UNIVERSITI TEKNIKAL MALAYSIA MELAKA

IMPROVEMENT DESIGN AND TESTING OF A PROSTHETIC LEG

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology

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**A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours**

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2022

DECLARATION

I declare that this Choose an item. Entitled " Improvement Design and Testing of a Prosthetic leg", results from my research except as cited in the references.

Signature :

Name : MOHD FAKHRUL HAFIZUDDIN ILMAN BIN MAHID

Date : 16/01/2022

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

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DEDICATION

This dedication firstly to Allah S.W.T for giving strength and good health to perform this duty to complete this project. Great appreciation to my beloved and respectful parents, Mahid @ Ibrahim Bin Sakaran and Norah Binti Marisin. Thank you for always provide me with support and motivation, and I hope that this achievement will fulfil their dreams. Also dedicated appreciation to my siblings for giving me consent and best dedicated to my supervisor, Sir Mohammad Rafi Bin Omar, for always guiding and advising me.

ABSTRACT

Prosthetic leg is a model of design that mimics the function of natural leg which can help people with leg amputation to get around more easily. There are various type of prosthetic leg that has been designed in this cosmopolitan era. However, most of the design is very expensive because of the material used, the design type and the adding of technology that been added to the design such as tracker, programable robot motor for feet movement and others. This project is focusing on improvement design and testing of a prosthetic leg that comfortable to use as it has affordable price and suitable for people with this disabilities. This design of prosthetic leg was designed by selection sketching of design idea. The first method of selecting this sketching idea was distributing questionnaire to public. Based on the questionnaire, some criterias were made and been proceeded to House of Quality (HOQ) and design selection matrix. Based on the HOQ and design selection matrix, the highest score of design was chosen to the Computer Aided Design (CAD) modelling and analysis of design. For CAD modelling, CATIA software was chosen because it can design complex shape and have advantages on designing prosthetic leg as it have workbench of Generative Shape Design and Mechanical Part Design. For Finite Element Analysis (FEA), Altair SIMSOLID software was chosen. The advantage of using this software is it can analysis assembly 3D model and very easy to use. The 3D printer used for printing this prosthetic leg model is Farsoon SS402P Selective Laser Sintering (SLS) 3D printer with material polymer based powder Nylon FS3200PA. Forces applied on the 3D model are the parameter for the result of analysis. The applied force loads were 100kg (980.665N), 80kg (784.532N), and 60kg (588.399N). The analysis will present results for displacement, factor of safety and Von Mises Stress. Based on the result of analysis, the maximum displacement was result by the model with 980.665 N force with the value of 1.1775×10^{-2}m, the maximum stress was result by the model with 980.665 N force with the value of 1.4013×10^{2} MPa and the factor of safety of this model still in range of 1.0-3.0 which is safe to use by prosthetic leg user and has been fabricated wtih the characteristic of lightweight, aesthetic design, have an airflow to prevent limb from sweating high durable can withstand the weight of user.

ABSTRAK

Kaki palsu ialah model reka bentuk yang meniru fungsi kaki semula jadi yang boleh membantu orang yang dipotong kaki untuk bergerak dengan lebih mudah. Terdapat pelbagai jenis kaki palsu yang telah direka pada era kosmopolitan ini. Walau bagaimanapun, kebanyakan reka bentuk adalah sangat mahal kerana bahan yang digunakan, jenis reka bentuk dan penambahan teknologi yang ditambah kepada reka bentuk seperti pengesan, motor robot yang boleh diprogramkan untuk pergerakan kaki dan lain-lain. Projek ini memberi tumpuan kepada penambahbaikan reka bentuk dan ujian kaki palsu yang selesa digunakan yang mempunyai harga yang berpatutan dan sesuai untuk orang yang memerlukan penggunaan kaki palsu. Reka bentuk kaki palsu ini direka dengan lakaran pemilihan idea reka bentuk. Kaedah pertama untuk memilih idea lakaran ini ialah mengedarkan soal selidik kepada orang ramai. Berdasarkan soal selidik, beberapa kriteria telah disenaraikan untuk dijadikan parameter dalam House of Quality (HOQ) dan matriks pemilihan reka bentuk. Berdasarkan HOQ dan matriks pemilihan reka bentuk, skor tertinggi reka bentuk telah dipilih untuk pemodelan Reka Bentuk Berbantu Komputer (CAD) dan analisis reka bentuk. Untuk pemodelan CAD, perisian CATIA dipilih kerana ia boleh mereka bentuk bahagian model 3D yang kompleks dan mempunyai kelebihan dalam mereka bentuk kaki palsu kerana ia mempunyai Reka Bentuk Bentuk Generatif dan Reka Bentuk Bahagian Mekanikal. Untuk Analisis Elemen Terhad (FEA), perisian Altair SIMSOLID telah dipilih. Kelebihan menggunakan perisian ini ialah, perisian ini boleh menganalisis pemasangan model 3D dan sangat mudah digunakan. Pencetak 3D yang digunakan untuk mencetak model kaki palsu ini ialah pencetak 3D Selective Laser Sintering (SLS) Farsoon SS402P dengan serbuk berasaskan bahan polimer Nylon FS3200PA. Berat yang digunakan pada model 3D kaki palsu ini adalah parameter untuk hasil analisis. Beban daya yang dikenakan ialah 100kg (980.665N), 80kg (784.532N), dan 60kg (588.399N). Analisis akan membentangkan keputusan untuk anjakan, faktor keselamatan dan Tekanan Von Mises. Berdasarkan hasil analisis, sesaran maksimum adalah hasil model dengan daya 980.665 N dengan nilai 1.1775 x 10-2m, tegasan maksimum adalah hasil model dengan daya 980.665 N dengan nilai 1.4013 x 102 MPa dan faktor keselamatan model ini masih dalam julat 1.0-3.0 yang selamat digunakan oleh pengguna kaki palsu dan telah direka dengan ciri reka bentuk yang ringan, estetik, mempunyai aliran udara untuk mengelakkan bahagian betis daripada berpeluh, tahan lama dan boleh menampung berat pengguna.

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I am grateful and would like to express my gratitude to Sir Mohammad Rafi Bin Omar for introducing me to this good project that gives me many chances to involve in designing knowledge and experience in fabricating products. Thank you for expanding my knowledge, guide, advice, and sharing ideas with me for completing my final year project.

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CHAPTER 1

INTRODUCTION

1.1 Background

In this chapter, an overview of the design, optimization, and fabrication of prosthetic leg by using 3D printing will be elaborated. In addition, the main idea, problem statement, objectives, and scope of this project will also be introduced.

1.2 Project Overview

3D printing is used widely in various fields such as engineering, medicine, biologies and other scopes. These prosthetic legs are produced using FS3200PA Nylon powder material utilizing an Additive Technology called Selective Laser Sintering (SLS). In medical and science, experts utilized 3D Scanning and Printing to make dental embeds, a human skull and models of organs.

A prosthetic leg or prostheses can help people with leg amputations to get around more easily. The prosthetic leg mimics the function and the appearance of a natural leg. The purpose of this project is to create a new design of prosthetic legs that easier and comfortable to wear, fit to the users, lightweight, hyperhidrosis, and excessive to sweating.

To design a new ergonomic prosthetic leg using 3D printing, this design comes from the latest advanced manufacturing technologies, CATIA and Altair Inspire software. Additionally, this product is produced using lightweight FS3200PA Nylon powder material utilizing an Additive Technology called Selective Laser Sintering (SLS).

1.3 Problem Statement

The design of prosthetic legs nowadays needs an improvement on the plan. While many people with limb loss do well with their prosthetic legs, not everyone is a good candidate for a leg prosthesis. This is due to some minor that needs to be improved or may be discussed. For example, the weight, the material, and the design of prosthetic legs. Moreover, many facts need to be highlighted to make this design good as required.

The problem statement that will be mainly focused on here are:

a) Type of material that can make a lightweight custom-fit prosthetic leg

b) The type of design that comfortable to use by prosthetic leg user

c) Strengths of material to withstand forces

1.4 Research Objective

The main aim of this research is to develop a prosthesis of the leg that is comfortable and suitable for people with this disabilities. The specific objectives are as follows:

i. To design custom-fit prosthetic leg by using CATIA and SIMSOLID software.

ii. To optimize the weight of the design by using material FS3200PA Nylon powder.

iii. To fabricate the design of prosthetic leg by using Selective Laser Sintering (SLS) 3D printer.

1.5 Scope of Research

The project scope is shown below:

i. The lower limb prosthesis was chosen as the parameter for designing

ii. CATIA and Altair SIMSOLID software beneficial to design and analysis the custom-fit prosthetic leg based on the user measurement

iii. 3D printed custom-fit prosthetic leg is fabricated and ready to fit.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

In this chapter, the gathering of information related to this 3D Printing of Prosthetic Leg from previous article or sources will be presented based on figure 2.1. The literature review will begin with the study on the study of a prosthetic leg.

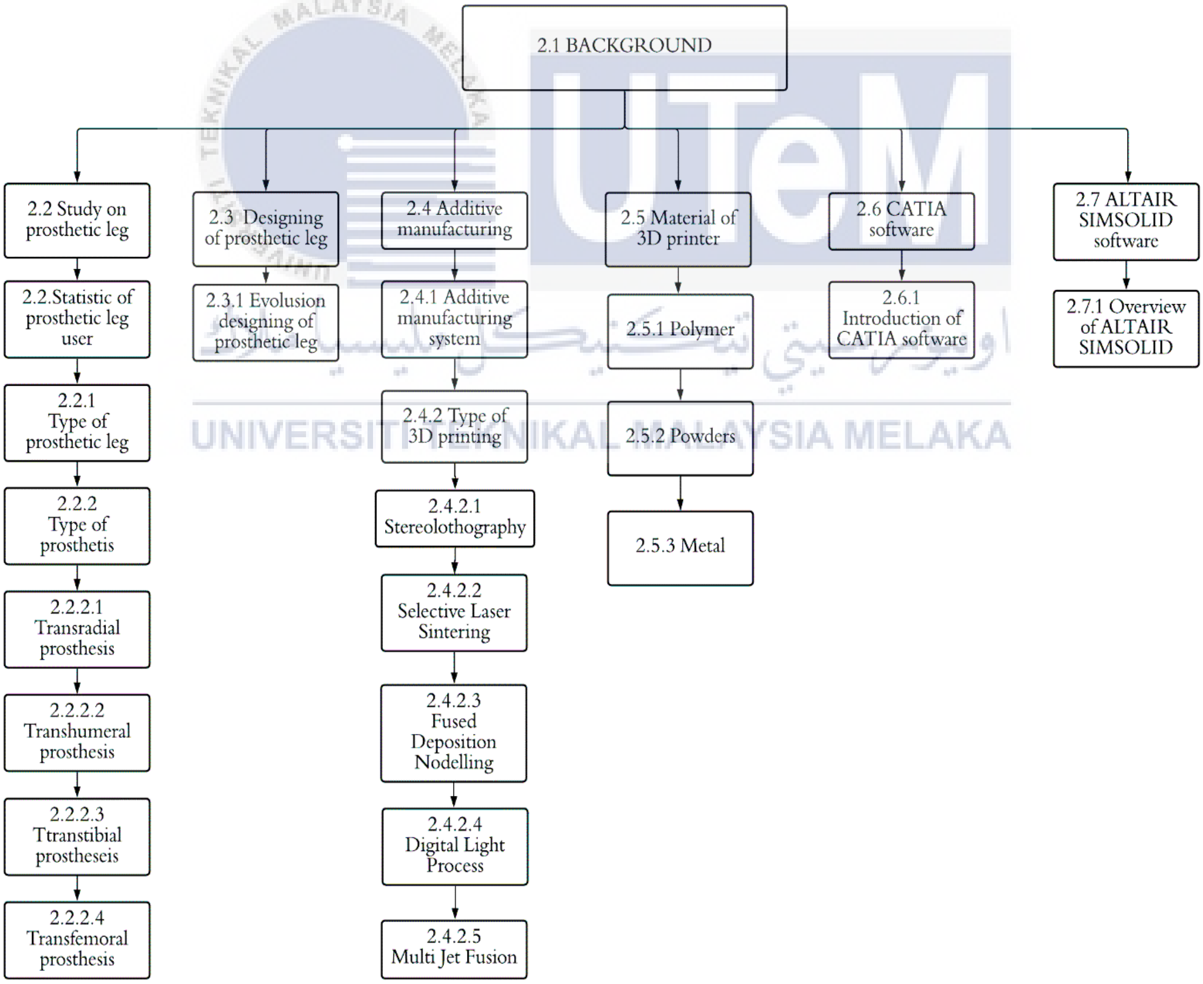

Figure 2. 1 K-Chart of work break down structure

2.2 Study on prosthetic leg

A prosthetic leg, also known as an artificial limb, is used to replace biological cells in humans and animals. A prosthesis is required when a person loses a limb due to injuries, congenital disabilities, fighting or other causes.

2.2.1 Statistic of prosthetic leg user

As defined by the International Classification of Functioning, Disability and Health (ICF), lower limb amputation is a physical disability that affects body structures. It results in activity restriction and participation restriction. Acquired amputation frequently occurs due to disease, injury, or surgery, whereas congenital amputation occurs at birth. Amputations of the lower limb account for 84% of amputations, while those of the upper limb account for only 16%. Lower extremity amputations are frequently the result of vascular-related diseases (with or without diabetes) and account for 80–90% of all amputations in Western countries. Diabetes patients have a 10–30 times higher increased risk of lower limb amputation than the general population. Around 20%–50% of diabetic amputees will require a second leg amputation within one to three years and more than 50% will require another amputation within five years (Arifin et al., 2017; Karim and Ming, 2020).

According to the World Health Organization (WHO), 0.5% of a developing national population has a disability that necessitates the use of a prosthesis or orthosis and related rehabilitation services. This prediction implies that approximately 160,000 of Malaysia's current 32 million-strong population will require prosthetic or orthotic devices. By 2040, the population is expected to reach 38.5 million, including approximately 200,000 people with disabilities. According to a previous National Health and Morbidity Survey (NHMS), diabetes mellitus increased from 6.3% to 8.2% among Malaysians. Surprisingly, as reported in the Third National Health and Morbidity Survey (NHMS III), this figure had increased to 17.5% by 2006.

This significantly exceeded the prediction that by 2025, diabetes mellitus prevalence in Malaysia would be between 11% and 14%. Diabetes prevalence appears to be increasing in this country. The most recent study discovered a prevalence of 22.6 %, nearly double what was previously reported in 2006. Despite the Ministry of Health's proactive efforts, such as the establishment of Diabetes Resource Centers in hospitals and a national steering committee to improve diabetes screening and management in clinics, the national prevalence of diabetes is expected to increase to around 22% in 2020 (Arifin et al., 2017; Karim and Ming, 2020).

2.2.2 Type of prosthesis

A prosthesis that replaces a missing extremity, such as the arms or legs, is an artificial limb. Based on Synergy Prosthetics main website, there are four types of prosthetics with current technology, which are Transtadial prosthesis, Transhumeral Prosthesis, Transtibial Prosthesis and Transfemoral Prosthesis. A prosthesis gives both mobility and emotional comfort. Therefore, the history of prosthetics is not simply a scientific storey but also the tale of human beings who have been left with a missing limb due to birth, injury, or accident from the dawn of civilization (Gorino, 2020).

2.2.2.1 Transradial prosthesis

A transradial prosthesis (figure 2.2) is arm prosthetic that replaces an arm that has been amputated below the elbow. There are two primary types of prosthetics available. Firstly, Cable-operated limbs. Cable-operated limbs are attached to the opposite shoulder of the injured arm via a harness and cable. The second type is Myoelectric arms. Myoelectric arms are another type of prosthetic available. These work by sensing, via electrodes, when the muscles in the upper arm move, thereby opening or closing an artificial hand.

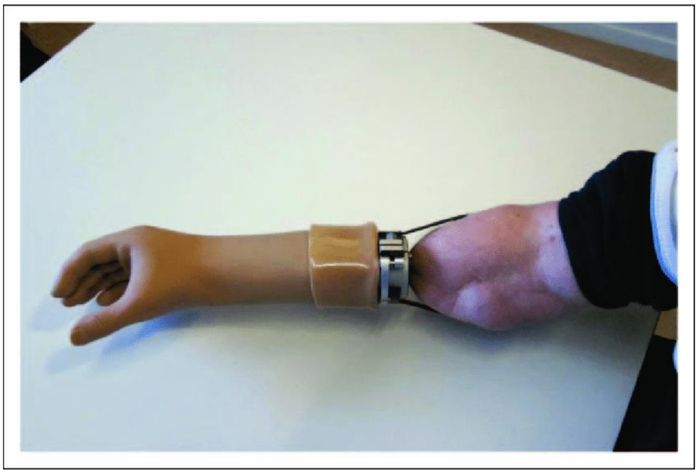

Figure 2. 2 Transtadial Prosthesis (Jönsson, Caine-Winterberger, and Branemark 2011)

2.2.2.2 Transhumeral prosthesis

A transhumeral prosthesis (figure 2.3) helps to replace the function of a missing anatomical segment from below the shoulder to the hand. The type of control system for these prostheses is determined by the patient's needs, functions, and goals. Transhumeral amputees experience some of the same problems as transfemoral amputees due to the similar complexities associated with the movement of the elbow. This makes mimicking the correct motion with an artificial limb very difficult (Gorino, 2020).

Figure 2. 3 Transhumeral Prosthesis (Source: www.ottobock.com.au)

2.2.2.3 Transtibial Prosthesis

A transtibial prosthesis (figure 2.4) replaces the function of missing anatomical segments from below the knee to the floor that excludes partial feet. The prosthetic socket is the primary connection between the residual limb and the prosthesis. Transtibial amputees typically regain normal movement more quickly than transfemoral amputees, owing mainly to the retention of the knee, which allows for more effortless movement (Gorino, 2020).

Figure 2. 4 Transtibial Prosthesis (Source: albertaoandp.com)

2.2.2.4 Transfemoral Prosthesis

A transfemoral prosthesis (Figure 2.5) is a prosthesis that replaces any amputated limb above the knee. Transfemoral amputees may have a challenging period of recovery from normal movement. A transfemoral amputee generally needs to use about 80% more energy than someone with two complete legs to walk on it. It is because of the complexity of the movement of the knee. In new and better designs, hydraulics, carbon fibre and mechanical connections give the user more control over the motors, computer microprocessors and innovative combinations of these techniques (Gorino, 2020).

Figure 2. 5 Transfemoral Prosthesis (Source: ottobock.com.au)

2.3 Designing of Prosthetic Leg

Prosthetics are commonly used to assist people with permanent disabilities and give them a new chance to live a regular, independent life. Prosthetics are made to order for each person, considering their intended use and physical characteristics. On the other hand, traditional prosthetics are heavier, and their manufacture is both costly and time-consuming. The current research discusses this issue and introduces a new prosthetic foot and calf design. A hybrid optimization technique combining generative design and topology optimization is used to reduce the weight of prosthetics. The proposed method has a compliant mechanism to minimize the load, and it provides ease to the wearer. The study concludes that the wearer will feel comfortable with the new design and will be able to walk naturally (Leg 2021).

2.3.1 Evolution designing of a prosthetic leg

The prosthetics industry is a large and rapidly growing industry due to manufacturing technologies and advancements in material science. Prosthetics are specifically designed for a person loses a limb due to injuries, congenital disabilities, fighting, or other causes, with proper measures to ensure an appropriate fitting. However, it increases the time and cost of production of these prosthetics. Another price increase comes with material selection. Prosthetics should be rigid enough to support an individual's weight while also being light enough not to cause hindrance in everyday functioning. Excess material removal can reduce weight to some extent, but it also impacts the structural strength of the prosthetic (Rajput et al. 2021). This issue can be solved by using advanced algorithms that can help generate designs with optimal distribution of material which produces the best balance between weight and stiffness.

Generate different designs for the same input parameters with other mechanical properties using generative design. One benefit is that we can choose the most appropriate template for our needs. This cuts down on the amount of design work needed. This field has advanced because 3D printing and design can be used to create designs and prototypes (dos Santos et al., 2021).

2.4 Additive manufacturing

2.4.1 Additive manufacturing system

Throughout the previous three decades, 3D printing technology has been present. Not long ago, it has proven to be widely accessible and inexpensive enough for the general public to use. It is a technique for turning digital designs into physical models. The software tools required to create printable objects and the materials used have become widely available, as have repositories for sharing and downloading designs. Polylactic acid and acrylonitrile butadiene styrene are the more commonly used materials for 3D printers. In general, 3D printers work by building objects out of several thin layers of material. Depending on the type of printer used, the choice of material and how the layers bond to one another vary (Hoy 2013).

Three-dimensional (3D) printing is a manufacturing process that added material layer by layer to produce the 3D object. This manufacturing process always used in academic and commercial sectors for prototyping and product realization purposes. Recently, the clinic has