DESIGN OF ANKLE FOOT ORTHOSIS (AFO) USING 3D PRINTING FOR PATIENT COMFORT AND AGILITY

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Declaration

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I hereby certify that the project work in this thesis is original and has been done under the guidance of my supervisor, except where otherwise stated. The other sources acknowledgement are given explicit references and appended in this report.

Signature : ______________________________

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Date : ______________________________

Acknowledgement

Firstly of all, I had to take the help and guidance of those people who deserve my deepest gratitude. I would like to thank my sincere supervisor, Assoc. Prof. Dr. Jamaluddin for guiding me throughout this project. Without his guidance and support, I am not able to complete this project when I encounter difficulties.

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In addition, I would like to express my gratitude to Mr. Norijas, Mr. Hadi and Mr. Kamarul for helping me in printing the prototype using a 3D printer. Lastly, I am very thankful to my beloved parents and all my friends for their constant support and encourage me.

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List of Abbreviations

ABS	Acrylonitrile butadiene styrene
AFO	Ankle Foot Orthosis
EVA	Ethylene-Vinyl Acetate
FEA	Finite Element Analysis
PLA	Polylactic Acid
PP	Polypropylene
SLA	Stereolithography

Abstrak

Pergelangan kaki orthosis adalah peranti perubatan yang digunakan untuk membantu pesakit bergerak semasa aktiviti harian. Walau bagaimanapun, produk yang sedia ada adalah mahal, dan reka bentuk tidak sesuai untuk pesakit tempatan disebabkan iklim yang panas dan profil pesakit. Tujuan kajian ini adalah untuk merekabentuk orthosis kaki baru menggunakan percetakan 3D untuk keselesaan pesakit dan ketangkasan. Reka bentuk prototaip dicipta menggunakan SolidWorks. Kemudian, analisis statik digunakan untuk model AFO menggunakan SolidWorks untuk menentukan tindak balas bahagian dan rakitan dalam bentuk tekanan, anjakan dan ketegangan apabila beban luar digunakan dalam model. Bahan yang digunakan dalam fabrikasi prototaip adalah PLA dan produk AFO dihasilkan menggunakan pencetak Anycubic I3 Mega 3D. Di samping itu, ujian dan analisis dijalankan untuk lima keadaan perjalanan yang berbeza untuk mengetahui perbezaan ukuran sudut kitaran perjalanan antara memakai dan tidak memakai AFO. Dua set hasil perbandingan dibincangkan, yang merupakan perbandingan antara produk semasa dan baru, dan perbandingan pengukuran sudut antara memakai dan tidak memakai AFO. Akhir sekali, beberapa cadangan diberikan untuk kerja masa depan.

Abstract

Ankle-foot orthosis is a medical device worn to assist the daily mobility of patients suffering from ankle-foot deformity as a result of stroke or accident. However, the available product in the market was costly, and the design was not suitable for local patients due to the hot and humid tropical climate. The current available product also does not fit very well to specific patient's foot profile, resulting in discomfort and therefore less usage by patient. The purpose of this research was to design of a new ankle-foot orthosis (AFO) using 3D printing for patient comfort and agility. The prototype design was created using SolidWorks. Then, static analysis was applied to the assembled AFO model using SolidWorks to determine the responses of parts and assemblies in the form of stress, displacement and strain when the external loads were applied in the assembled model. The material used in the fabrication of prototype was PLA and fabricated using Anycubic I3 Mega 3D printer. Besides, gait testing and analysis were done for five different walking conditions to find out the difference angle measurement of the gait cycle between wearing and non-wearing AFO. Two sets of comparison result were discussed, which were the comparison between the current and new product, and the comparison of angle measurement between wearing and non-wearing AFO. Lastly, some suggestions were given for future work.

Chapter I: Introduction

1.1 Research Background

Ankle-foot-orthosis (AFO) is a medical device that is used to improve aberrant lower limb motor functions, control the ranges of the mobility of the ankle and subtler joints, recoup for the muscle weakness and congenital anomalies like injuries, stroke, and cerebral palsy. Besides, it helps to improve and enhance the efficiency of walking during post-operative stages [1].

However, the majority of local patients refuse to put on the ankle-foot-orthosis for some reasons. They feel discomfort and inconvenient, as the size of the AFO does not fit to their profiles and it is too rigid. Besides, their legs easily get sweating which causes skin infection as the AFO is fully covered their leg. But if they are not prescribed an AFO, the treatment of the ankle-foot deformity through rehabilitation will not work [2].

Recently, there are a number of studies about the customized ankle foot orthosis using a 3D printer have been carried out. The researchers discovered that the customized AFO is designed to uniquely fit patients and has good performance [3]. Besides, through rapid prototyping method, the manufacturing time to fabricate an AFO is highly reduced as compared to the traditional manufacturing method [4].

Also, there are researched doing on the customized AFO model with the carbon fibre composite using a 3D printer [5]. However, this previous work can only focus on the improvement of the model quality but the cost to build this model is high. The patients from the lower income group cannot afford to buy this model even it is much better than the previous product.

Therefore, the current work presents the design of a low cost and a short manufacturing time of the ankle foot orthosis (AFO) using 3D printing for patient comfort and agility.

1.2 Problem Statement

Ankle foot orthosis is a brace worn on the patients' lower leg in order to assist their mobility during their daily activities. However, the available product is sourced from aboard. It requires 3 months to manufacture a product. Besides, it is costly (RM 1000) and its design is not suitable to the local patients due to the hot and humid tropical climate. When the patients are wearing on the current device, they will easily get sweating, which causes skin infections and their movements are highly restricted as the ankle joint is too rigid. This leads to less adoption by patients to wear on it and doctor has difficulty knowing how much the patient has use the device when just relying on the patient's interview during doctor consultation. There is no monitoring system applied in the available product. Thus, the doctors are unable to monitor the patient's usage and the treatment progress accurately, which lead to ineffective rehabilitation treatment.

1.3 Objectives

The objectives of this project are:

1. To develop a new design of ankle foot orthosis (AFO) that fits local conditions and the patient profiles.
2. To reduce the manufacturing time and cost of AFO by using a 3D printer to manufacture the new model.
3. To perform testing and analysis to the AFO in order to meet the clinical needs of patients.

1.4 Scope of Work

In this project, the current product of ankle-foot orthosis (AFO) will be revised and investigated. Comfort, cost, flexibility on the ankle joint, the local conditions, and the patient's profiles are taken into considerations in designing a new AFO. In the design phase, 3D assembly modelling is created using SolidWorks. The Finite Element Analysis (FEA) method is then used to perform effective stress, strain and displacement analysis of the model. Besides, the model is fabricated using a 3D printer available in the laboratory and the assembly work will be done once it has finished. Lastly, a volunteer will be wearing on the AFO to perform the gait testing and analysis using Kinovea.

1.5 Thesis Outlines

There are five chapters included in this project. In Chapter 1, the research background is firstly discussed, followed by problem statements, objectives and the project scope of this project.

In Chapter 2, the literature review is discussed. The previous works from the researchers are being reviewed and discussed. Meanwhile, all the discussion topics are related to this project.

In Chapter 3, the research methodology is discussed. The design concept and the fabrication method are firstly studied. Then, the finite element analysis is done in the aspect of stress, displacement and strain analysis for the new model. For the electrical and control system, it involves the electric circuit design and the monitoring apps creation. The assembly process and the gait testing analysis will be shown in detailed.

In Chapter 4 involves in the result and discussion of this project. The FEA simulation result, the costing calculation and the gait testing result are shown. Then, the comparison between the current product and new design product is discussed.

In Chapter 5, the conclusion is made based on the experimental result. Then, the suggestions for future work are discussed to achieve a better result.

Chapter II: Literature Review

2.1 Introduction

This chapter highlights the research works have been done by other people to investigate the customized ankle-foot orthosis through traditional way and rapid prototyping. Besides, gait analysis is discussed to find out the abnormalities of biomechanical during the gait cycle. Also, the discussion of climate and humidity in Malaysia are in the aspect of human comfort level.

2.2 Ankle Foot Orthosis

Ankle-foot-orthosis (AFO) is a medical device that assists in the correction of walking gait, and modification of skeletal and practical characteristic in the musculoskeletal and neuromuscular system [4]; [6]; [7].

There are a few types of AFOs in the market (as shown in *Figure 2.1*) such as Solid AFO (SAFO), Dynamic AFO (DAFO), Hinged AFO (HAFO), Floor Reaction AFO (FRAFO), Ground reaction ankle foot orthosis (GRAFO) and Posterior Leaf Spring ankle foot orthosis (PLS-AFO) [1]. All these types of AFOs are specially designed for the different needs of patients and thus, they differ in size, shape, and function. However, Solid AFO (SAFO) is the only model to focus in this research work.

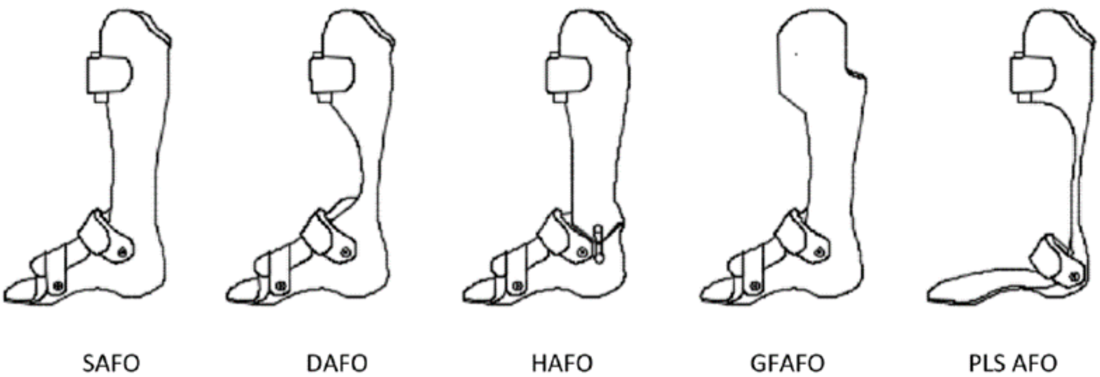


Figure 2. 1: Various Type of AFO Model [1]

Therefore, it is important to understand the exact function of AFO to a patient who suffers from stroke, cerebral palsy (CP), spinal cord injuries or any damage to muscular and neuromuscular system linked to the foot [1]; [4]; [5]. This common symptom to patients is called foot-drop.

Foot drop (as shown in *Figure 2.2*) is caused by the weakness of plantar flexor and dorsiflex muscle [8]. This sign is a gait deformity which will give risen to uncontrolled plantar flexion and problem in raising the front of the foot, because of the weakness and nerve destructions.

Figure 2. 2: Foot Drop [9]

2.2.1 Fabrication through the Traditional Method

Plaster casting is the most common manufacturing method to manufacture an AFO. The most common thermoplastic used to fabricate AFO is Polypropylene (PP). Before starting the fabrication of the AFO model, the measurements of the patient's lower leg limb are taken [4].

The manufacturing process is started with the moulding of Ethylene-vinyl acetate (EVA) [10]. Then, the EVA is stapled to the plaster model to improve the patient's comfort when they wear on the AFO.

The plaster model is marked with the necessary trim lines [10]. Then, the heating and vacuum forming process are applied to the PP sheet. The cooling process is needed before the PP sheet is cut based on the drawn trim lines [4].

Besides, a cutter is used to make holes for the straps placements [10]. The product has already done and shown in *Figure 2.3*.

Figure 2. 3: AFO Model using Plaster Casting Method [10]

The AFO model is perfectly fit the patient's profile, but it takes a long time to finish the fabrication. Also, it requires a skilful technician to do the hand on things.

2.2.2 Fabrication through the Rapid Prototyping Method

In recent years, rapid prototyping has been proposed for the fabrication of the ankle foot orthosis (AFO). Besides, it has the potential to produce a customized product uniquely fitted to an individual patient. Through this method, it can reduce significantly to the manufacturing cost, and time, meanwhile, its performance is getting better [4]; [5].

The material used in rapid prototyping is the carbon fibre composite. Carbon fibre composite provides high strength and stiffness, [11] and thus, the AFO product must be strong and flexible at the ankle joint movement [5].

In other words, the quality of the AFO is good, but the material cost of carbon fibre composite is expensive. It does not fulfill the requirement of building a low cost product.

2.3 3D Printing

3D printing is a type of technology which relies on the aid of computer-aided design (CAD) software to create a virtual 3D model [12]. This method is able to produce objects with excellent dimensional accuracy and manufacturing precision [13].

2.3.1 3D Printing in Medical Field

3D printing is recently expected promptly to revolutionize medical fields. The applications are the design of complex surgery operation, tissue engineering development, and customizations of medical devices [14, 15].

In the development of tissue engineering, tissues and human organs can be printed directly through 3D printing for a direct transplant of patients [14, 16]. Besides, stereolithography (SLA) is used to perform a surgery operation, as it produces high accuracy and transparency model [15].

Also, through this technology, a medical device like AFO can be specially customized to a particular patient. The scan data can be transferred accurately to build the model [17].

2.4 Gait Analysis

Gait analysis is the standardized measurement, characterization, and judgment of those quantities thought to identify human mobility. Kinetic and kinematic data are collected through gait analysis and its data will be analyzed to provide information which describes the theoretical gait characteristics to form a clinical assessment. Through the clinical assessment of gait analysis, patients' gait will be evaluated by clinicians [7, 18].

There are 2 phases in the gait cycle, which are stance phase and swing phase (as shown in *Figure 2.4*). The stance phase is the phase when the foot touches with the ground while the swing phase is the phase when the foot is perfectly away from the ground. Then, the stance phase consists of five core actions that are heel strike, foot flat, midstance, heel off and toe off. For the swing phase, it consists of three core actions which are toe off, mid swing and heel strike [18, 19].

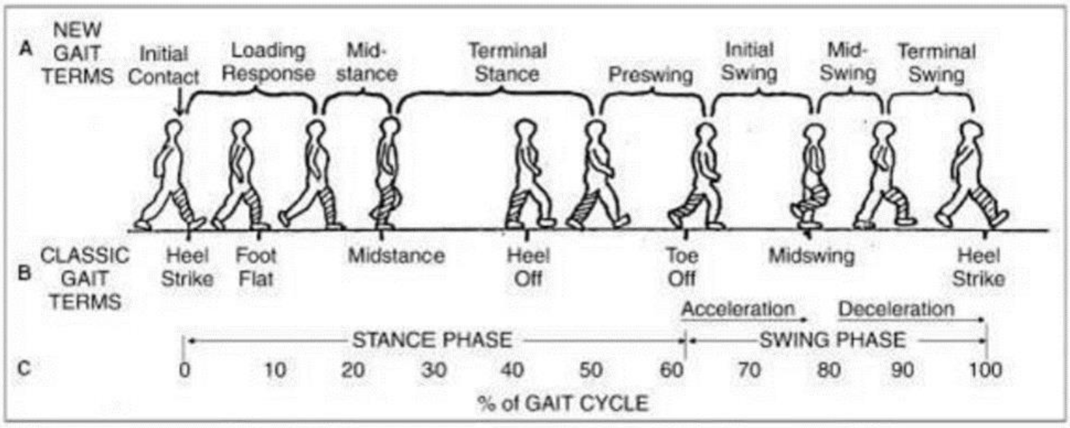


Figure 2. 4: Gait Cycle [18]

Furthermore, there are few studies shown that patients wearing on an AFO can perform well in gait testing. This is because AFOs limit the ankle and subtalar movement, and control the amount of dorsiflexion and plantarflexion [7].

2.5 Climate and Humidity in Malaysia

In Malaysia, the average daily temperature alters from 24^{o}C to 38^{o}C while the humidity varies from 70% to 90%, but the reported minimum temperature is usually at night [20].

AFO is acted as an extra clothing for patients who suffer from neuromuscular dysfunctions. Due to the hot and humid climate in Malaysia, clothing with high vapour resistance will lead to high skin wettedness like sweating [21]. Hence, it will lower the tolerance of human comfort level [20].

Besides, the body movement will affect the comfort limit in terms of skin wittedness [21]. When the activity of body movement becomes greater, skin wettedness becomes greater, and hence human comfort level becomes lesser.

Based on the article, [20] local and international students have a different opinion on climate and humidity condition. Thus, the AFO design from overseas is not comfortable for local patients as the condition between local and overseas is totally different.

Chapter III: Research Methodology

3.1 Introduction

This chapter outlines the development method for a new product. An analysis of current product is made and problems with the current product in market which led to patients discomfort and low usage are identified. A new design to overcome the problem is proposed. The new AFO is designed and simulated with FEA using SolidWorks. The fabrication process is done by using Anycubic I3 Mega 3D printer. Then, the electrical circuit design and monitoring apps creation are discussed. The assembly process is done when all the parts are ready. Lastly, gait testing and analysis are carried out using Kinovea software.

3.2 Mechanical Design

3.2.1 Conceptual Design

There are many limitations to the current product (as shown in *Figure 3.1*). Its flaw in design leads to discomfort and inconvenient for patients. The details of the current product are shown in *Table 3.1*.

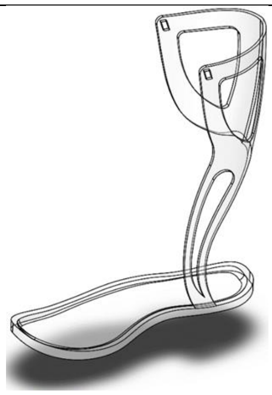
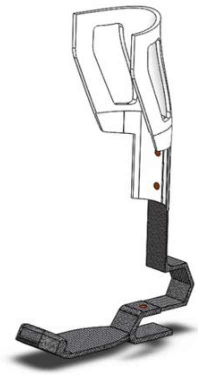
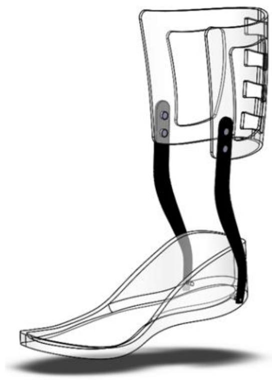
Figure 3. 1: The Currently Available AFO Product

Table 3. 1: Advantages and Disadvantages of Current Product

Advantages	Disadvantages
• Adjustable Straps. • Keep the ankle and foot in a neutral position.	• Rigid ankle joint. • Limit the movement of the patient. • Feel discomfort and inconvenient from patients. • Get sweating easily and cause skin infection. • Expensive.

Three design ideas are created using SolidWorks and listed in *Table 3.2* after considering the advantages and disadvantages of the current product. Each design idea is explained in terms of their height, weight, advantages and disadvantages.

Table 3. 2: Descriptions of Three Prototype Designs

	Prototype 1	**Prototype 2**	**Prototype 3**
Isometric View			
Height (cm)	50	37.8	39.8
Weight (kg)	0.936	0.295	1.202
Advantages	• Breathable • Adjustable straps	• Light • Breathable • Adjustable straps	• Breathable • Adjustable straps • Keep foot and

		• Flexible on ankle joint	ankle in a neutral position
Disadvantages	• Unbalance of leg support	• Difficult to wear	• Heavy

Prototype 2 is selected to have a further modification, as it is difficult for patients to wear on it. While, its advantages like good ventilation, light, flexible on ankle joint and has adjustable straps to comfort fit the leg position will be retained in the next prototype design.

3.2.2 Modification of Selected Prototype

There are some necessary criteria needed to be considered in the modification of the selected prototype. Those criteria are good ventilation, light, flexible on ankle joint, easy to wear and have the adjustable straps to comfort fit the position of ankle and foot. The new AFO assemble prototype is modified using SolidWorks and shown in *Figure 3.2*. Also, all the four individual parts of the new prototype are explained and listed in *Table 3.3*.

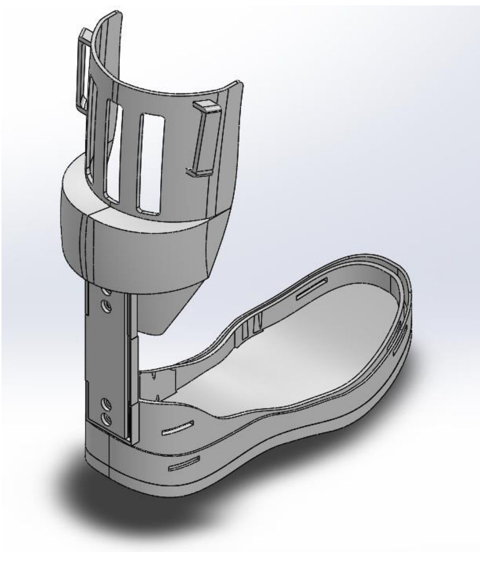
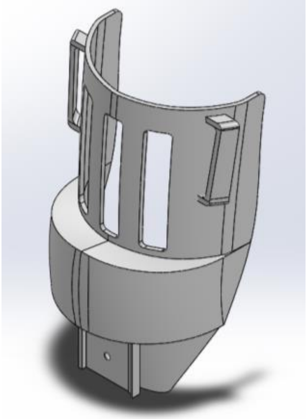
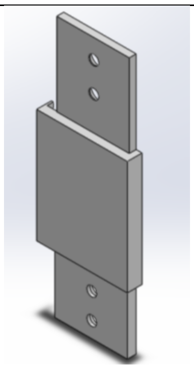
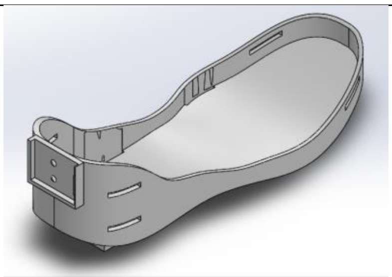
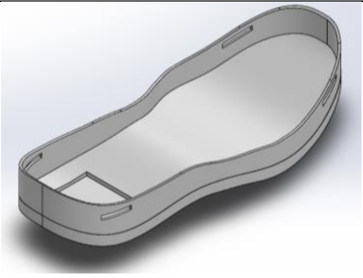


Figure 3. 2: Modification AFO Design

Table 3. 3: Individual Part Descriptions

Part Name	Isometric View of Part	Part Description
Calf		This part is used to support the weak or contracted muscle of the patient's calf into a normal position. The straps holders are added to fix the position of the strap. Then, three holes are added for ventilation purpose. The protruding semi-circular part is designed for putting in the electronic parts [*Appendix 3*].
Back Support		This part is designed to increase the flexibility of the AFO model. The protruding part is to add extra support to the model. It is used to connect the Calf and Feet part [*Appendix 4*].
Feet		The holes are added to fix the positions of the straps and use to tie up with the Shoe [*Appendix 5*].
Shoe		This part is the base of the whole model. The holes are used to tie up with the Feet. The sunken rectangular part is designed to attach closely with the Feet [Appendix 6].

3.2.3 Material Selection

Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are the most familiar material used for the 3D printer. Both of the filaments are thermoplastics, which mean that they become soft and ductile when heated and return to its solid state when cooled. In this way, the heated plastic can be created and shapes and preserved permanently when cooled. Although they are look alike, they do have their corresponding differences. *Table 3.4* will show the different properties between ABS and PLA material.

Table 3. 4: Material Properties of ABS and PLA [22]

Comparison Category	**ABS**	**PLA**
Flexural Modulus (GPa)	2.28	2.3
Tensile Modulus (GPa)	2.21	3.3
Flexural Strength (MPa)	75.84	55.3
Tensile Strength (MPa)	44.81	57.8
Glass Transition (^{o} C)	105	60 - 65
Elongation at Break (%)	20	3.8
Density (g/cm^3)	1.04	1.23 – 1.25
Printing Smell	Bad	Pleasant
Warping	High	Low
Glossy Finish	Good	Better
Biodegradable	No	Yes
Melting Point (^{o} C)	205	175

Both materials have the similar cost and different advantages, but PLA is selected to print the parts. As it requires a lower printing temperature, thus it is much easier and safer to use. Also, PLA is more flexible, precise and results in the better surface finish of 3D objects. It is biodegradable and will produce pleasant printing smell.

3.2.4 Fabrication Process

All the individual parts are printed using Anycubic I3 Mega 3D printer as shown in *Figure 3.3*. The material used for this printing is PLA filament as shown in *Figure 3.4*. However, the sizes of the three parts are too big and needed to split into two printing pieces, then these two printing pieces are assembled and joined to become a completed part. All the printing details of every part are listed in *Table 3.5*.

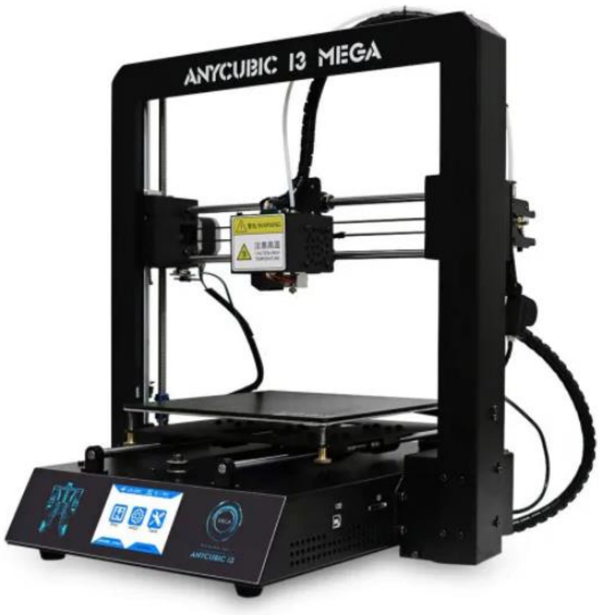


Figure 3. 3 : Anycubic I3 Mega 3D Printer

Figure 3. 4: PLA Filament

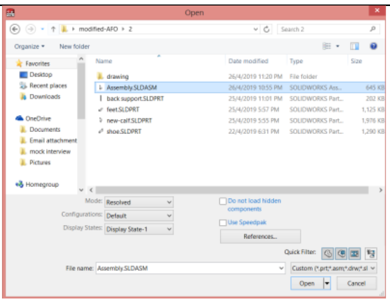
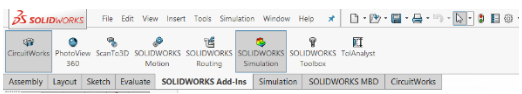
Table 3. 5: Printing Details of Every Part

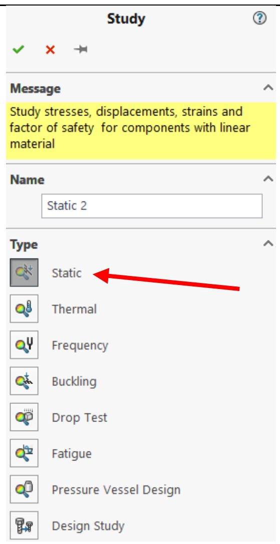
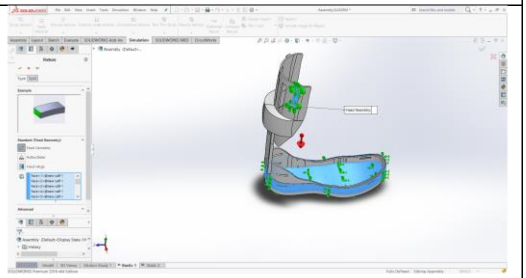
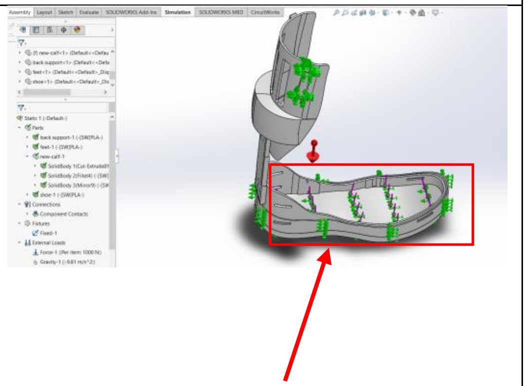
Part	Printing Time	Amount of Material Used (g)
Back Support	2 hour 40 minutes	40
Calf (Cut 1)	7 hour 04 minutes	84
Calf (Cut 2)	10 hour 11 minutes	143
Feet (Cut 1)	10 hour 3 minutes	136
Feet (Cut 2)	7 hour 31 minutes	97
Shoe (Cut 1)	6 hour 22 minutes	71
Shoe (Cut 2)	8 hour 38 minutes	119
Total	52 hour 18 minutes	690

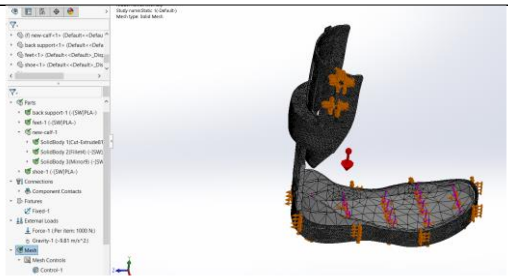
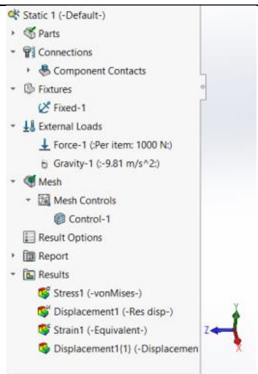
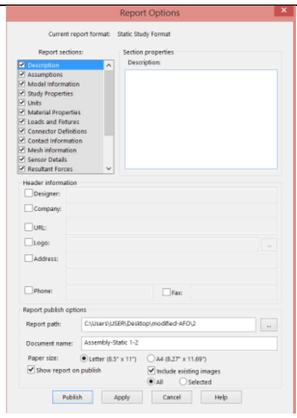
3.3 Finite Element Analysis

Static Analysis is applied to the assembled AFO model using SolidWorks. This action is to determine the responses of parts and assemblies in the form of stress, displacement and strain when the external loads are applied in the assembled model. The steps to perform static analysis are shown and listed in *Table 3.6*.

Table 3. 6: Steps of Creating Static Analysis in SolidWorks

No	Steps	Description	Illustration
1	Open File	Click "Open" and select the file of "Assembly. SLDASM".	
2	Check Simulation Menu	Click "SOLIDWORKS Add-Ins" and select "SOLIDWORKS Simulation", then the "Simulation" will appear in the Command Manager.	

3	Create Study	Click on “Simulation”, then click “Study Advisor” and choose “New Study”, choose the “Static” and click OK.	
4	Apply Fixtures	Right click “Fixtures” and select “Fixed Geometry”, then click the faces and edges in the graphical area, and click OK. **Fixed-1** will appear under “Fixtures” and it can be modified anytime.	
5	Apply Load	Right click “External Loads” and select “Force”, 1000N (purple arrow) is applied to the faces shown in figure and click OK. Right click again “External Loads”, and select “Gravity” and click OK (red arrow will be shown). **Force-1** and **Gravity-1** will appear under External Loads and can be modified anytime.	

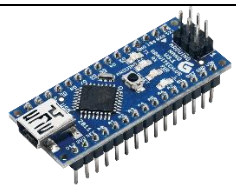
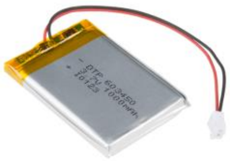
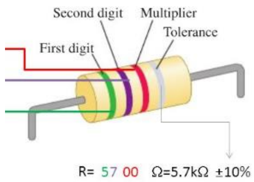
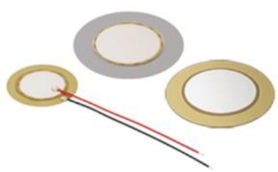
6	Create Mesh	Right Click “Mesh” and select “Create Mesh”, expand the “Mesh Parameters” and click “Curvature Based Mesh” and click OK to begin meshing.	
7	Run Simulation	Click “Run This Study” to run the simulation.	
8	Get Result	The result plot will store under the folder of “Results”.	
9	Make Report	Click “Simulation” and select “Report” and click “Publish”.	

3.4 Electrical and Control System Design

3.4.1 Electric Circuit Design

The components involved in the electric circuit are mini switch, Arduino Nano, Bluetooth Module, two Lithium Polymer Batteries, 5.7k Ohm resistor, and piezoelectric ceramic sensor. The functions of each component is explained and tabulated in *Table 3.7*. Meanwhile, the electric circuit is designed as shown in *Figure 3.5*.

Table 3. 7: Function of Each Component

No	Component	Function
1	 Mini Switch	Open or close the electric circuit.
2	 Arduino Nano	Allow to create modular pieces of code that perform a defined task and return to the area of function code. (Code refer to Appendix 7).
3	 Bluetooth Module	Setup for the transparent wireless serial connection
4	 Lithium Polymer Battery	Power supply to the circuit
5	 5.7k Ohm Resistor	Control the flow of current to other components
6	 Piezoelectric Ceramic Sensor	Convert a mechanical effect into an electrical signal.

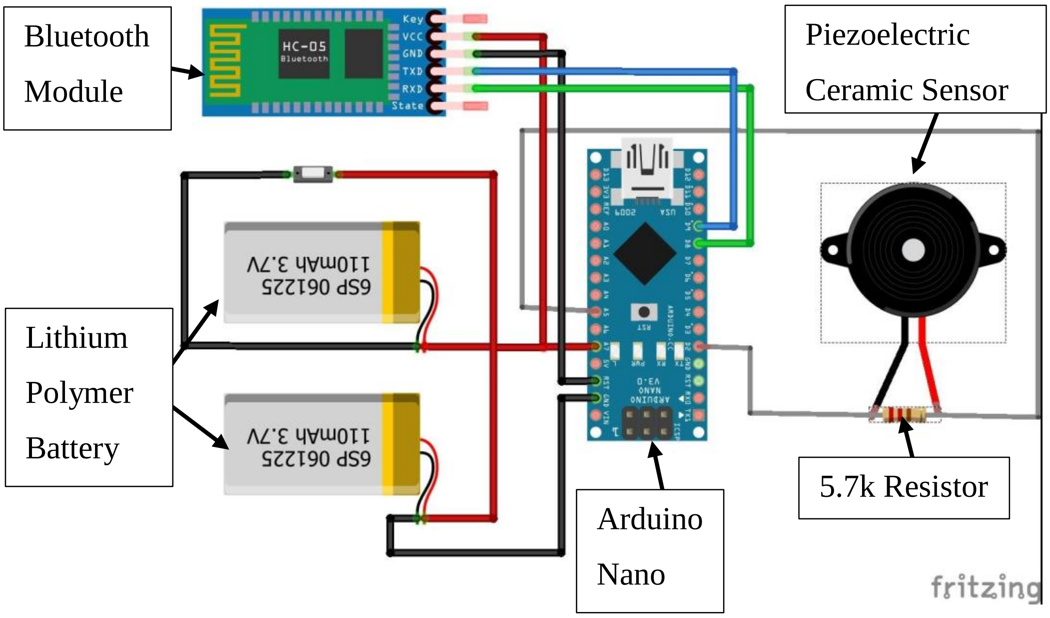
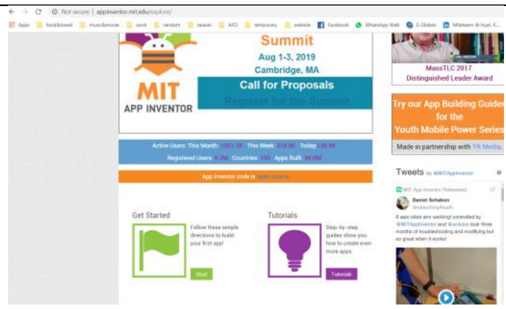
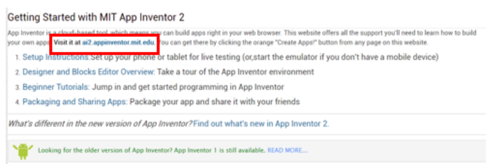


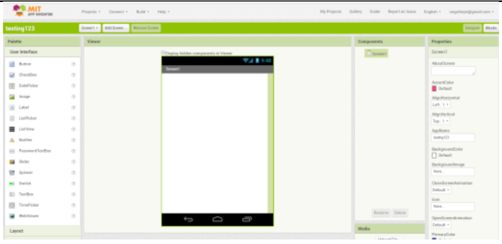
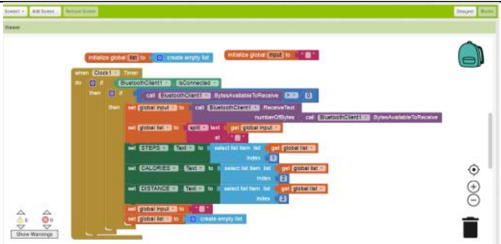
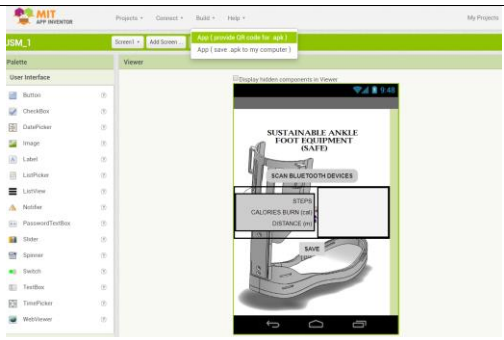
Figure 3. 5: Electric Circuit Design

3.4.2 Monitoring App

The monitoring app is used to track and monitor the AFO usage of patients. This creation is through Google MIT App Inventor. The steps are described and listed in *Table 3.8.*

Table 3. 8: Steps for App Creation

No	Step	Description	Illustration
1	Access Webpage	Access http://appinventor.mit.edu/explore/, scroll down and click "Start".	
2	Get Started	Click the link shown in the red box.	

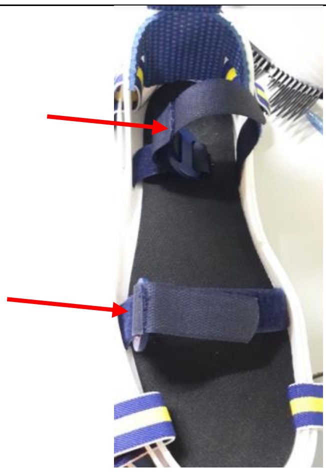
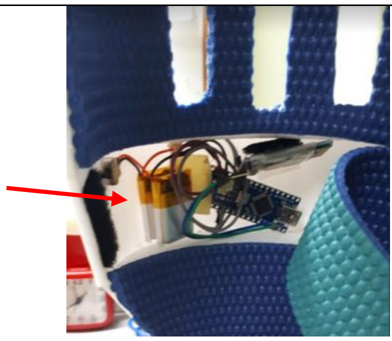
3	Start Project	Click “Project” and select “Start New Project” and type the Project Name. The workspace will be shown.	
4	Develop Content	Design your app with User interface (shown in left sidebar)	
5	Arrange Content	Arrange the content in “Blocks” (shown on the upper right corner)	
6	Export file	Once finished, click “Build” and select either one to export the .apk file. The app is created.	

The monitoring system can be used once the mini switch is turned on. The patients will wear on the AFO and the patient’s walking movement will be detected by the piezoelectric ceramic sensor. This mechanical effect will convert into the electrical signal and transfer the data to the mobile apps through the Bluetooth Module. The data like calories, steps and distance travelled will be shown in the mobile apps.

3.5 Assembly Process

The assembly process was easy to handle. The process steps are described and listed in *Table 3.9*. The assemble AFO is shown in *Figure 3.6*.

Table 3. 9: Assembly Process Steps

Step	Explanation	Illustration
1	Four M5 Screws, four nuts and two washers were needed to assemble the printed part.	
2	Two secure adjustable straps and the insole was putting into the Feet.	
3	The electrical and control system was added into the protruding semi-circular part, while the piezoelectric sensor was put inside the insole.	

4	The convenient strap was added to tie up the patient’s leg.	
5	The cushion was added to avoid the friction between skin and the model.	
6	Four convenient straps were added to tie up the Feet and the Shoe.	

Figure 3. 6: Assemble AFO

3.6 Gait Testing and Analysis

The gait testing and analysis system were developed and tested with a phone camera and Kinovea software. This experiment was carried out with five different walking conditions, which is walking on flat ground, walking upstairs, walking downstairs, walking up the sloped surface and walking down a sloped surface. Besides, a volunteer, who has no significant foot deformity or surgery, was involved in this experiment.

3.6.1 System Setup

The markings were prepared and placed to the three segments of the volunteer's leg, which are knee joint, ankle joint and toe section as shown in *Figure 3.7*.

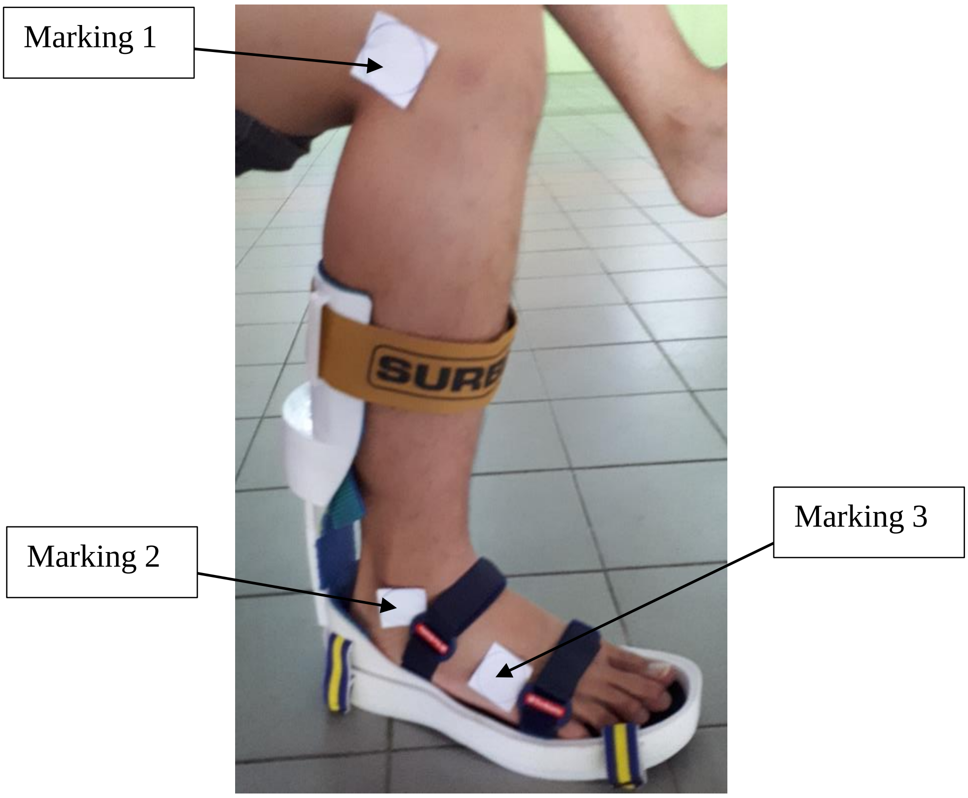


Figure 3. 7: Markings in Volunteer's Leg

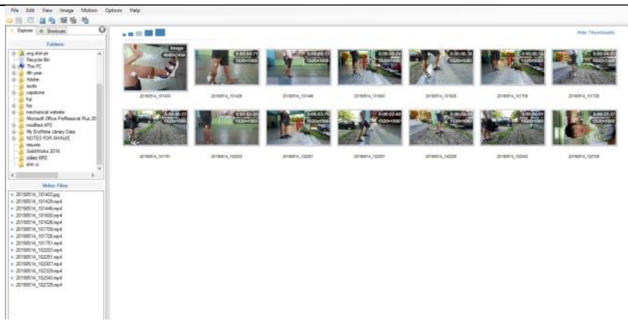
A phone camera was set up to record the gait cycle of the volunteer. The capture screen fully covered with the leg's movement of the volunteer, as shown in *Figure 3.8*.

Figure 3. 8: Leg Movement Captured by Phone Camera

3.6.2 Angle Measurement using Kinovea

The steps for the angle measurement using Kinovea software were explained and listed in *Table 3.10.*

Table 3. 10: Steps for the Angle Measurement using Kinovea

No	Step	Description	Illustration
1	Browse File	Double Click the selected file.	
2	Set Time Frame	Adjust the wanted time frame using the symbol in the red box. The adjusted time frame will be shown in the blue box. "[" starting point "]" end point