# DEVELOPMENT OF SMART MODULAR LOWER BODY SUPPORT FOR PROLONGED STANDING

RAJAMUNIRANT A/L KANDASAMY

MASTER OF MANUFACTURING ENGINEERING (INDUSTRIAL ENGINEERING)

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FACULTY OF INDUSTRIAL AND MANUFACTURING TECHNOLOGY AND ENGINEERING

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**RAJAMUNIRANT A/L KANDASAMY**

**A thesis submitted**
**in fulfillment of the requirements for the master of**
**Master of Manufacturing Engineering (Industrial Engineering)**

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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

**DECLARATION**

I declare that this report entitled "Development of Smart Modular Lower Body Support for Prolonged Standing" is the result of my own research except as cited in reference. The thesis has not been accepted for any master and is not concurrently submitted in candidature of any master.

Signature : ……………………………………

Name : Rajamunirant a/l Kandasamy

Date :

**APPROVAL**

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Industrial Engineering)

Signature : ……………………………………..

Supervisor Name : ……………………………………..

Date : ……………………………………..

**DEDICATION**

This report is dedicated to my beloved family, friend and my lecturers.

## ABSTRACT

Musculoskeletal diseases (MSD) remain a major source of threat for industry workers. A good understanding and handling musculoskeletal health in the workplace establish a secure and effective working environment. Workers in industry are more likely to have MSD disease in the workplace due to overexertion from manually operating machinery. In this project a metal fabrication company which uses a large number of welders requested to carry out a study and find solution on MSD faced by metal inert gas (MIG) welders. The welders were influenced by prolonged standing when they carried out their daily task which leads to MSD. To overcome the MSD during work, the welders took a long break in interval for recovery which leads the increase of cycle time in producing a product. The aim of this research is to improvise current Modular Lower Body Support in the market which lack of height adjustability and lack of sensor to detect poor bending movements and prolonged sitting. The objectives of this study were to analyze the user's requirements, technical specifications and ergonomics considerations for developing the Smart Modular Lower Body Support, designing and developing the Smart Modular Lower Body Support and carry out evaluation on the functionality and usability for the Smart Modular Lower Body Support. The current Smart Modular Lower Body is not similar to the other Modular Lower Body Support in the market. The Smart Modular Lower Body Support is a portable product which can be located in any flat desired location. The height of the lower body support is adjustable, solve the height issue of the welders in the industry and well-integrated with Internet of Things (IoT) monitoring system required by the industry. This Smart Modular Lower Body Support is equipped with 2 types of sensors which are load cells and ultrasonic sensors, play a crucial role in identifying the load exerted by the welders on the lower body support and detects the over bending movement of the welders when they carry out their daily task. The IoT system was build up with a notification system connected to cellular phone software, email notification and alarming electronic product such as buzzer and LED. To develop the Smart Modular Lower Body Support, technical data, user's requirements, ergonomics and work space specifications had been collected at the workplace. House of Quality (HoQ) had been carried out to reflect welder's idea on the product to be developed. The data that had been gathered were used to design a lower body support using SolidWorks software and been tested with Finite Element Analysis (FEA) to understand how the product behave under various physical condition. The best design had been chosen and fabricated from the analysis of (FEA), (HoQ) and Pugh Matrix Analysis (PMA). The fabricated lower body support had been fixed with a few mechanical parts and electrical components. IoT system had been set up with parameter for internal testing. Finally, the Smart Modular Lower Body Support had been tested in the fabrication industry for evaluation on the functionality and usability. As a result, the cycle time of the welding process had been reduced, MIG welders are free from MSD and the welders can use the Smart Modular Lower Body Support continuously without prolong standing issue. A questionnaire had been carried out with 21 respondents on the usability testing of the Smart Modular Lower Body Support and the usability testing gained a score of 51.31 which stand in the grade of "D" with the acceptability of "OK".

# PEMBANGUNAN SOKONGAN BADAN BAWAH MODULAR PINTAR UNTUK BERDIRI BERPANJANGAN

## *ABSTRAK*

Gangguan otot berangka kekal (MSD) sebagai ancaman utama bagi pekerja industri. Adalah penting untuk memahami dan mengendalikan kesihatan otot berangka di tempat kerja untuk mewujudkan persekitaran kerja yang selamat dan cekap. Pekerja industri berisiko mengalami gangguan otot berangka MSD disebabkan oleh penggunaan tenaga yang berlebihan ketika mengendali mesin secara manual. Dalam projek ini, sebuah industri fabrikasi yang menggunakan banyak pengimpal gas inert logam (MIG) meminta untuk menjalankan kajian dan mencari solusi terhadap masalah gangguan otot berangka MSD yang dihadapi oleh pengimpal. Pekerja kimpalan terpengaruh dengan posisi berdiri yang lama dalam menjalankan tugasan harian mengakibatkan kepada gangguan otot berangka MSD. Untuk mengatasi gangguan otot berangka MSD, pengimpal rehat untuk jangka masa panjang ketika berkerja bagi pemulihan sakit yang mengakibatkan peningkatan dalam kitaran masa dalam penghasilan produk. Tujuan kajian ini adalah untuk penambahbaikan Sokongan Bawah Badan Modular yang kini digunakan mempunyai kekurangan daripada aspek kebolehlarasan ketinggian dan deria untuk mengesan pergerakan postur badan yang tidak neutral dan posisi berdiri yang lama. Kajian ini bertujuan untuk menganalisis keperluan pengguna, spesifikasi teknikal dan pertimbangan ergonomik untuk membangunkan Sokongan Bawah Badan Modular Pintar, mereka bentuk dan membangunkan Sokongan Bawah Badan Modular Pintar dan penilaian kefungsian dan kebolehgunaan Sokongan Bawah Badan Pintar. Sokongan Bawah Badan Modular Pintar terkini tidak sama seperti sokongan bawah badan di pasaran. Sokongan Bawah Bawah Badan Modular Pintar adalah produk mudah alih dan boleh digunakan di mana-mana lokasi rata. Ketinggiannya boleh dilaras dan menyelesaikan isu ketinggian pengimpal dan disepadukan dengan sistem pemantauan Internet Pelbagai Benda (IoT) yang diperlukan oleh industri. Sokongan Bawah Badan Modular Pintar ini dilengkapi dengan 2 jenis penderia iaitu sel beban dan penderia ultrasonik yang memainkan peranan penting dalam mengenal pasti beban yang dikenakan oleh pengimpal pada sokongan bawah badan dan mengesan pergerakan postur badan yang tidak neutral pengimpal ketika menjalankan tugas harian. Sistem pemantauan Internet Pelbagai Benda dibina dengan sistem notifikasi berhubungan melalui perisian telefon selular, notifikasi e-mel dan produk elektronik seperti buzzer dan LED. Untuk membangunkan Sokongan Bawah Badan Modular Pintar, spesifikasi teknikal, keperluan pengguna, ergonomik dan ruang kerja telah diambil kira. Analisa rumah kualiti (HoQ) telah dijalankan untuk mendapatkan idea pengimpal untuk membina produk. Data yang telah dikumpul digunakan untuk mereka sokongan bawah badan menggunakan perisian "SolidWorks" dan diuji dengan kaedah unsur terhingga (FEA) untuk memahami bagaimana produk berkelakuan di bawah pelbagai keadaan fizikal. Reka bentuk yang terbaik telah dipilih dan direka melalui analisa (FEA), (HoQ) dan Matriks Pugh (PMA). Sokongan bawah badan yang telah dibangunkan telah dipasang dengan beberapa barang mekanikal dan elektrik. Sistem pemantauan Internet Pelbagai Benda telah diaplikasi dengan parameter untuk ujian dalaman. Akhirnya, Sokongan Bawah Badan Modular Pintar telah diuji dalam industri fabrikasi untuk penilaian kefungsian dan kebolehgunaan. Kesimpulanya, kitaran masa telah dikurangakan, pengimpal bebas daripada gangguan otot berangka dan pengimpal boleh menggunakkan Sokongan Badan Bawah Modular Pintar secara berterusan tanpa berdiri untuk jangka masa panjang. Satu soal selidik telah dijalnkan dengan 21 responden mengenai ujian kebolehgunaan Sokongan Bawah Badan Modular Pintar dan kebolehgunaan memperoleh skor 51.31 yang berapa dalam gred “D” dengan kobolehterimaan “OK”. Semua pengimpal boleh menggunakan produk ini tanpa sebarang keraguan.

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Apart from that, a special thanks to my family and friends for their moral support in completing this degree and not forgetting, those who have directly or indirectly contributed to the realization of this thesis.

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| | |
|---|---|
| IoT | Internet of Things |
| ICT | Information and Communication Technology |
| MIG | Metal Inert Gas |
| MSD | Musculoskeletal Disorders |
| SOCSO | Social Security Organization |
| WMSD | Work Related Musculoskeletal Disorders |
| AusDiab | Australian Diabetes, Obesity and Lifestyle Study |
| FEA | Finite Element Analysis |
| GMAW | Gas Metal Arc Welding |
| TIG | Tungsten Inert Gas |
| CNC | Computer Numerical Control |
| CAD | Computer Aided Design |
| ASTM | American Society for Testing and Materials |
| ISO | International Organization for Standardization |
| LED | Light Emitting Diode |
| HoQ | House of Quality |
| PMA | Pugh Matrix Analysis |

# LIST OF UNITS

| | |
|---|---|
| lb/ft^3 | Density |
| kg/m^3 | Mass Density |
| $kg/m^2$ | Mass Index |
| kg | Kilogram |
| N/m^2 | Yield Strength |
| ksi | Yield Strength |
| 10^6 psi | Young Modulus |
| N/m^2 | Tensile Strength |
| ksi | Tensile Strength |
| N/m^2 | Elastic Modulus |
| Kg | Mass |
| Seconds | Time |
| mm | Millimeter |
| N | Newton |
| IN | Inch |
| m^3 | Volume (Solid) |
| g | Gravity |
| m | Mass of load |
| mAH | Ampere-Hour |

# CHAPTER 1

# INTRODUCTION

The first chapter of this master project report sets the stage by providing a comprehensive overview of the study. It begins with an exploration of the background of the study, delving into the intricacies of the musculoskeletal system. The focus then shifts to the health issues experienced by employees as a result of musculoskeletal problems, with specific attention given to ergonomic considerations, the working environment, and the body posture of employees while performing various tasks. The problem statement identifies and articulates the challenges faced by employees in their daily tasks, particularly the prolonged periods of standing and bending posture required in industrial settings. These challenges serve as the driving force behind the conceptualization and execution of the project, leading to the development and evaluation of innovative solutions. Within the framework of this chapter, the objectives of the project are clearly defined, encapsulating the primary goals that the research aims to achieve. Additionally, the scope of the study is outlined, providing insights into the specific focus and limitations inherent in the project. Together, these elements lay the foundation for a comprehensive understanding of the context, purpose, and boundaries of the research endeavor.



## 1.1 Background of Study

The industrial landscape comprises a diverse array of businesses and organizations engaged in the creation and provision of products, services, and revenue streams across various sectors such as wholesale, retail, transportation, professional services, tourism, and entertainment. Within this expansive array, the working conditions in an industrial environment are often characterized by challenges more demanding than those encountered in conventional workplaces.

Industrial workers shoulder responsibilities ranging from machinery operation and product assembly to quality assurance inspections. Their duties extend beyond operational tasks to encompass maintaining workspaces, equipment, and adherence to safety regulations. Proficiency in interpreting technical drawings, familiarity with technical software, and adept utilization of a range of tools and equipment are integral to their roles.

Given the multitude of industries, a substantial workforce is essential for their seamless operation. Consequently, an effective strategic approach is indispensable for organizing the workflow of employees within a company. This study, however, narrows its focus to metal inert gas (MIG) welders engaged in tasks requiring either standing or sitting postures. It is noteworthy that not all industries uniformly implement standing or sitting postures; specific departments mandate prolonged periods of standing or sitting.

Examining statistical data provided by Social Security Organization (SOCSO), Figure 1.1 illustrates a significant upward trend in musculoskeletal diseases. This alarming trend underscores the magnitude of the issues faced by employees, particularly those related to prolonged standing as shown in Figure 1.2 and Figure 1.3 which provides a comprehensive depiction of the exact working conditions prevalent in the manufacturing industry, contributing to the onset of musculoskeletal diseases.



Figure 1.2 and Figure 1.3 collectively highlight the challenges inherent in performing tasks in a standing position. These conditions may result in discomfort, muscle fatigue, swelling inflammation, varicose veins, and pain in the back and feet, as illustrated in Figure 1.4. The empirical evidence presented in these figures forms the basis for the critical investigation undertaken in this study to address the ergonomic issues associated with prolonged standing and sitting in industrial settings.

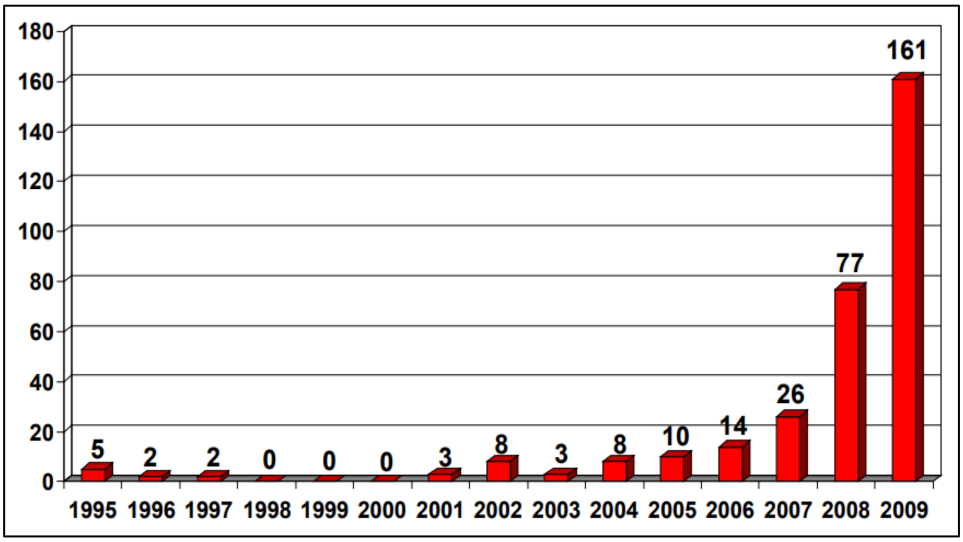



Figure 1.1: Annual musculoskeletal disease statistics reported by SOCSO 1995 – 2009. Department of Occupational Safety and Health, 2023

Figure 1.2: Prolonged standing position of worker at a fabric manufacturing company. Vietnam News (2023)

Figure 1.3: Prolong standing position of worker at an air conditioning copper pipe welding assembly line. Taizhou Youyi Automation Technology Co., Ltd. China (2023)



Figure 1.4: Prolonged standing and sitting may cause discomfort, muscle fatigue, swelling inflammation, varicose vein and pain in back and feet. Strauss Scoliosis Correction (2024)

In recent years, the impact of work-related musculoskeletal diseases (WMSD) has become increasingly evident, particularly in occupations demanding prolonged standing and maintaining an upright posture, revealing a notable association between WMSD and adverse effects on the lower back and lower extremities (Anderson et al., 2007; Coenen et al., 2016). The elevated risk observed in these occupational settings prompts a critical examination of the ergonomic challenges faced by workers, laying the foundation for the investigation undertaken in this study.

Beyond the musculoskeletal and cardiovascular impacts, the study extends its purview to the exoskeleton of the human body. While an internal endoskeleton provides structural support beneath soft tissues, prolonged standing and sitting postures can exert detrimental effects on the external exoskeleton. Unlike endoskeletons, exoskeletons offer external support to shield and enhance a person's bodily functions. Recognizing their potential to reduce fatigue, increase productivity, and assist in various physical tasks, the study acknowledges the role of exoskeletons in preventing musculoskeletal diseases. Besides that, a programmed software is developed to study the usage of the Smart Modular Lower Body Support by the MIG welder Implementation of IoT had been carried out to study on the usage of pressure sensors and postural angle sensors which seamlessly integrated with a smartphone through the Blynk cloud platform. This project is not only covered by providing comfortability to worker whereas to record and send signals to user of lower body support regarding the pressure and postural angle exerted by the welder during the MIG welding process.



This study aims to contribute significantly to addressing these multifaceted challenges by developing a “Smart Modular Lower Body Support” tailored for welders engaged in prolonged standing tasks. By doing so, it seeks to impact the workforce positively, not only by addressing musculoskeletal and occupational health but also by advancing the integration of innovative solutions to enhance work environments and employee well-being.

## 1.2 Problem Statement

In various industries such as electronics, automotive assembly, metal machining, and service sectors, employees are routinely subjected to prolonged standing postures. Workers engaged in tasks like drilling, milling, welding, and mold installation maintain static standing postures, while professionals in quality control and service sectors, such as surgeons, dentists, cashiers, and nurse practitioners, spend considerable hours in standing positions.

Prolonged exposure to these postures leads to discomfort and fatigue, particularly affecting muscles in the lower extremities and the lower back, thighs, calves, and feet. Furthermore, the health ramifications extend to chronic venous insufficiency, occupational injuries, and work-related musculoskeletal disorders (WMSDs). Recognizing these adverse effects, best practices emphasize the importance of alternating between sitting and standing positions, incorporating body movement, and maintaining good posture to mitigate the risk of WMSDs.

Figure 1.5 highlights the challenges faced by users of sit-stand exoskeletons in determining when to alternate between standing and sitting positions, underscoring the need for a comprehensive solution to address these ergonomic concerns and enhance the overall well-being of employee. Besides that, there are many other factors that influence the compatibility of sit-stand exoskeletons. Firstly, the cost is a significant factor, as it requires a high initial investment. Users need to invest a considerable amount to purchase the product. Additionally, some exoskeletons can be heavy and cumbersome, leading to discomfort or reduced mobility. The size of the device can restrict ease of movement in confined spaces, and it may not fit all body types comfortably, requiring custom adjustments. Some models might not accommodate the full range of motion needed for all tasks. Prolonged use can lead to muscle atrophy due to the reduced use of natural muscle strength. Users might become overly dependent on the device, potentially reducing their motivation to engage in physical rehabilitation. Furthermore, there is a risk of mechanical failure or malfunction, which can cause injury. Improper use or poor fit can also lead to discomfort or musculoskeletal issues.

Users might feel self-conscious or stigmatized due to wearing an exoskeleton, which can impact social interactions or be perceived as a sign of weakness or disability.

Figure 1.5: An employee implements the usage of Sit – Stand Exoskeleton
Liz Stinson (2015)

## 1.3 Objectives

The objectives of this study are

- Analyze the user's requirements, technical specifications, and ergonomics considerations for developing a Smart Modular Lower Body Support for MIG welders.
- Design and develop a Smart Modular Lower Body Support for MIG welders who are performing tasks in prolonged standing.
- Evaluate the functionality and usability of the Smart Modular Lower Body Support for MIG welders engaged in prolonged standing tasks.

### 1.3.1 Relationship between Problem Statement and Objectives

A problem statement serves as an elucidation of an immediate issue or problem that requires prompt attention to enhance the current situation. The primary aim of the project was to tackle this identified problem. Table 1.1 below illustrates the correlation between the problem statement and the project's objectives.

Table 1.1: Relationship between problem statement and objectives

| Problem Statements | Objectives |
|---|---|
| In various industries such as electronics, automotive assembly, metal machining, and service sectors, employees are routinely subjected to prolonged standing postures. Workers engaged in tasks like drilling, milling, welding, and mold installation maintain static standing postures, while professionals in quality control and service sectors, such as surgeons, dentists, cashiers, and nurse practitioners, spend considerable hours in standing positions. | Analyze the user's requirements, technical specifications, and ergonomics considerations for developing a Smart Modular Lower Body Support for MIG welders. |
| Prolonged exposure to these postures leads to discomfort and fatigue, particularly affecting muscles in the lower extremities and the lower back, thighs, calves, and feet. Furthermore, the health ramifications extend to chronic venous insufficiency, occupational injuries, and musculoskeletal disorders (MSDs). Recognizing these adverse effects, best practices emphasize the importance of alternating between sitting and standing positions, incorporating body movement, and maintaining good posture to mitigate the risk of MSDs. | Design and develop a Smart Modular Lower Body Support for MIG welders who are performing tasks in prolonged standing. |
| Current Lower Body Support lack crucial features such as height adjustability and stable basement support. Additionally, they lack sensors to detect poor bending | Evaluate the functionality and usability of the Smart Modular Lower Body Support for MIG welders engaged in prolonged |

| | |
|---|---|
| movements or prolonged sitting, which can exert excessive pressure on the lower back, contributing to health issues. | standing tasks<br>. |

**1.4 Scope**

This project aims to design a Smart Modular Lower Body Support for use by employees in various industries and work environments. The process began with a visit to Wentel Engineering Sdn. Bhd. to gather insights into the specific needs of employees in their industry. The design phase involves utilizing SolidWorks software to create the Smart Modular Lower Body Support.

Once the design is complete, Finite Element Analysis (FEA) is conducted to assess parameters such as Safety Factor, Von Mises Stress, and Resultant Displacement. Upon successful FEA results, the fabrication of the Smart Modular Lower Body Support commences. Internal evaluations, including mechanical testing, are conducted to ensure the product's functionality and usability.



Subsequently, the Smart Modular Lower Body Support undergoes testing at Wentel Engineering Sdn. Bhd. to align with customer requirements. The project's overarching goal is to enhance employee productivity and mitigate the risk of musculoskeletal disorders. The effectiveness of the Smart Modular Lower Body Support is validated through comprehensive evaluation, involving mechanical testing and real-world assessments at the employee's workplace. The number of products focused during the testing was focused to one product because this project is carried only carried out preliminary test.

The project's scope is confined to addressing the challenges faced by employees who engage in prolonged standing and sitting during their daily tasks. Table 1.2 shows the relationship between scope and objective and Table 1.3 shows the scope of Smart Modular Lower Body Support.

Table 1.2: Relationship between scope and objectives

| Objectives | Scope |
|---|---|
| Analyze the user's requirements, technical specifications, and ergonomics considerations for developing a Smart Modular Lower Body Support for MIG welders. | To design a Smart Modular Lower Body Support for use by employees in various industries and work environments. The process began with a visit to Wentel Engineering Sdn. Bhd. to gather insights into the specific needs of employees in their industry. The design phase involves utilizing SolidWorks software to create the Smart Modular Lower Body Support. |
| Design and develop a Smart Modular Lower Body Support for MIG welders who are performing tasks in prolonged standing. | Finite Element Analysis (FEA) is conducted to assess parameters such as Safety Factor, Von Mises Stress, and Resultant Displacement. Upon successful FEA results, the fabrication of the Smart Modular Lower Body Support commences. Internal evaluations, including mechanical testing, are conducted to ensure the product's functionality and usability. |
| Evaluate the functionality and usability of the Smart Modular Lower Body Support for MIG welders engaged in prolonged standing tasks | The Smart Modular Lower Body Support undergoes testing at Wentel Engineering Sdn. Bhd. to align with customer requirements. The project's overarching goal is to enhance employee productivity and mitigate the risk of musculoskeletal disorders. The effectiveness of the Smart Modular Lower Body Support is validated through comprehensive evaluation, involving mechanical testing and real-world assessments at the employee's workplace. |

Table 1.3: Scope of Smart Modular Lower Body Support

| **Specifications** | **Limitation** |
|---|---|
| Process | MIG Welding |
| Gender | Male & Female |
| Age | (18-60) years old |
| Industry | Fabrication Industry |
| Assigned Worker | MIG Welding Department |
| Type of Lower Body Support | Passive |
| Maximum Worker Weight | 100 kg |
| Worker Body Mass Index | 18.5 – 25 (kg/m$^2$) |
| Floor Surface | Flat Surface |
| Number of Product | 1 |
| Degree of Freedom | • The worker can easily move or bend their body when utilizing the Smart Modular Lower Body Support.<br>• The worker can easily walk away from the product in any direction. |



## 1.5 Summary

In summary, this chapter delves into the foundational aspects of the project aimed at developing a Smart Modular Lower Body Support to address the challenges faced by employees enduring prolonged standing postures during their work hours. The identification of this problem stemmed from a comprehensive observation of employee working methods during an industrial visit, offering valuable insights into the actual working conditions. The chapter proceeds to outline the objectives set to be achieved throughout the project, providing a clear roadmap for the development of the Smart Modular Lower Body Support. Additionally, the scope of the project is elucidated, focusing on the specific aspects that will be addressed. Given the paramount importance of work-related musculoskeletal diseases in informing the design of the Smart Modular Lower Body Support, the project is strategically situated at Wentel Engineering Sdn. Bhd.

Moreover, an integral aspect of this project involves the incorporation of an Internet of Things (IoT) system. This system utilizes pressure sensors and postural angle sensors, seamlessly integrated with a smartphone through the Blynk cloud platform. This innovative technology adds a layer of sophistication to the Smart Modular Lower Body Support, allowing for real-time monitoring and adjustment based on individual needs and environmental conditions. This IoT integration enhances the overall functionality and user experience, aligning with the project's overarching goal of addressing ergonomic challenges and improving the well-being of employees in their workplace.

# CHAPTER 2

# LITERATURE REVIEW

This chapter had covered the study's literature review, where it contains an important review of the existing knowledge and enables readers to easily recognize significant concepts and research methods. This chapter starts with the literature review on design requirement for developing a Smart Modular Lower Body Support. In this section, elaboration on different types of standing and sitting postures had been given included the health issues due to the bad posture. The third section of this study is to focus on the musculoskeletal system and its disorders condition that effects the workers. Next the factor of ergonomics and best practice of ergonomics had been elaborated. To enhance the study on Smart Modular Lower Body Support, design and development of such as types of lower body support, design consideration, material, durability and cost had been studied. In the fifth section the study on Internet of Thing (IoT) had been implemented due the usage of Blynk software in the project. The focus of the study in MIG welding had been reviewed, as well as literature survey on the fabrication, evaluation of functionality and usability of lower body support.

## 2.1 Design Requirements for Developing a Smart Modular Lower Body Support



Designing a lower body support is to allow users to walk and move at speed, standing or sitting while they are at their work place. It is a product which designed parallel with the function of the human body, segments and joints. It supports users to rest their leg muscles by directing their body weight towards a variable shaft attach to the frame and directs the weight to the ground. To come out with the idea on developing the products, basic knowledge to develop Smart Modular Lower Body Support need to be carried out.

### 2.1.1 Analysis of Literature on Purposes of Smart Modular Lower Body Support

#### 2.1.1.1 Improve Body Alignment

Improving body posture leads to a number of reasons, such as energy, confidence, and health. By maintaining proper posture can boost energy levels, lessen back and neck pain, and boost confidence. Besides that, it also provides better blood circulation, ideal muscular function, and a lower chance of injury during exercise. Better posture can also result in easier breathing, better balance, and more self-esteem. As a result, working to develop and maintain proper posture can benefit one's physical and mental health. Moreover, by implementing good posture the entire organ such as stomach will be correctly oriented and maintaining proper posture can enhance a good digestion for the employee.

#### 2.1.1.2 Remove Back and Neck Pain

Your bones and spine can easily and effectively balance and sustain the weight of your body when you have good posture. When the body posture of the employee is poor, organ such as muscles, tendons, and ligaments must work continuously to sustain the same weight. Besides that, tension headaches, back discomfort, and neck pain are possible side effects of this additional and ineffective effort. When an employee corrects the body posture, it will greatly help in this issue. A major contributing reason to low back pain, incorrect posture affects about 25% of working adults annually. Prolonged slouching can place undue strain on the muscles, ligaments, and discs in the spine, resulting in low back discomfort. Even when you're seated, maintaining proper posture can significantly lower your chance of experiencing back pain. (LVMC, 2021)

#### 2.1.1.3 Higher Lung Capacity & Energy Levels

The lungs may be compressed from slouching and bad posture, which can lead to difficulty in breathing and lower respiratory function. Maintaining proper posture will typically expand your lung capacity, which allows for better breathing. Good breathing and proper posture may additionally render aerobic exercises simpler, such swimming, jogging, and walking. Due to bad posture distorts bones and joints affects blood circulation, which can make you feel fatigued and lack of energy. To ensure oxygen and nutrients reaches to the cell successfully, it is a necessary to have a good blood circulation system. A perfect degree of muscular function can be supported by well-positioned bones and joints, which can help you feel less worn out and more energetic.

### 2.1.2 Standing

Standing is known as orthostatic; a posture in which the body is supported fully by the feet and keep the body in an upright orthostatic position. The body moves slightly back and forth from the ankle in sagittal plane although it appeared to be immobile. The body is divided into right and left sides by the sagittal plane. It's common to compare the sway of calm standing to the swing of an inverted pendulum.

To ensure a person have a good standing posture, maintain a straight back as you stand to your full height. Assume that someone is lifting your head towards the ceiling to make sure you are doing this correctly. Avoid locking your knees and maintain a slight bend in them. Keep the core muscles active and tuck in your tummy while enabling your arms hang loosely. Keep your legs wider than your shoulders, transfer your weight gently from your heels to the front of your feet. Try not to move your head in any direction such as forward, backward, or sideways; and maintain eye level as shown in Figure 2.1.



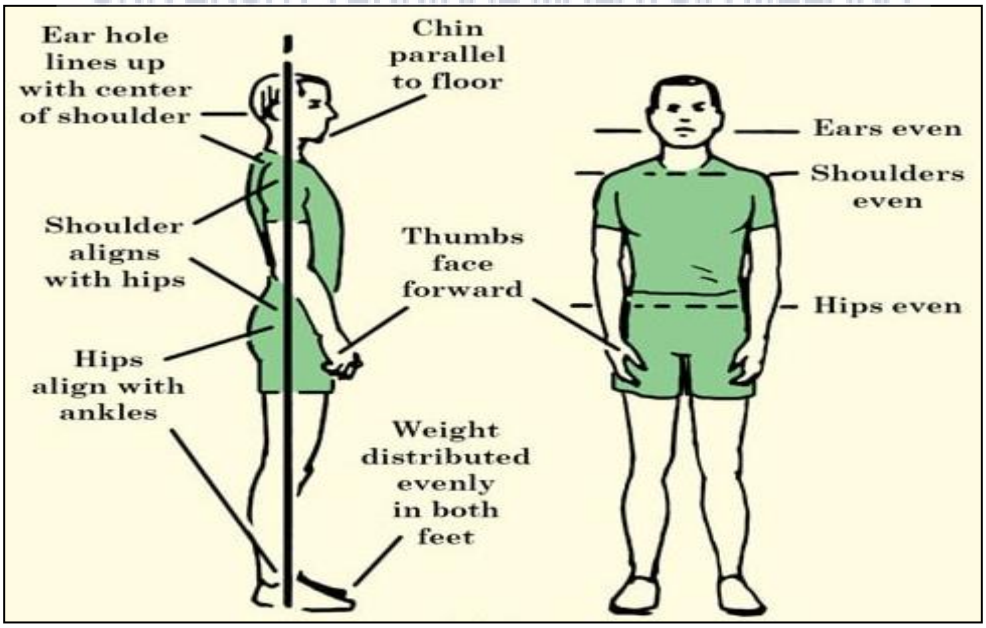
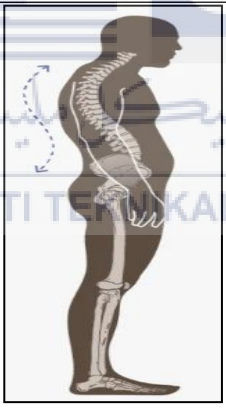


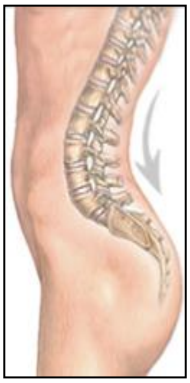
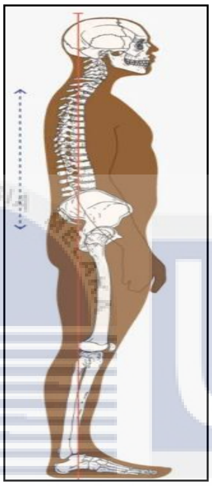
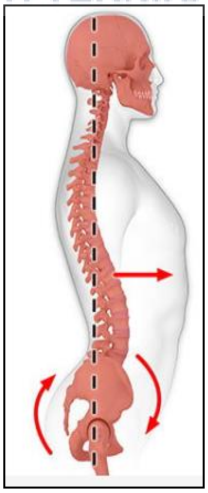

Figure 2.1: A good standing posture (Brett, 2016)

### 2.1.2.1 Health Issue Due to Non-Neutral Standing Posture

A potbelly, rounded shoulders, joint degeneration, back discomfort, and spinal dysfunction are an example of health problems that can result from poor standing posture. Besides that, it also led to incontinence, migraines, poor balance, and breathing problems. Muscle strain caused by bad posture might result in inflammation and long-term harm. Increased pressure on the abdomen and bladder, may cause stiffness, pain in the neck, back, and shoulders, as well as an increased risk of injury and stress incontinence. In addition, to enhance standing posture some adjustments such as keeping the arms and shoulders at a 90-degree angle when sitting, setting the display at eye level, and maintaining a neutral spine when standing is recommended. Table 2.1 shows some examples of health issue due to non-neutral standing posture.

Table 2.1: Health issue due to non-neutral standing posture. Caitlin Scheib (2021, March 12)

| **Health issue due to non-neutral standing posture** | **Images** | **Description** |
|---|---|---|
| **Kyphosis** |  | Kyphosis is an excessive forward curve in the upper back. Age, spinal characteristics, and posture all contribute to it. It require necessitate therapy since it can cause back discomfort and other issues. |
| **Scoliosis** |  | Scoliosis is a lateral curvature of the spine that is often diagnosed in adolescence. While scoliosis can affect adults who have diseases like cerebral palsy and muscular dystrophy, the majority of infantile scoliosis has an unknown origin. |

| | | |
|---|---|---|
| **Lordosis** |  | People with lordosis posture have a pronounced lower back curve which can be called as swayback, a pronounced neck curve, and frequently a pronounced pelvic tilt as well. Their buttocks may also protrude as their stomach and head thrust forward. |
| **Flat Back** |  | A muscular imbalance that causes the spine to be flatter than usual and devoid of its natural curves commonly results in a flat back. People with flat backs frequently slouch forward due to the tucked-in pelvis. Long periods of standing are difficult for them, and they frequently complain of leg and back pain. Compression fractures and degenerating discs are contributing factors in flat backs. |
| **Forward Head** |  | When the head is held in a forward head posture, the ears are placed in front of the body's midline rather than aligning with the shoulders. Regular neck ache, stiffness, and even an unsteady walk are side effects of this position. A hefty backpack, spending too much time on the internet or while driving, and sleeping with your head too high are all contributing reasons. |

### 2.1.3 Sitting

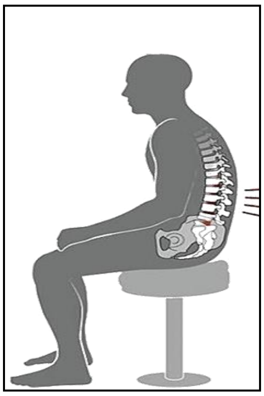
Sitting is a basic movement and resting posture in which the lower limbs are not used to support the body's weight as they are in standing, squatting, or kneeling, but rather the bony ischial tuberosities with the buttocks in contact with the ground or a horizontal surface, such as a chair seat. The torso is more or less erect when seated, however it may occasionally rest on something else for a more comfortable posture. Reading a book, watching a movie, or attending a conference are a few examples of activities that is linked to sitting.

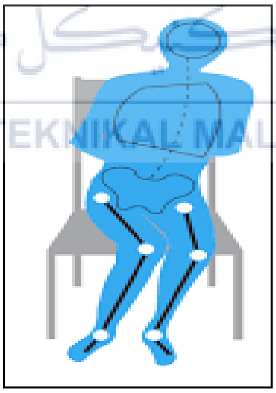
Practicing a good posture when sitting is crucial to maintain the back and spine healthy. The example of equipment an individual uses, such as a car seat, office chair, armchair, ergonomic chair, stool, or beanbag, may impact the way they sit. A person's height, the chair they use, and the activity they are performing while sitting influence the best sitting position.

#### 2.1.3.1 Health Issue Due to Poor Sitting Posture

Poor sitting posture strains the body, it can cause an array of health problems. Poor sitting posture can have a number of detrimental repercussions, including shoulder, neck, and back pain. In addition, poor sitting position may reduce incontinence, restricted nerves, poor circulation, lung function, and digestive problems. The body's incapacity to preserve its normal alignment, stress, and muscle exhaustion are frequently the causes of the effects. These disorders may eventually worsen and lead to serious health complications. In order to avoid these detrimental impacts on health, it is crucial to give careful attention to sitting position and make necessary adjustments. Table 2.2 shows some examples of health issues due to poor sitting posture.

Table 2.2: Health issue due to poor sitting posture. Stephen Jia Wang (2018)

| Health issue due to poor sitting posture | Images | Description |
|---|---|---|
| **Upright, With or Without Lumbar Support** |  | Prolonged static position will probably be uncomfortable or put strain on certain sections of our body. The lumbosacral discs are put under strain when a person seat on a chair without lumbar support. In a long-term this may impacts on posture, joints, tissues, and our spine. |
| **Hunched Forward** |  | When a person's head is tilted forward and out of neutral alignment with their spine, this is known as forward head posture (FHP). Medical conditions, such as neck stiffness, discomfort, and balance problems, are due to this incorrect head position. |
| **Slumped Backward** |  | Slouching doesn't always make you feel bad, it might eventually put stress on your muscles and soft tissues if they are already sensitive. This stress may make the muscles more tense, which might lead to discomfort. |

| | | |
|---|---|---|
| **Kneeling** |  | Knee cap cartilage might get irritated if it is bent deeply. If you're sitting on a hard surface, your ankle joints are put under stress due to the weight of your upper body. Your lower legs are compressed by the weight of your upper torso, which prevents blood flow. There won't be enough oxygen available for the muscles in your lower legs. Sitting on your knees while you have knee or ankle problems might make it worse. |
| **Slouching To One Side** |  | Slouching causes the bladder to be under pressure from an increase in abdominal pressure. The pelvic floor muscles' capacity to resist pressure will be reduced by this posture. Constipation can be exacerbated by slouching, which partially seals the anus and makes it more difficult for the abdominal muscles to assist in feces removal. |

### 2.1.4 A Poor Posture

A poor posture can affect our health badly. Poor posture is a body position which is non-neutral or asymmetrical. It happens due to our daily activities which leads to some muscle to be weak or tight. Due to the imbalance in muscle strength is leads to body position askew. Certain people have this poor posture due to their illness whereas the others are due to stress, strain and daily activities. Most of the poor posture issue is due to the weak muscles, tight muscles, excess body mass, high stress job, carrying a heavy bag, standing for a long duration of time and bending for long period to carry out certain task or job which leads to musculoskeletal system problem.

### 2.1.5 Musculoskeletal System

Musculoskeletal system is one of the major components of human health; it acts as an endocrine system which is stimulated by exercise and interacts thru biochemical signal with other body organ such as bones, cartilage, ligaments, tendons and connective tissues. The combinations of these parts help to support the body's weight maintain the body posture and help human to move. Factors such as injuries, aging, disease and congenital anomalies are some parts of musculoskeletal disorders that can cause pain and limits the movement of human. To ensure a good and healthy musculoskeletal system, regular exercise, balance diet food and maintaining healthy weight need to be carried out.



#### 2.1.5.1 Musculoskeletal System Disorders Conditions

A wide range of illnesses affecting the bones, joints, muscles, and connective tissues are collectively referred to as musculoskeletal disorders. These problems frequently cause pain and functional impairment. Numerous factors, such as infectious, inflammatory, degenerative, traumatic, or neoplastic processes, in addition to genetic and developmental events, can lead to these illnesses. These are some of the most expensive and incapacitating medical illnesses, resulting in functional limits and persistent agony. All ages can be affected by musculoskeletal impairments, which are typified by discomfort, movement restrictions, and a decreased capacity to work and engage in daily activities.

Tendinitis, carpal tunnel syndrome, osteoarthritis, rheumatoid arthritis, fibromyalgia, bone fractures, osteoporosis, muscular dystrophy, and myasthenia gravis are a few prevalent musculoskeletal illnesses. These conditions can have a substantial negative influence on a person's quality of life by causing discomfort, immobility, and loss of function.

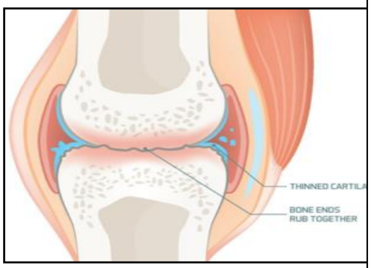
Among the common musculoskeletal conditions are tendinitis, carpal tunnel syndrome, osteoarthritis, rheumatoid arthritis, fibromyalgia, bone fractures, osteoporosis, muscular dystrophy, and myasthenia gravis. These illnesses can cause discomfort, immobility, and loss of function, all of which can have a significant detrimental impact on a person's quality of life as shown in Table 2.3 the types of disorders condition.

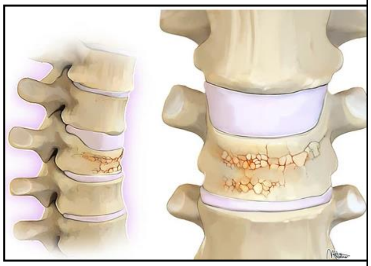
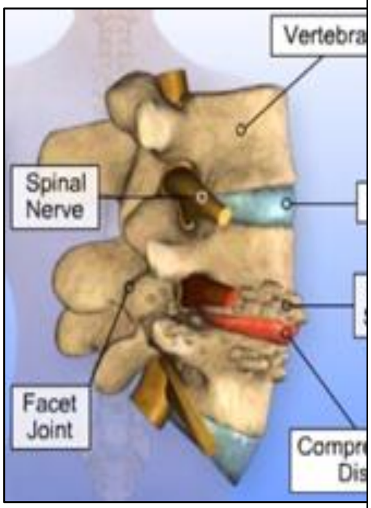
The main ways that musculoskeletal problems affect health are through diminished capacity to work and participate in daily activities, movement limits, and chronic pain. For musculoskeletal problems to be managed and prevented, early diagnosis, treatment, and adoption of healthy lifestyle practices such as regular exercise and safe daily activities are crucial.

In conclusion, musculoskeletal diseases can significantly affect a person's health and quality of life by causing chronic pain, decreased mobility, and difficulties doing daily tasks. To preserve a good musculoskeletal system and general quality of life, it is crucial to comprehend the risk factors, symptoms, and preventive strategies connected to these disorders.



Table 2.3: The types of disorders condition. Managing Editor (2024, April 10)

| Types of disorders condition | Description | Images |
| --- | --- | --- |
| **Osteoarthritis** | Joints in the body became damaged. As time passes, cartilage layer between the intersection of bone wears away, it causes the joints to rub each other which leads to pain, swelling and reduce movements. |  |

| | | |
|---|---|---|
| **Osteoporosis** | A bone disease which develops when bone mass and bone mineral density decreases or structure of bone changes. It also leads to low strength of bone and increases the risk of broken bone. |  |
| **Back Pain** | Back discomfort, and lower back pain, is fairly typical. It normally gets better within a few weeks, although it might occasionally stay longer or keep returning. The common causes are due to the pulled muscle (strain). |  |
| **Muscle Pain** | Muscle pain can be short-term or chronic, and it can be caused by tension, stress, overuse, minor injuries, infections, diseases, and other health problems, it can be a sign of conditions affecting the whole body such as anemia, lupus and fibromyalgia. Muscle pain causes difficulty to a person daily activity and can causes fatigue, headaches and sleep difficulties. |  |
| **Mechanical Back Syndrome** | Numerous spinal structures, including bones, ligaments, discs, joints, nerves, and meninges, are capable of resulting in mechanical back pain. Spinal stenosis, herniated discs, zygapophysial joint pain, discogenic pain, vertebral fractures, sacroiliac joint pain, and myofascial pain are among the common causes of mechanical back pain. |  |

### 2.1.6 A Good Posture

A good posture is more than just standing up straight to look at the best. It plays an important role in a long-term health. Either when you are moving, holding your body in a correct posture can help to avoid discomfort, injuries and other health issues. Postures are divided into two types which are Dynamic Posture and Static Posture. Dynamic posture is on how we are moving to carry out an activity whereas in static posture is on how we stay static at one place for a long duration. Implementation of good posture in our daily life style helps to keep our muscles strong and active therefore ergonomic had been practiced to avoid any health issue.

### 2.1.7 Ergonomics

The designation of ergonomic draws on multiple disciplines such as anthropometry, industrial design, industrial engineering, psychology, physiology, mechanical engineering, biomechanics, information design, kinesiology and etc.

Based on the International Ergonomics Association there are three major domains of ergonomics which are physical, cognitive and organizational. As in the study, physical ergonomics was taken into consideration. Physical Ergonomics is closely interconnected with the workplace ergonomics. Implementation of workplace ergonomics is a solution to deal with work related musculoskeletal disorders. Workplace ergonomic builds a better workplace and designed to match the capabilities of the worker and produce a better work results outcome. Through the implementation, ergonomic creates value on several benefits such as lower costs, produces higher productivity, better product quality, improve employee engagement and better safety culture. The improvements identify ergonomics hazard and ensure administrative and engineering under control measures to reduce risk factors.

#### 2.1.7.1 The Best Practice of Ergonomics

The best practices of ergonomics are to create a productive and comfortable work environment that reduces the risk of accident and enhances general health and well-being. The following are some essential ergonomic techniques as shown in Table 2.4. This technique derived from information and data from a variety of disciplines are gathered and utilized to build, alter, or reorganize equipment so that it benefits users and lowers the possibility of accidents. (Pheasant S, 1991)

Table 2.4: Essential ergonomic techniques. (Pheasant S, 1991)

| Techniques | Data |
|---|---|
| **Anthropometry** | Body, Sizes, Shapes |
| **Biomechanics** | Muscles, Levers, Forces, Strength |
| **Environmental Physics** | Noise, Hear, Cold, Hearing, Vision, Radiation, Light |
| **Applied Psychology** | Skill, Learning, Errors, Differences |
| **Social Psychology** | Groups, Communication, Learning, Behaviors |

### 2.1.8 Synthesis of Literature on Methodologies to Determine Design Requirements

#### 2.1.8.1 Worker Anthropometry

Anthropometry is the study of the measurement of the human body. There are a number of things to take into account when choosing the right sample size for collecting anthropometric data. These variables include the requirement to capture population variability, the degree of precision needed for a certain application, and the degree of result confidence. The heterogeneity within the population under study determines the sample size, not the size of the population overall. (Anthrotech, 2017).



To build growth reference centiles, for example, it has been proposed that studies with the best design could need to include a sample size of 7000 – 25,000 participants each sex. (Cole TJ, 2021). When it comes to space projects, anthropometric information was gathered through a poll of real users, and a sample of 192 male and 22 female astronaut candidates was utilized to create a computer model. (McConville, 2000).

Achieving the reliability and validity of the study's findings requires accurate sample size calculation. It plays a vital role in maintaining ethical standards in research and lessens the possibility of errors. (Martinez-Mesa J, 2014). The particular needs of the study and the specific features of the target population must therefore be carefully taken into account when calculating the sample size for anthropometric studies. Figure 2.2 shows standard anthropometry dimension to ease collecting anthropometric data. According to Figure 2.2, the dimension that had been assessed for this project were body weight, body height, shoulder height, elbow height, total arm length, forearm circumference, upper arm circumference, popliteal height and sitting height.

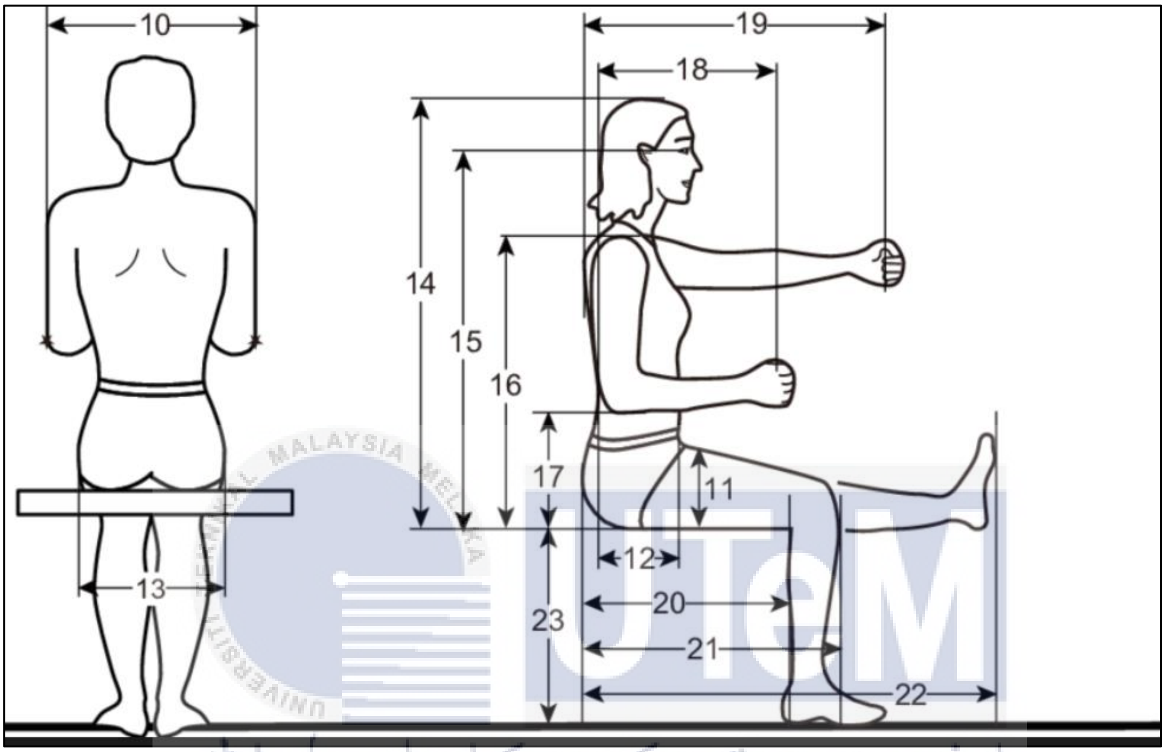



Figure 2.2: Standard anthropometry dimension to ease collecting anthropometric data. Karmegam Karuppiah (2011)



#### 2.1.8.2 Malaysia Anthropometric Parameter

Table 2.5 shows the anthropometric parameter of Malaysia males age between 18-24 years with the number of 595 participants. Karmegam Karuppiah (2011)

Table 2.5: Malaysia anthropometric parameter

| | Male (n=595) | | | |
|---|---|---|---|---|
| | **Min** | **Mean** | **Max** | **SD** |
| **Body Weight (kg)** | 41.00 | 64.33 | 120.00 | 15.24 |
| **Body Height (cm)** | 150.50 | 168.01 | 186.18 | 6.08 |
| **Shoulder Height (cm)** | 122.30 | 139.57 | 157.30 | 6.07 |
| **Elbow Height (cm)** | 92.50 | 106.02 | 120.20 | 4.68 |
| **Total Arm Length (cm)** | 59.70 | 73.88 | 87.90 | 4.74 |
| **Forearm Circumference (cm)** | - | - | - | - |
| **Upper Arm Circumference (cm)** | - | - | - | - |
| **Popliteal Height (cm)** | 37.60 | 41.44 | 45.70 | 1.42 |
| **Sitting Height (cm)** | 94.60 | 109.48 | 122.80 | 5.32 |



### 2.1.8.3 Sensors

Anthropometry makes extensive use of sensors to measure a variety of body parameters precisely and non-invasively. A variety of sensors, such as RGB-D sensors, load cells, proximity sensors, temperature sensors, ultrasonic sensors, infrared sensors, and Hall effect sensors, are used for anthropometric measurements. The body parameter being measured and the particular application will determine which sensors are best. For instance, static anthropometry measurements are made using RGB-D sensors, but load, proximity, and temperature sensors are used in a multisensor-based non-contact anthropometric system for the early detection of stunting. (Umiatin, U et al., 2022).

Novel approaches to measuring anthropometric traits have been developed as a result of recent developments in deep learning and sensing technologies. Among these techniques are deep learning-based computer vision-based anthropometric measurements, human body scanning, and sensors and non-contact anthropometry technologies. (Adrian Munteanu and

Pengpeng Hu, 2021).

In conclusion, sensors are essential to anthropometry because they allow for precise and non-invasive measurements of a variety of bodily parameters. The particular application and the body parameter being measured determine which sensors are best. New techniques for anthropometric measurements have been developed as a result of recent developments in deep learning and sensing technologies. In this project sensors such as load sensors as shown in Table 2.6 and ultrasonic sensors as shown in Table 2.7 had been in used to measure the force exerted at the lower part of the body and to measure the bending constrain of the MIG welder.

Table 2.6: Types of load sensor / load cell. RealPars B.V. (2023)

| **Sensor's Type** | **Example of sensor** | **Measure** | **Operation Mechanism** | **Units** | **Advantage** | **Limitations** |
|---|---|---|---|---|---|---|
| Load Sensor/Load cell | Piezoelectric | Dynamic and quasistatic forces, both tensile and compression. | A strain is applied to the device, which compresses a crystal inside the unit | kg/lbs | Compact and easy to handle | Can only be used for dynamic pressure measurement |
| | Hydraulic | Measure force or weight | A load or force acting on a loading head transferred to a piston that in turn compresses a filling fluid confined with an elastomeric diaphragm chamber | Kg, kN, N,m² | Waterproof, shock-proof, resistant to weather damage | Relatively slow speed of response and need for clean, dry, regulated air or nitrogen |
| | Pneumatic | Weight as a change in pressure of the internal medium | Using the principle of air pressure | Kgf | Inherently safe and resistance to environmental factors | Lower sensitivity and resolution and require air supply |
| | Magnetic | Force measurement | The change in the magnetic field is measured and converted into an electrical signal for force measurement | millivolts | High accuracy | Difficult to measure complex structure and difficult to downsize |

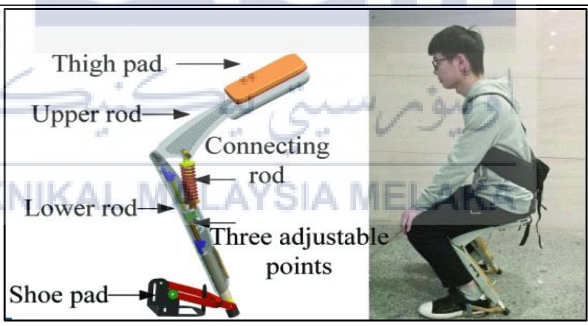
Table 2.7: Types of ultrasonic sensor. Schneider Electric (2024)

| Sensor's Type | Example of sensor | Measure | Operation Mechanism | Units | Advantage | Limitations |
|---|---|---|---|---|---|---|
| Ultrasonic Sensor | Rangefinders | Distance based on the time taken between ultrasonic waves to an object and back to sensor | Emitting ultrasonic waves, detecting the echoes or reflections of these waves from objects, measuring the time taken for the waves to travel to and from the object, and then calculating the distance based on this time measurement | Meters (m) | Versatility, accurate distance measurement and fast response time | Environmental Interference and Vulnerability to Acoustic Interference |
| | Flow Sensors | Flow rate of a fluid (liquid or gas) by using ultrasonic waves | Ultrasonic waves traveling through a fluid and detecting changes in their propagation time | Litre per minute (L/min)<br>Milliliters per minute (mL/min) | No pressure drops, wide compatibility, minimal maintenance and energy efficiency | Fluid properties, pipe material, and flow velocity range |
| | Level Sensors | The level of a liquid or solid substance within a container using ultrasonic waves | Emitting ultrasonic waves towards a liquid or solid surface, detecting the reflections of these waves, measuring the time taken for the waves to travel to the surface and back, and then calculating the distance based on this time measurement | Meters (m) | Output options, minimal maintenance, accuracy and precision | Reflective surfaces, multi-path interference, cost and complexity |
| | Distance Sensors | The distance between sensor and an object using ultrasonic waves | Emitting ultrasonic waves, detecting the echoes or reflections of these waves from objects, measuring the time taken for the waves to travel to and from the object, and then calculating the distance based on this time measurement. | Meters (m) | Fast response time, minimal maintenance, cost effectiveness | Environmental interference, resolution for small objects, size and weight considerations |

### 2.1.8.4 Ergonomic Lower Body Support

An ergonomic lower body support is a kind of lower body support intended to support, comfort, and encourage proper posture when seated. The features and attributes of ergonomic lower body support include tilting mechanisms, adjustable height, stability, back support, ergonomic design, and long-lasting construction. By extending your legs, keeping an active body pace, and tilting when sitting, they are intended to help prevent joint issues and back pain. Many people believe that ergonomic lower body support is a great way to encourage good posture and lower the risk of back pain. They are made especially to support you in finding relief from standing for extended periods of time. In summary, the benefits of using an ergonomic lower body support for sitting include promoting active sitting, reducing muscle tension, improving focus, enhancing circulation, and providing relief for back pain, all while offering customizable and durable features. Table 2.8 shows some examples of ergonomic lower body support.

Table 2.8: Example of ergonomic lower body support

| Title &Author | Design |
|---|---|
| Design and Preliminary Experimentation of Passive Weight-Support Exoskeleton<br><br>Aibin Zhu (2018) |  |
| Effect evaluation of a wearable exoskeleton chair based on surface EMG<br><br>Zhiyuan Li (2019) |  |

| | |
|---|---|
| A Wearable Virtual Chair with the Passive Stability Assist<br><br>Hyundo Choi (2015) |  |

**2.1.8.5 Allowable Pressure**

The human body has a range of pressure tolerances depending on the situation. A human can withstand up to 30 atmospheres (atm), or 701 meters of sea level, which is equivalent to 70.1 bar or 69.2 atm. It is stated that the body can withstand up to 400 pounds per square inch (psi) of pressure if the weight is gradually increased, and that it can withstand up to 50 psi of sudden impact without suffering any harm or discomfort. On the other hand, there are a number of variables that determine how much pressure a human body can bear without becoming harmed or uncomfortable such as body weight, posture, health condition, duration and posture.

In condition of standing posture, your feet bear all of your body weight when you stand. Approximately 1.5 times one's body weight is the average pressure applied to the feet when standing. The pressure that a 150-pound (68-kg) person would apply to their feet would be approximately 225-pound (102-kg) pounds whereas in a sitting posture the lower back, as well as the buttocks and thighs, are the main areas of pressure if there is insufficient lumbar support. A chair's design, seating surface area, and posture are just a few of the variables that affect how much pressure is applied while sitting. The pressure on the buttocks can rise by two to three times the body weight when one is seated. For instance, while seated, a 150-pound (68-kg) person could press between 300 and 450 pounds (136 and 204 kilograms) on their buttocks.

Standing or sitting for a prolonged duration of time can raise your risk of discomfort, fatigue, and musculoskeletal issues such as leg swelling, back pain, and pressure sores. Thus, it's recommended to alternate on your sitting and standing positions, take frequent pauses to stretch and move around, and use ergonomic furniture and accessories to support good posture and lessen body pressure.

### 2.1.9 Evaluation of Literature on Methodologies to Determine Design Requirements

Table 2.9: Evaluation of literature on methodologies to determine design requirements

| Authors | Studies | Objective | Key Finding |
|---|---|---|---|
| (Jin Wang et al., 2023) | A method of aircraft seat dimension design for long-term use by passengers with different body types. | To the design of passenger seats for short-distance flights in China | There is one optimal dimension for seat height (430.5 mm), backrest inclination (104.2°), lumbar support height (98.8 mm), and neck support thickness (44.4 mm). However, seat pan inclination (5.8°, 7.2°, and 9.3°), neck support height (582.6 mm and 622.5 mm), and lumbar support thickness (40.6 mm and 48.7 mm) need multiple dimensions to meet passenger comfort requirements. |
| (Liesbeth Groenesteijn et al., 2009) | Effects of differences in office chair controls, seat and backrest angle design in relation to tasks. | To determine whether end-users notice small differences between office chairs and to find out whether these differences are task related. | No differences are found between seat pan comfort and discomfort, first impressions and peak interface pressure. |
| (Peter Vink et al., 2017) | Sensitivity of the human back and buttocks: The missing link in comfort seat design. | To examine the differences in pressure sensitivity for areas of the human body in contact with the seat pan and backrest of a vehicle seat | The area of the body having contact with the front of the seat pan was more sensitive than the rest of those parts touching the seat pan. The area of the seat touching the shoulders was significantly more sensitive than the area in between the shoulders and lower down the back. |
| (T Brosh et al., 2000) | Modeling the body/chair interaction – an integrative experimental–numerical approach | To develop a systematic methodology towards a realistic model, of the body/chair interaction as a tool to analyze sitting posture and the cushioning system influence on the pelvis/lower back stress development. | Validation of the model was achieved by comparing its results with in vivo measurements of contact stresses developed between the body and a stiff target seat area. Loading the model using two alternative cushioning materials lead to different sets of stresses within the model; as the stiffness of the seat decreased, the peak contact stresses, as well as the internal body stresses substantially decreased. |

## 2.2 Design and Development of Smart Modular Lower Body Support.

Smart Modular Lower Body Support is a device that had been design and develop to those workers whom have difficulty to stand or sit during working for a prolong duration. Prolong standing and sitting may reduce the efficiency of the worker at work place. Therefore, to overcome this problem a Smart Modular Lower Body Support had been develop by satisfying the ergonomic factor and a low-cost exoskeleton.

The device in this work act as a Modular Lower Body Support which built based on the shape of a chair. It serves as a chair and a mechanical mechanism when an individual required carryout a prolong job. The seat is rotatable so the worker doesn't need to rotate their hip to the left or right and ensure the worker to move into their desired position. As an external body portion experiences, the greatest stresses from the body the product will closely conform the lower section of the body. Below are some examples of products that had been in market, under research and prototype.

### 2.2.1 Types of Lower Body Support

Human lower body support come in a variety of forms. Each lower body support is designed for specific body region and function. Examples of some type of lower body support are described in Table 2.10.

Table 2.10: Types of human lower body support. Westcoast Brace and Limb (2024)

| Types of human lower body support | Description |
|---|---|
| **Orthopedic Shoes and Insoles** | These are intended to support and align the feet properly, which can have an impact on the lower body as a whole. |
| **Orthopedic Braces and Supports** | In order to give extra support and prevent injuries, these devices are frequently used for particular joints or areas, such as knee braces, ankle supports, or hip stabilizers. |
| **Canes** | Walking aids called canes give extra stability by distributing weight and supporting one side of the body. |
| **Crutches** | Crutches facilitate the transfer of weight from the lower to the upper body for people who are injured or disabled. They are available in different styles, like forearm or underarm crutches. |
| **Walkers** | Walkers are four-legged frames that offer a more expansive base of support. For people who require more stability than a cane can offer, they are advantageous. |
| **Wheelchairs** | Wheelchairs provide complete lower body support and enable independent or assisted mobility for people with severe mobility issues. |
| **Orthopedic Belts and Bands** | These are intended to provide particular regions, such as the hips or lower back, compression, support, or stabilization. |
| **Orthopedic Seat Cushions** | Particularly after prolonged periods of sitting, these cushions can be used to support and ease pressure on the hips and lower back. |
| **Compression Stockings** | People with ailments like varicose veins or edema may benefit from wearing these stockings, which are intended to increase blood circulation in the legs. |
| **Prosthetic Devices** | Prosthetic devices help people move around more easily and offer support to those who have lost a limb. |

### 2.2.2 Design Consideration

A design consideration is very important in producing a product. It is a major factor that need to be taken into consideration because it ensures the material and components that will be used is to find and in a good supply. In this project a few designs consideration had been take into consideration such as material, flexibility, function ability and durability

#### 2.2.2.1 Material

Material is a must for a design consideration. This is to ensure, how best the incorporate materials considerations into the design process are. The consideration can be put in a line with three main elements which are Form, Function and Fabrication. Based on the aspect of form, we should ensure the material satisfies the design that we had planned out; whereas for the function, we should ensure the function of the material for the design.

For example, we should consider the type of material that used in the industry; this is because different type of industry has different type of environment. For an example industry such semiconductor, chemical company, fabrication. These types of company have its own nature of environment. In semiconductor company, the working place are fully air conditioned. In a chemical company, the working place are covered with chemical exposure whereas in fabrication company the working place are covered with metal dust. Therefore, a centralized material needed to be choosing to satisfy different type of environment usage. For the aspect of fabrication, the material should be good enough to be fabricated, if it is hard to be fabricated then it may lead to material wastage.

In addition, the materials used to design usually determine or influence the relationships between the three factors. Based on the reality, the choice of materials is influenced by each of these three aspects. As a prior information, if the initial materials selection decisions are made based on one of the elements only, then the balance between form, function and fabrication is adversely affected, as the other two design elements are driven by the need to accommodate the capabilities of the materials chosen. Specific materials considerations should be considered as an integral element throughout the design process. In materials considerations for all other aspects of design, it is inevitable that there will be a need to compromise some aspects of the design to achieve others. The consideration of those details determines these objectives and it truly test the skill of the designer. The materials aspects of the design have no different from any other in the factor of ability to achieve this, it is totally dependent on the ability of the designer to comprehensively and accurately define all the design requirements and develop a design solution that meets them. Table 2.11 shows 4 types of materials and the characteristics of the material which are aluminium, stainless steel, PVC and low carbon steel whereas Figure 2.3 shows the relationship between material and element of design. To produce a good product the element of design and material plays a major role. Understanding these elements and materials allows designers to create effective and engaging designs, ensuring both functionality and aesthetic appeal. Each material's unique properties influence the design process, dictating form, function, and style. By listing down and making comparison between the materials is one of the best ways to identify the best material to be choose for the project.

Table 2.11: Types and characteristics of material. (Ansys Granta Selector (2024)

| | **Material** | | | |
|---|---|---|---|---|
| | **Aluminium** | **Stainless Steel** | **PVC** | **Low Carbon Steel** |
| Density (lb/ft^3) | 156-181 | 474-506 | 81.2-98.6 | 487-493 |
| Yield Strength (ksi) | 4.35-72.5 | 24.7-145 | 5.13-7.56 | 36.3-57.3 |
| Tensile Strength (ksi) | 8.41-79.8 | 69.6-325 | 5.9-9.45 | 50-84.1 |
| Young Modulus (10^6 psi) | 9.86-11.9 | 27.4-30.5 | 0.31-0.60 | 29-31.2 |

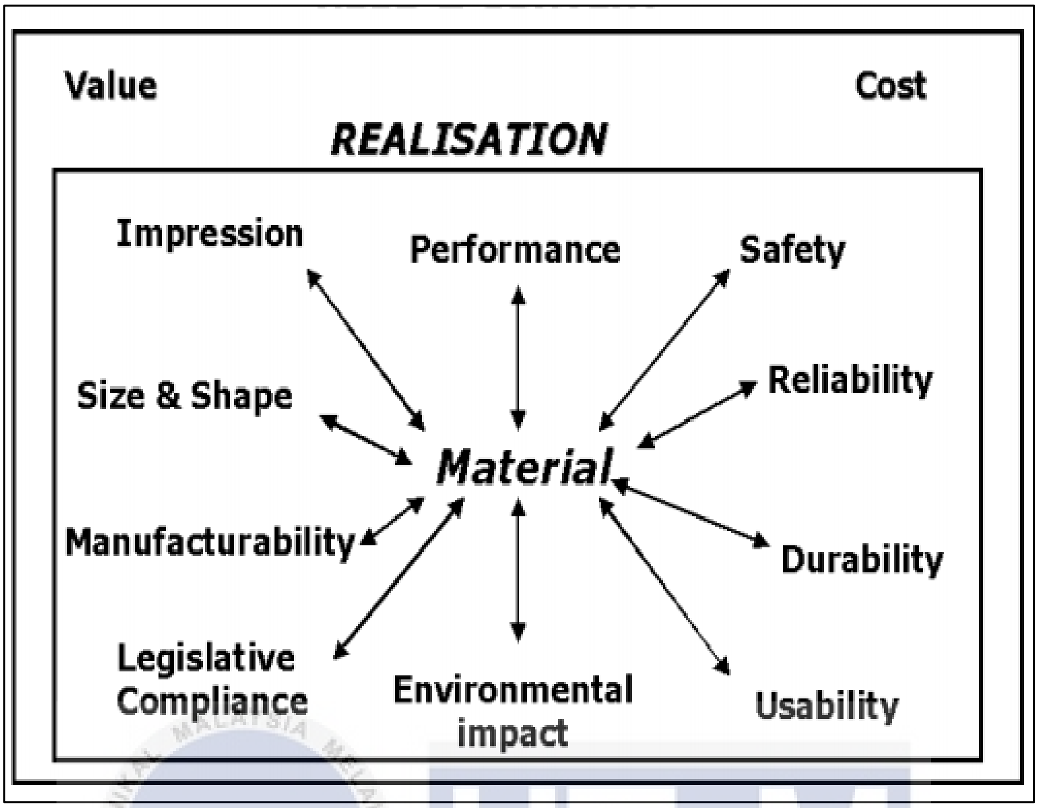


Figure 2.3: Relationship between materials & element of design. Hodgson and Harper (2004)

### 2.2.2 Durability

The durability of the Smart Modular Lower Body Support is depending on the number of factors. Even though there is a stipulated manufacturer durability life span, it may not achieve it if some aspect is not been carefully put in consideration. The shaft and base structure are very important because it determines the durability of the product and the main function of the shaft and base structure is always giving the best support. Therefore, reduction of the motion resistance with reducing resistance for the material which is been conveyed. The durability of the Smart Modular Lower Body Support also depends on the number of engineering operational.

#### 2.2.2.3 Cost

Cost is one of the major factors considered in producing a product. No matter how impressive the demand for the product, if its production method is inefficient, it is unlikely to profit from selling it. One of the best ways to increase the profit margin in manufacturing is usually to lower the product's manufacturing costs rather than increasing the price of the product. Various cost-saving methods are available to reduce the cost of the manufacturing process. (Lance Taylor, 2013).

In many companies, the most significant expense incurred by a manufacturing company is in the medical expenses of certain workers. It means that, a big number of company insurance had been used for the worker to undergo medical treatment and in another factor, meanwhile a worker undergoes medical treatment there will be a shortage of manpower in the production line. Therefore, the company needed to replace the current worker's task to another or need to give some overtime salary to those workers to cover up the task that had been assigned to the worker that undergo medical treatment. It leads to high-cost labor due to the medical issue.

Besides that, material is another important part of the production costs involved in manufacturing a Smart Modular Lower Body Support. A good design of lower body support should be selected and fabricated. A comparison of material should take place. When much of your manufacturing expenses is due to material costs, therefore sense to look for ways to reduce this expense should be carried out. Another way to reduce material costs is to use fewer materials in your products or uses a good quality material with a cheap price. If a good material is used with a low cost, it reduces impacting the quality of the product. Looking improving the efficiency of the production process so that less material is wasted. Therefore, the material of the product should be studied careful and the material is rigid to support multiple weight or size of worker whom uses it.

## 2.3 Internet of Things (IoT)

A network of physical objects, devices, and other things that have sensors, software, and other technologies embedded in them that allow them to connect with one another and exchange data with other devices and the cloud is known as the Internet of Things, or IoT. Simple home items, advanced industrial tools, wearable technology, and even entire smart cities can all be considered IoT gadgets. The backbone of an IoT ecosystem is IoT sensors, which enable devices to function and gather data by identifying changes in their surroundings. The Internet of Things (IoT) has many different kinds of sensors, such as level, motion, pressure, temperature, humidity, proximity, and many more. IoT sensors can be classified as full-body, upper-body, and lower-body exoskeletons according to the body portions they in contact. They are further classified according to whether they are powered or not. Static sensors need the actuators to be turned on constantly, whereas powered sensors use batteries or electrical cable connections to run sensors and actuators. IoT sensors are used in many different industries, such as the industrial, construction, healthcare, and automotive sectors. The function and customer usage of a device determine the type of sensor that is best suited for it.

### 2.3.1 Blynk



Blynk is a commonly used IoT platform which provides a variety of software solutions for connecting, deploying, and remotely controlling electronic devices at different scales. More than 500,000 developers and companies utilize it and Blynk has been designed for developers. ESP32, Arduino, Raspberry Pi, Seeed, Particle, SparkFun, Adafruit, and TI are a few types of hardware which users can connect to the platform's cloud. A wide variety of widgets, including buttons, sliders, and charts, can be used to create user interfaces for controlling electronics and analyzing sensor data. There are some key features of Blynk platform such as unified platform, fast and easy setup, device provisioning and user-friendly apps. In a conclusion agricultural equipment, complex HVAC systems, smart home devices, and more can benefit from the Blynk IoT platform. It is a flexible option for Internet of Things projects because it is also compatible with a large variety of devices.

## 2.4 MIG Welding

MIG welding, sometimes referred to as wire welding or Gas Metal Arc Welding (GMAW), is an acronym for metal inert gas welding. It is an arc welding procedure that joins two base materials together by feeding a continuous solid wire electrode into the weld pool via a welding gun. To prevent contamination of the weld pool, a shielding gas is further passed through the welding gun. Because MIG welding is so much faster than TIG welding, it is typically utilized for heavy-duty fabrication tasks like metal gates, which reduces lead times and production costs. MIG also generates welds that require little to no finishing and cleaning, and it is easy to learn. Figure 2.4 shows an MIG welders carried out welding process.


Figure 2.4: A welder performing MIG Welding

## 2.5 Modular Lower Body Support in Welding Industry

Among workers in several professions, including welders, lower body support can be extremely helpful. Lower body support upholds against physical overload and provide support for the lower body muscles, which reduces tension on these areas. One example of a passive lower-body support that allows for free movement but with the ability to lock in place at any moment is the Orbital Modular Ergonomic Chair (Orbital Support Systems Inc). Modular lower body support chairs can minimize harmful impacts on workers' health and assist them maintain an ergonomic posture when welding. Because welders are more likely to develop musculoskeletal issues, exoskeleton chairs can help ease shoulder pulls, back pain, and strain in the neck. Reducing tiredness, enhancing posture, and lowering the chance of injury are some advantages of utilizing an exoskeleton chair in the MIG process. Figure 2.5 shows an example of modular lower body support.

Figure 2.5: Modular Lower Body Support (Orbital Support Systems Inc, 2023)



## 2.6 Fabrication and Evaluation of Functionality and Usability of Smart Modular Lower Body Support.

### 2.6.1 Fabrication of Lower Body Support

Figure 2.6: Design and fabrication of an ergonomic sitting stool with storage capability (H Wessam, 2019)

The stool's shape was CNC routed onto five plywood sheets that were 800 x 600 x 18 mm in size. The sheets were cut using a band saw. Sanding was then utilized to smooth out all of the CNC-routed plywood. Once that was done, the entire structure was clamped and glued. To cut the flexiply sheets, a scroll saw was utilized. Onto the plywood framework, these flexiply sheets were clamped and bonded. To achieve a shiny finish and shield the product from moisture and insects, three coats of polycrylic were applied to the entire structure after it had been thoroughly sanded with the finest grit sandpaper. The storage compartment's base and shelving units were laser-cut and incorporated into the product. There were screws used to fasten the base as shown in Figure 2.6.

Figure 2.7: Fabrication of Exoskeleton Chair with Simple Linkage Mechanism (M. S. Chaudhari et al., 2020)



In this case, the user's load will determine the use of a pressurized cylinder filled with compressed air. A 25 millimeter bore diameter and a 250-millimeter stroke length characterize the cylinder. With 2 mm MS sheet bent into the desired shape, a leg holder that can support the thigh was created. Using fasteners, the square block is secured to the cylinder after the leg holder is rotated to face it. It was this part that allowed the cylinder to pivot to the leg holder. Every pivot has been fastened with M-10 nut bolts. Currently, the individual will sit, stand, and walk with ease. The "Exoskeleton Chair" is made up of two similar "chairs," one that is strapped to the wearer's leg and one that is not. The Exoskeleton Chair needs to be customized for every user. Just like a piece of cloth, a chair won't feel right if it doesn't function. After the chair is correctly adjusted, you can unwind in comfort while placing all of your weight on it. A cylinder presses the chair's upper member against the back of the thigh while the lower member is strapped to the calf. The body is supported as the user squats because the compression bar that has been released pushes the chair leg into a locked position. When the user stands up, the lower member unlocks and retracts with the help of a cylinder to its starting position, where it won't get in the way of their movements. A slider's bush pin arrangement allows it to be adjusted to any locking position in accordance with conditional requirements as shown in Figure 2.7

Figure 2.8: Wearable lower body exoskeleton for lumbar pain reduction
(G. Lavanya et al., 2022)



Develop a lower body support for this project to help those who are working for a long period of time. Therefore, a lower body support model is developed. It consists of iron, which has a lighter weight. Regardless of the weld is also guaranteed. Shaft, washer, bolt (size 5 cm), and nut (size 1 cm) are additional parts used in this project. Drilling and arc welding equipment are being used. We use ergonomic seats to increase user comfort. Our lower body support model is created using the 3D CAD design software SOLIDWORKS. Initially, screws and welding were used to construct and assemble the components. A rectangular rod placed parallel to the butt region in the lower hip area. To support the thigh area, stainless steel rods are welded on the opposite side end. We have the ability to bend the area on our thigh for chair-less chair designs. The calf region support is the next area, which aids in the calf's support. In comparison to the support of the thigh region, the calf region is longer. Lastly, shoes are used to secure the end of the calf support area as shown in Figure 2.8.

### 2.6.2 Evaluation of Lower Body Support Functionality

Table 2.12: The evaluation of lower body support functionality

| Author | Objective | Topic Concern | Result |
|---|---|---|---|
| (Siu Shing Man et al., 2022) | To evaluate biomechanically back and hip extensor activities and kinematics at the thoracic and lumber spines and bilateral hips and exploring exertion level changes and user acceptance of a passive exoskeleton as a tool for transfer | Work related musculoskeletal disorders (WMSDs) | 1) Using a passive exoskeleton in performing transfer tasks significantly decreased the SEMG activities of thoracic erector spinae, lumbar erector spinae and gluteal muscles, decreasing the maximum voluntary isometric contraction by 7.8%-10.95%.<br>2) No significant differences in the maximal flexion angles of thoracic and lumbar spines and trunk between performing the task with and without the exoskeleton<br>3) A nonsignificant decrease in exertion level when performing the transfer task with the exoskeleton<br>4) No significant between-group differences in the score of acceptance questionnaire |
| (Sang-Chul Hwang et al., 2011) | To develop a modular design methodology for products with improved adaptability for customers of various body sizes. | Modular design considering customer adaptability for products | 1) The study had maximized customer satisfaction considering physical interaction between human and product.<br>2) The proposal consists of customer requirement analysis, modularization, and modularization assessment procedure.<br>3) The proposal includes a method to determine size variation of defined modules at the detail product design stage for mass customization. |
| (Yan W, Zhao D et al., 2023) | Propose a computational design tool to enable casual end-users to easily design, fabricate, and assemble flat-pack furniture with guaranteed manufacturability. | Computational design tool | 1) Demonstrated the validity of the approach by designing, fabricating, and assembling a variety of flat-pack (scaled) furniture on demand. |
| (Billy Chun Lung So et al., 2022) | To examine the effects of a PBSE on the activity of trunk muscles, the spine kinematics and physical capacity of workers during repetitive lifting and carrying tasks. | Lower back pain (LBP) disease | 1) By using the PBSE, the activities of the thoracic erector spinae and lumbar erector spinae muscles were reduced significantly by nearly 7% MVC and 3% MVC in the repetitive lifting task and the carrying task, respectively. |

| | | | |
|---|---|---|---|
| (Costalonga Martins et al., 2020) | To explore the use of a TFP preform as an embedded fabrication frame for CFW. | Design and prototyping a stool | 1) Through a bottom-up iterative method, material and structure are explored in an integrative design process. This culminates in a lightweight FlexFlax Stool design (ca. 1 kg), which can carry approximately 80 times its weight, articulated in a new material-based design tectonic. |

### 2.6.3 Evaluation of Lower Body Support Usability

Table 2.13: The evaluation of lower body support usability

| Author | Objective | Topic Concern | Result |
|---|---|---|---|
| (Kim, Taesun., 2020) | To identify the major factors influencing the usability of a rehabilitation robotic device for lower limbs and the reasons for involving several diverse user groups for a more comprehensive evaluation. | Evaluate the usability of rehabilitation robotic devices for lower limbs. | 1) The industry and design community should move toward implementing a more explorative perspective to enable a more human-centered and posture-concerned approach to provide better usability to the diverse users of medical devices. |
| (Hoevenaars D et al., 2021) | The objectives of this study were to develop the WHEELS mHealth app, and explore its usability, feasibility, and effectiveness. | Functionality of mobile health (mHealth) for wheel chair users with spinal cord injury or lower limb amputation | 1) The interviews and questionnaires showed a varied user experience. Participants scored a mean of 58.6 (SD 25.2) on the SUS questionnaire, 5.4 (SD 3.1) on ease of use, 5.2 (SD 3.1) on satisfaction, and 5.9 (3.7) on ease of learning. Positive developments in body composition were found on waist circumference (*P*=.02, *g*=0.76), fat mass percentage (*P*=.004, *g*=0.97), and fat-free mass percentage (*P*=.004, *g*=0.97). Positive trends were found in body mass (*P*=.09, *g*=0.49), BMI (*P*=.07, *g*=0.53), daily grams of fat consumed (*P*=.07, *g*=0.56), and sleep quality score (*P*=.06, *g*=0.57). |
| (Greg Orekhov et al., 2021) | To design and validate a lightweight untethered ankle exoskeleton that was effective across moderate-to-high intensity ambulation in children through adults with and without walking impairment. | Validation of lightweight untethered ankle exoskeleton. | 1) There was a 9.9 ± 2.6% (p = 0.012, range = 0–18%) reduction in metabolic power during exoskeleton-assisted inclined walking compared to no device in the unimpaired cohort. The cohort with CP was able to ascend 38.4 ± 23.6% (p = 0.013, range = 3–132%) more floors compared to no device without increasing metabolic power (p = 0.49) or perceived exertion (p = 0.50). Users with CP had mean device don and setup times of 3.5 ± 0.7 min and 28 ± 6 s, respectively. Unimpaired users had a mean don time of 1.5 ± 0.2 min and setup time of 14 ± 1 s. The average exoskeleton score on the System Usability Scale was 81.8 ± 8.4 (“excellent”). |

| | | | |
|---|---|---|---|
| (Dr. Benjamin Steinhilber et al., 2017) | To provide a sophisticated study design in which participants simulate assembly work related to that performed in the Audi factories. | The passive exoskeleton 'Chairless Chair' | 1) For the discontinuous measurements, i.e. subjective discomfort ratings, we will calculate the difference value of the pre- and post-condition measurements. Participant evaluations will not be tested but only discussed narrative. The current study has a repeated measures design including three within-subject factors (exoskeleton, working height, and working distance). |
| (Biao Liu et al., 2023) | To study on normal healthy subjects under five different weight-supported conditions, motor and surface electromyography (sEMG) signals of the lower limb muscles. | Lower limb muscles | 1) A slight decrease in joint motion of the lower extremities in the reference (free walking) and weight-supported-only assisted conditions, while there was no change in the joint angle curve waveform.<br>2) There was a significant change in the joint angle waveform between weight support plus trunk transfer and free walking. |

## 2.7 Standards of Industrial Exoskeletons

Staying up to date with the most recent standards and guidelines is crucial for researchers, users, and manufacturers involved in the development and deployment of industrial exoskeletons. Regulatory agencies may create specialized guidelines as the field develops to guarantee the security, effectiveness, and compatibility of industrial exoskeletons. It is advisable to verify with pertinent standards organizations and regulatory authorities for the most up-to-date and accurate information. There are a few standards of industrial exoskeletons. Table 2.14 shows the standards for industrial exoskeletons.

Table 2.14: The standards for industrial exoskeletons (NIST Engineering Laboratory, 2019)

| **Standard for industrial exoskeletons** | **Code** |
|---|---|
| **ISO Standards** | ISO 13482 – Robots and Robotic Devices |
| | ISO/TR 23482 – Robotics |
| **ASTM** | ASTM F48 – Exoskeletons and Exosuits |
| **EN Standards (European Norms)** | EN ISO 13849 – Safety of Machinery |
| | EN 1005-4-Safety of Machinery |
| **ANSI/RIA Standards (American National Standards Institute/Robotic Industries Association)** | ANSI/RIA R15.06 |

Workplace safety, ergonomics, and personal protective equipment are some of the general categories that standards pertaining to exoskeletons may fall under. Standards in these domains may be developed with assistance from groups such as ASTM International, the International Organization for Standardization (ISO), and others. Therefore, the standards of ASTM had been taken into consideration for this project to provide a good standard of Smart Modular Lower Body Support. ASTM has established a committee (F48) to develop standards related to exoskeletons and exosuits. ASTM F48 aims to provide guidelines for the design, testing and use of these lower body support product. (Lowe BD, Billotte WG and Peterson, 2019)

## 2.8 Summary

Table 2.15: Analysis of literature review of the past five-year studies related to human behaviour on exoskeleton use

| Studies | Research methods | Focus of the studies | Results |
|---|---|---|---|
| Sajjapongse Krittanai et al., (2021) | • Gravity compensation mechanism based on conservation of energy and geometry<br>• One-way damping mechanism to reduce fatigue during knee bending | • Gravity compensation mechanism for lower-body support<br>• One-way damping mechanism to reduce fatigue | • Gravity compensation mechanism for lower-body support with one-way damping<br>• Reduces fatigue during prolonged knee bending or squatting |
| Kosuke Takeuchi et al., (2020) | • Wearable systems with passive mechanisms<br>• Elastic material body support structures conform to ground surface | • Wearable system for lower body support during floor-level tasks<br>• Passive mechanisms and auxiliary body support structures for enhanced support | • Wearable systems support weight during crouched tasks near ground level<br>• Passive mechanisms change configuration based on user's body movements |
| Cornelis Franciscus De La Haye et al., (2020) | • First flow path for ambient air with heat exchanger<br>• Second flow path for air with heat exchanger and outlets | • Body support assembly with upper and lower cushion zones<br>• Dual flow paths for air with Peltier effect heat exchanges | • Body support assembly with dual flow paths and Peltier effect unit<br>• Heat exchangers part of Peltier unit within cushion volume |
| Gagliardo Monee Denine, (2018) | • Lower Body Support<br>• Compression garment for outerwear | • Fashion garment for lower body support and compression<br>• Includes waistband, leg panels, hip panels, and gusset panel | • Lower body support and compression garment for comfortable outwear<br>• Provides compression to waist, pelvis, buttocks, hips, legs and crotch |

| | | | |
|---|---|---|---|
| Nishi Taketane, (2018) | • Thigh muscles rotation medically using leg and waist belts<br>• Right and left leg belts connected by waist belt | • Lower body support for medial tight muscle rotation<br>• Waist belt connects right and left leg belts | • Thigh muscles rotation medially using leg and waist belts<br>• Right and left leg belts connected by waist belt |
| Sinan Coruk et al., (2020) | • Hardware properties and capabilities of lower body exoskeleton Co-Ex<br>• Preliminary squatting experiments for crutch-free 3-D movement support | • Lower body exoskeleton Co-Ex for crutch-free 3-D walking support<br>• Custom-built actuators for torque sensing and controllability at joints | • Co-Ex may provide crutch-free 3-D movement support<br>• Preliminary squatting experiments show potential for self-balancing walking support |
| Hurford Alexander et al., (2019) | • Body support device with lower structure and body support part<br>• Optional unit attached by being fitted to lower structure | • Simplifying body support part while supporting user's body<br>• Firmly fitting optional equipment to lower structure | • Body support device supports user's body with optional equipment attachment<br>• Lower structure allows optional unit attachment for user support |
| Michael Neal et al., (2016) | • 14 male recreational runners completed 15 randomized trials on an LBPP treadmill at 5 levels of BWS and 3 velocities<br>• Knee and ankle kinematic data were recorded continuously via electrogoniometry | • BWS running alters lower-limb kinematics, reducing ankle and knee range of motion<br>• Increased BWS leads to shorter ground contact time and longer flight time | • Increased BWS led to reduced stride frequency and ground contact time<br>• BWS caused significant reductions in knee and ankle range of motion |

| | | | |
|---|---|---|---|
| Li Sicheng et al., (2015) | • First positioning pin between support pipes with protection pad<br>• Second positioning pin with clamping device and telescopic arms | • Adjustable lower limb and body support part with multiple points<br>• Stable fixation, good support effect, adjustable angle and height | • Stable support for lower limb from multiple points<br>• Adjustable angle and height for different patient needs |
| **This Study** | • Collecting data of workers working with and without using Modular Lower Body Support.<br>• Collect the data pressure exerted and angle of bending of the worker when using the Modular Lower Body Support using Blynk App.<br>• Interview the worker acceptance for the product | • To analyze the user's requirements technical specifications, and ergonomics considerations for developing a Smart Modular Lower Body Support for MIG welders.<br>• To design and develop a Smart Modular Lower Body Support for MIG welders who are performing tasks in prolonged standing.<br>• To evaluate the functionality and usability of the Smart Modular Lower Body Support for MIG welders engaged in prolonged standing tasks. | • Stable support for lower body support<br>• Effectiveness of Blynk software to trigger alarm such as buzzer and LED system<br>• Effectiveness of Blynk software to send notifications thru software and email<br>• Adjustable height of lower body support<br>• Small and strong basement support<br>• 360° degree of freedom for welders to carry out their task |

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter discuss about the framework of the project and design used for this study. It will explain about the theoretical analysis of the working methods to achieve the objective of this study. This chapter also acts as guideline to make sure all the process follows according to the plan including the designing and implementation of software component for the exoskeleton sit-stand chair. Hence, it discusses about the method on how the data are collected and analyses for this semester will be attached to indicate the planning throughout the process of the research.

This project was carried out to build a prototype of Smart Modular Lower Body Support for manufacturing industry workers that uses an Arduino board and multiple types of sensors as input to analyze ergonomic data in order to reduce muscle pain and fatigue.

According to the process flow of study the project will be begin with the project planning, research & data collection, objective & scope, literature review, methodology, planning on hardware, electronic and software, developing design, identification of simulation parameter and carrying out simulation process. Then the process proceeds with finite element analysis and implementation of sensors in the hardware that had been fabricated and tested at the company.

## 3.2 Workflow and Planning

### 3.2.1 Workflow

Figure 3.1 shows the project workflow, including a sequence of subsequent tasks needed to develop a project.

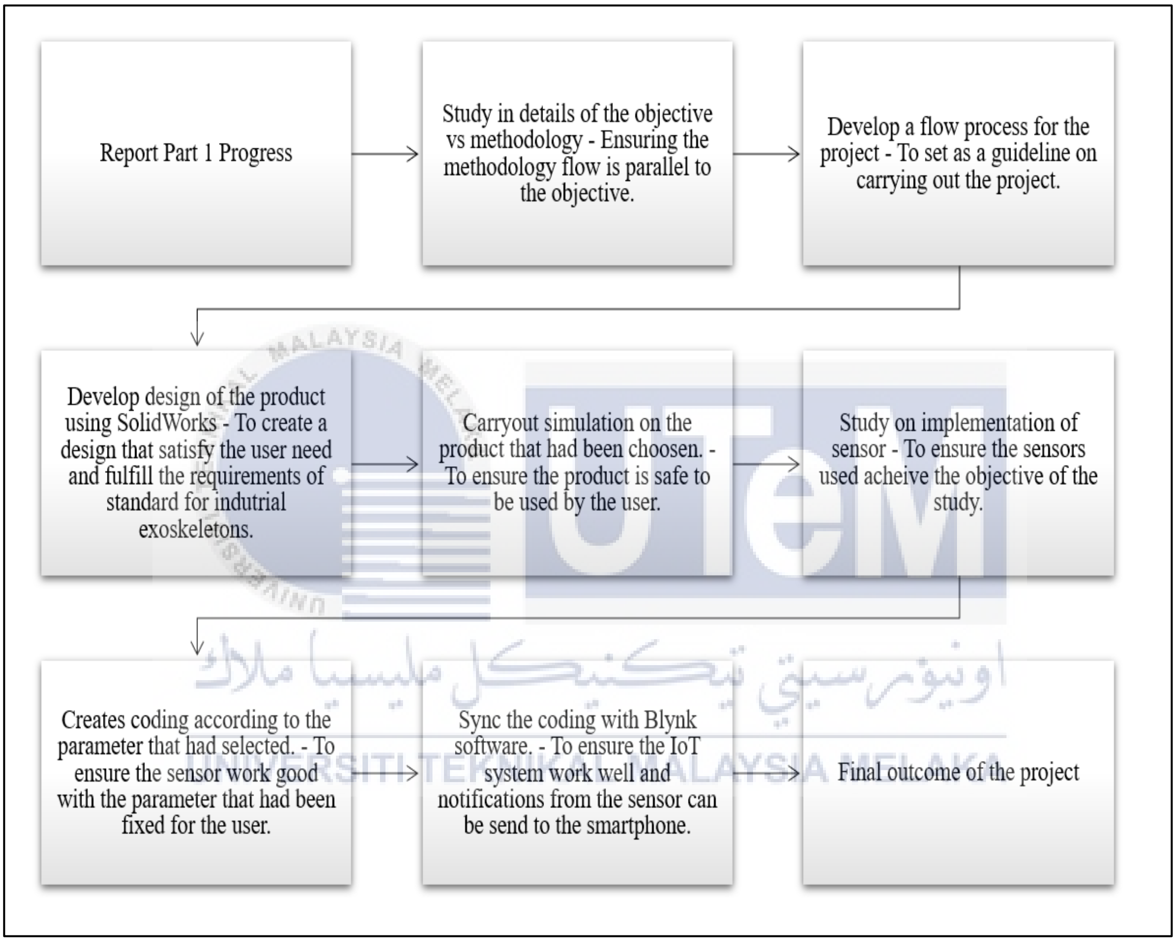



Figure 3.1: Project workflow of development of Smart Modular Lower Body Support

### 3.2.2 Planning

Project management or project planning, is the process of organizing and summarizing the project's progress. Figure 3. 2 shows the process flow of the project.

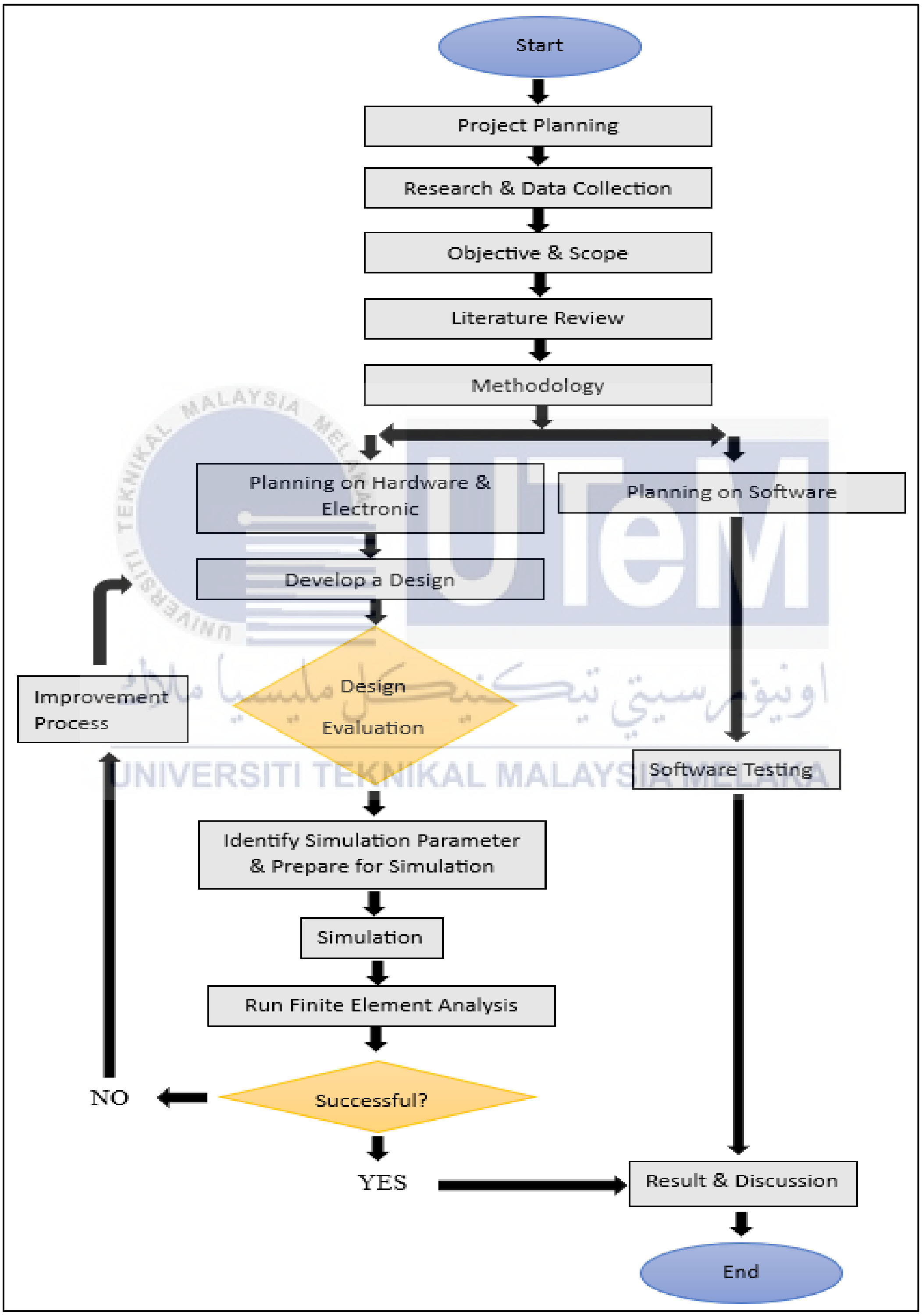



Figure 3.2: Process flow of development of Smart Modular Lower Body Support

### 3.2.2.1 Stage of Study

Stage of study is different phases or steps involved in the project life cycle. This stage is depended on the project management methodology used such as initiation, planning, execution, monitoring and controlling and closing. Figure 3.3 shows the stage of study for this project.

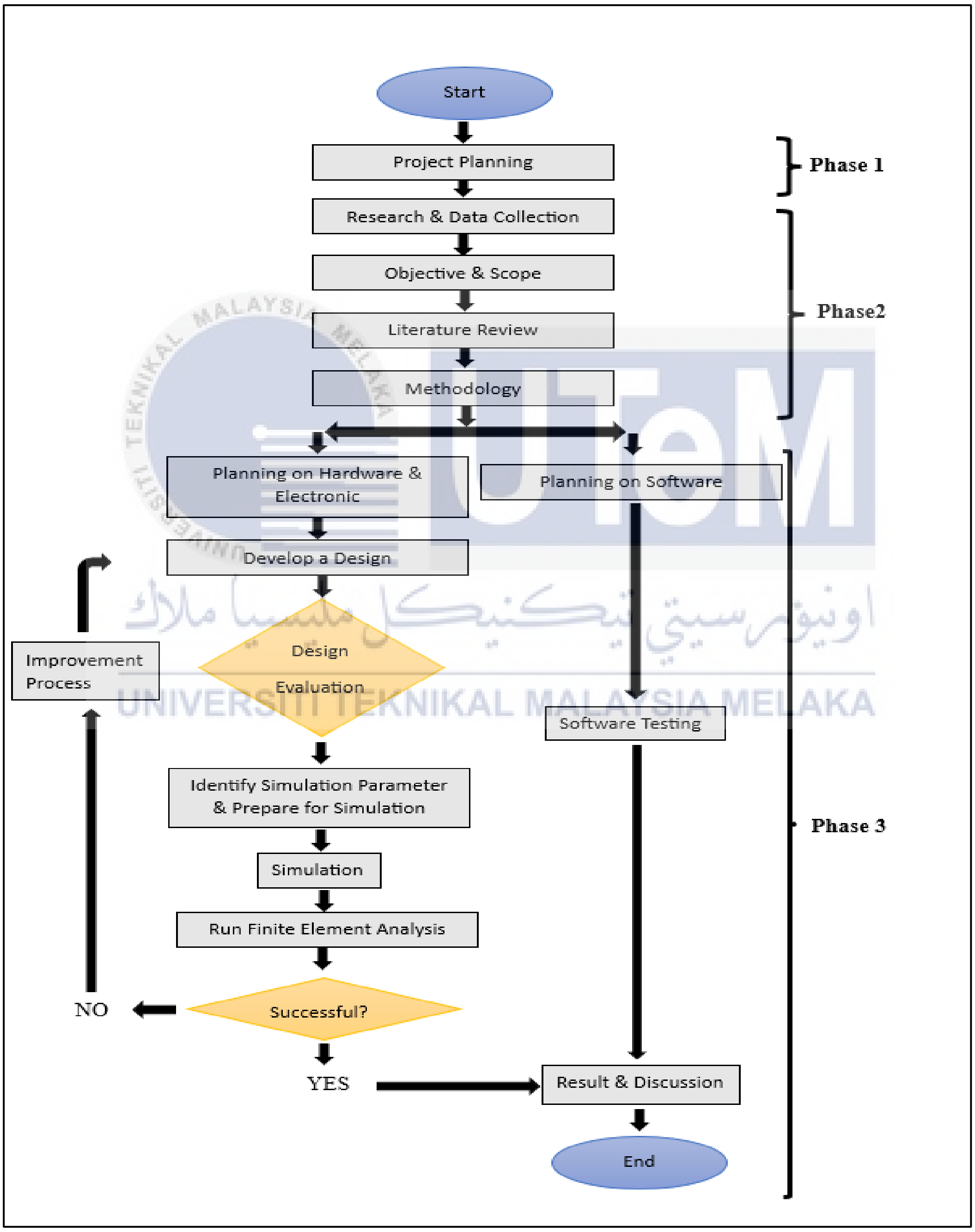



Figure 3.3: The stage of study development of Smart Modular Lower Body Support

## 3.3 Phase 1: Preliminary Study

In order to strengthen the fundamentals of designing the Smart Modular Lower Body Support, the studies of the past problem related to the work place had to be done. The company faces problem due to musculoskeletal disease during carrying out their daily task. Therefore, to enhance the required knowledge, understanding the problem faced by the company and the best lower body support from the various sources such as the journals, article, internet, book and paper was carried out. The purpose of the study carried out is to get a clearer view on the problem and solution all about through the past problem from the previous designers regarding solving the problem and solution on choosing the best lower body support at work place. The view on creating a good design of lower body support was clearer when more literature review studied had been carried out. Throughout the literature review study, comparison about how the previous design, simulation and implementation of IoT were conducted had been carried out to improve this project efficiency. By these studies, we can learn how they design, simulate and implement IoT in the Smart Modular Lower Body Support. Wide information and knowledge teach on how to make decision and make further improvement for a better design of lower body support.

## 3.4 Phase 2: Define The User Requirements



During this phase, an industrial visit to the fabrication of metal parts and product company had been arranged to identify the problems faced by the MIG welding worker. The visit gives an opportunity to get know the current work place conditions, setting of the current machinery to carry out the process and posture that commonly used by the worker to carry out their daily task. The purpose of the visit is to understand more deeply about the difficulties that faced by worker from the company.

Identification of the problems at the work place enhance the idea on improving the flow of project to be smooth and clear. The investigation during the industrial visit was specifically to improve the problem faced by the worker at MIG welding area.

After the process of data collection, a discussion had been carried out to study on the cycle time needed by the worker to carry out their daily task, the method on how they carry out the process and the duration that will be taken usually to complete the process.

## 3.5 Technical Specifications

Table 3.1 shows the data that had been collected during the company visit. These data are based on the number of products that can be produce by each welder per hour.

Table 3.1: Target of producing a product/hour

| **Participants** | **Target of producing a product/hour** |
|---|---|
| **A** | 4 |
| **B** | 5 |
| **C** | 4 |
| **D** | 4 |
| **E** | 5 |
| **F** | 4 |
| **G** | 4 |
| **H** | 5 |
| **I** | 5 |
| **J** | 4 |

### 3.5.1 Anthropometric Parameter of Worker

Anthropometric parameters are vital in many domains, such as ergonomics, workplace planning, occupational health and safety, and product design. These parameters involve measuring different physical measurements and features of the human body. Anthropometric measurements of workers are advantageous for a number of reasons such as ergonomics and workplace design, safety and health, biomechanical studies, demographic analysis, accessibility and inclusivity. Table 3.2 shows the anthropometric parameters of workers. A goniometer and measuring tape had been used to calculate and measure the data of the worker.

Table 3.2: Anthropometric parameters of workers

| | **Male (n=10)** | | | |
|---|---|---|---|---|
| | **Min** | **Mean** | **Max** | **SD** |
| Body Weight (kg) | 54 | 65.56 | 87 | 11.91 |
| Body Height (cm) | 160 | 169.55 | 180 | 6.13 |
| Shoulder Height (cm) | 112 | 119.92 | 136 | 6.82 |
| Elbow Height (cm) | 76.5 | 86.51 | 105 | 7.55 |
| Total Arm Length (cm) | 64 | 74.86 | 81.5 | 5.04 |
| Forearm Circumference (cm) | 24 | 27.61 | 34 | 3.09 |
| Upper Arm Circumference (cm) | 27.2 | 31.88 | 37.9 | 3.13 |
| Popliteal Height (cm) | 58 | 66.24 | 84 | 7.53 |
| Sitting Height (cm) | 79 | 87.1 | 92 | 3.51 |

### 3.5.2 Comparison of Wentel Engineering Sdn Bhd and Malaysian Anthropometric Parameter.

Table 3.3 shows the comparison parameter between Wentel Engineering Sdn Bhd and Malaysia Anthropometric.

Table 3.3: Comparison parameter between Wentel Engineering Sdn Bhd and Malaysia Anthropometry

| | **Anthropometry Data of Male** | | | |
|---|---|---|---|---|
| | **Wentel Engineering Sdn Bhd** | | **Malaysia (Karmegam Karuppiah, 2011)** | |
| | **Mean** | **SD** | **Mean** | **SD** |
| **Body Weight (kg)** | 65.56 | 11.91 | 64.33 | 15.24 |
| **Body Height (cm)** | 169.55 | 6.13 | 168.01 | 6.08 |
| **Shoulder Height (cm)** | 119.92 | 6.82 | 139.57 | 6.07 |
| **Elbow Height (cm)** | 86.51 | 7.55 | 106.02 | 4.68 |
| **Total Arm Length (cm)** | 74.86 | 5.04 | 73.88 | 4.74 |
| **Forearm Circumference (cm)** | 27.61 | 3.09 | - | - |
| **Upper Arm Circumference (cm)** | 31.88 | 3.13 | - | - |
| **Popliteal Height (cm)** | 66.24 | 7.53 | 41.44 | 1.42 |
| **Sitting Height (cm)** | 87.1 | 3.51 | 109.48 | 5.32 |



### 3.5.3 Ergonomics Considerations

An analysis of occupational safety and health was carried out to determine the risk variables that result in accidents and injuries to workers. The phases in the prototype development technique, which specify the parameters observed in the environment, are the framework in constructing the suggested lower body support. Table 3.4 shows ergonomics risk factors faced by workers at workplace.

Table 3.4: Ergonomics risk factors faced by workers

| Risk Factor | Associated Hazards |
|---|---|
| **Awkward or Poor Posture** | Performing task that require non-neutral body positions, such as twisting, bending or overreaching |
| **Static and Sustained Posture** | Working for extended periods while maintaining a specific position with little to no movement such as continuous standing |
| **Environmental Risk Factor** | Poor working conditions, including inadequate lighting, air ventilation, extreme temperatures or excessive noise |

## 3.6 Engineering Characteristics

Engineering characteristics are the quantitative performance parameters and their associated units of the designed product. They are utilized to evaluate the measurement and fulfilment the company necessity, it is imperative to decide designing trademark as they are the physical properties that depict the conduct of Smart Modular Lower Body Support. The engineering characteristics of this project are listed in the Table 3.5 below.

Table 3.5: Engineering characteristics with units

| Description | Units |
|---|---|
| **Total weight of product** | kg |
| **Type of material used** | • Aluminium – 6061-T6 (SS)<br>• Steel – AISI 1035 Steel (SS)<br>• Plastic (Nylon 6/10) |
| **Dimensions (length and width)** | mm |

### 3.6.1 Product Design and Develop Specification

Before continuing to concept design, the product design specification details the requirements that must be met for the product to be effective. Table 3.6 shows the design and develop specification of the Smart Modular Lower Body Support.

Table 3.6: Design and develop specification of Smart Modular Lower Body Support

| Specification | Details |
|---|---|
| **Performance** | • Suitable for the usage for MIG welder.<br>• Easy handling. |
| **Function** | • To reduce the musculoskeletal disease and lower back bone pain.<br>• To trigger via buzzer, led light and thru IoT (Blynk) cloud when the worker reaches to certain bending angle or exert high pressure on lower back bone while sitting. |
| **Life Span** | • Can be more than 5 years.<br>• Parts can be easily replaced if there is faulty. |
| **Material** | • Long lasting and high durability. |
| **Weight** | • Based on the size and materials used. |
| **Safety** | • No sharp edges<br>• Environmentally friendly<br>• Worker's safety should be a priority. |
| **Stability** | • The base support of the product is round shaped and made up of heavy steel material.<br>• Anti-slip rubber is attached to avoid from topping |
| **Durability** | • The product can support weight up to 100 kg. |
| **Height Adjustment** | • The product height is adjustable from the range of (0-6) cm according to the worker comfortability. |



## 3.7 Phase 3: Evaluation of Functionality and Usability

As the needed data form the previous phase complete, the study had been continued by gathering the concept generation for the Smart Modular Lower Body Support based on the requirement needed. Once the morphological chart had been completed, listing down the concept design had been done. Three different ideas of concept design had been presented. Based on the concept design, House of Quality and Pugh concept evaluation had been carried out to counter the best concept of lower body support that fit the current situation faced by the company. Next, the progress of the project had been started by the 3D Sketching using SolidWorks. Each part of the lower body support had been drawn and finally it had been assembled. Based on the 3D Sketching, parameter had been set up for the simulation process and finite element analysis had been carried out to identify the Von Mises Stress, Resultant Displacement and Factor of Safety of the seat and structure of lower body support. Improvement on design had been carried out to improve the design structure, stability and etc. Once the design had been completed, the lower body support had been fabricated. The lower body support had been tested internally to identity the maximum support that can be exerted by the chair and finally the IoT system will be implemented to achieve the objective of the project successfully. Then discussion had been carried out based on the literature review, current problem faced by the company compared with this project. Finally, the report is completed with conclusion and recommendation. Below shows the types of the Finite Element Analysis that had been carried and the progress that had been.

### 3.7.1 Von Mises Stress

Von Mises Stress is a data to determine the yield or fracture of a material and it is used to obtain the data for ductile material such as metal. The design will be failing when maximum value of Von Mises Stress induced in the material is more than the strength of the material.



### 3.7.2 Resultant Displacement

Resultant is the vector sum of two or more vectors. It is the results of adding two or more vectors together. If displacement vectors A, B and C are added together, the result will be vector R. As shown in diagram, vector R can be determined by the use of an accurately drawn, scaled, vector addition diagram. Vector R is the resultant displacement of displacement vectors A, B and C. Displacement vector R gives the same results as displacement vectors A+B+C and is can be explained as A+B+C=R.

### 3.7.3 Factor of Safety

Factor of safety is an ability of a system's structural capacity to be viewed beyond its expectation or actual loads. Factor of safety may be expressed as a ratio of absolute strength to actual applied load or it can be expressed as constant value that the structure needs to meet or exceed according to law, specification or standard. If the consequences of failure analysis are significant, a higher factor of safety is likely to be required by design.

## 3.8 Concept Generation

The process of generating up with ideas or concepts that can be developed upon to become products, services, or solutions is known as concept generation. In many creative and problem-solving activities, including project development, invention, and product design, it is an essential stage. Generating a wide range of potential ideas that can solve a certain need or issue is the aim of concept generation. During this stage, brainstorming sessions, creative thinking exercises, and teamwork to investigate a multitude of options are frequently employed. Table 3.7 shows the concept generation for the Smart Modular Lower Body Support.

Table 3.7: Concept generation for Smart Modular Lower Body Support

| Features | Description |
|---|---|
| **IoT Sensors** | **Load cell sensor –** To detect fatigue and muscle pain exerted by the worker's body.<br>**Ultrasonic sensor –** To indicate back pain and cardiovascular disease of the worker.<br>**Buzzer & LED** – To alarm /notify the worker if any of the sensor gives out signal. |
| **Rotation of chair** | 360° |
| **Product's Position** | Infront of the work table |
| **Floor Surface** | Anti-slip rubber is located under the base of the exoskeleton chair to avoid it slide and move away from the worker. |
| **Power supply for IoT system** | 10000mAH power bank |



### 3.8.1 Concept Design

The first stage of product design, known as concept design, is when ideas and concepts are created and assessed. During this stage, models, prototypes, and sketches are made in order to assess the design's viability and pinpoint any possible problems. Concept design is a crucial phase in the creation of new exoskeleton systems and parts in the context of exoskeletons. It enables designers to investigate various design alternatives and weigh the advantages and disadvantages. It is essential to keep a line of communication open, encourage teamwork, and exercise flexibility throughout the concept design process in order to adapt with evolving circumstances and fresh perspectives. The aim is to develop original and workable concepts that effectively address the project's objectives while inspiring and connecting with the target customer.

#### 3.8.1.1 Design 1

The Figure 3.4 shows the first design of the Smart Modular Lower Body Support. The design consists of 1 seat attached with load cell, 2 cylindrical adjustable shafts with locking mechanism, a box of TC enclosure attached with ultrasonic sensor and a square base.

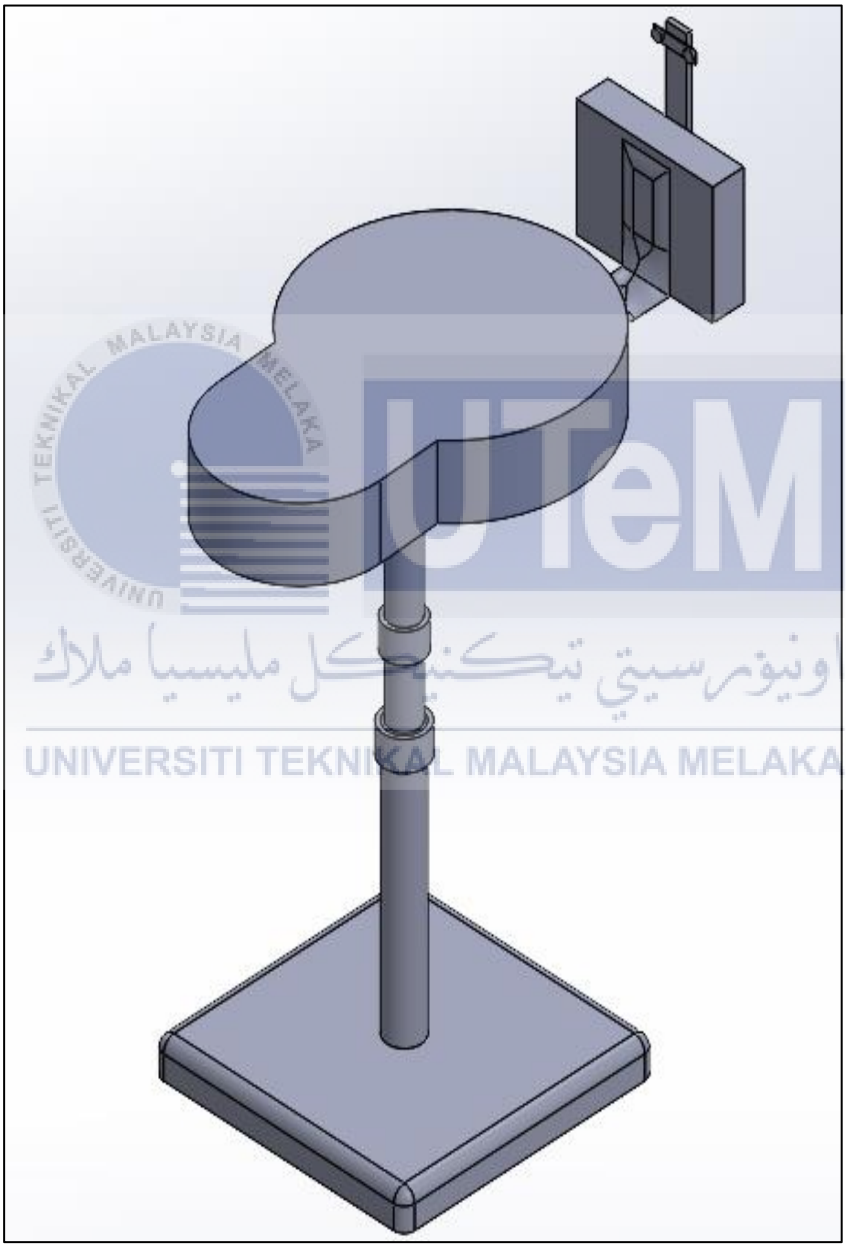


Figure 3.4: Design 1 of Smart Modular Lower Body Support

#### 3.8.1.2 Design 2

The Figure 3.5 shows the second design of the Smart Modular Lower Body Support. The design consists of 1 seat attached with load cell, 2 cylindrical adjustable shafts with locking mechanism, 1 back seat, 1 TC enclosure box with ultrasonic sensor and a circular base supported with “X” shaped legs.

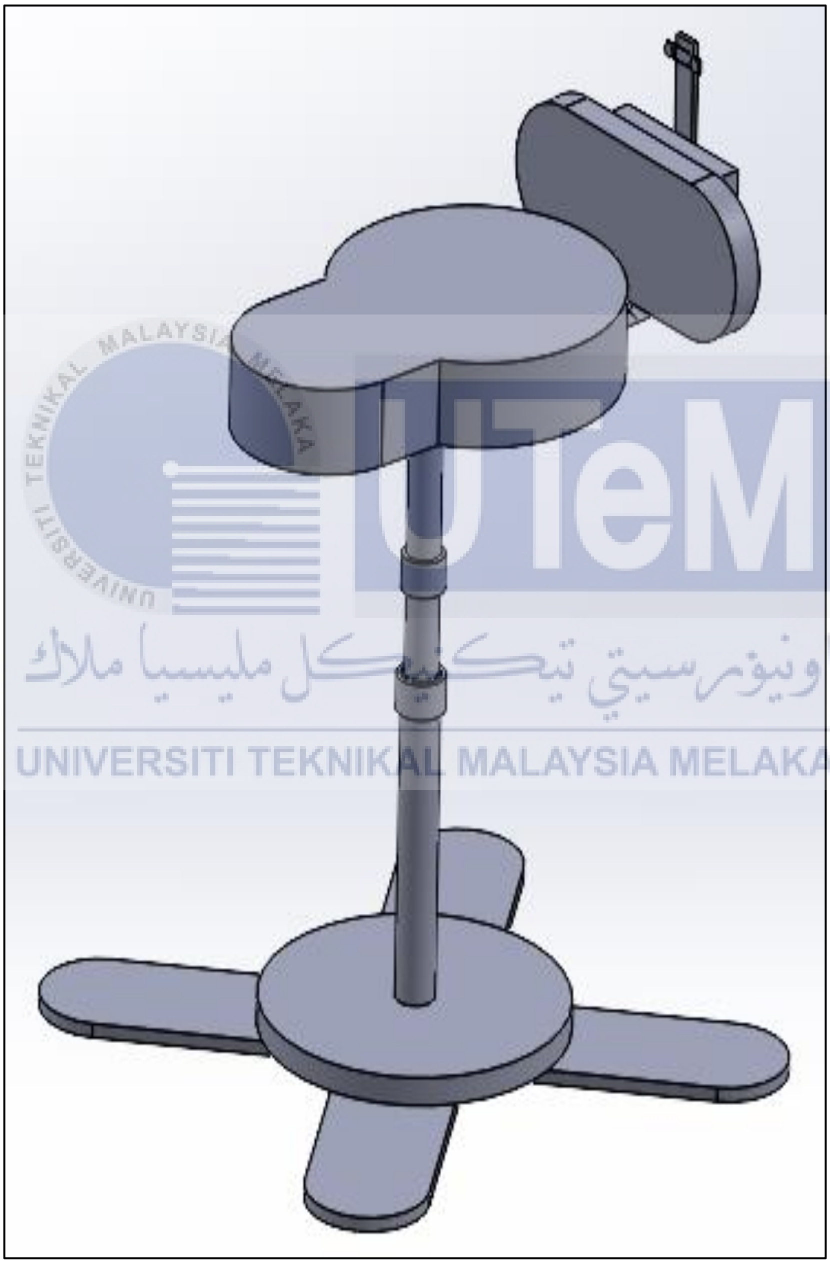




Figure 3.5: Design 2 of Smart Modular Lower Body Support

#### 3.8.1.3 Design 3

The Figure 3.6 shows the third design of the Smart Modular Lower Body Support. The design consists of 1 seat attached with load cell, 2 cylindrical adjustable shafts with locking mechanism, 1 back seat, 1 TC enclosure box with ultrasonic sensor and a circular base support.

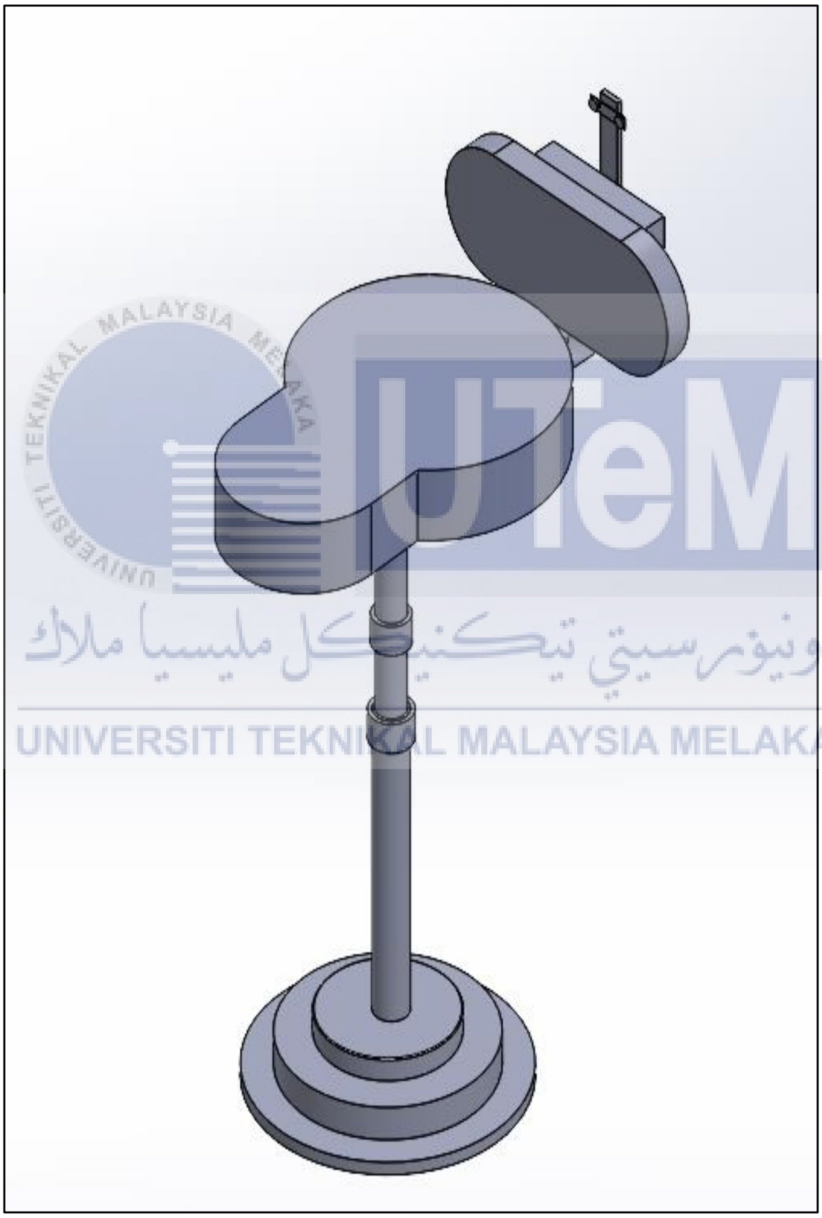




Figure 3.6: Design 3 of Smart Modular Lower Body Support

### 3.9 Concept Evaluation

A critical stage in the design process is idea evaluation, which entails evaluating and contrasting several design concepts to ascertain their viability, efficacy, and appropriateness for the intended use. Finding the most promising concept or concepts combined that best fits the needs and objectives of the project is the aim.

#### 3.9.1 House of Quality

In the process of designing and developing Smart Modular Lower Body Support, House of Quality matrix help to prioritize and align user requirement to carry out the project. Table 3.8 shows the data of the user requirements.

Table 3.8 Data of user requirements

| **User requirements** | **Score** | | | | | **Relative importance** | **Priority** |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | | |
| **Static and dynamic** | 0 | 0 | 13 | 35 | 55 | 4.4 | 8 |
| **Safety** | 0 | 0 | 5 | 31 | 67 | 5.0 | 1 |
| **Portable** | 0 | 0 | 10 | 32 | 61 | 4.5 | 6 |
| **Easy to use** | 0 | 0 | 6 | 35 | 62 | 4.6 | 5 |
| **Light and strong material** | 0 | 0 | 3 | 37 | 63 | 4.9 | 4 |
| **Affordable** | 0 | 0 | 15 | 35 | 53 | 4.3 | 9 |
| **Simple design** | 0 | 0 | 6 | 38 | 59 | 4.4 | 7 |
| **Stability** | 0 | 0 | 12 | 25 | 66 | 4.9 | 2 |
| **Low maintenance** | 0 | 0 | 10 | 42 | 51 | 4.0 | 10 |
| **Comfortableness** | 0 | 0 | 7 | 31 | 65 | 4.9 | 3 |

### 3.9.2 Data of Concept Design 1, Design 2 and Design 3

**DESIGN 1**

Figure 3.7 shows the results of Von Mises Stress for Design 1 with value of deformation scale is 162,013 and Figure 3.8 shows the results of Factor of Safety with the value of 53.

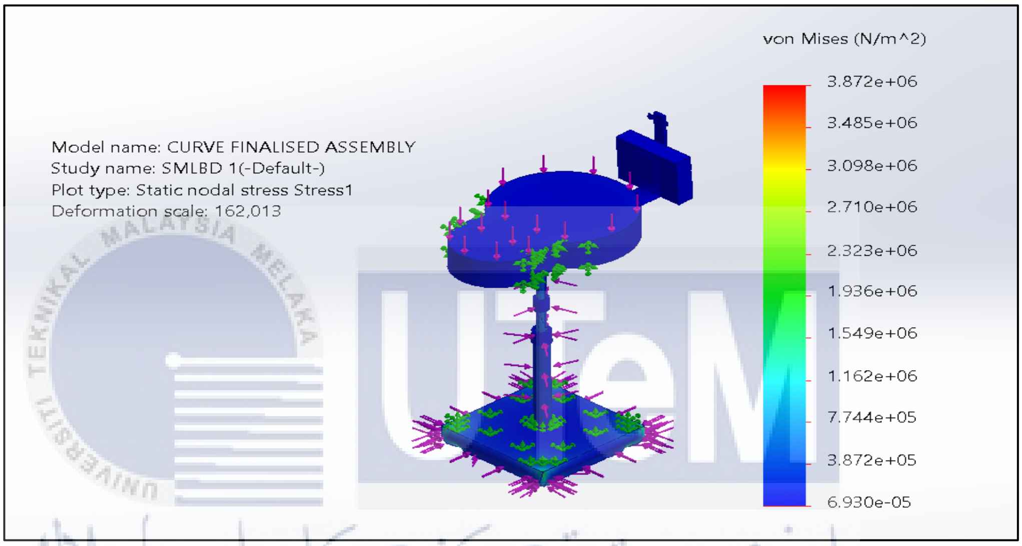



Figure 3.7: Results of Von Mises Stress for Design 1



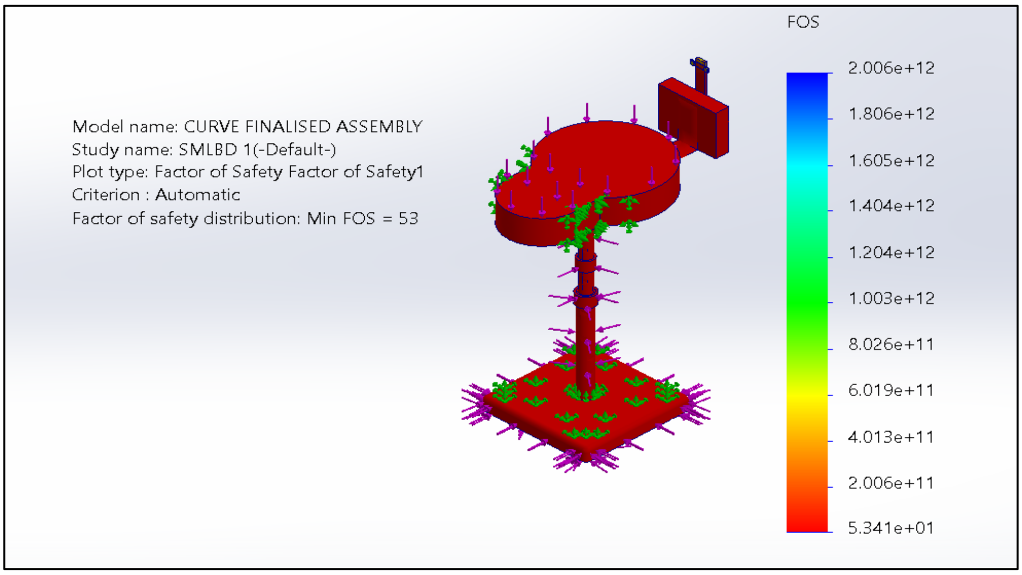



Figure 3.8: Results of Factor of Safety for Design 1

## DESIGN 2

Figure 3.9 shows the results of Von Mises Stress for Design 1 with value of deformation scale is 1.32932e+06 and Figure 3.10 shows the results of Factor of Safety with the value of 2.9e+02.

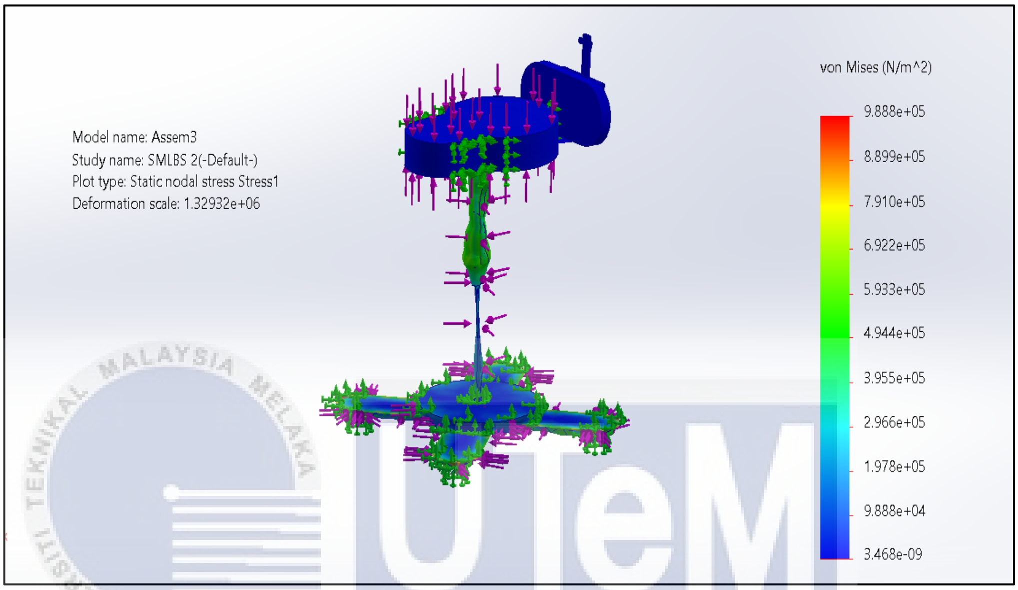



Figure 3.9: Results of Von Mises Stress for Design 2



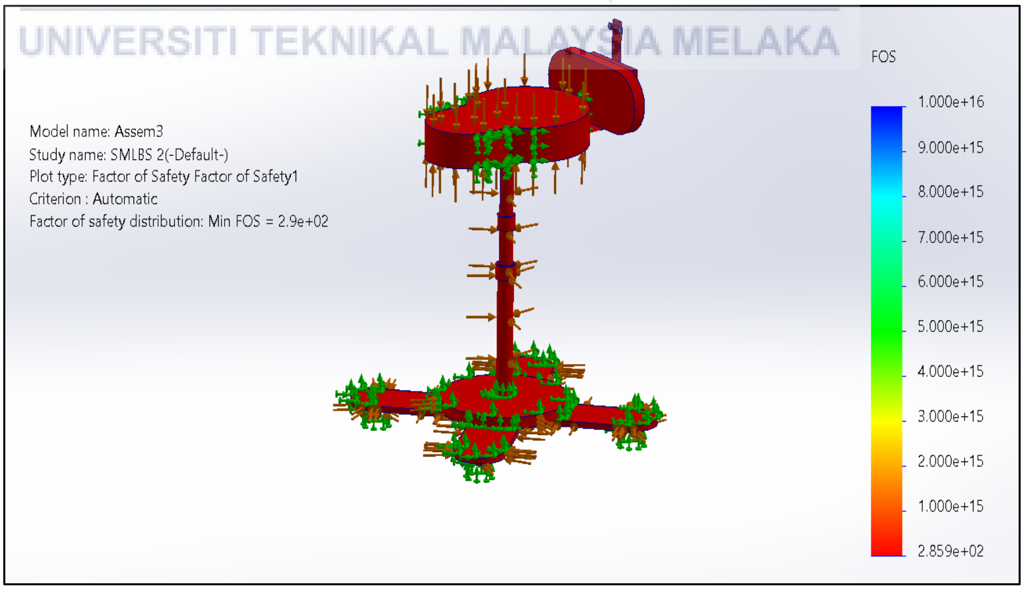



Figure 3.10: Results of Factor of Safety for Design 2

**DESIGN 3**

Figure 3.9 shows the results of Von Mises Stress for Design 1 with value of deformation scale is 1.04728e+07 and Figure 3.10 shows the results of Factor of Safety with the value of 2.2e+02.

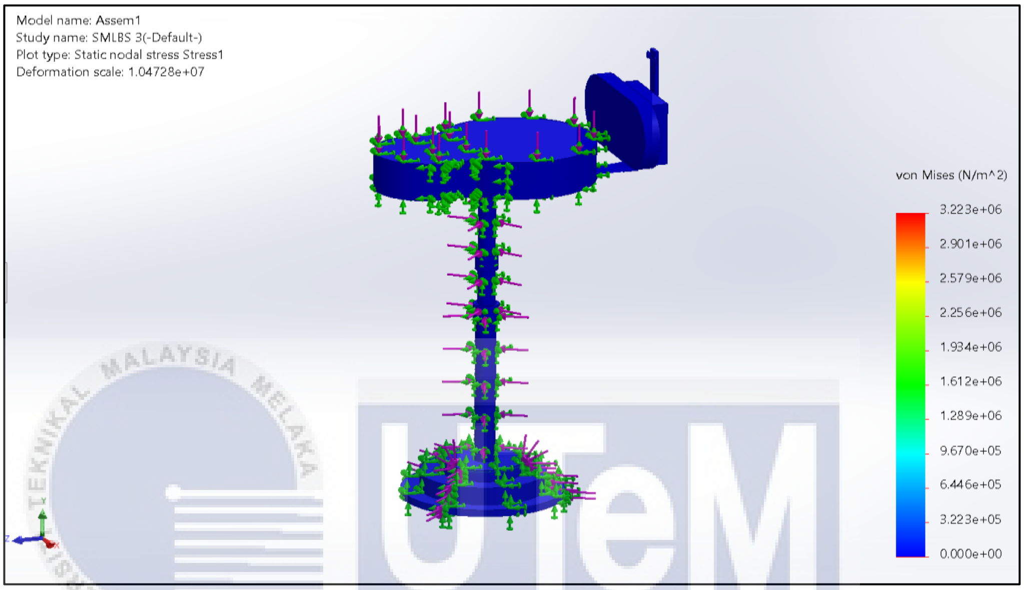



Figure 3.11: Results of Von Mises Stress for Design 3



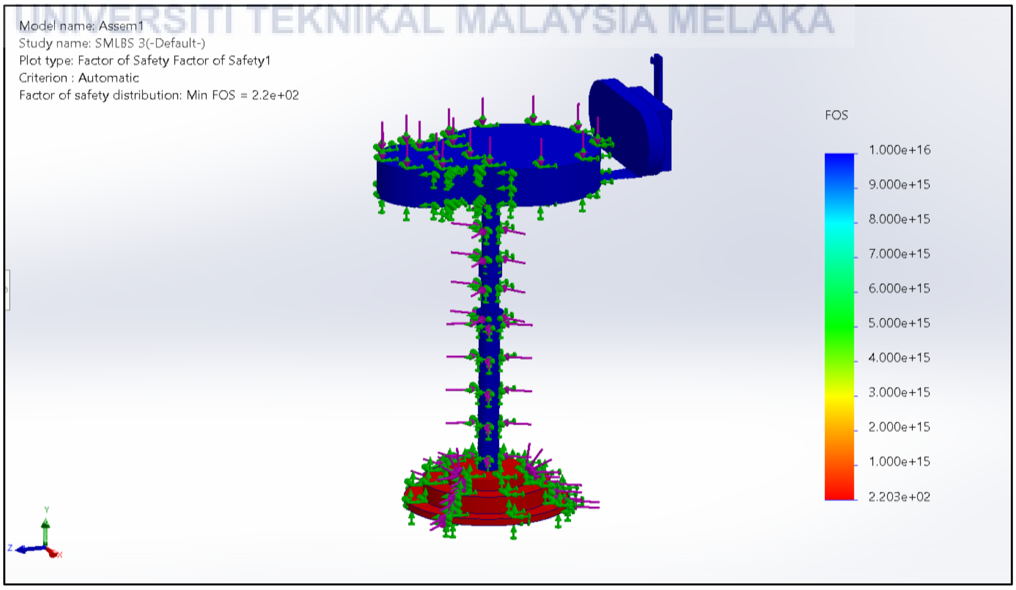



Figure 3.12: Results of Factor of Safety for Design 3

#### 3.9.2.1 Comparison of Data

According to the Table 3.9, a comparison of data had gained based on the SolidWorks simulation results. The von mises stress (deformation scale) and factor of safety of the design had been taken into consideration to select the best design. Design 3 have the highest deformation scale and low factor of safety compared to Design 1 and Design 2.

Table 3.9: Comparison data of Design 1. Design 2 and Design 3

| Design | Von Mises Stress (Deformation Scale) | Factor of Safety |
|---|---|---|
| **1** | 162,013 | 53 |
| **2** | 1.32932e+06 | 2.9e+02 |
| **3** | 1.04728e+07 | 2.2e+02 |

### 3.9.3 Pugh Matrix Concept Selection

Pugh Matrix Concept Selection is a decision-making tool used in this project to evaluate and compare different concepts or solutions against a set of criteria. Table 3.10 shows the Pugh Matrix Concept Evaluation of the Smart Modular Lower Body Support.

Table 3.10: Pugh Matrix Concept Evaluation of Smart Modular Lower Body Support

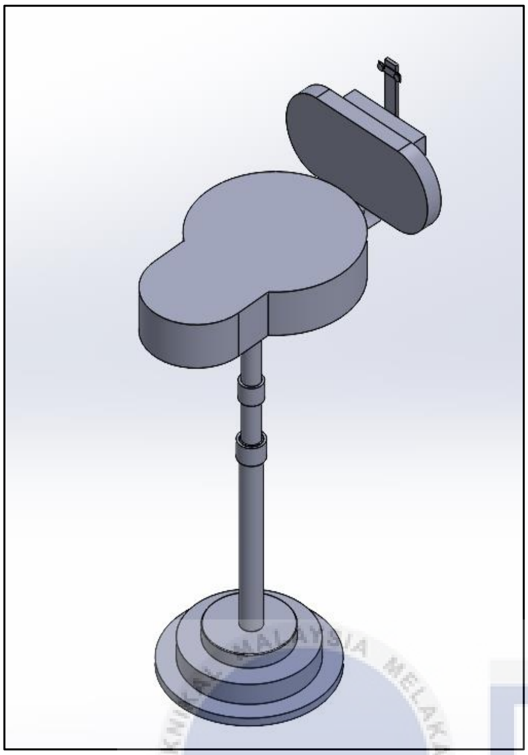
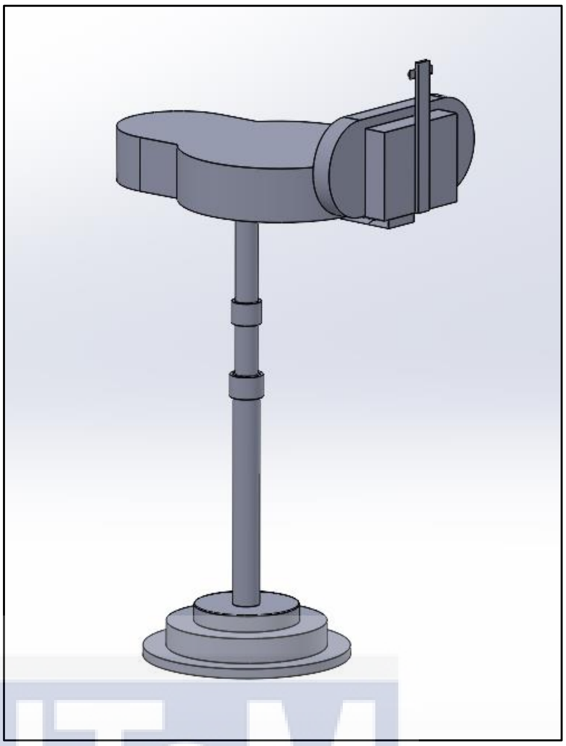
| CRITERION | IMPORTANCE | | CONCEPT 1 | CONCEPT 2 | CONCEPT 3 |
|---|---|---|---|---|---|
| Performance | HML | DATUM | + | + | + |
| Functionality | | | - | + | + |
| Ergonomics | | | + | + | + |
| Size | | | + | - | + |
| Material | | | S | S | S |
| Weight | | | + | + | - |
| Safety | | | + | + | + |
| Cost | | | - | - | + |
| ADDITION | | | 5 | 5 | 6 |
| SUBSTRUCTION | | | 2 | 2 | 1 |
| FINAL SCORE | | | 3 | 3 | 5 |



### 3.9.4 Best Concept

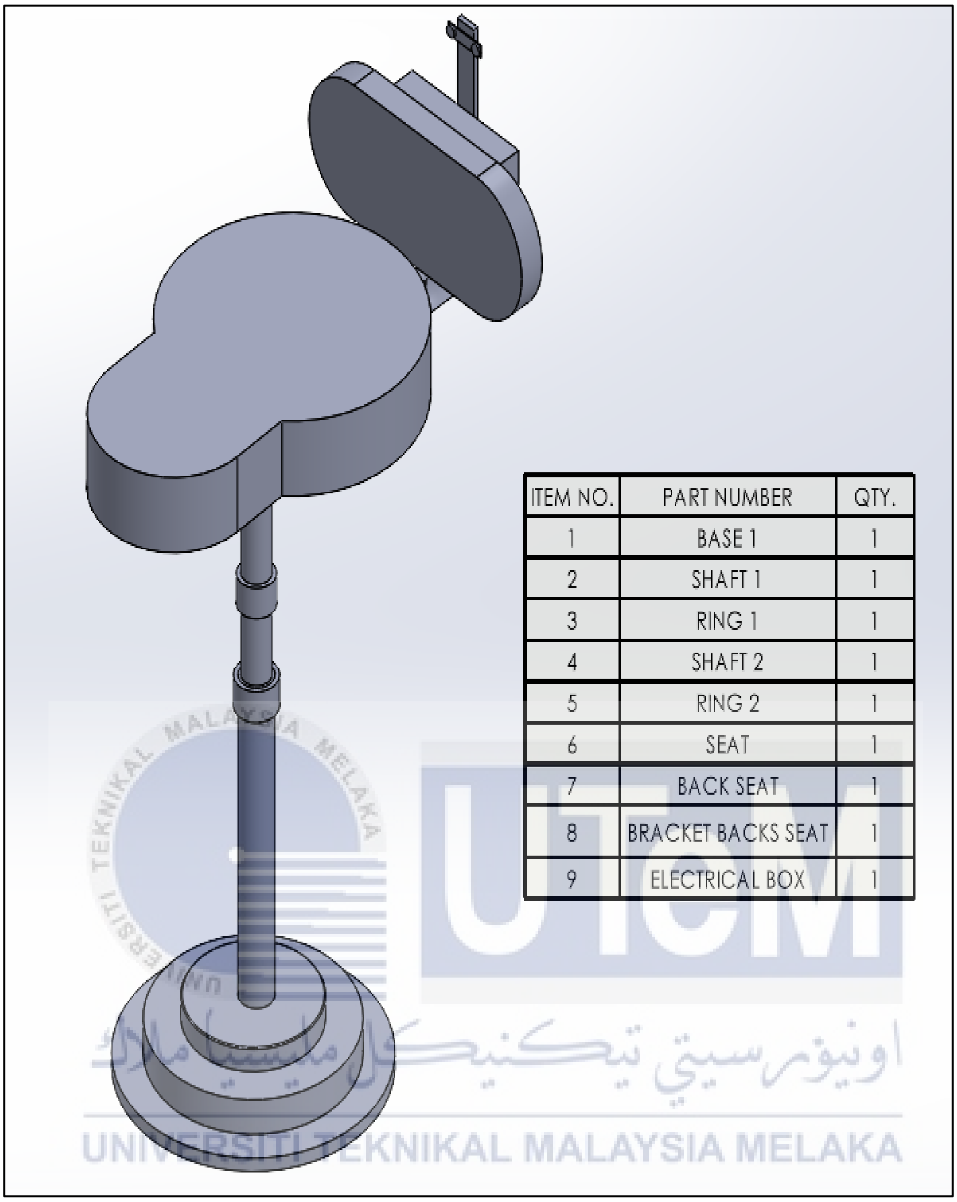
Best concept depends on the specific context, criteria and goals of a particular decision. Based on the House of Quality and Pugh Matrix Selection helps in evaluating different concepts based on predefined criteria. Table 3.11 shows the best concept of the Smart Modular Lower Body Support.

Table 3.11: Selection of the best design concept

| | |
|---|---|
|  |  |

## 3.10 Detail Design

The detailed design step involves refining the design and creating plans, specifications and estimates. Therefore, the detail design for the Smart Modular Lower Body Support is done by using SolidWorks software to show it in the form of 3D. The drawing in Figure 3.13 shows the assembly parts of the Smart Modular Lower Body Support.



| ITEM NO. | PART NUMBER | QTY. |
| --- | --- | --- |
| 1 | BASE 1 | 1 |
| 2 | SHAFT 1 | 1 |
| 3 | RING 1 | 1 |
| 4 | SHAFT 2 | 1 |
| 5 | RING 2 | 1 |
| 6 | SEAT | 1 |
| 7 | BACK SEAT | 1 |
| 8 | BRACKET BACKS SEAT | 1 |
| 9 | ELECTRICAL BOX | 1 |



Figure 3.13: Assembly parts of The Smart Modular Lower Body Support

### 3.10.1 Product Structure

The Smart Modular Lower Body Support described into one structure. This breakdown is for a better understanding of components which are assembled in the design. Therefore, Figure 3.14 shows the product structure of the Smart Modular Lower Body Support.

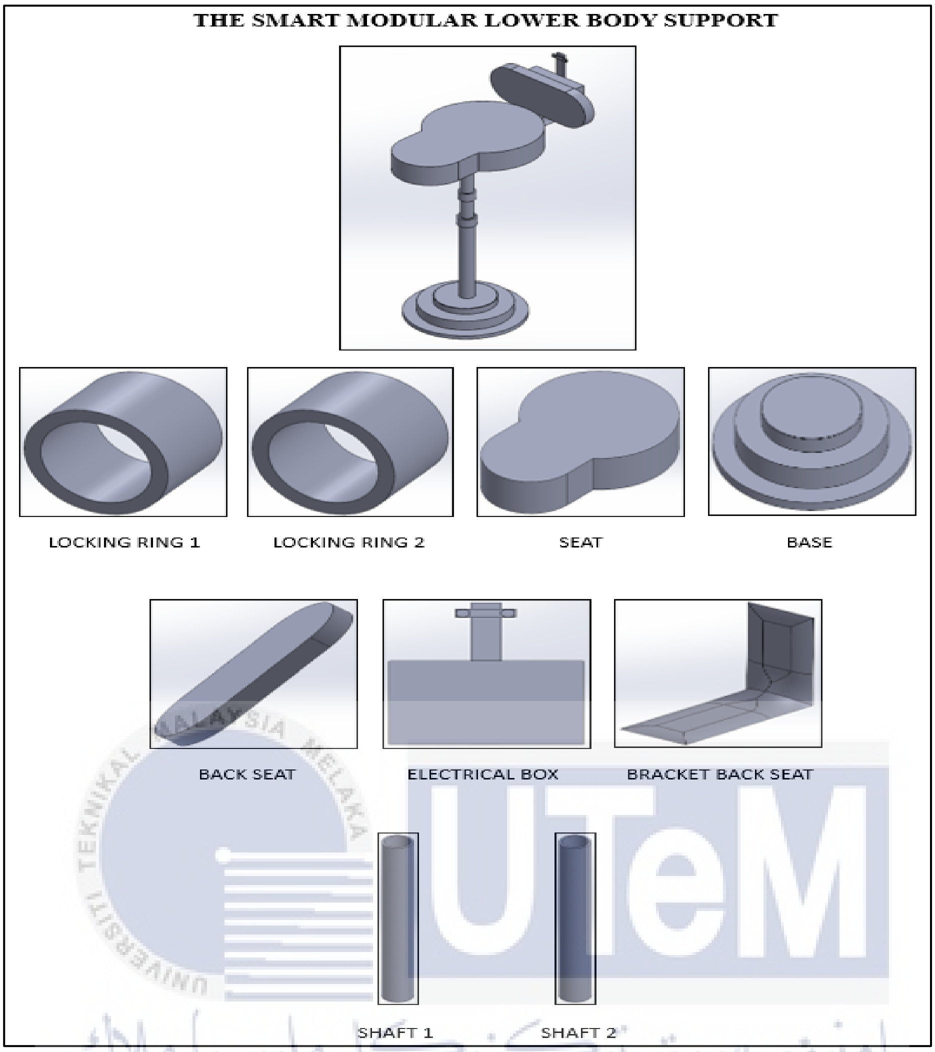



Figure 3.14: The product structure of Smart Modular Lower Body Support



### 3.10.2 Finite Element Analysis

The finite element analysis for the Smart Modular Lower Body Support described into two structures in the results. The first structure of finite element analysis is the Seat Analysis and the second structure is the Shaft and Base Analysis. This breakdown is for a better understanding of component which are assembled in the design. Details result of the Von Mises Stress, Resultant Displacement, and Factor of Safety for both of the structure will be discussed in the result chapter. To carry out finite element analysis for the two-structure a few considerations should be taken into consideration. Firstly, the surface of the Smart Modular Lower Body Support is fixed as the position for the fixture data that should be applied in this study Secondly, the direction of the external force is fixed downwards rather that upwards. Then mesh is created before proceeding with the study is analyzed.

#### 3.10.2.1 Von Mises Stress

Figure 3.15 shows Von Mises Stress of Smart Modular Lower Body Support generated from the SolidWorks.

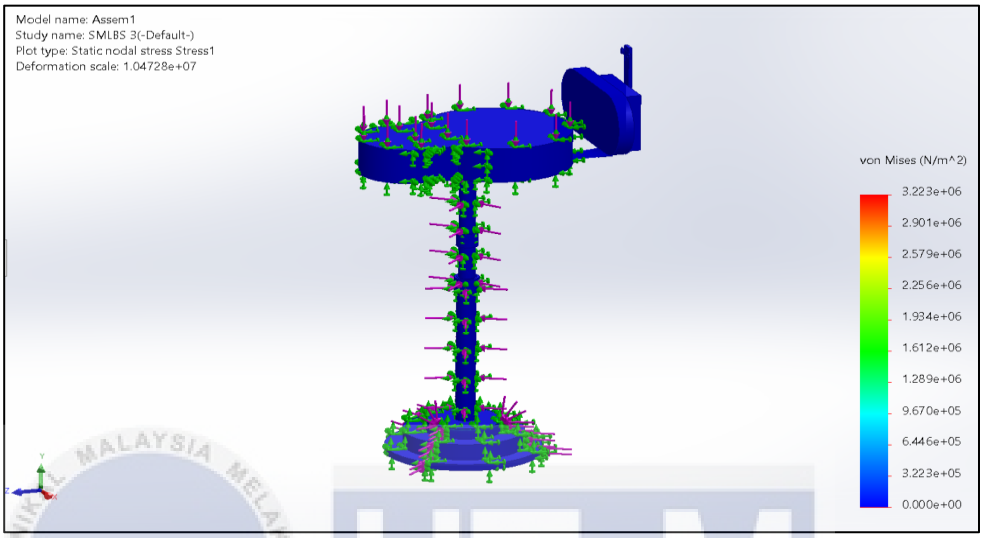



Figure 3.15: Von Mises Stress of Smart Modular Lower Body Support

#### 3.10.2.2 Resultant Displacement

Figure 3.16 shows Resultant Displacement of Smart Modular Lower Body Support generated from the SolidWorks.



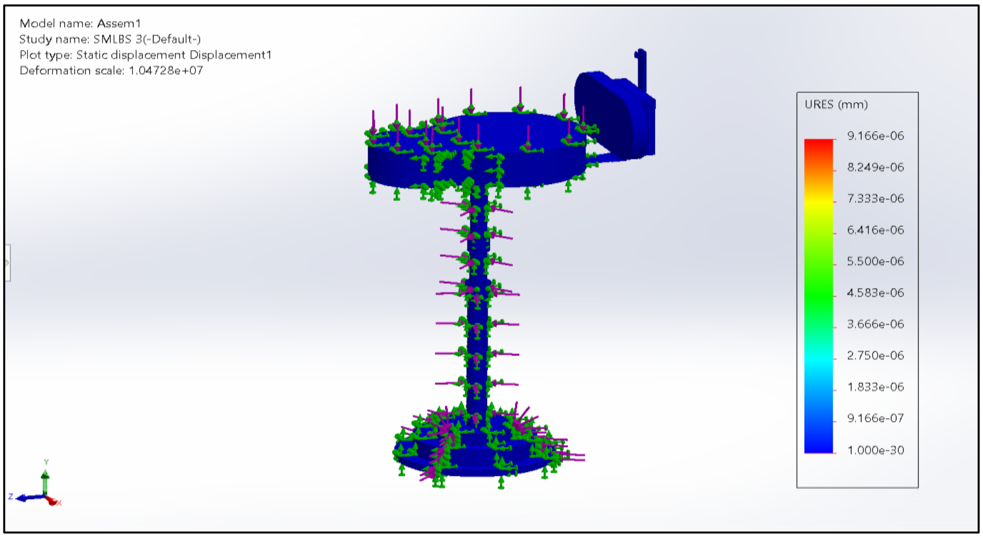



Figure 3.16: Resultant Displacement of Smart Modular Lower Body Support

### 3.10.2.3 Factor of Safety

Figure 3.17 shows Factor of Safety of Smart Modular Lower Body Support generated from the SolidWorks.

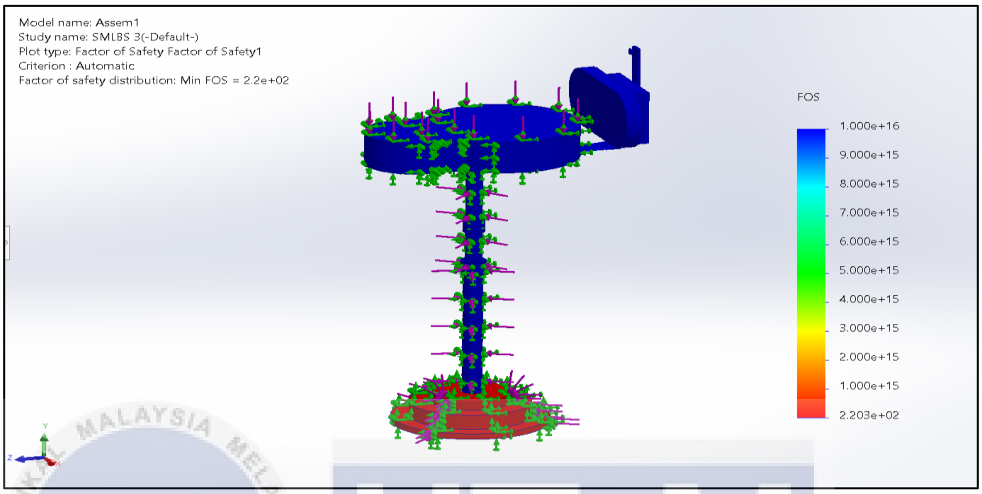



Figure 3.17: Factor of Safety of Smart Modular Lower Body Support

### 3.10.2.4 Strain

Figure 3.18 shows Strain of Smart Modular Lower Body Support generated from the SolidWorks.



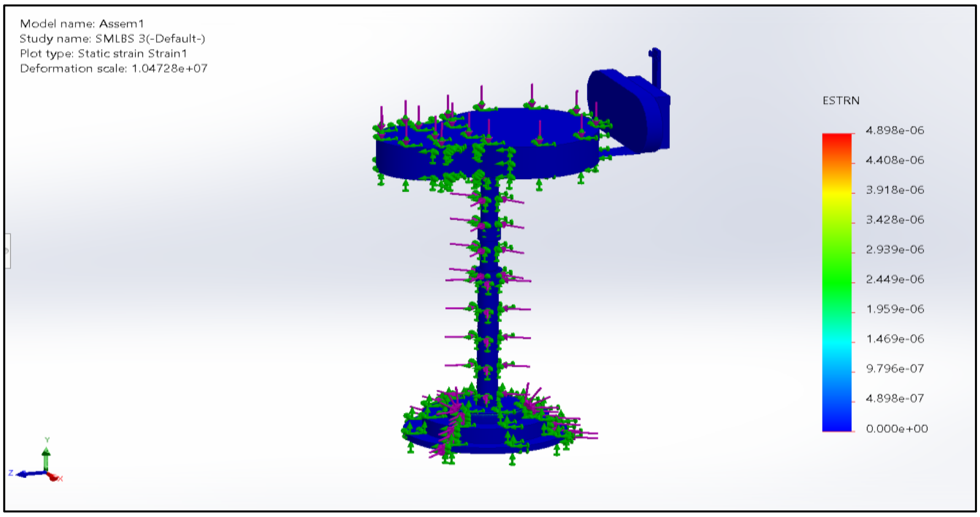



Figure 3.18: Strain of Smart Modular Lower Body Support

### 3.11 Justification on Self Designed Smart Modular Lower Body Support

As a comparison with the modular lower body support in market, there are many types of lower body support with multiple usage. There are a few lower bodies supports that had been used in industries but there are a few disadvantages of the lower body support in the market. Firstly, lower body support in market come out with a fix height design. Due to the fix design, company may not achieve the target since different type of worker have different anthropometry criteria. The company may face financial problem due to purchasing different height of lower body support to be used in the work place. The Smart Modular Lower Body Support have the criteria of adjustable seat height. The height of the seat can be adjusted based on the worker's requirement. Besides that, this Smart Modular Lower Body Support is equipped with IoT based system to monitor the posture and angle of the worker when the worker uses the lower body support to carry out their daily task. The IoT system is set to trigger alert into two different ways, first thru the LED which light up when the lower body support detects any abnormality and a buzzer is also fixed on the chair to alarm the worker incase if the worker doesn't see the LED signals. These two types of electronic parts are used to satisfy the different types of industrial environmental. As an example, if the industrial environment is fulfilled with noise, buzzer could not function well because the sound might not loud enough to alarm the worker therefore the LED is implemented. In addition, the system of IoT is also linked to the worker phone via Blynk application, thru the implementation of the IoT system, workers do not only get their health awareness notification but they also can download the data of their working posture at work. Therefore, by designing and developing the Smart Modular Lower Body Support, employers do not need to invest in many lower bodies support since the height of the chair is adjustable, safety committee in the industry does not need to have a frequent monitor on the worker because they can receive the data of each worker through the Blynk system and overall, of the product main objective is to reduce the musculoskeletal diseases will be achieved.

### 3.12 Hardware Platform

The fundamental material components and technological advances that provide the framework for electronic systems, devices, or applications are referred to as a hardware and electronic platform. This platform consists of the electrical parts (processors, circuits, etc.)

and the hardware parts (physical devices) that combine to make a given system function. Here are a few essential elements. Table 3.12 shows fundamental of hardware and electronic platform.

Table 3.12: Fundamental of hardware and electronic platform

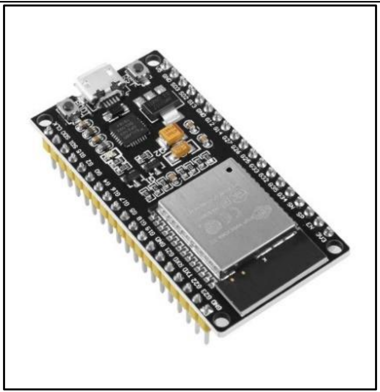
| Components | Element | Description |
|---|---|---|
| **Hardware** | Power Supply | Provides electrical power to the system. |
| | Connectors & Interfaces | Ports and connectors for connecting external devices and peripherals. |
| | Motherboard | The main circuit board that connects and facilitates communication between various components |
| **Electronic** | Integrated circuits (ICs) | Chips that combine multiple electronic components into a single package, enhancing efficiency and functionality. |
| | Sensors | Device that detects and measure physical quantities, converting them into electrical signals. |
| **Platform** | Mobile platform | The combination of hardware and software in mobile devices like smartphones and tablets. |
| | IoT (Internet of Things) | Integrated platforms designed for IoT applications, often including sensors, connectivity and data processing capabilities. |
| **Communication** | Networking interfaces | Components enabling communication between devices in a network. |
| | Wireless technologies | Such as Wi-Fi, Bluetooth and cellular connectivity for wireless communication. |

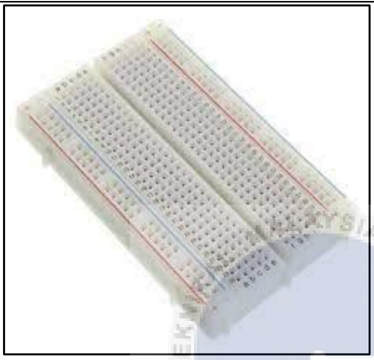
### 3.12.1 Sensors and Electronic Parts of Smart Modular Lower Body Support

The Table 3.13 shows the sensors and electronic parts that had been used in the Smart Modular Lower Body Support. These sensors and electronic parts play a major role in the implementation of IoT.

Table 3.13: Sensors and electronic part

| Parts | Description | Application |
|---|---|---|
|  **Load Sensor** | A load sensor, often referred to as a load cell, is a tool used to measure the force or load placed on it. These sensors are widely utilized in many different applications where force, weight, or load monitoring is required. | The load sensor is located on the seat of the Smart Exoskeleton Chair to measure the force exerted by the worker when the worker carries out their daily task. |
|  **Ultrasonic Sensor** | A type of resistive sensor that modifies its resistance in response to bending and distance is the ultrasonic sensor. These sensors are frequently employed in applications where it is crucial to monitor the flexion of a device or structure since they are made to detect the amount of bending deformation and distance of the worker. | The ultrasonic sensor is located on the back seat of the Smart Exoskeleton Chair to measure the bending exerted and the distance of worker from the backseat. |

| | | |
|---|---|---|
|  **ESP 32** | ESP32 is a widely used microcontroller and system-on-chip (SoC) for embedded systems, the Internet of Things (IoT), and other electronic applications. | Attached in the electronic circuit system. |
|  **Buzzer** | A buzzer is a basic electronic device that emits a beeping or buzzing sound when power is provided. It has been used in many different electrical systems, gadgets, and applications as an aural indication. | Attach above the TC Enclosure Box to emit beeping sound when the worker triggers the sensors. |
|  **LED** | An electric current flowing through an LED, also known as a light-emitting diode, causes it to emit light. | Attached in the electronic circuit system. |

| | | |
|---|---|---|
| <br>**Resistor 330Ω** | A resistor is an electronic component that restricts the flow of electric current. | To control the amount of current flowing through a circuit or to divide voltage in a circuit. |
| <br>**Breadboard** | A breadboard is a prototyping tool used in electronics to quickly and easily build and test electronic circuits without the need for soldering. | Attached in the electronic circuit system. |
| <br>**Jumper Cable**<br>**Male – Male Wire**<br>**Male – Female Wire** | In the field of electronics, wires or cables used to temporarily establish electrical connections between different spots on a breadboard or other prototyping platforms can be referred as jumper cables. In the stages of experimentation and prototyping, these cables are crucial for constructing and testing circuits. | Attached in the electronic circuit system. |

### 3.13 Software

Blynk is a platform that allows developers may easily develop projects requiring the interaction of mobile devices and hardware (such microcontrollers, sensors, and actuators) for the Internet of Things (IoT). It makes it easier to create a smartphone app that will operate and monitor Internet of Things (IoT) devices. The application is an engine for developing mobile apps that allows users design unique interfaces and dashboards for Internet of Things projects. The software works with both iOS and Android smartphones by simply dropping and dragging widgets buttons, sliders, graphs, displays onto the Blynk app canvas. Users may customize the look and feel of their mobile application and making an easy-to-use control interface for Internet of Things applications.

Besides that, multiple hardware platforms are supported by Blynk, such as widely recognized microcontrollers Arduino, Raspberry Pi, ESP8266, ESP32, Particle devices, and Blynk libraries allow developers to link devices to the Blynk cloud platform and the cloud-based platform facilitates communication between connected hardware and mobile app.

The key features and benefits of the Blynk platform to ensure the compelling and accessible solution to IoT are the cloud connectivity, mobile app interface, extensive hardware support, real time data visualization and community and support. Figure 3.19 shows how the Blynk app works.

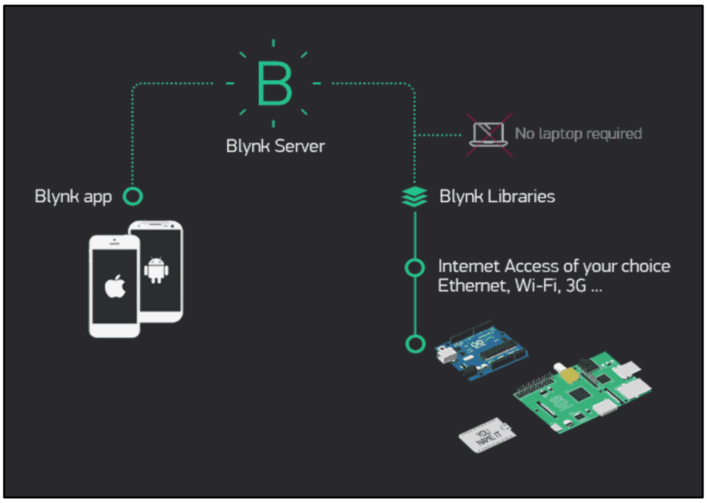



Figure 3.19: How the Blynk App works

### 3.14 Cost Estimation

The project's main objective is to construct a smart sit-stand exoskeleton with IOT implementation for MIG welding worker, therefore the cost estimation is as below: Table 3.14 show the cost estimation of the project.

Table 3.14: Cost estimation of the project

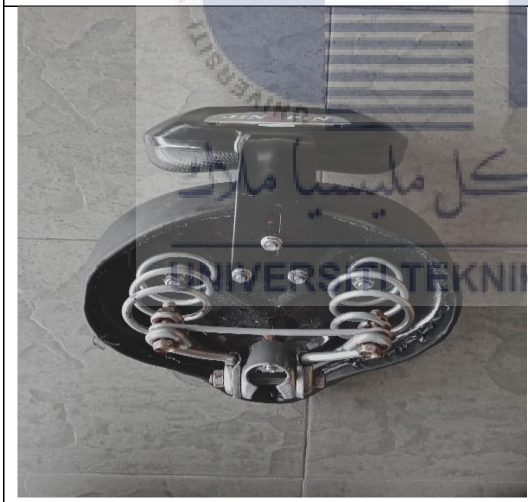
| **Component** | **Quantity** | **Price** | **Total Price** |
|---|---|---|---|
| Bicycle Seat | 1 | RM 14.30 | RM 14.30 |
| TC Enclosure Box 6x8 | 1 | RM 9.00 | RM 9.00 |
| Adjustable DC-DC | 1 | RM 18.00 | RM 18.00 |
| Anti-slip Sticker Tape | 1 | RM 9.95 | RM 9.95 |
| Nitto Hi-Coupler (SS,SG) | 1 | RM 19.60 | RM 19.60 |
| Nitto Hi-Coupler (SS41) | 1 | RM 9.05 | RM 9.05 |
| SYK Aluminium Stick (Fruit Picker) | 1 | RM 35.00 | RM 35.00 |
| ESP 32 | 1 | RM 22.00 | RM 22.00 |
| Ultrasonic Sensor (Posture Sensor) | 1 | RM 20.00 | RM 20.00 |
| Load Cell Sensor (Pressure Sensor) | 2 | RM 10.00 | RM 20.00 |
| Buzzer | 1 | RM 3.00 | RM 3.00 |
| Led | 3 | RM 0.30 | RM 0.90 |
| Resistor | 10 | RM 10.00 | RM 10.00 |
| Breadboard | 1 | RM 12.00 | RM 12.00 |
| Male-Male Wire | 1 | RM 7.00 | RM 7.00 |
| Male-Female Wire | 1 | RM 7.00 | RM 7.00 |
| **TOTAL** | | | **RM 216.80** |

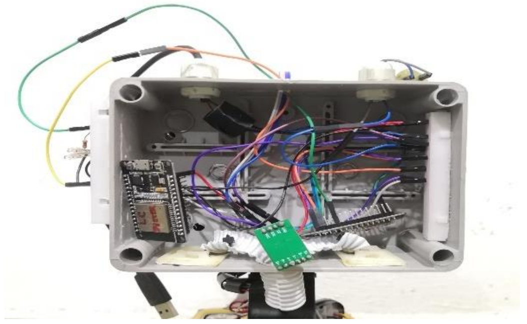
## 3.15 Fabrication of Smart Modular Lower Body Support

Table 3.15 shows fabrication process of the Smart Modular Lower Body Support

Table 3.15: Fabrication process of Smart Modular Lower Body Support

| Parts | Description |
|---|---|
|  | Preparation of the base support for the Smart Modular Lower Body Support |
|  | Measured and cutting the aluminium shaft |
|  | Welding process of an additional mild steel shaft to the base to ensure the aluminium shaft doesn’t play when it is fixed to base support. |

| | |
|---|---|
|  | Welded the mild steel shaft to the base support. |
|  | Applied hardener to the welded area. |
|  | Assembled the seat with backrest. |
|  | Completed part were sprayed with black color. |

| | |
|---|---|
|  | The process of fixing electronic parts for the use of IoT.<br><br>Electronic parts assembled in PVC link junction box. |

### 3.16 System Usability Scale (SUS)

System Usability Scale (SUS) is a scale which is widely used questionnaire-based tool for evaluation of a product. The SUS contains a few numbers of questions to address a specific aspect of usability of a product. In this project, SUS had been implemented to receive response from the welders regarding the project. A higher SUS score indicates better usability. The SUS provide a quick and reliable access to the overall usability of the product from the welder’s perspective and help to counter the areas for improvements.

### 3.17 Summary

This chapter presents the suggested process for creating a new, efficient, and connected system. The main innovation of the suggested approach is the execution of an efficient, less rigorous, simple estimation, which eliminates the findings' notable lack of precision. The method's ultimate purpose is to be effective, user-friendly, and manipulate the practicality of the development rather than to get the maximum degree of accuracy. Table 3.16 shows the relationship between objective and methodology of the project.

Table 3.16: Relationship between objective and methodology

| Objective | Methodology |
|---|---|
| To analyze the user's requirements, technical specifications, and ergonomics considerations for developing a Smart Modular Lower Body Support for MIG welders. | Collected the data of user requirements, technical specifications and ergonomics factor at the work place of the MIG welder. |
| To design and develop a Smart Modular Lower Body Support for MIG welders who are performing tasks in prolonged standing. | Design and developed a Smart Modular Lower Body Support based on the requirements and according to the work place using SolidWorks 2023. Evaluation of the design was obtained from the results of Von Mises Stress, Displacement and Factor of Safety |
| To evaluate the functionality and usability of the Smart Modular Lower Body Support for MIG welders engaged in prolong standing task. | The Smart Modular Lower Body Support had undergone testing at the industrial site to align with customer requirements. the effectiveness of the Smart Modular Lower Body Support is validated through comprehensive evaluation involving mechanical testing and real-world assessment. |

# CHAPTER 4

# RESULTS AND DISCUSSION

This technical report presents the results and analysis of the Smart Modular Lower Body Support project conducted for Wentel Engineering Sdn Bhd. The study aimed to ascertain the needs of MIG welders regarding lower body support systems. Through a comprehensive research process, including user requirement analysis, design development, and product testing, the project aimed to address the ergonomic needs of welders during their daily tasks. The objective of this study was to identify and address the specific needs of MIG welders for effective lower body support. To achieve this goal, a thorough analysis of user requirements, technical specifications, and ergonomic considerations was conducted. Observation sessions at the workplace, body symptom surveys, and data collection on production targets were carried out to gather relevant information.

The study progressed to the design and development phase, where three models of the lower body support system were created. Through an iterative process of evaluation and material testing using SolidWorks simulation, the final design, Model 3, was selected. Fabrication processes were carried out according to specified protocols, including internal stability testing and integration with IoT sensors. The Smart Modular Lower Body Support system incorporated two sensors, namely load cells and ultrasonic sensors, to monitor load exertion and bending movements. An alarm system comprising a buzzer and LED indicators was integrated with the sensors to alert users of abnormalities detected during work. Additionally, the system was linked with Blynk software to provide real-time notifications and data visualization for welders.

The functionality and usability of the Smart Modular Lower Body Support were evaluated through on-site testing with MIG welders. Data collected from the Blynk software, including screenshots and email notifications, provided insights into the system's performance. A System Usability Scale survey was conducted to assess user satisfaction and preferences. The findings from the testing and surveys revealed that MIG welders prioritize comfort and ergonomics in a lower body support system. They expressed a preference for features such as real-time posture monitoring, data collection, and notifications to improve their sitting posture and reduce discomfort during long working hours.

In conclusion, the Smart Modular Lower Body Support system has been designed and developed to address the specific needs of MIG welders for ergonomic support. The findings from the evaluation process offer valuable insights for further refinement and improvement of the system, ensuring enhanced comfort and usability for welders in their daily tasks.

## 4.1 Welder requirements and technical specifications

An ergonomic assessment conducted on the workstations of welders in order to address concerns regarding musculoskeletal health and productivity. The assessment aimed to identify ergonomic risk factors associated with current work practices and propose solutions to mitigate these risks. Table 4.1 provides an overview of the current situation observed at welder workstations. Welders typically spend 8 hours per day completing their tasks, during the period, the welder adopt non-neutral postures and endure prolonged standing. These ergonomic stressors predispose welders to musculoskeletal disorders (MSDs) without their awareness. Additionally, observations revealed the utilization of plastic chairs by welders during breaks due to musculoskeletal pain induced by continuous standing. The usage of plastic chairs poses safety concerns as they are susceptible to melting when exposed to sparks from the MIG welding process. This has led to instances where chairs have melted due to heat exposure, compromising both safety and ergonomic comfort. Furthermore, the utilization of breaks for pain alleviation interrupts production cycles, impacting overall efficiency.

Considering the anthropometric data collected and the nature of welding tasks, ergonomic seating options tailored to the specific needs of welders had been explored. These options may include adjustable chairs with lumbar support to promote neutral postures and alleviate musculoskeletal strain. Implementation of heat-resistant seating materials or covers to mitigate the risk of chair damage from MIG welding sparks, ensuring both safety and durability. Introducing workstation design modifications to facilitate ergonomic movement and reduce prolonged standing, thereby minimizing the risk of MSDs. To assess the impact of MSDs on workforce health and productivity, collaboration with the Human Resources department was initiated. Analysis of medical leave data as shown in Table 4.2 due to MSDs provide valuable insights into the prevalence and severity of ergonomic-related health issues among welders, informing the development and prioritization of ergonomic interventions.

Table 4.1: Current situation of the welder

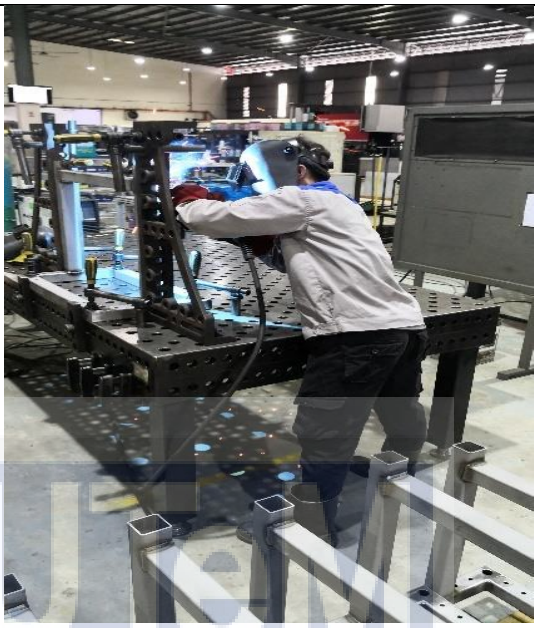


Table 4.2: Medical leave taken by welder due musculoskeletal disease

| Period: 01/01/2023 to 20/12/2023 | |
|---|---|
| **Welder** | **Total No of Medical Leave** |
| Welder 1 | 10 |
| Welder 2 | 5 |
| Welder 3 | 7 |
| Welder 4 | 9 |
| Welder 5 | 7 |
| Welder 6 | 11 |
| Welder 7 | 4 |
| Welder 8 | 10 |
| Welder 9 | 6 |
| Welder 10 | 9 |

Note: Data extracted from Wentel Engineering Sdn Bhd MC Report

## 4.2 Discussion on welder requirements and technical specifications

In response to the rising incidence of musculoskeletal diseases among welders, a comprehensive study was undertaken at the workplace to assess and address this issue. The study was prompted by the significant number of welders reporting musculoskeletal ailments, attributed primarily to prolonged standing during their work shifts. Recognizing the importance of welders' health and well-being, discussions were initiated with researchers to devise effective solutions.

To gather pertinent data, researchers conducted an industrial visit to the workplace. During this visit, observations were made regarding the ergonomic practices of welders, revealing a prevalence of non-neutral postures during their tasks. Surveys and discussions were subsequently conducted with welders to identify areas for improvement in their work environment and address musculoskeletal issues. Visual documentation, including images depicting workers' postures and the workplace setup, was also captured for reference.

Additionally, analysis of medical leave records provided insights into the frequency and severity of musculoskeletal complaints among welders. Furthermore, welders were given the opportunity to express their ergonomic needs, particularly concerning lower body support during their daily tasks. To ensure the efficacy of proposed solutions, anthropometric data of welders were collected and analysed as shown in Table 3.1. This data was instrumental in designing a lower body support system that accommodates the diverse height variations among welders. A height-adjustable mechanism was thus incorporated into the design to cater to individual requirements.

Moreover, the weight-bearing capacity of the lower body support was evaluated to ensure its durability over prolonged usage. This analysis aimed to ascertain that the support system can adequately withstand the load exerted by welders throughout their work shifts. In addition to addressing ergonomic concerns, efforts were made to enhance productivity. Baseline data on the rate of product output per hour was collected and analysed. By studying the cycle time required for completing tasks against time, it was possible to identify opportunities for productivity improvement. Notably, breaks taken by welders to alleviate musculoskeletal discomfort were observed to contribute to increased cycle times. The implementation of an effective lower body support system aimed to mitigate the need for frequent breaks, thereby enhancing focus and productivity.

Based on observations and feedback from welders, design specifications for the lower body support system were formulated. In particular, the need for rotational capability to facilitate varied welding angles was identified. The design incorporated a 360° rotating mechanism, enabling welders to maintain optimal positions while performing tasks as shown in Figure 4.1. This Smart Modular Lower Body Support minimizes the need for extensive body movements, thereby reducing strain and fatigue.

The study underscores the importance of ergonomics in mitigating musculoskeletal issues among welders. By integrating anthropometric considerations, productivity enhancement strategies, and innovative design features, the proposed lower body support system aims to alleviate discomfort and improve overall work performance. Moving forward, ongoing evaluation and feedback mechanisms will be essential to ensure the sustained effectiveness of these ergonomic interventions.



Figure 4.1: Welder rotates his body to achieve welding angle

## 4.3 Developing of Smart Modular Lower Body Support

The satisfaction of welders is paramount in the design of equipment intended for their use. This technical report outlines the process of designing and fabricating a Smart Modular Lower Body Support, aimed at enhancing the comfort and efficiency of welders during their work. To ensure a successful design, extensive data collection and parameter analysis were conducted in advance. Key points were identified through discussions with welders, focusing on aspects such as base support, product weight, height adjustability, rotation capability, and maximum load acceptance. Several design models were sketched based on these discussions, resulting in the selection of three potential designs (Figure 3.4, 3.5, and 3.6). Each design was developed in accordance with welders' suggestions, prioritizing their needs and preferences.

Following the design phase, Finite Element Analysis (FEA) was employed to assess the structural integrity and performance of each design under various physical conditions. Material properties were assigned to simulate real-world scenarios, ensuring compliance with criteria such as Yield Strength, Deformation Scale, and Factor of Safety. A House of Quality analysis was conducted to compare and evaluate the three design options. Based on this analysis, the third model was selected for fabrication due to its superior performance and alignment with welders' requirements.



The finalized design, as depicted in Table 4.3, was fabricated according to the specifications and dimensions outlined by welders. Mechanical mechanisms integral to the Smart Modular Lower Body Support are labeled and their functions detailed in Figure 4.2 and Table 4.4, respectively. Additionally, Figure 4.3 showcases the hardware setup of the IoT system integrated into the support structure, with its functionalities outlined in Table 4.5. Figure 4.6 shows the modularity of the Smart Modular Lower Body Support, the disassembled part of the Smart Modular Lower Body Support.

In conclusion, the design and fabrication process of the Smart Modular Lower Body Support involved rigorous data collection, iterative design refinement, structural analysis, and stakeholder feedback integration. The resulting product not only meets the functional requirements of welders but also incorporates innovative features to enhance usability and comfort during welding operations It provides a comprehensive overview of the methodology and outcomes of the design and fabrication process, laying the foundation for further research and development in the field of ergonomic equipment for industrial applications.

Table 4.3: Finalized product of the Smart Modular Lower Body Support

| Angle View | Images | Angle View | Images |
|---|---|---|---|
| Front View |  | Right View |  |
| Left View |  | Back View |  |

| | |
|---|---|
| Top View |  |


Figure 4.2: The label of mechanical mechanism used in the Smart Modular Lower Body Support

Table 4.4: Function of each mechanical mechanism used in Smart Modular Lower Body Support

| Part No. | Part Name | Function |
|---|---|---|
| 1 | Seat | To support the welder's lower body |
| 2 | TC Enclosure Box | Storage to locate electronic parts and wiring |
| 3 | Load Cell | To measure the weight exerted by the welders |
| 4 | Ultrasonic Sensor | To measure the bending movement of welder |
| 5 | Nitto Hi-Coupler | Acts as rotating mechanism for the lower body support |
| 6 | Shaft | Acts as an adjustable mechanism (height) |
| 7 | Locking Mechanism | To lock the shaft at a position once the height of shaft adjusted |
| 8 | Back Rest | Support the back bone of the welder |
| 9 | Back Rest bracket | Acts as a locking mechanism for the back rest and the seat |
| 10 | Base | To support and withstand the total load exerted by the welder and the lower body support. |



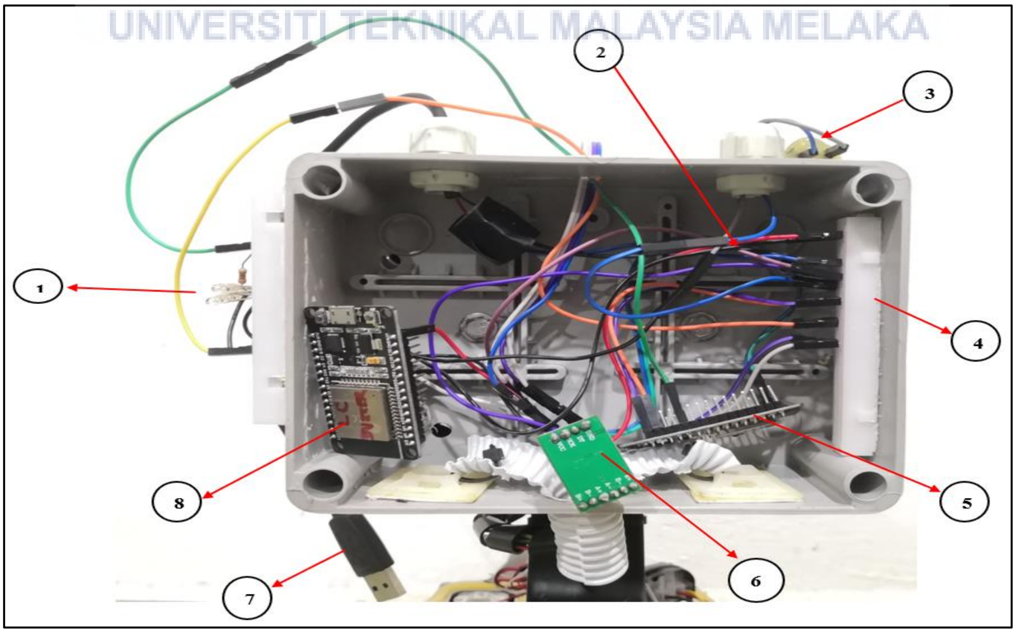



Figure 4.3: Built-up hardware of IoT system

Table 4.5: Function of IoT used in Smart Modular Lower Body Support

| Part No. | Part Name | Function |
|---|---|---|
| 1 | LED | To notify the welder if any abnormalities detected by the ultrasonic sensor |
| 2 | Jumper Cable | To connect the load cells, buzzer, ultrasonic sensor, LED, ESP 32, HX711 amplifier and power supply |
| 3 | Buzzer | To notify the welder if any abnormalities detected by the load cell |
| 4 | Breadboard | Acts as assemble platform of all the wiring. |
| 5 | ESP 32 (US) | Microcontroller for ultrasonic sensor |
| 6 | HX711 amplifier | Amplify signal from load cell and transfer to microcontroller |
| 7 | USB Cable | To transfer power supply from the power bank to the breadboard, to be distributed for all the connected electronic component |
| 8 | ESP 32 (LC) | Microcontroller for load cell |

Table 4.6: Modularity of Smart Modular Lower Body Support

<table>
<tr><th>Part Name</th><th>Images</th></tr>
<tr><td><ul><li>Base + Shaft 1</li><li>Shaft 2</li><li>Adjustable Shaft + Rotating Nitto Hi-Coupler</li><li>Seat + Back Rest + Electronic Box</li></ul></td><td></td></tr>
<tr><td><ul><li>Seat + Back Rest + Electronic Box</li></ul></td><td></td></tr>
</table>



## 4.4 Discussion on Developing a Smart Modular Lower Body Support

This technical report presents the design and development process of the Smart Modular Lower Body Support, aimed at enhancing comfort, safety, and efficiency for welders during their work. The project involved the creation of three initial design models, followed by finite element analysis (FEA) to determine the most suitable model for fabrication. Key features of the support include height adjustability, rotation capability, material selection, and integration of an Arduino system for monitoring and data collection.

Three design models were initially developed based on specifications provided by welders. To ensure the selected model not only met the welders' requirements but also complied with safety and stability standards, FEA was conducted. Model 3 emerged as the optimal choice based on the FEA analysis results.

The Smart Modular Lower Body Support offers several innovative features to enhance usability and comfort for welders such as height adjustability to accommodate welders of varying heights, the support features two shafts with locking mechanisms, allowing for easy adjustment, rotation capability which the seat of the support can rotate 360°, providing welders with greater freedom of movement compared to traditional plastic chairs and material selection whereby the support constructed from aluminum and mild steel, the support balances durability with cost-effectiveness, making it easy to handle for welders while remaining affordable to fabricate and achieve the objective of the project in the aspect of modularity. The features in the Smart Modular Lower Body Support can be disassembled and assembled or be adjusted to provide customized support.

To further improve the functionality, an Arduino system was integrated into the support. This system monitors welder movements during work and helps identify potential issues related to musculoskeletal disorders (MSD). The Arduino system comprises Ultrasonic Sensor and Load Cell components, which detect abnormal pressures and bending movements exerted by welders. A buzzer alarm and LED indicators alert welders to any detected abnormalities, ensuring prompt attention to potential health risks.

To facilitate remote monitoring and data collection, Blynk software was incorporated into the Smart Modular Lower Body Support. This software allows for real-time visualization of sensor data, customizable parameter settings, and generation of notifications via email or software alerts. During industrial testing at Wentel Engineering Sdn Bhd, a predefined set of parameters was utilized as shown in Table 4.7, which can be adjusted as per welder or company requirements.



The design and development of the Smart Modular Lower Body Support represent a significant advancement in ergonomic equipment for welders. By integrating features such as height adjustability, rotation capability, and an Arduino monitoring system, the support enhances both comfort and safety in the workplace. The incorporation of Blynk software further enables efficient data collection and remote monitoring, contributing to the overall well-being and productivity of welders. This provides a comprehensive overview of the design process, key features, and technological implementations of the Smart Modular

Lower Body Support, laying the groundwork for future advancements in industrial ergonomic solutions.

Table 4.7: Parameter of Arduino System (Testing in Industrial Visit)

| **Sensor** | **Parameter** |
|---|---|
| Load Cell | • Weight: ≥10kg<br>• Delay: 5 minutes<br>• Blynk notification to phone: Every 1 minute upon delay time |
| Ultrasonic Sensor | • Distance: ≥15cm<br>• Delay: 5 seconds<br>• Blynk notification to phone: Every 1 minute upon delay time |

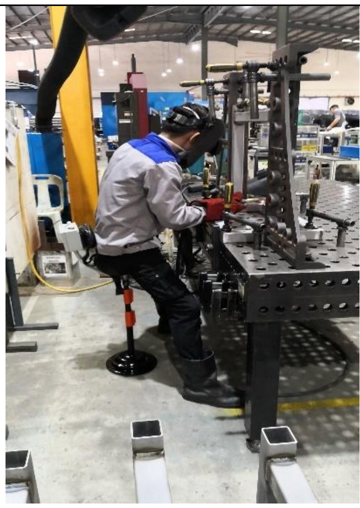
## 4.5 Evaluation of the Functionality and Usability of Smart Modular Lower Body Support

### 4.5.1 Welder utilizing Smart Modular Lower Body Support

Table 4.8 shows the welder utilize the Smart Modular Lower Body Support to carry out their task.

Table 4.8: The welders use the Smart Modular Lower Body Support

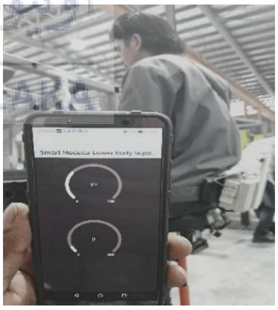
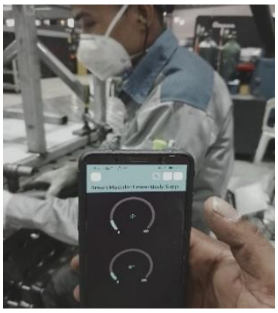
| **The welder uses the Smart Modular Lower Body Support** | | |
|---|---|---|
|   |  |  |

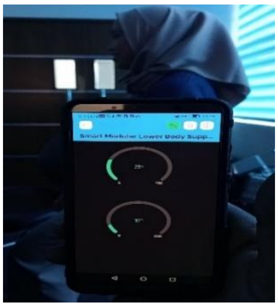
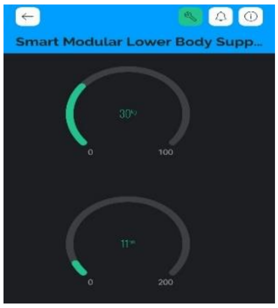
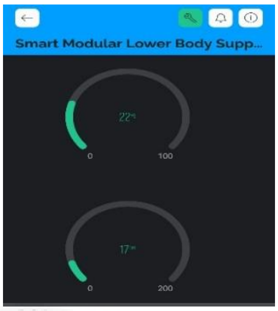
| | | |
|---|---|---|
|  |  |  |

### 4.5.2 Blynk Software Data

The Smart Modular Lower Body Support had been tested at Wentel Engineering Sdn Bhd. The product had been tested by a few welders in the company and Table 4.9 shows the reading of Blynk Software.

Table 4.9: The reading of Blynk software

| Worker | Blynk Data | Images | Worker | Blynk Data | Images |
|---|---|---|---|---|---|
| 1 | Load Cell: 18 kg<br><br>Ultrasonic Sensor: 11 cm |  | 2 | Load Cell: 18 kg<br><br>Ultrasonic Sensor: 11 cm |  |
| 3 | Load Cell: 22 kg<br><br>Ultrasonic Sensor: 11 cm |  | 4 | Load Cell: 10 kg<br><br>Ultrasonic Sensor: 16 cm |  |

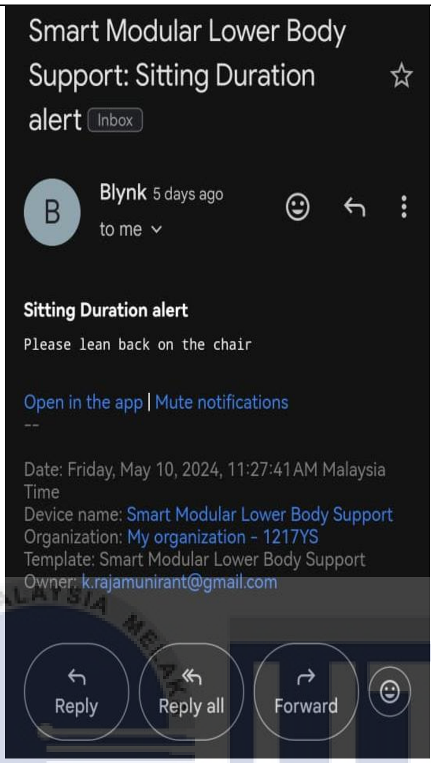
| | | | | | |
|---|---|---|---|---|---|
| 5 | Load Cell: 23 kg<br><br>Ultrasonic Sensor: 16 cm |  | 6 | Load Cell: 30 kg<br><br>Ultrasonic Sensor: 11 cm |   |
| 7 | Load Cell: 22 kg<br><br>Ultrasonic Sensor: 17 cm |   | | | |

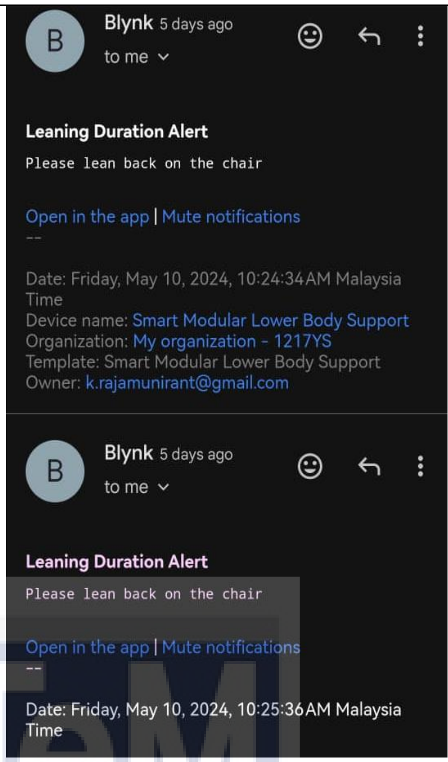
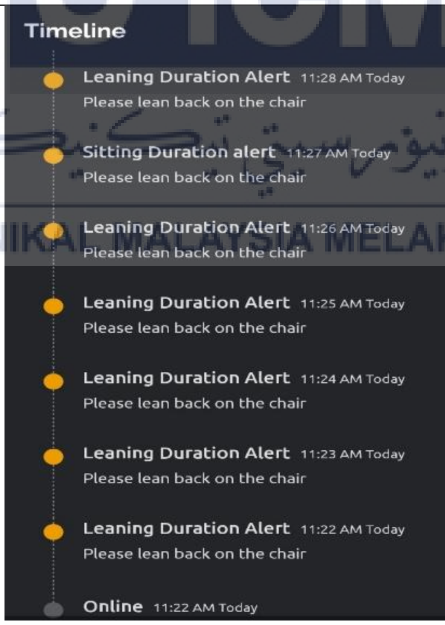


### 4.5.3 Blynk Software Message and Email Notifications

Sensors trigger system that had been used in the product not only triggers the buzzers and LED but it does send notification thru Blynk software and email. The Blynk software can be linked to welder phone and company officers' phone to generate notification of the abnormalities as shown in Table 4.10. Therefore, the company officers don't need to go thru the production line to monitor the abnormalities but they can monitor the abnormalities of their worker in their company thru messages and email notifications.

Table 4.10: Blynk software message and email notifications

<table>
<tr><th>Notification</th><th>Images</th></tr>
<tr><td>Via Email</td><td>


</td></tr>
<tr><td>Via Software</td><td>
</td></tr>
</table>



### 4.5.4 Improvement on Number of Product Production vs Actual

Table 4.11: shows the comparison for producing a product/hour according to actual vs after improvement.

Table 4.11: Producing a product/hour (Actual vs After Improvement)

| **Participant** | **Baseline of producing a product/hour** | |
|---|---|---|
| | **Actual** | **After Improvement** |
| A | 4 | 6 |
| B | 5 | 6 |
| C | 4 | 5 |
| D | 4 | 6 |
| E | 5 | 7 |
| F | 4 | 5 |
| G | 4 | 6 |
| H | 5 | 7 |
| I | 5 | 7 |
| J | 4 | 5 |

### 4.5.5 Questionnaire Survey

The purpose of conducting this survey is to gather feedback from welders who are working in the Wentel Engineering Sdn Bhd about the system usability scale and acceptance level for the Smart Modular Lower Body Support that incorporates with IoT technology. The feedback was completed by 18 respondents currently employed in the industry. The summarized findings will be presented using various visual tools such as pie charts, tables, and bar graphs.

#### 4.5.5.1 Basic Information of Respondent

Figure 4.4 reveal the gender of respondent whom are working at MIG welding department. The percentage shows the gender of welders whom answered the question. Male welder 76.2% whereas female welders was 23.8%.

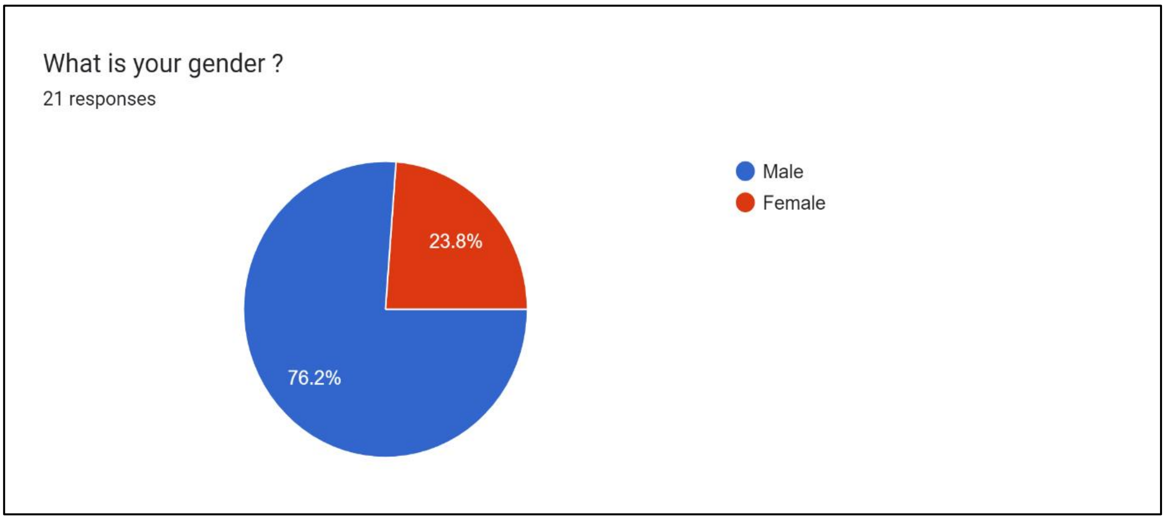



Figure 4.4: Percentage of male and female gender answered the feedback questions.

Figure 4.5 shows the range of welder's age whom are working in the MIG department. The range age of 23 years old – 26 years old covered 61.9% of the feedback whereas the age range 27 years old to 30 years old covered 28.6% and respectively.

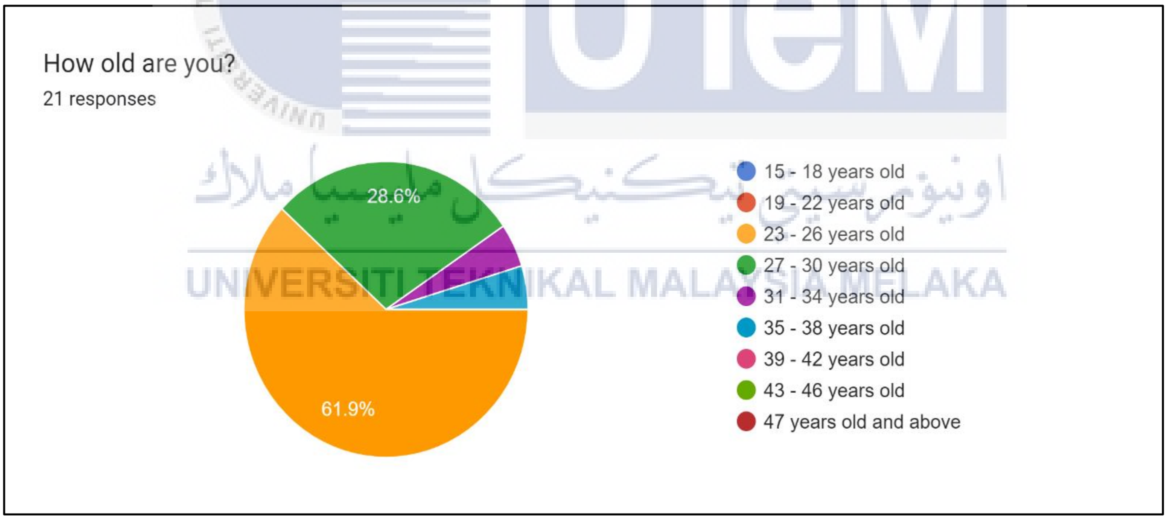



Figure 4.5: The age range of welder

#### 4.5.5.2 System Usability Scale

System Usability Scale tool was used to measure the perceived usability of a product. In this project, researcher had used the tool to identify the feedback of the welder on the Smart Modular Lower Body Support. Figure 4.6 shows the usability score for Smart Modular Lower Body Support, Table 4.12 shows grade ranking of

SUS score and Figure 4.7 shows the average score for each question on the questionnaire.

| SYSTEM U | I think, I wo | I need to st | I feel confic | I found this | I think I will | I found thi | I think I ne | I thought th | I thought th | I found is lo | Total Sur | Overall SU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 5 | 2 | 2 | 21 | 52.5 |
| 2 | 3 | 4 | 4 | 1 | 3 | 3 | 1 | 4 | 3 | 2 | 20 | 50 |
| 3 | 4 | 4 | 4 | 1 | 4 | 4 | 3 | 4 | 1 | 1 | 22 | 55 |
| 4 | 4 | 5 | 4 | 1 | 5 | 5 | 3 | 3 | 2 | 2 | 22 | 55 |
| 5 | 5 | 4 | 3 | 3 | 2 | 3 | 2 | 4 | 2 | 3 | 11 | 27.5 |
| 6 | 3 | 4 | 3 | 2 | 4 | 4 | 4 | 4 | 2 | 1 | 21 | 52.5 |
| 7 | 4 | 4 | 5 | 2 | 5 | 5 | 3 | 5 | 2 | 2 | 21 | 52.5 |
| 8 | 5 | 5 | 5 | 1 | 5 | 5 | 5 | 5 | 2 | 3 | 23 | 57.5 |
| 9 | 5 | 5 | 5 | 1 | 4 | 4 | 5 | 5 | 1 | 1 | 24 | 60 |
| 10 | 4 | 3 | 4 | 1 | 4 | 4 | 2 | 5 | 3 | 2 | 22 | 55 |
| 11 | 4 | 3 | 4 | 2 | 5 | 5 | 2 | 4 | 1 | 1 | 21 | 52.5 |
| 12 | 4 | 5 | 4 | 1 | 4 | 5 | 3 | 2 | 2 | 1 | 23 | 57.5 |
| 13 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 19 | 47.5 |
| 14 | 4 | 3 | 4 | 2 | 4 | 4 | 3 | 4 | 2 | 2 | 22 | 55 |
| 15 | 5 | 4 | 5 | 2 | 5 | 5 | 2 | 2 | 2 | 4 | 22 | 55 |
| 16 | 3 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 20 | 50 |
| 17 | 3 | 4 | 3 | 1 | 4 | 4 | 4 | 5 | 1 | 2 | 19 | 47.5 |
| 18 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 19 | 47.5 |
| 19 | 4 | 4 | 4 | 1 | 4 | 4 | 4 | 4 | 1 | 1 | 23 | 57.5 |
| 20 | 4 | 3 | 4 | 1 | 4 | 5 | 1 | 5 | 1 | 1 | 19 | 47.5 |
| 21 | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 3 | 17 | 42.5 |
| **AVERAGE** | **3.952381** | **3.952381** | **3.904762** | **1.857143** | **4** | **4.19048** | **3.047619** | **4.047619** | **1.952381** | **2** | | **1077.5** |

Figure 4.6: The usability score for Smart Modular Lower Body Support

**Calculation SUS Score:** Total SUS Score ÷ No. of respondent = Score

1077.5 ÷ 21 = 51.31



According to grad ranking of SUS score as shown in Table 4.12, the Smart Modular Lower Body Support had gained a score of 51.31 which stand in the grade of “D” with the acceptability of “OK”, which pre-described that the welders accept the Smart Modular Lower Body Support to be used in the daily task.

Table 4.12: Grade ranking of SUS score

| Score | Grade | Acceptability |
|---|---|---|
| 80 and above | A | Best Imaginable |
| Between 74 and 79 | B | Excellent |
| Between 68 and 73 | C | Good |
| Between 51 and 67 | D | OK |
| Less than 51 | F | Not Acceptable |

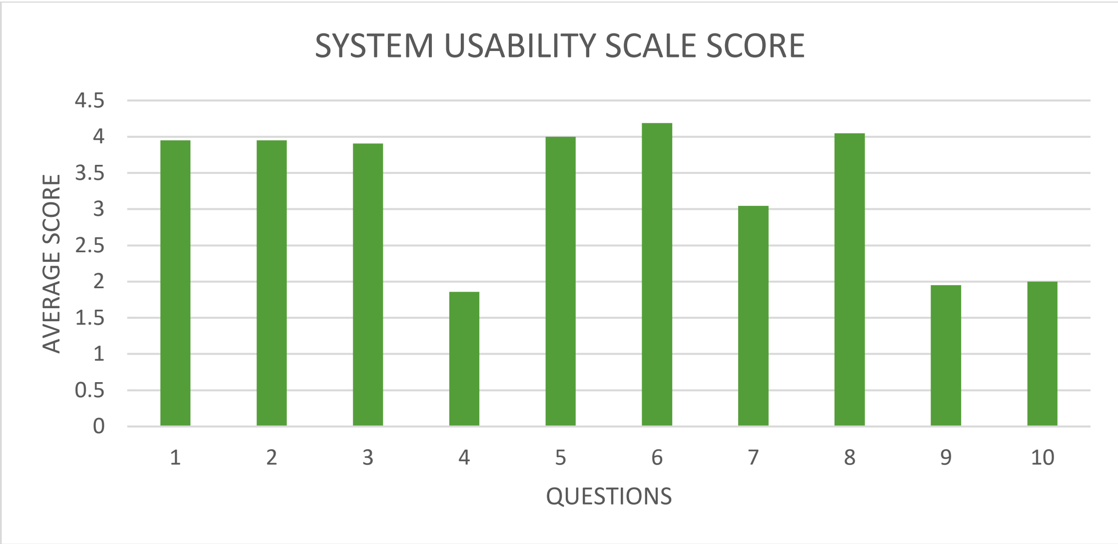



Figure 4.7: Average score for each question on the questionnaire

1. I think, I would like to use this lower body support frequently.
2. I need to study on the manual before using the lower body support.
3. I feel confident when using this lower body support.
4. I found this lower body support very awkward and cumbersome.
5. I think I will learn to use this lower body support very quickly.
6. I found this lower body support have various functions and well-integrated.
7. I think I need technical assistance to guide on the usage of the lower body support.
8. I thought this lower body support was very easy to be used.
9. I thought there was too much of inconsistency in this lower body support.
10. I found this lower body support is unnecessarily complex.

#### 4.5.5.3 Acceptance

Acceptance for a product involves several steps and criteria to ensure that the product meets the required standards and fulfills the needs of its intended users. In this project researcher had set a few criteria and receives the feedback from the welder. Table 4.13 shows the feedback of welder on the acceptance of the Smart Modular Lower Body Support project whereas Figure 4.8 shows the pie chart of the acceptance level.

Table 4.13: Acceptance for the Smart Modular Lower Body Support

| CRITERIA | COMMENT | RESPONSE (%) |
|---|---|---|
| Visual Appeal of Design | The design should be both visually appealing and smart. | 100% |
| Comfort of Use | The Smart Modular Lower Body Support appear and feel comfortable when in use. | 100% |
| Preferred Colour | Suggested colour for the Smart Modular Lower Body Support. | Black |
| Likely using the product | Welder likely uses the Smart Modular Lower Body Support in daily task | 85.7% |
| Likelihood of Recommendation | Users have a tendency to recommend the Smart Modular Lower Body Support to friends and families | 100% |
| Willingness to purchase the product | Welder willing to purchase the Smart Modular Lower Body Support upon commercialized in the market | 100% |
| Affordable to Pay | Welder has different expectations for the Smart Modular Lower Body Support price range. | (RM 0 – RM 200) |
| Ergonomic | Welder has suggestion on the seat used | - |
| Design Improvement Suggestions | Welder has suggestions for design improvements | - |

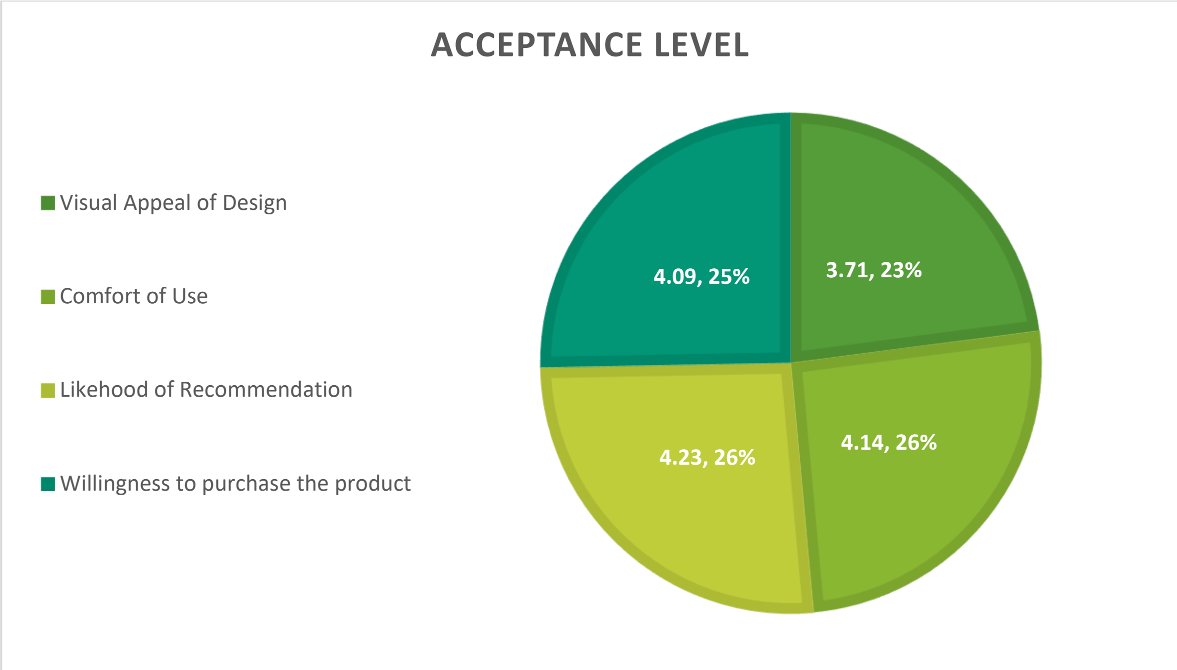



Figure 4.8: The pie chart of the acceptance level

## 4.6 Discussion on data of Functionality and Usability of the Smart Modular Lower Body Support.

This report details the industrial testing of the Smart Modular Lower Body Support conducted at a welder's workplace. The objective of the testing was to evaluate the functionality and usability of the Smart Modular Lower Body Support in a real-world industrial setting. Following the completion of internal testing, an industrial visit was conducted. Parameters for the industrial testing were established beforehand to facilitate a smooth testing process as shown in Table 4.6. During the industrial visit, welders using the Smart Modular Lower Body Support were observed while performing MIG welding tasks. Images of welders utilizing the lower body support are provided in Table 4.7. The researcher trained the welders on the correct usage of the Smart Modular Lower Body Support to ensure comfort during their daily tasks. Additionally, a briefing on the method of gathering data using the Blynk software was provided to ease the collection of results.

Welders were assigned to carry out their usual tasks while using the Smart Modular Lower Body Support. The researcher collected data by taking pictures of the results displayed on the Blynk software. Detailed results of each testing instance are documented in Table 4.8. The Blynk software generated notifications to alert welders to any abnormalities. These notifications were designed to appear both within the software and via email to ensure timely alerts as shown in Table 4.9. The use of the Smart Modular Lower Body Support led to significant improvements in production efficiency. As shown in Table 4.10, welders were able to work more efficiently, reducing cycle times and increasing the number of products produced. These results indicate that the Smart Modular Lower Body Support successfully meets its objective in terms of functionality.

Following the successful industrial testing of the Smart Modular Lower Body Support, a survey was conducted to evaluate its usability among welders. This report summarizes the findings from the usability survey, highlighting key aspects such as learning curve, confidence in use, and overall satisfaction. The survey was designed to assess various aspects of the Smart Modular Lower Body Support's usability, including quick learning curve, confidence in use, integration of function, overall satisfaction, frequency of use, ease of use, need for technical assistance and consistency and complexity. Welders were provided with comprehensive training on the correct usage of the Smart Modular Lower Body Support to ensure they could utilize the device effectively and comfortably. Based on the survey responses, the following key findings were observed such as quick learning curve, confidence in use, integration of function, and overall satisfaction scored 100%. Welders found the Smart Modular Lower Body Support easy to learn and use, welders felt confident in its operation, and were highly satisfied overall. This high satisfaction can be attributed to the proper guidance provided during training. In the aspect of body load and posture adjustment welders felt very confident using the Smart Modular Lower Body Support, particularly after seeing data on body load and bending movements via the Blynk app. This data helped them adjust their body posture to avoid musculoskeletal disorders whereas in the aspect of frequency of use, learning curve, ease of use, consistency, and complexity scored above 90%, indicating that welders were happy with the product and found it easy to integrate into their daily routines without any major issues. Besides that, in the aspect of awkwardness and need for technical assistance, a small number of welders (33.3%) found the Smart Modular Lower Body Support awkward initially due to their habituation to standing while working. However, this awkwardness decreased with continued use. Additionally, some welders required technical assistance, mainly due to language barriers and unfamiliarity with smartphones, particularly among older welders. According to the System Usability Scale Score gathered as shown in Figure 4.6 shows a total point of 1077.5

had been collected from the survey. Then the total points were been divided into 21 respondent which gives a result of 51.31. The results of 51.31 scored the grade of "D" with the acceptability of "OK" which shows that the welders are satisfied with the Smart Modular Lower Body Support and ready to use the product in their daily task.

In terms of acceptance, the survey considered seven criteria, with the following results which were design. The design of the Smart Modular Lower Body Support was found to be visually appealing by 100% of the welders. Next, the comfort of use gained 100% of the welder's support that the Smart Modular Lower Body Support was comfortable to use. In the aspect of likelihood of recommendation 100% of the welders indicated they would recommend the Smart Modular Lower Body Support to others while willingness to purchase 100% of the welders expressed their willingness to purchase the Smart Modular Lower Body Support once it is commercialized. Besides that, in the aspect of likelihood of continued use, 85.7% of the welders were likely to continue using the Smart Modular Lower Body Support, with the initial lower score due to the sudden implementation of the product. Preferred colour and affordability, welders preferred the Smart Modular Lower Body Support to be black and affordable within the range of RM 0 – RM 200 and in the aspect of ergonomic and design improvement suggestions no comments were made regarding ergonomic or design improvements, indicating general satisfaction with the current design.



The usability and acceptance survey has shown that the Smart Modular Lower Body Support is well-received by welders, with high ratings in most aspects of usability. The initial awkwardness and need for technical assistance are areas that could be addressed through continued support and training, particularly for older and less tech-savvy workers. Overall, the Smart Modular Lower Body Support has proven to be an effective and user-friendly tool that enhances welders' comfort and productivity while helping to prevent musculoskeletal issues. Further refinements and continued user education will help in maximizing the benefits of the Smart Modular Lower Body Support in industrial settings.

## 4.7 Impact on the quality of welded parts when using Smart Modular Lower Body Support during MIG Welding Process

By providing stability to the welder, the Smart Modular Lower Body Support helps reduce hand tremors and other involuntary movements, leading to more precise and consistent welds. This improves the overall quality and appearance of the welded part. With reduced fatigue and better ergonomics, welders can maintain a steady hand and consistent technique throughout the welding process. This consistency is crucial for producing high-quality welds with uniform bead appearance and strength.

Fatigue and poor posture can lead to welding defects such as porosity, cracks, or weak joints. By addressing these factors, the lower body support minimizes defects and ensures the integrity of the welds. Stability and precision allow for better control of the welding torch, resulting in proper penetration and fusion of the weld metal with the base metal. This ensures strong, durable welds with good mechanical properties.

Better posture and reduced strain can prevent accidents and injuries, which can disrupt the welding process and compromise the quality of the welded part. A safer, more comfortable welder is likely to produce higher quality work. Reduced physical discomfort allows welders to focus better on the task at hand, leading to greater attention to detail and higher quality welds.



In summary, the use of Smart Modular Lower Body Support during MIG welding significantly improves the quality of the welded part by enhancing precision, consistency, and overall weld integrity, while reducing the risk of defects and improving welder ergonomics and safety.

# CHAPTER 5

# CONCLUSION

The primary aim of this project is to develop and evaluate a Smart Lower Body Support system tailored for welders. The project was initiated in response to a request from an industrial company to address musculoskeletal issues faced by welders due to prolonged standing during their work. This report outlines the objectives, methodology, data collection, analysis, and design considerations involved in developing the support system.

## 5.1 User's requirements, technical specifications, and ergonomics



The project began by analysing user requirements and technical specifications. Welders often face severe musculoskeletal disease due to prolonged standing at the workplace, typically spending 8 hours on their feet to complete their tasks. An initial attempt to provide plastic chairs failed because the chairs melted from the heat and sparks produced by MIG welding, creating safety hazards. Additionally, the chairs were not compatible with the work table heights and did not accommodate the varying heights of the welders in the company. This led to welders taking extended breaks due to musculoskeletal pain, increasing the cycle time in product production. To address these issues, a survey was conducted to understand the welders' requirements better. Data was collected during an industrial visit to the welders' workplaces to understand the practical challenges and causes of musculoskeletal issues. This involved interacting with welders, gathering input on support systems, collecting anthropometric data, and studying the workspace environment. The project focused on designing a lower body support system using heat-resistant and durable materials, taking into account factory environmental factors like temperature and space constraints. A goniometer was used to collect the postural angle of the worker to be used in designing a support system that minimized strain and supported natural body movements. Throughout the design process, House of Quality analysis and welders' feedback was incorporated to ensure the final product met their needs and ergonomic requirements.

## 5.2 Designing and Developing a Smart Modular Lower Body Support

The project's second objective was to design and develop a Smart Modular Lower Body Support system for MIG welders, incorporating IoT technology. The process included designing three models using SolidWorks, followed by Finite Element Analysis (FEA) and Pugh Matrix Selection to select the best model based on stress distribution, displacement, and Factor of Safety. Fabrication involved grinding, welding, and integrating market-sourced components. The IoT system, implemented with Blynk software, included load cells and ultrasonic sensors for real-time monitoring and feedback via buzzers, LEDs, alerts, and emails. After internal testing, the system was validated in an industrial setting. The project successfully achieved its goal, resulting in a system that enhances comfort, reduces strain, and boosts productivity for welders.



## 5.3 Evaluation of the Functionality and Usability of the Smart Modular Lower Body Support

Then the third objective was achieved by evaluation of the functionality and usability of the Smart Modular Lower Body Support had been collected from the welders. The industrial testing and subsequent usability survey of the Smart Modular Lower Body Support demonstrated its functionality and usability in a real-world welding environment. Key findings indicate that welders experienced a quick learning curve, high confidence in use, and overall satisfaction, with significant improvements in production efficiency and comfort. Welders adjusted their body posture effectively using the Smart Modular Lower Body Support, reducing the risk of musculoskeletal disorders. Despite minor issues such as initial awkwardness and the need for technical assistance, particularly among older workers, the Smart Modular Lower Body Support received high marks for comfort, ease of use, and IoT integration. Acceptance criteria, including design, comfort, recommendation likelihood, and willingness to purchase, all scored 100%. While some welders initially found the product awkward, this decreased with continued use. For future recommendation, a study on the materials used for the Smart Modular Lower Body Support can be done by replacing by a material that is lightweight and has higher strength. Other than that, the materials can also go through sustainability analysis. Overall, the Smart Modular Lower Body Support is highly effective and well-received, with further refinements and user education poised to enhance its benefits in industrial settings.

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# APPENDICES

## ARDUINO Source Code

```
#define BLYNK_TEMPLATE_ID "TMPL68tnu2sTE"
#define BLYNK_TEMPLATE_NAME "Smart Modular Lower Body Support"
#define BLYNK_AUTH_TOKEN "zSG0CmEMez0xxeseBkjgkLix5NLAITac"
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
#include <HX711.h>


// Replace with your Wi-Fi credentials
char auth[ ] = BLYNK_AUTH_TOKEN;
char ssid[] = "HUAWEI Mate 10 Pro";
char pass[] = "04040404";

const int hx711DT1Pin = 4; // D4 pin
const int hx711SCKPin = 5; // D5 pin

const float calibrationFactor = 15.744154; // Calibration factor for load cells
const unsigned long sittingDurationThreshold = 300000; // 15 minutes
unsigned long startTime;
unsigned long elapsedTime;
const int buzzer1 = 15;

HX711 hx711;

void setup() {
  Serial.begin(9600);
  Blynk.begin(auth, ssid, pass);
 // Initialize HX711 module
  hx711.begin(hx711DT1Pin, hx711SCKPin);

  // Set calibration factor for load cell
  hx711.set_scale(calibrationFactor);

  // Tare the load cell
  hx711.tare();

  pinMode(buzzer1, OUTPUT);
}
// Loop function runs repeatedly
```

```
void loop() {
  Blynk.run();
    // Read weight from load cell
  float weight_gram = hx711.get_units();
  float weight_kg = weight_gram / 1000.0;

  // Print the weight and FSR sensor value
  Serial.println("Weight: ");
  Serial.println(weight_kg);
  Serial.println(" kg");

  // Check sitting duration
  if (weight_kg > 10.0 ) {
    if (elapsedTime > sittingDurationThreshold) {
      digitalWrite(buzzer1, HIGH);
      Blynk.logEvent("sitting_duration_alert","Please lean back on the chair");
      startTime = millis(); // Reset the timer

    }
  } else {
    startTime = millis(); // Reset the timer
    digitalWrite(buzzer1, LOW);
  }

    elapsedTime = millis() - startTime;
    Blynk.virtualWrite(V0, weight_kg);
    delay(1000); // Delay for 1 second

}
```

HOUSE OF QUALITY SMART MODULAR LOWER BODY SUPPORT