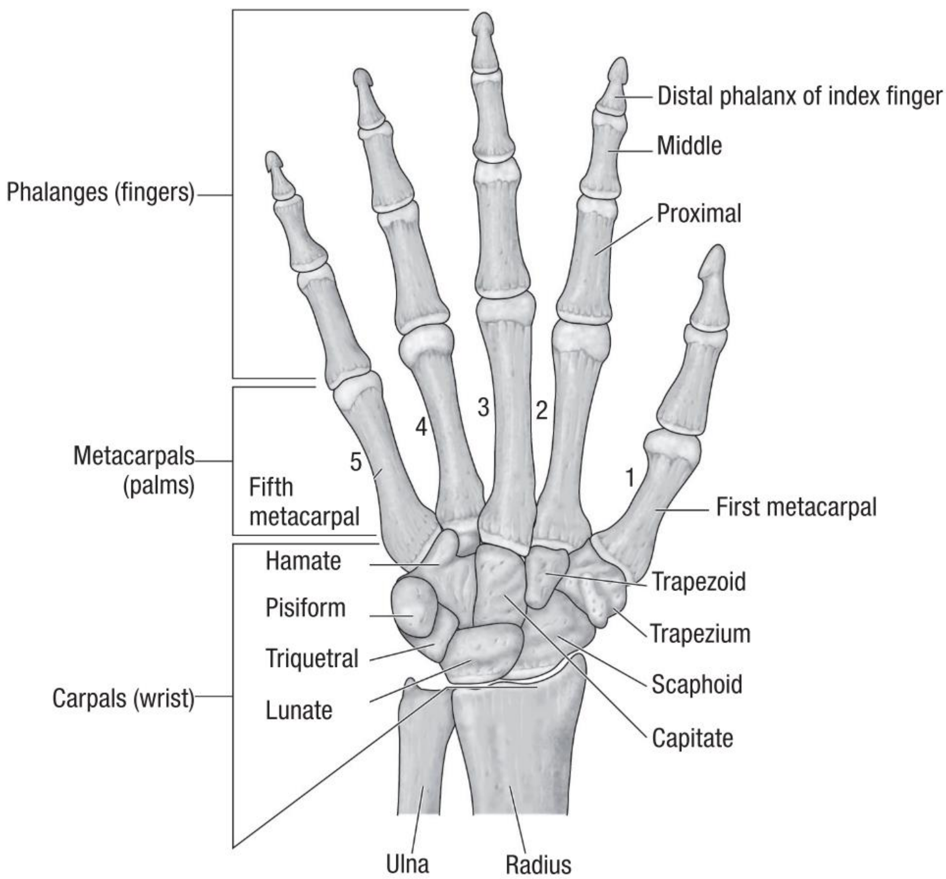

Figure 6: The skeletal hand structure [10]

2.3 The mechanism of movement

The mechanism of movement control for this hand model is by pulling the fishing line. Each finger was controlled by one fishing line. Each phalanx was connected by respective fastener. The fastener will act as a fulcrum to move the finger into grasping position as shown in Figure 6.

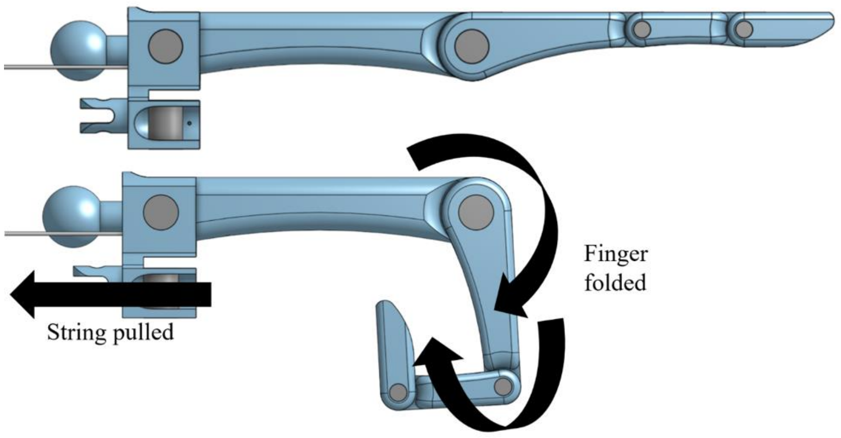

Figure 7: The mechanism of the finger's movement

2.3 Load test simulation

This process was conducted using SolidWorks software to exploit one of its function which static simulation. Since the hand is responsible to grasp and lift an object, only the hand part was selected to undergo the test simulation to calculate the maximum pressure it can sustain. To start this simulation, first, export the assembly of the hand model into the simulation software and select 'new study' to create static simulation. The next step is to define the fixed geometry for the assembly. The fixed geometry is the immovable parts of the hand during grasping action. Figure 8 illustrated the process to define the fixed geometry.

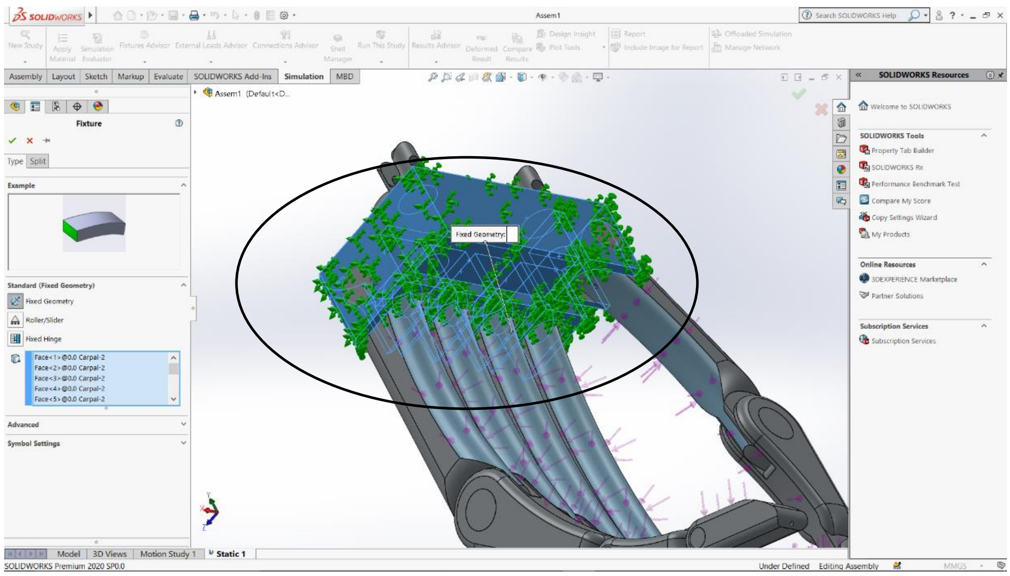

Figure 8: The process to define fixed geometry

The next step is to define the force value and the surfaces it exerted. The surface involve is the part that touches the surface of the objects during grasping operation. Figure 9 illustrated the process to define the force value and the surface it exerted. For the last step, to acquire the result for the simulation, create and run mesh operation. Depending on the force value and the number of surfaces the force applied to, mesh process will run longer to calculate the results.

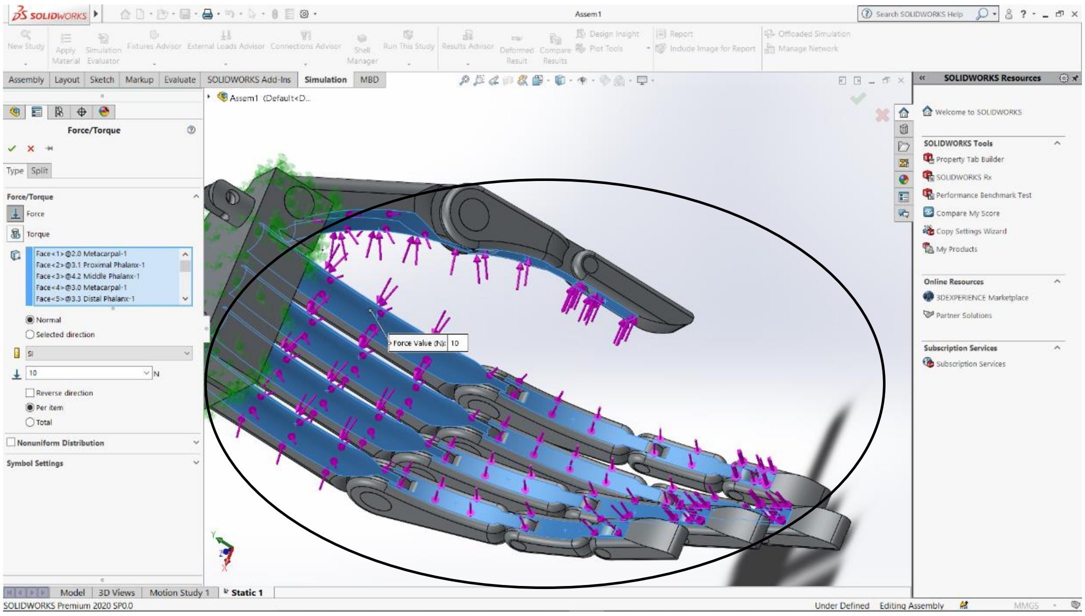

Figure 9: The process to define the force

3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section will be responsible on deciding the conclusion for this project by analysing the results and relate it to the objectives.

3.1 3D modelling dimensions

In this section, the 3D model dimensions of the prosthetic forearm will be shown. The results will decide the practicality of the prosthetic forearm design in terms of size. Figure 10 illustrated the dimensions of the forearm (left) and the hand (left).

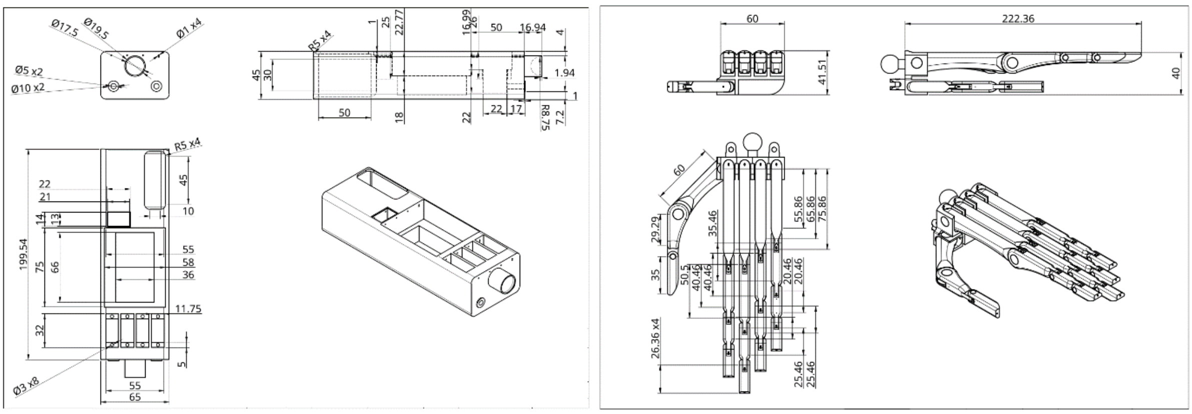

Figure 10: Drawing of the forearm (left) and hand (right with dimensions)

In Figure 11, the visual of 3D modelling of the prosthetic forearm were shown. The figure shows the action of the prosthetic forearm can achieve. While Figure 12 shows the front and rear view of the forearm without the electrical components installed.

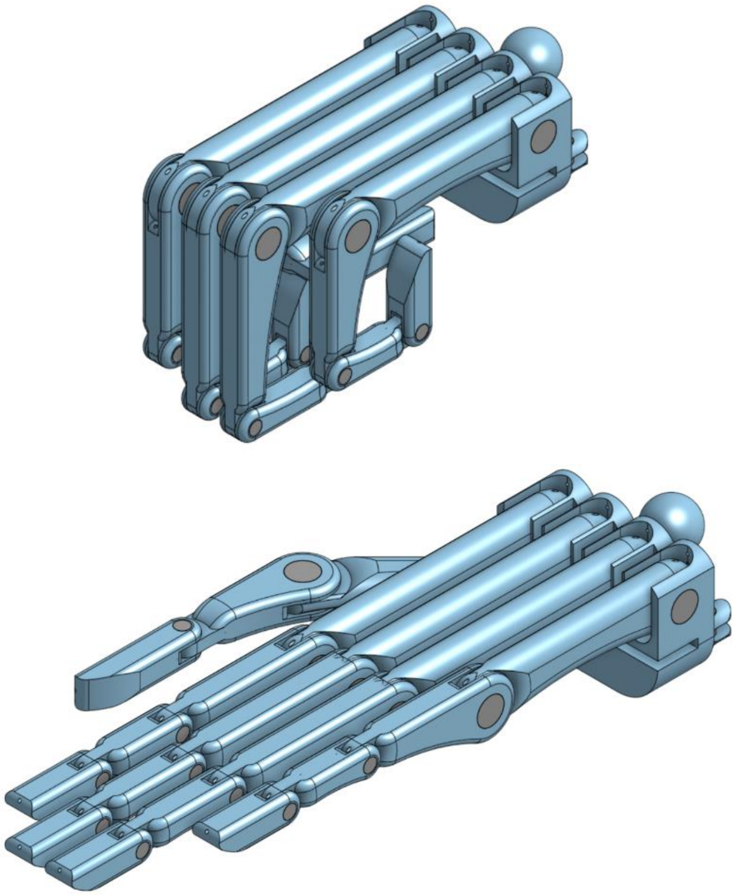

Figure 11: The view of prosthetic hand when open-palm (left) and closed-knuckle (right) action

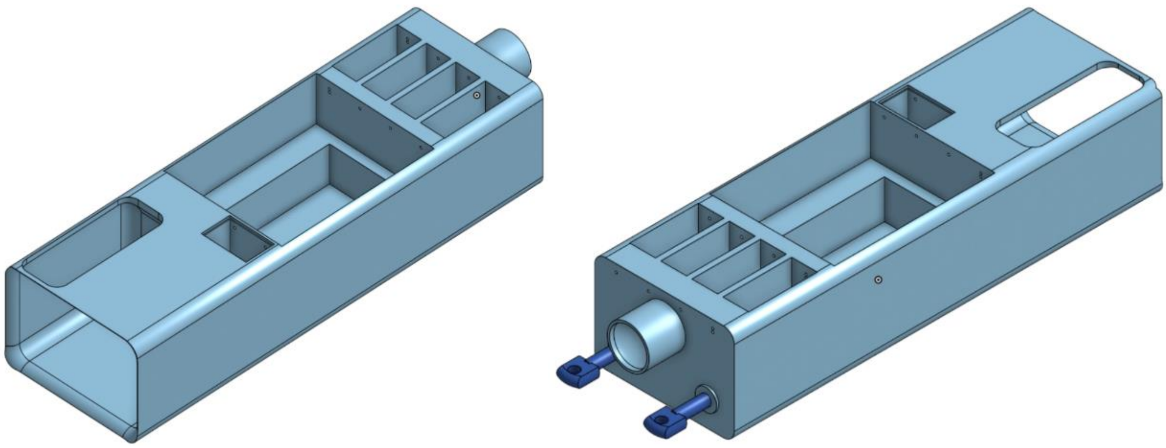

Figure 12: Rear (left) and front (right) view of the forearm part

3.2 Grasping operation

With the success of the design in performing open-palm and closed-knuckle action, the next process is for the design to simulate a grasping operation on two objects with different geometrical shape. The object chosen for this simulation is of cylindrical and spherical shaped object. For cylindrical object, water bottle with 230 mm of length and diameter of 58 mm is used while for spherical object, a ball with diameter of 100 mm is chosen. Figure 13 illustrated before and after the operation of grasping the ball. The flexibility of hand model design allows it to grasp the bottle.

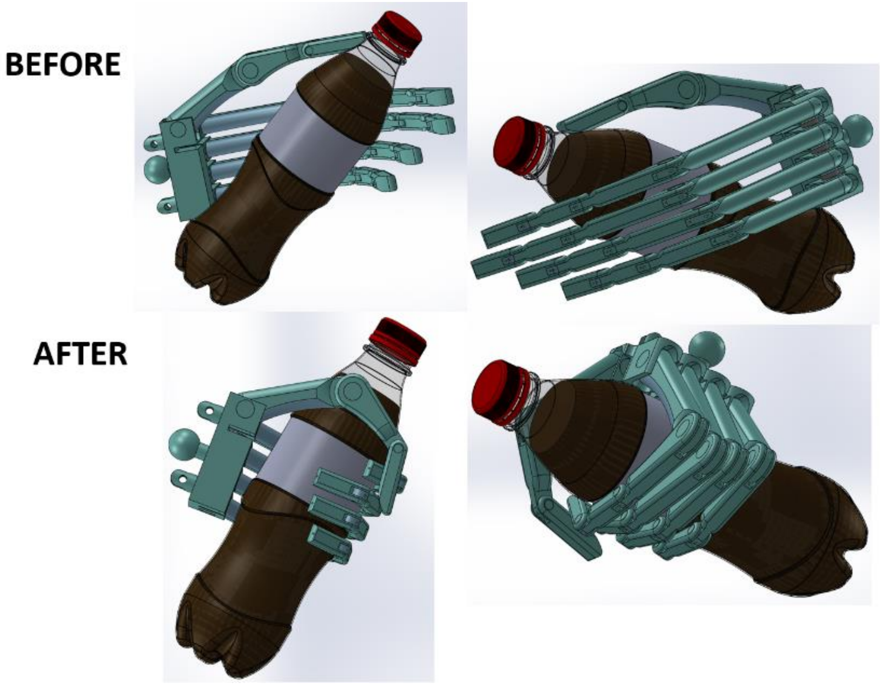

Figure 13: Hand model before and after grasping cylindrical object

Figure 14 illustrated the movement of grasping the ball. The flexibility of hand model design allows it to grasp the ball.

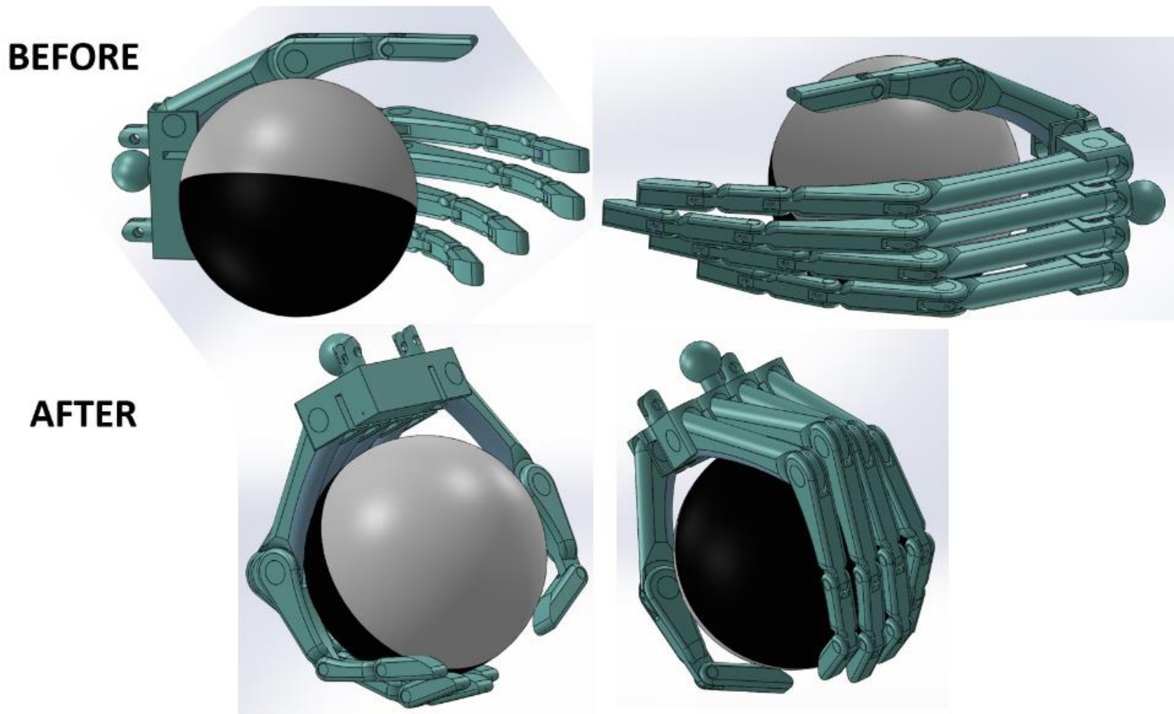

Figure 14: Hand model before and after grasping spherical object

3.3 Stress and displacement analysis

Throughout this project, only two simulation that can be conducted which is stress and strain analysis of a static model. The reason for this shortage is because of the limited access of the simulation software.

Table 2: Data on stress and displacement analysis

Force applied, N	Equivalent Stress, N/m^2	Displacement, mm
10	6.29E+07	1.091E+01
20	1.72E+08	2.093E+01
30	3.14E+08	2.973E+01
40	4.75E+08	3.733E+01
50	6.44E+08	4.400E+01
60	7.96E+08	5.123E+01
70	9.63E+08	5.772E+01
80	1.13E+09	6.235E+01
90	1.28E+09	6.799E+01
100	1.41E+09	7.337E+01

Table 2 shows the data calculated by SolidWorks throughout the simulation. Only the hand model was chosen to experience the simulation as an effort to proof the practicality of the design. The hand model was set at a fix position (green arrow) and the force applied on the surface of each fingers (purple arrow). Because of the material set for this model, which is PETg, the yield of strength of the materials is equal to 5.040E+07 N/m^2. The force applied is gradually increase by 10 starting from 10 N until 100 N. This prosthetic forearm model was designed to use for common activity in everyday life. It is highly unlikely for this prosthetic forearm to be exposed to high force frequently. Hence, the range of the force applied.

Figures 15 illustrated the difference in visual of the hand model when force applied at 10 N and 100 N. The red arrow represents the yield strength of the material. At 10 N, the red arrow point at the yellow-coloured bar and the hand model is in blue coloured. This can be concluded that the hand model able to handle a 10 N of force without breaking. When the force applied at 100 N the red arrow point at the blue-coloured bar and the entire hand model is in blue. Hence, at 100 N the hand model may break because the pressure applied is exceed its yield strength.

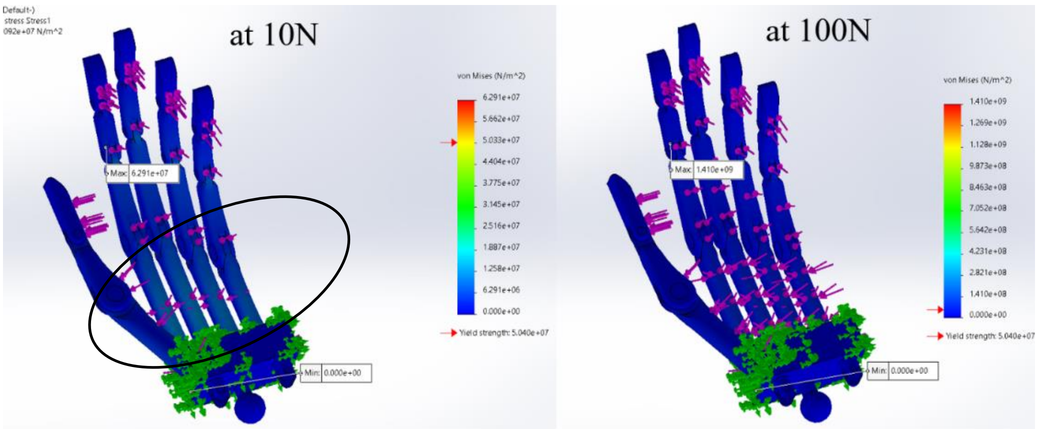

Figure 15: Comparison of hand model stress when at 10 N and 100 N of force

Figures 16 shows the changes that happen in the hand model during the simulation. When the force applied is at 10 N the displacement can be seen happen vividly in the circled part. Comparing when the force applied at 100 N, the displacement can be seen more clearly in the circle part. This proved that when applying high force on the hand model can and will cause great changes in its shape[11], [12].

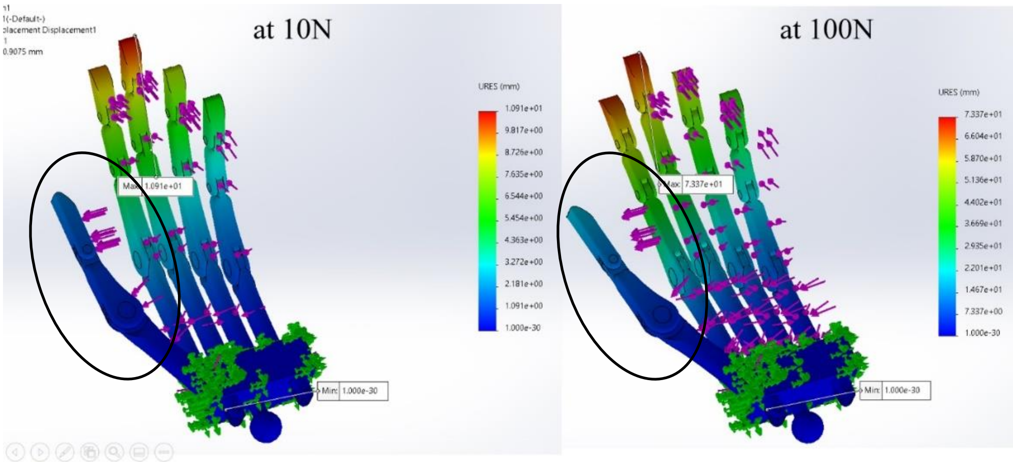

Figure 16: Comparison of hand model displacement when at 10 N and 100 N of force

4. Conclusion

To summarize, the first objectives which is to design a 3D model of a prosthetic forearm is a success with the realization of the actual design. Using human skeletal hand shape and design for reference, the achieved 3D design succeeds in imitating it in terms of appearance. The next objective is for the design of the 3D model prosthetic forearm able to perform open-palm and closed-knuckle action. With this design the, the action is feasibly achieved without any harm. Even though there is no actual product to test this design, by referring to the design itself, theoretically the design should be able to perform those actions. Thorough out this project, even though that the objectives were successfully achieve. It is also undeniable to say that this project is not entirely perfect. One of the reasons for this claim is because of the appearance of this design. Prosthetics forearm were meant to be wore by amputee to help them in their daily life. No matter how functional the prosthesis is if the design failed to satisfy the user, they will not be happy. Because of the concept of this design were based on human skeletal forearm, the actual design is not attractive. Some improvement that can be applied is by adding more cover around the upper section. The cover can also act as protective measure for the components. For the lower section, by adding a cover for the electrical parts that serve as a protective measure can be included for improvement. Other recommendation for this project is by making the place for the amputee to wear comfier. In terms of the design system, an improvement can be applied in future research by adding more system that represent hand joint like tendon or ligament. By adding this system, the gripping power and accuracy might increase.

Acknowledgement

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