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Design and Fabrication of a Prototype Mobile Platform with Holonomic and Omnidirectional Motion

FYP-18-7

Final Year Project Report

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Declaration

We hereby declare that the work contained in this report is original; researched and documented by the undersigned students. It has not been used or presented elsewhere in any form for award of any academic qualification or otherwise. Any material obtained from other parties have been duly acknowledged. We have ensured that no violation of copyright or intellectual property rights have been committed.

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Abstract

Mobile platforms are a relatively new technology compared to the advancements made in the motor vehicle industry. When producing mobile platforms, inventors and manufacturers have followed the tested blueprint of the motor vehicle industry, which includes four-wheeled rectilinear or translational motion. There has been little progress in developing platforms with omnidirectional and holonomic motion. The mecanum wheel, which has 3 degrees of freedom and can move in any direction, is the best iteration of this technology. There is a need to develop a mobile platform that can rival the mecanum wheel by providing holonomic motion and having a wider range of applications, especially in the industry.

This study explores the design and fabrication of such a mobile platform. The inspiration for this project comes from the use of caster wheels in various applications such as shopping carts, hospital carts, and in the industry for moving heavy payloads. The main objective was to add some form of control to these caster wheels, which would be achieved using Direct Current (DC) motors and stepper motors. By varying the speed of the DC motors and the angle of turn of the stepper motors, the speed and direction of the caster wheels could be controlled. The steering and driving motions of each wheel are mechanically coupled by belts and are actuated synchronously, ensuring that the wheel orientations are always identical, resulting in omnidirectional motion. The aim was to control these parameters remotely using a mobile application and a hand motion control device. The results of this process were conclusive, and a mobile platform with omnidirectional motion was developed. By utilizing the relatively untapped technology of caster wheels, this project makes a significant contribution to the advancements in omnidirectional and holonomic control of mobile platforms.

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Nomenclature

DC Direct Current

UN United Nations

SDG Sustainable Development Goals

UGVs Unamanned Ground Vehicles

GNSS Global navigation satellite system

LiDAR Light Detection and Ranging

SLAM Simultaneous Localization and Mapping

API Application Programming Interface

AC Alternating Current

SMPS Switched Mode Power Supply

RPM Revolutions Per Minute

PWM Pulse Width Modulation

MOSFET Metal-Oxide Semiconductor Field Effect Transistor

BJT Bipolar Junction Transistor

PCB Printed Circuit Board

MCU Microcontroller Unit

IMU Inertial Measurement Unit

CPU Central Processing Unit

MQTT Message Queuing Telemetry Transport

HTTP Hypertext Transfer Protocol

JWT JSON Web Token

ACL Access Control Lists

IoT Internet of Things

1 Introduction

1.1 Background

Mobile robots are gaining popularity, particularly in non-industrial applications such as military, disaster management, and home applications. This growth is driven by advancements in technology and the motor vehicle industry. Like traditional vehicles, mobile robots can be classified based on their type of motion. Most mobile robots have rectilinear motion, similar to regular cars. However, other platforms have omnidirectional motion, allowing them to move in any direction at any point in time or holonomic motion allowing them to move without changing the orientation of the platform's body. This type of motion is known as holonomic, the robots can be controlled by degrees of freedom equal to the total degrees of freedom of the mobile robot. A good example of this type of motion is the mecanum wheel. Another example that inspired this project is the caster wheel. This project proposal aims to apply the concept of omnidirectional and holonomic motion in caster wheels to develop a mobile platform with potential applications in commercial settings such as industries, hospitals, and supermarkets. The goal of this project is to design and fabricate a mobile platform with omnidirectional and holonomic motion using caster wheels and to evaluate the control challenges associated with this type of motion. The results of this project could contribute to the advancement of omnidirectional and holonomic control of mobile platforms.

1.2 Problem statement

Mobile robots and platforms have found general applications in homes and other non-industrial applications. These vehicles are largely unmanned and operated remotely. This technology can be adopted for commercial use by improving on caster technology. Casters are used to move heavy and large objects on the warehouse or factory floor. This process is manual and the operator has to push around the caster physically. Casters require an initial push force to begin rolling. Furthermore, labourers get tired easily when pushing the heavy casters around especially due to difficulty in maintaining the correct swivelling. The need, therefore, arises to develop unmanned mobile platforms that use caster wheels which is able to achieve holonomic and omnidirectional motion.

1.3 Objectives

1.3.1 Main Objective

To design and fabricate a prototype mobile platform capable of omnidirectional and holonomic motion.

1.3.2 Specific Objectives

1. To design and build a mechanical chassis and body that will hold the wheels and carry the bulk of the load respectively.
2. To design and build a wheel frame to hold the wheel and the power transmission system.
3. To design a motor control circuit for translation and rotational motion for each caster wheels.
4. To develop algorithms to control the platform and achieve holonomic and omnidirectional motion.

1.4 Justification of the study

The design and fabrication of a prototype mobile platform with holonomic and omnidirectional motion is a justified study for several reasons.

Firstly, mobile platforms are an important and growing technology, with a wide range of potential applications in various fields, such as transportation, material handling, logistics, and military operations. However, most mobile platforms currently available are limited to rectilinear or translational motion, meaning they can only move in a straight line or turn about a fixed axis. This limitation restricts their capabilities and limits their potential use in certain scenarios, such as navigating complex or cluttered environments or performing precise movements.

Secondly, omnidirectional and holonomic motion, which allows a mobile platform to move in any direction with equal ease, has the potential to greatly enhance the capabilities and versatility of mobile platforms. This type of motion is typically achieved using specialized wheels or motors, such as mecanum wheels or Mecanum drive systems, which have 3 degrees of freedom and can move in any direction. However, these technologies can be expensive and complex to implement, and may not be suitable for all applications.

Overall, the design and fabrication of a prototype mobile platform with holonomic and omnidirectional motion is a justified study due to the potential benefits and advancements it could bring to the field of mobile platforms, as well as the need for a more affordable and practical solution for achieving this type of motion.

The apparent availability of cheap and accessible technologies that are bridging the gap between holonomic and nonholonomic motion control is the main motivation behind this study. Holonomic motion is very efficient, with navigation to and from tight spaces being a reality. Furthermore, developing a cheap holonomic mobile platform in the field of mobile robots, especially in Sub-Saharan Africa aligns with one of the United Nations United Nations (UN) Sustainable Development Goals Sustainable Development Goals (SDG) goals, building infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation [1].

1.5 Expected Outcomes

1. A fully operational mobile platform with a chassis and body
2. Omnidirectional and holonomic motion control
3. Unmanned control using a mobile application and a hand motion control device

2 Literature Review

2.1 Introduction

The majority of mobile platforms or unmanned vehicles in use today are non-holonomic. They only have one or two degrees of freedom that are independent. As a result, their manoeuvrability is limited, and frequently require a large amount of space to control functions such as turning and parking [2]. This is apparent when an automobile wants to make a 180^0 turn. By increasing a vehicles degrees of freedom its manoeuvrability is greatly improved. It can follow many complex trajectories that conventional non-holonomic vehicles find difficult or impossible. Holonomic refers to the relationship between controllable and total degrees of freedom of a robot. A holonomic platform is any mobile platform with three independent degrees of freedom in a plane. If the controllable degree of freedom is equal to the total degrees of freedom, then the robot is said to be holonomic [3]. Independent degrees of freedom indicate that it can change its orientation or position without affecting other motions, as opposed to car-type vehicles, which must turn or change their orientation when moving. A robot built on castor wheels or Omni-wheels is a good example of a holonomic drive as it can freely move in any direction and the controllable degrees of freedom are equal to total degrees of freedom. Holonomic drive makes a robot omnidirectional, meaning that the robot can move in any direction, forward/backwards but also sideways left/right, and turn on the spot, thanks to its wheels, giving the robot omnidirectional capabilities for movement on the horizontal axis on a drivetrain, as well as forward and backward movement [4].

2.2 Mobile Robots

There are different iterations of mobile robots, categorized into three broad categories - ground vehicles, underwater vehicles and aerial vehicles. This research narrows its focus to unmanned ground vehicles. Unamanned Ground Vehicles (UGVs) are robotic systems that operate on land without an onboard human operator [5]. They are used for a wide variety of both civilian and military applications, particularly in environments that are hazardous or unpleasant to humans and for tasks that are difficult, dull or pose unacceptable risks. The three main locomotion methods for ground mobile robots are wheels, tracks and legs [5]. Wheels are power-efficient and allow the highest speeds on flat ground, but are not good for traversing off-road and uneven terrain, as they can get stuck or sink into the ground due to low contact surface area and thus higher pressure. Tracks are the best option for rugged terrain but are slower, less efficient, involve more mechanical complexity and cause more vibration. Legged ground robots can cope with a wide variety of terrain, but are limited in speed and require complex control and stability hardware.

Figure 2.1: Tracked Ground Vehicle

For unmanned ground robots, wireless communication is used to relay sensor data and control instructions. UGVs can be equipped with a variety of sensors and payloads. Due to operating in indoor and other environments deprived of the Global navigation satellite system (GNSS), UGVs may rely on Light Detection and Ranging (LiDAR) sensors, combined with inertial navigation systems and vehicle odometry, for accurate navigation [5]. Mission-specific sensors and payloads include RGB and thermal cameras, manipulator arms, chemical and explosives sensors, and weapons systems [5]. Consequently, unmanned ground vehicles have found applications in commercial and non-commercial use, including the military, firefighting, crowd control and in agriculture.

2.3 Caster Wheel

A castor or caster wheel is a relatively free-rolling, non-powered, small un-driven wheel. It is designed for attachment to the bottom of a larger object, thus enabling easy movement across a floor or other hard surfaces. Caster wheels are manufactured in either a single-wheel, double-wheel, or compound-wheel configuration. Most castors are used simply to make a heavy or cumbersome piece of furniture or machinery - the vehicle - easier to move. Affixing small, unobtrusive wheels to the bottom of any large or bulky item is a great way to make it more mobile in certain scenarios. In most cases, they are attached to the underside of the vehicle via a fixed top plate, from which the wheel assembly hangs. The caster wheel, through this attachment, has omnidirectional motion based on user input. It can move forward, backward and sideways in any direction and provides at least four degrees of freedom.

2.4 Existing Technologies and Research

2.4.1 Mecanum Wheels

Mecanum wheels achieve holonomic and omnidirectional motion by having a series of rollers attached to their circumference [6]. These rollers have an axis of rotation at 450 to the plane of the wheel. The angled peripheral rollers translate a portion of the force in the rotational direction of the wheel [6]. Each mecanum wheel in a drive system has independent actuation and the resulting combination of forces to move these wheels produces a total force vector that allows the platform to move freely in any direction. Different variations of mecanum wheels depend on the number of rollers attached to individual wheels, as shown in 2.2.

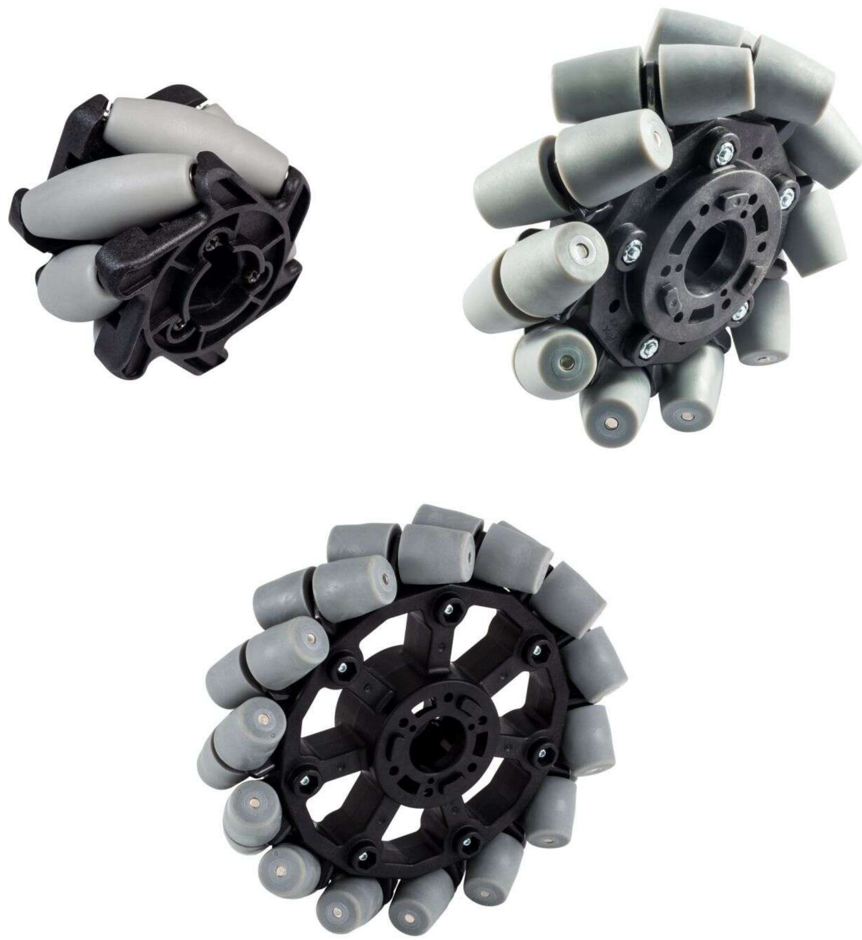

Figure 2.2: Different variations of mecanum wheels [6].

In the development of mecanum and other omnidirectional wheels [7] [5], undesirable vibrations are frequently present in the motion due to a large number of small rollers on the wheels periphery.

2.4.2 Onidirectional and Holonomic Motion

A lot of research and design work on omnidirectional vehicles has been conducted over the years. The earliest omnidirectional mobile vehicle to be proposed was based on introducing a methodology for the kinematic modelling of an omnidirectional wheeled mobile robot equipped with four omnidirectional wheels which were based on passive rollers arranged in an overlapping way [8]. These wheels were positioned in pairs on the same axle but with opposite orientations. Another proposal by Wada and Mori [9] presented a new type of holonomic mobile robot which was equipped with steerable and coordinated driving wheels using conventional tires to provide an omnidirectional capability by actuating the wheels axis and a steering axis independently. In another paper by Javier Moreno, Eduard Clotet, and others designed a three-wheel holonomic motion system for an assistant personal robot [8]. The paper analyzes the kinematics of the motion system and validates the estimation of the trajectory by comparing the displacement estimated with the internal odometry of the motors and the displacement estimated with a Simultaneous Localization and Mapping (SLAM) procedure based on LiDAR information.

2.4.3 Remote Control Strategies

Remote control strategies refer to the methods and technologies used to remotely operate a device or system from a distance. These strategies are commonly used in various applications, including industrial automation, robotics, and military operations. In the context of mobile platforms, remote control strategies can be used to remotely operate and control the movement of the platform.

One commonly used remote control strategy for mobile platforms is the use of wireless communication technologies, such as Bluetooth, Wi-Fi, and radio frequency (RF) communication. These technologies allow the remote operator to send commands to the platform and receive feedback from the platform through a wireless connection. Wireless communication technologies have the advantage of being easy to set up and use, as well as being relatively inexpensive. However, they can be prone to interference and have limited range.

Another remote control strategy for mobile platforms is the use of remote control devices, such as joysticks, game controllers, and hand motion control devices. These devices allow the operator to control the movement of the platform through physical input, such as pressing buttons or moving a joystick. Remote control devices have the advantage of providing a more intuitive and immersive experience for the operator, as they can directly control the movement of the platform. However, they may require training and practice to use effectively, and may not be suitable for all applications.

Another remote control strategy for mobile platforms is the use of computer-based control systems, such as programmable logic controllers (PLCs) and industrial control systems (ICS). These systems allow the operator to remotely control the platform through a computer interface, using software programs and algorithms to control the movement of the platform. Computer-based control systems have the advantage of being highly flexible and customizable, as they can be programmed to perform a wide range of tasks. However, they may require specialized knowledge and expertise to set up and use, and may be more complex and expensive compared to other remote control strategies.

The operator controls the remote robot with the control device while keeping an eye on the monitor, which displays visual data from the visual sensors. Expert operators who understand and are capable of training the remote-controlled robot are required to operate it flexibly. Thus, operating a remote-controlled robot is difficult and may result in operational errors. This is because using a monitor that only displays visual information makes it difficult for the operator to understand real-world environmental situations. As a result, numerous stages of training are required for the operator to recognise the surroundings from visual information for expert operation [10]. Methods for improving the operability of the remote-controlled robot in terms of the mechanical design of the control device and the operation-assist control method have been discovered. Wireless control strategies have advanced the multi-operability of robots [11] but they are just a network to which control strategies connect. This study proposes a remote-controlled method with an Application Programming Interface (API) to improve the diversity of remote-control applications.

2.5 Gap Analysis

Huge leaps have been made in the development of mobile vehicles or robots with holonomic and omnidirectional motion. Mecanum wheels have taken centre stage, and the use of rollers attached to a conventional wheel has found great applications in small-scale robots and mobile platforms. However, these wheels cannot be applied to certain applications that involve heavy payloads or rough terrains. Such applications are moving objects in warehouses or factory floors. Castors are predominantly used in these areas, but they have to be manually controlled. This process can be automated by modifying the castors through adding motors for directional control and adding the concept of remote control. Furthermore, robots have lacked the design of APIs embedded in their control. Most robots, if not all, have a fixed mode of control. This project seeks to explore how APIs can be added to robot control.

3 Methodology

In this section, the design and fabrication techniques for the development of the mobile platform are described.

3.1 Initial Design Considerations

The mobile platform was envisioned to be a representative prototype. Some of the measurable design considerations that were made to come up with the prototype were:

i. The prototype should be able to carry a total payload of 20kg inclusive of its own weight

ii. The platform should move at an average velocity of approximately $0.5 m/s$ adjusted from the speed of an average walking human being and have an acceleration of $0.25 m/s^2$

iii. An operating time of 30 minutes

iv. The size of the platform should be less than $45 cm$ in length, width and height.

v. The platform should have four drive motors and a minimum of two steering motors

vi. A mobile application to remotely control the platform

3.2 Platform Body

3.2.1 Design

The following design considerations were made in the process of developing the physical structure of the platform:

i. Total load

ii. Material selection

iii. Ease of assembly and disassembly

iv. Weight of the platform

v. Aesthetics

The mobile platform had to be lightweight and simultaneously have the ability to resist bending and compressive stresses. Table 3.1 below shows the different properties of the various metals that were considered. Aluminium has the lowest mass per cubic meter and has a relatively high yield and tensile strength. It was, therefore, determined to be the best material for the platform. An alternative material for use would have been mild steel due to the ease with which it can be acquired.

Table 3.1: Different Material Properties [12]

Types of Metals	Tensile Strength (PSI)	Yield Strength (PSI)	Hardness Rockwell (B-Scale)	Density (kg/m^3)
Stainless steel	90000	40000	88	8000
Aluminium 6061	45000	40000	60	2720
Mild Steel A36	58-80000	36000	-	7800
Titanium	63000	37000	80	4500
Copper	32000	28000	10	8940

Figures 3.1, 3.2, and 3.3 represent the platform body design as modelled on the AutoDesk Inventor 3-D modelling software.

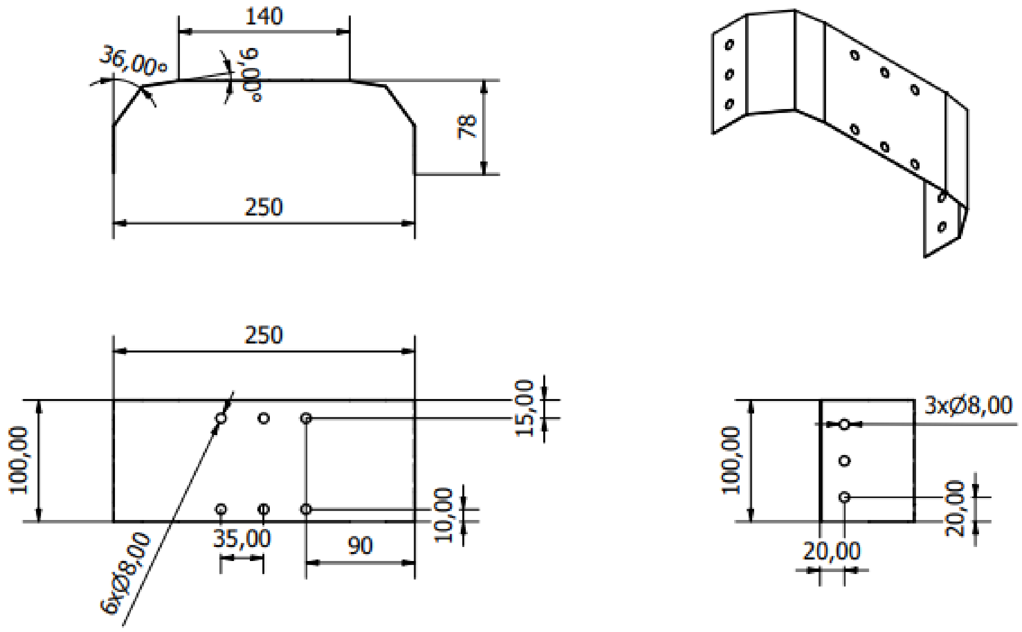

Figure 3.1: Platform Front and Back Design

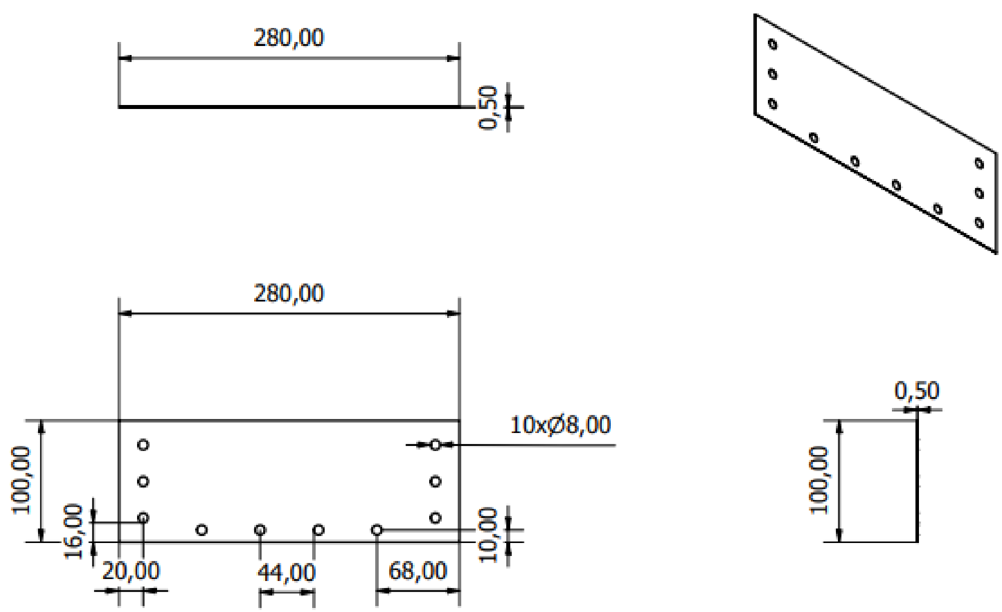

Figure 3.2: Platform Side Design

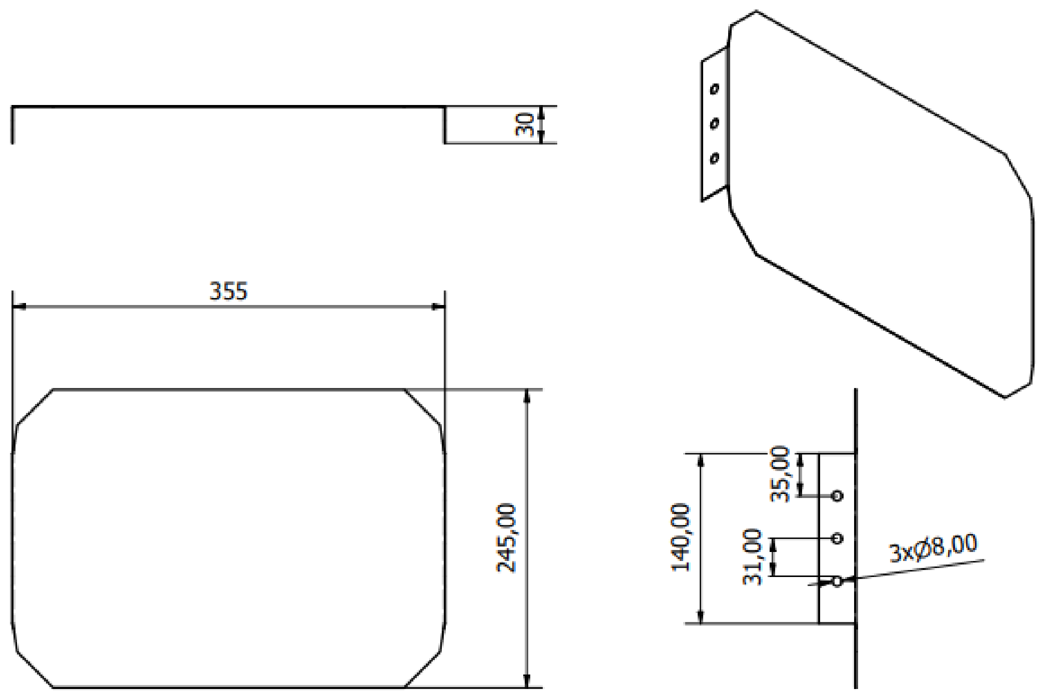

Figure 3.3: Platform Top Design

Figure 3.1 represents the front and the back of the platform while figure 3.2 represents the sides of the platform. Figure 3.3 shows the design for the top of the platform. This part will hold the payload. The dimensions were selected to ensure the platform meets the maximum size of 450mm in length, width and height as set out in the design considerations.

The final platform design is as shown in figure 3.4.

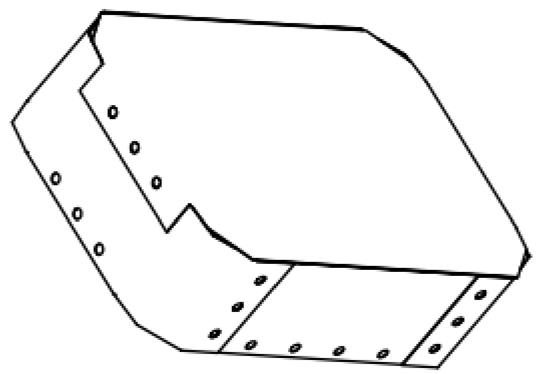

Figure 3.4: Platform Assembly

3.2.2 Fabrication

Fabrication of the different parts of the platform body involved various sheet metal operations, including cutting, bending, drilling and joining. From the design considerations in 3.2.1, the primary material selected for fabrication was aluminium. However, several challenges emerged when it came to the acquisition, that is:

i. Aluminium was difficult to find, especially in local shops. Consequently, online international shops had to be considered, but due to time constraints, they were considered unrealistic sources.

ii. Aluminium was expensive compared to other materials such as mild steel and galvanized steel. Most retailers listed aluminium at three times the price of mild steel.

iii. Retailers further sold the material in large proportions which would mean a lot of waste material once the fabrication was done. This made little financial sense in the long run.

Due to these challenges, aluminium was disregarded as the material of choice. Mild steel was the best alternative mainly due to the fact that it is readily available and relatively cheap to acquire. Furthermore, cost sharing was a real possibility due to most projects having mild steel as their material of choice.

Once the material was acquired, the next step was machining. The first step was cutting the sheet metal into the design dimensions. For instance, the platform side part was cut into two 280mm by 100mm pieces, whereas the front was cut into two 360mm by 100mm pieces and the top part was cut into a 355mm by 245mm piece. This was achieved using a hydraulic shearing machine.

The next step was bending the platform front parts (Figure 3.1) The folding angles were 9^0, 36^0 and 45^0. That precise order was followed to produce the desired shape on a manual bending machine. However, there were several limitations to this process, given that measuring the angles during bending was impossible. This meant approximations had to be made by eye during the process and confirmed later using a protractor. This might have resulted in some inaccurate angles but tolerances had been accounted for in the design process. The platform top (Figure 3.3) was also machined to create the 45^0 bend on either of its ends.

The final step in sheet fabrication was joining. Several joining methods were considered in the design process, including welding, screws and riveting. However, the two best were determined to be spot welding and using machine screws and nuts. To accommodate the machine screws, holes had to be created on the sheet metals. Diameter 3mm screws and nuts were the sizes selected. The holes were created using a drilling machine and 3mm drill bits. The holes were made on the bottom part of the platform side (Figure 3.2) and the bottom part of the platform front (Figure 3.1). These holes would be used to join the platform body to the chassis.

The platform side and front were joined using spot welding. To carry out the spot weld, the surfaces had to be cleared of all stains and roughness. An emery paper was used to achieve a smooth and shiny surface on all the surfaces that would be used for joining.

The platform top was joined to the other parts using machine screws and nuts. This fulfilled a design consideration in Section 3.2.1 as it made the design easy to assemble and disassemble.

Figure 3.5: Front and side assembly

Figure 3.6: Fabricated Platform Body

3.3 Platform Chassis

3.3.1 Design

The design considerations made for the platform chassis were:

i. Load capacity

ii. Material selection

iii. Chassis type

The first two considerations are directly related as it was important to select the chassis material based on its ability to handle a payload, a factor determined by the tensile strength, compressive strength, and torsional strength. The chassis carries the whole load and therefore the material selected needed to have high tensile strength. Table 3.1 was used to make this determination and mild steel was settled on as the material of choice. Stainless steel was considered but material cost was a huge factor in the design process.

There are many types of chassis designs each suited to handle the load cases described above. There are ladder frames that carry all load and have good bending strength and stiffness. Other types are cruciform frames which can carry torsional loads. They are made of two straight beams and have only bending loads. The torque tube backbone (tube-frame) frame is made of a closed box section as the main backbone. Traverse beams resist lateral loads and backbone frame bending and torsion.

Considering all these properties, it was determined that a blend of cruciform frames and traverse beams would be ideal to accommodate all forces. The developed chassis design is as shown by figure 3.7. These designs were made using Autodesk Inventor 3-D modelling software.

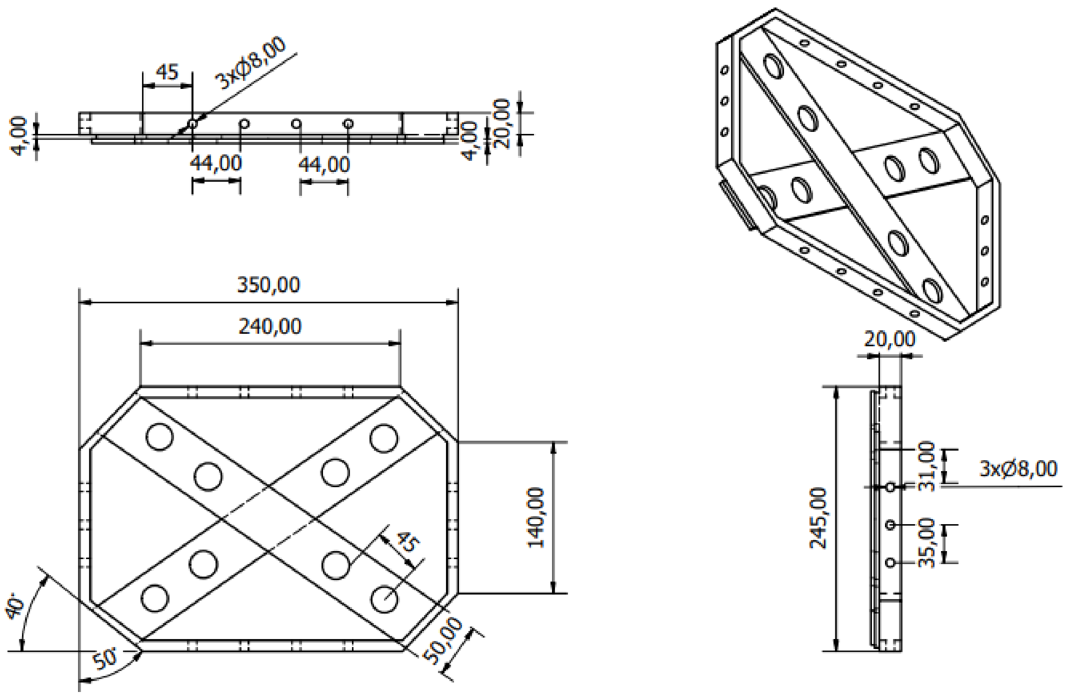

Figure 3.7: Chassis Design

3.3.2 Fabrication

The material selected for use was rectangular mild steel bars with a $2mm$ thickness and $20mm$ width. Several processes needed to be carried out to come up with the design in Figure 3.7, including marking, cutting, filing, drilling and joining. Some of the tools and equipment required to do this include:

i. steel rule

ii. scriber

iii. file

iv. hacksaw

v. hydraulic shearing machine

vi. drilling machine

vii. drill bits

viii. arc welding machine

First, the general length dimensions were marked out and four bars were produced by cutting the raw material on a hydraulic shearing machine. The lengths of these bars were 240mm and 140mm, two of each. Four smaller bars that would join the front and side bars were cut using a hacksaw because of their relatively small lengths. Two more bars that would form the diagonals to form some form of cruciform were cut separately with dimensions of 50mm width and 350mm length.

All the holes were then made on the drilling machine. Holes were made on the diagonal metal bars using an 8mm drill bit and would be used to attach the wheels and motors to the chassis. The front and side bars were also drilled using 3mm drill bits for assembly to the platform body in Figure 3.5

Once all the individual parts were fabricated, they were all joined using metal arc welding, a fusion welding process used to join metals. They were joined as depicted in Figure 3.7 and Figure 3.8

Figure 3.8 is a visual representation of the results of the chassis fabrication process.

Figure 3.8: Chassis

3.4 Wheel Frame

3.4.1 Design

The wheel frame had similar payload design considerations as the chassis because the frame would be supporting all the weight from the platform. The frame would handle the bulk of the load and therefore a high tensile and yield strength material would be required. Mild steel was the go-to material for the chassis and would be here as well. Other considerations would be the size since it would hold the caster wheel, drive DC motor, and the power transmission system. The most common DC motors have diameters ranging between 25mm and 30mm while their lengths range between 40mm and 70mm. The motor selected had a diameter of 25mm and a total length of 45mm. Section 3.7 provides more information on motor selection. The power transmission system of choice would be a belt and pulley of a maximum diameter of 16mm. The caster wheel of choice had a diameter of 70mm.

Taking all these dimensions and parameters into consideration, the dimensions of the wheel frame were determined to be a height of 90mm, length of 50mm, and width of 50mm as in Figure 3.9.

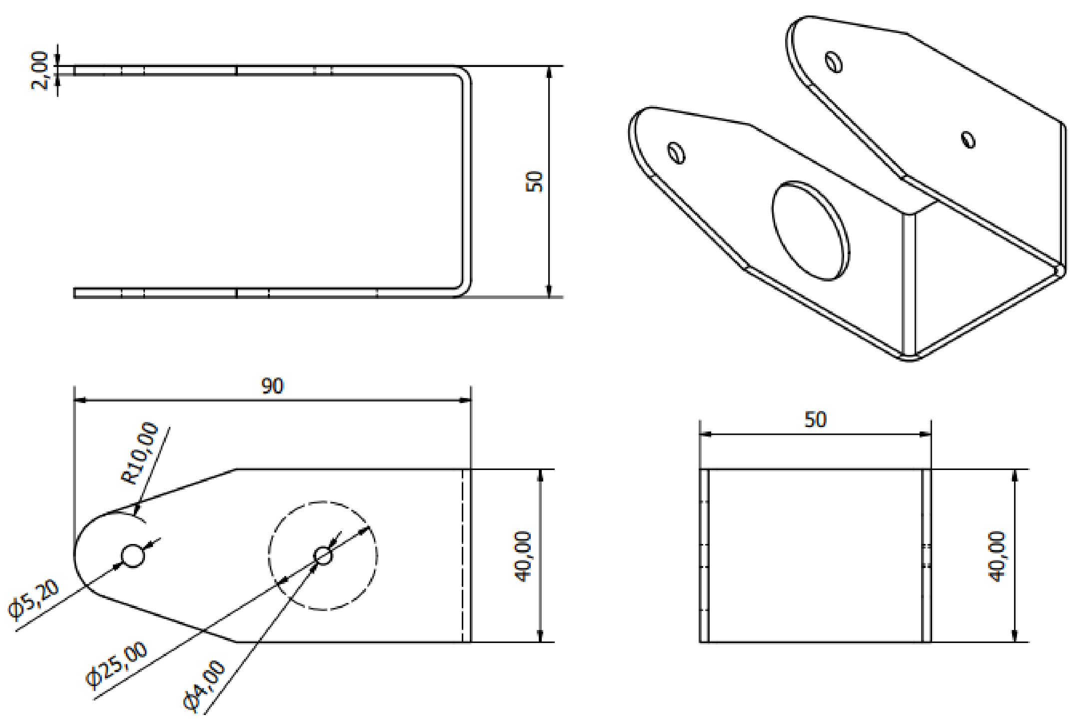

Figure 3.9: Wheel Frame Design

3.4.2 Fabrication

The wheel frame material used was similar to the material used to fabricate the platform body in Figure 3.5. A mild steel metal sheet of thickness 1.5mm was machined to produce the frame by going through processes such as cutting, bending, drilling and filling.

The first operation was cutting the wheel frame to a length of 230mm and width of 40mm using the hydraulic shearing machine. Next, various holes that would hold bearings and the motor were made using a drilling machine. The bearing holes were made using 10mm drill bits while the motor holes were made using 25mm drill bits. However, to make the 25mm hole, several drill bits were used to offset the torque generated by the drilling machines. This consideration was made due to one of the wheel frames getting destroyed by a 25mm drill bit due to high torque and a large drill bit diameter as in Figure 3.10.

Figure 3.10: Wheel Frame Fabrication Challenge

The next step was filing the wheel frame to achieve the angled shape at either end of the wheel frame. Finally, the frame was bent as in Figure 3.12 using a manual bending machine to create 90^0 bends, to give the final result.

Figure 3.11: Wheel Frame

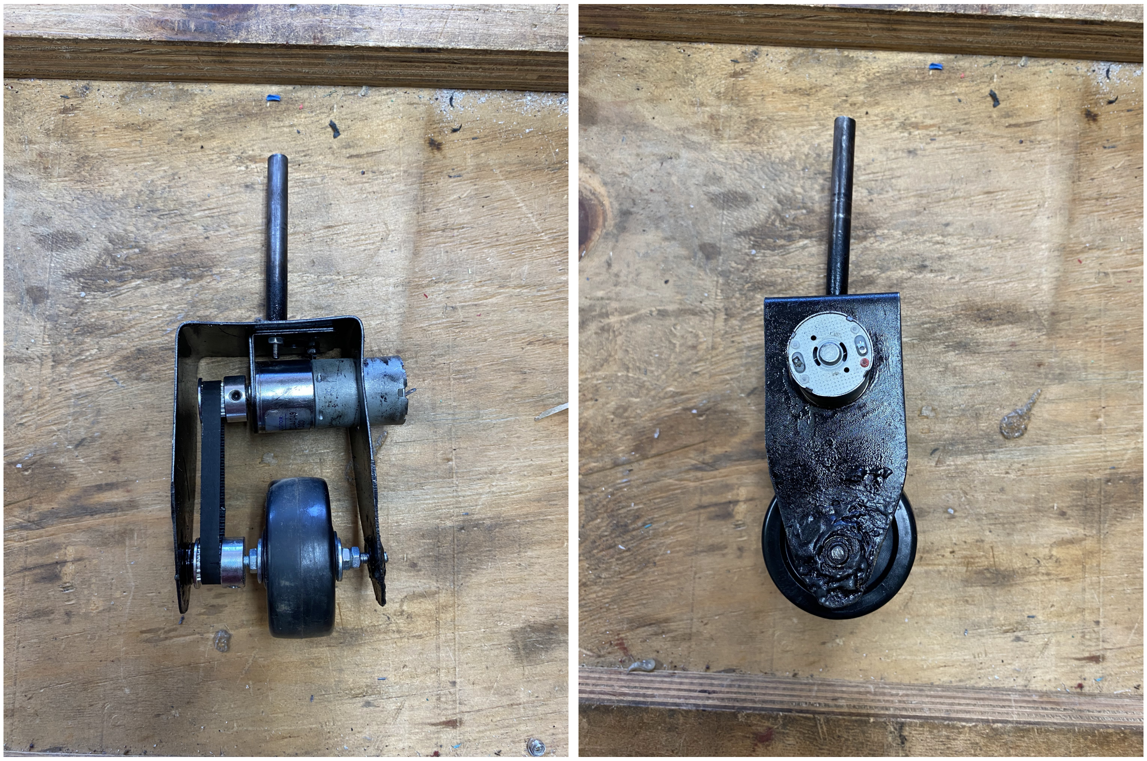

Figure 3.12: Wheel-on-Frame Assembly

As described in Section 3.3.2, several holes were made to attach the wheel frame to the chassis. This attachment was made using an $8mm$ diameter shaft. The $8mm$ shaft would be joined to the chassis using a bearing. To join the shaft to the wheel frame, gas welding was used. Other choices considered were arc welding, Araldite adhesive, and using machine screws. These were disregarded for various reasons. Arc welding was ruled out because the heat from the electrode, which gets as high as 3500^0 Celcius [13] would melt the sheet metal which has a melting point of $1350^0C - 1530^0C$. [14]

Araldite adhesive was eliminated as there was uncertainty over whether it would hold the weight for an extended period of time. Finally, machine screws were eliminated due to the difficulty in drilling through the whole length of the $8mm$ shaft.

The final wheel-on-chassis assembly in Figure 3.13 was done once all the individual parts were fabricated, and once the DC motor, power transmission system and caster wheel were attached to the wheel frame.

Figure 3.13: Wheel Frame-on-Chassis Assembly

3.5 Power Transmission

3.5.1 Design

The main design consideration when deciding on the power transmission system was that a certain amount of power had to be transferred from the DC motors to the caster wheels for work to be done. Several power transmission systems were considered, but ultimately belt drives were considered the best choice for the following reasons:

i. There would be a centre distance between the motor and wheel shafts, a distance that would require several gears to fill which would make the design bulky. This eliminated gears as a means of transmission

ii. The design did not require speed reduction which eliminated gear drives

iii. Belt drives require less maintenance than chain drives, for example, lubrication

iv. Belt drives are lighter than chain drives and gear drives, and given that the weight of the platform is one of the main design considerations, belt drives were the preferred choice

Once belt drives were selected for use, other considerations were taken into account, including: The following factors were considered when selecting a belt drive:

i. The speed of the driving and driven shafts

ii. Speed reduction ratio

iii. Power to be transmitted

iv. Center distance between shafts

v. Positive drive requirements

vi. Wheel frame dimensions

The mobile platform was conceived as a low-speed application, with the highest speed being comparable to the speed of a walking human being. There was therefore no need for speed reduction, meaning that the velocity ratio (speed reduction ratio) was one. This also meant that the pulleys could have the same diameter. To establish the relationship between the speed of the driving and driven shafts:

Velocity ratio:

$$\frac{N_2}{N_1} = \left(\frac{d_1}{d_2}\right) \tag{3.1}$$

where:

- d_1 is the diameter of the driver pulley

- d_2 is the diameter of the driven pulley
- N_1 is the speed of the driver pulley in rpm
- N_2 is the speed of the driven pulley in rpm

Given that the velocity ratio is equal to 1, $N_1 = N_2$ and $d_1 = d_2$

The velocity of the driving and driven shafts was determined to be equal.

From the considerations made in Section 3.4.1 on the design of the wheel frame, the centre distance between the pulley attached to the DC motor and the pulley attached to the wheel shaft was established to be $45mm$. The diameter of the pulley was determined using bore diameter. The bore diameter is dependent on the diameter of the wheel and motor shafts. These diameters are both $5mm$ and the industry-standard outside diameter for a pulley with $5mm$ bore diameter ranges from $9.68mm$ to $37.68mm$. The industry standard is based on the common 2GT synchronous pulleys found in many small actuator applications such as 3-D printers. To make the wheel frame design more compact, a maximum pulley diameter of $16mm$ was selected for the pulley design.

Length of belt:

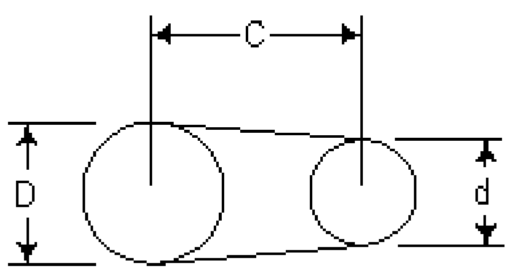

Figure 3.14: Center distance [15]

$$L = \frac{\pi}{2}(d_1 + d_2) + 2C + \frac{(d_1 + d_2)^2}{4C} \tag{3.2}$$

where:

- L is the total length of the belt
- d_1 is the diameter of the driver pulley
- d_2 is the diameter of the driven pulley
- C is the centre distance of the shaft

Based on the parameters established above, the total length of the belt is: Length of belt:

$$\begin{aligned} L &= \frac{\pi}{2}(16+16) + 2*45 + \frac{(16+16)^2}{4*45} \\ L &= 146 \end{aligned} \tag{3.3}$$

Arc of contact: The angle of contact between the belt and pulleys as shown in Figure 3.14 is given by:

$$\begin{aligned} \theta_{\mathrm{d}} &= \pi - 2\sin^{-1}\frac{D-d}{2C} \\ \theta_{\mathrm{D}} &= \pi + 2\sin^{-1}\frac{D-d}{2C} \end{aligned} \tag{3.4}$$

Since the pulleys have an equal diameter, the angle of contact of the belt on both pulleys is 90° or 1.57 radians.

Power transmitted: Power transmitted by a belt drive:

$$Power = (T_1 + T_2)v \tag{3.5}$$

where:

- T_1 is the belt tension in the tight size (N)
- T_2 is the belt tension in the slack side (N) v is the belt speed. Maximum drive speed is $0.5m/s^2$ (Section 3.1)

Assuming that the friction is uniform throughout the arc of contact and ignoring centrifugal effects, the ratio of the tensions in the belts can be modeled by Eytleweins formula:

$$\frac{T_1}{T_2} = e^{\mu\theta} \tag{3.6}$$

where:

- θ is the angle of contact
- μ is the coefficient of friction

The maximum allowable tension, $T_{1,max}$, on the tight side of a belt, depends on the allowable stress, α_{max}, of the belt material in this case rubber.

$$T_{1,max} = \alpha_{max} A \tag{3.7}$$

where:

- A is the cross-sectional area of the belt, i.e.,

$$A = bt \tag{3.8}$$

- b is the belt width
- t is the belt thickness

For standard 2GT synchronous pulleys, the maximum tooth width is 11mm and maximum thickness is 1.8mm. The maximum allowable stress for rubber is 5MPa.

Therefore:

$$\begin{aligned} T_{1,max} &= 5 * 10^6 * \frac{11}{1000} * \frac{1.8}{1000} \\ &= 99N \end{aligned} \tag{3.9}$$

Given that:

$$\begin{aligned}
&\frac{T_1}{T_2} = e^{\mu\theta}, and\ T_1 = 99N, \mu = 0.32, \theta = 1.57radians \\
&T_2 = 61.81N
\end{aligned} \tag{3.10}$$

Power transmitted by the belt drive:

$$\begin{aligned}
&P = (T_1 + T_2)v \\
&P = (T_1 + T_2) * 0.5 \\
&P = 80.4W
\end{aligned} \tag{3.11}$$

Torque transmitted by the belt drive:

$$\begin{aligned}
&T = (T_1 + T_2)r \\
&T = (T_1 + T_2)\frac{8}{1000} \\
&T = 1.28Nm
\end{aligned} \tag{3.12}$$

This torque value is important when considering the kind of DC motor to use.

3.5.2 Fabrication

Based on design considerations, the pulley was selected from the industry standard 2GT synchronous pulleys. These pulleys have a bore diameter of $6mm$ and a smaller shaft can be screwed tight using an Allen key. The pulley has twenty teeth along its diameter, along which the belt fits perfectly as in Figure 3.17.

Figure 3.15: Pulley Selected

The belt also exists in standard form as represented in Figure 3.16.

Figure 3.16: Timing Belt Selected

Figure 3.17: Timing Belt and Pulley

3.6 Bearing Selection

3.6.1 Design

The choice of bearing depended on the type of payload the platform was going to carry. This would dictate whether the load was axial or radial, or a combination of the two. A very large axial load would require the use of axial or thrust bearings which withstand force in the same direction as the shaft. Roller and radial ball bearings, on the other hand, are designed to withstand radial loads. However, some radial ball bearings are able to withstand both medium-large radial and axial loads [16], which makes them a perfect fit for the platform. Moreover, radial ball bearings are easy to acquire due to their affordability. The bore diameter of the bearings was dependent on the diameter of the shafts. The wheel shaft diameter was listed as being $1mm$ whereas the wheel frame shaft had a diameter of $8mm$. Bearings with these respective diameters were chosen for the design.

3.6.2 Fabrication

When it came to attaching the bearing to the chassis in Figure 3.8, a bearing housing had to be machined. However, to save time and resources, a bearing with a fitted housing and attachment block was purchased. It was a much cheaper option and turned out to be very effective.

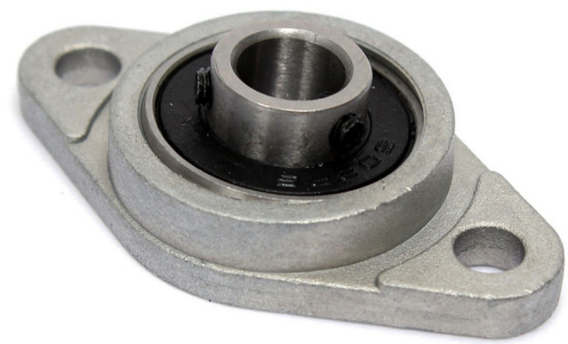

Figure 3.18: 8mm Bearing with Housing

The bearing in Figure 3.18 also had a provision for fitting shafts with a diameter less than 8mm with screws that could be tightened with an Allen key.

Figure 3.19: $1mm$ Bearing

3.7 Motor Selection

3.7.1 Design

The motor is responsible for supplying the drive to the transmission system responsible for the movement of the robot. There are numerous motor types that can be used in robotic applications. Each type of motor serves a distinct purpose. The motors help the robot move and act as actuators in the mechanical design of the robot. Since this is a mobile robot with a small payload size, Alternating Current (AC) motors are ruled out. The remaining DC motors used for locomotion are:

i. Brushed DC motors use brushes to conduct current between the source and the armature. There are several types of brushed DC motors, but permanent magnet DC motors are used in robotics. These motors have a high torque-to-inertia ratio. Brush DC motors are capable of producing torque three to four times greater than their rated torque. The brush DC motors have two terminals. When a voltage is applied across the two terminals, a proportional speed is output to the brush DC motor's shaft.

ii. Brushless DC motors are built similarly to brushed DC motors, but they are controlled by closed-loop controllers and require inverters or Switched Mode Power Supply (SMPS) for power. Permanent magnets rotate a fixed armature in these motors. Unlike Brush DC motors, they have a closed-loop electronic controller instead of a commutator assembly. These motors are typically used in industrial robotics where precise motion and positioning control are required. These motors, however, are quite expensive and involve complex construction and electronics.

iii. Geared DC motors are a more advanced version of brush DC motors. A gear assembly is attached to the motor. The motor's speed is reduced as the torque increases thanks to the gear assembly. The speed of the DC motor can be reduced while increasing torque by using the proper combination of gears to the motor. This ensures that the motor rotates steadily and that it can be stopped or changed speed in a controlled manner. DC motors operate within a specific voltage range, and the higher the input voltage, the higher the Revolutions Per Minute (RPM).

When selecting the right motor to use in this application the following design considerations were made:

1. a high torque motor of approximately $1Nm$ that could carry a payload of $20kg$ (Section 3.1) at low speed
2. the operating voltage, which has a direct correlation with the power drawn from the battery, thus influencing the capacity of the battery
3. Cost and availability

From the motor choices listed above, the geared DC motor was selected for this application. This choice was influenced by various parameters showcased in Table 3.2.

Once the geared DC motor was chosen, the specific properties of the right geared DC motor had to be established. The following considerations were taken when selecting this motor.

Table 3.2: Comparison between different motors

Parameters	Brushed DC motors	Brushless DC motors	Geared DC motors
Speed	Fast	High	Low
Torque	Low	Low	High
Cost	Inexpensive	Expensive	Inexpensive
Availability	Available	Available	Available
Operating Voltage	$6V$ - $12V$	$12V$	$6V$ - $12V$
Lifetime	Short	Long	Short
Efficiency	Low	High	Low
Noise	High	Low	Low

i. Nominal Voltage. The higher the voltage, the less current will be needed to supply the electrical power to the motors. A $6V$ motor will draw twice as much current as a $12V$ motor for the same application

ii. No Load RPM and full load RPM

iii. Stall current and Stall torque - The system ought to be designed to never allow the motor to come anywhere near this point, This can be done by ensuring the motor operated at least 30% of the stall torque.

iv. Gear down - This helps to achieve the required torque at the output of the shaft and allows the transmission unit to run at a gear ratio of 1:1. The output speed is reduced to a manageable level while the torque is increased.

v. Rotary encoders. This would be a great addition, but finding a geared DC motor with the rotary encoder attached to it is difficult.

Torque is another important element when selecting the right motor. This torque, therefore, has to be determined as follows:

From Figure 3.20 with a 5° inclined surface, only one component of its weight, mg_x parallel to the surface, causes the robot to move downwards. The other component, mg_y,

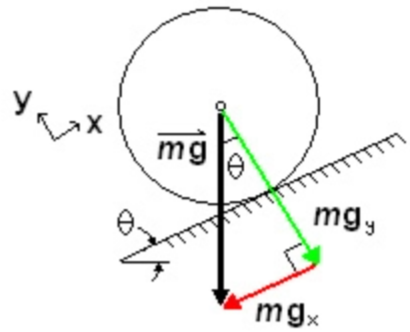

Figure 3.20: Simple Torque Representation On an Inclined Surface

is balanced by the normal force the surface exerts on the wheels. mg_x is calculated as shown by Equation 3.13 and mg_y is calculated as shown by Equation 3.14

$$\begin{aligned} mg_x &= mg * sin(\theta) \\ &= 45 * 9.81 * sin(5) \\ &= 38.4749N \end{aligned} \tag{3.13}$$

$$\begin{aligned} mg_y &= mg * cos(\theta) \\ &= 45 * 9.81 * cos(5) \\ &= 439.7701N \end{aligned} \tag{3.14}$$

For the robot not to slide down the incline, there must be friction between the wheel and the surface. The torque (T) required is given by equation 3.15.

$$T = f * R \tag{3.15}$$

To select the proper motor, we must consider the worst-case scenario, where the robot is not only on an incline but accelerating up it. Note now that all forces (F) are along the x and y axes. The forces in the x-direction are balanced as shown in equation 3.16

$$\begin{aligned} F_x &= m * a \\ &= f - mg_x \\ &= \frac{T}{R} - mg_x \end{aligned} \tag{3.16}$$

$$T = R * M * (a + g * sin(\theta)) \tag{3.17}$$

This torque given by equation 3.17 value represents the total torque required to accelerate the robot up an incline. However, this value must be divided by the total number (N) of drive wheels to obtain the torque needed for each drive motor. The final point to consider is the efficiency (e) of the motor, gearing, and wheel (slip). This results to the torque required by each wheel as shown by equation 3.18

$$T = \frac{100}{e} * \frac{R * M * (a + g * sin(\theta))}{N} \tag{3.18}$$

The value for efficiency here represents the total efficiency, as shown by equation 3.24, of the system and can be estimated as follows:

- Battery to Motor Controller: 90% efficient
- Motor Controller to Motors: 70% efficient
- Transmission to Wheels 80% efficient

The lost energy is transferred mostly to heat and noise.

$$\begin{aligned} e &= 0.9 * 0.7 * 0.8 \\ &= 50.4\% \end{aligned} \tag{3.19}$$

With a total efficiency of the system as 50.4% torque required by each wheel is calculated as shown in equation 3.20.

$$\begin{aligned} T &= \frac{100}{50.4} * \frac{0.015 * 45 * (0.25 + 9.81 * sin(5))}{4} \\ &= 0.37Nm \end{aligned} \tag{3.20}$$

With this a motor of $12V$ 250 RPM DC motor of $0.8629N/m$ in torque can suffice for this operation. This motor can provide the required torque for this application but the Speed will be reduced to $0.3927m/s$ as shown by equation 3.22 which is not far off from the expected $0.5m/s$.

$$w = \frac{2 * \pi * N}{60} \tag{3.21}$$

$$\begin{aligned} v &= r * w \\ &= 0.015 * \frac{2 * \pi * 250}{60} \\ &= 0.3927m/s \end{aligned} \tag{3.22}$$

The total power (P) per motor can be calculated using the following relation:

$$\begin{aligned} P &= T * w \\ &= 0.37 * \frac{2 * \pi * 250}{60} \\ &= 9.6866W \end{aligned} \tag{3.23}$$

$$\begin{aligned} I &= \frac{P}{V} \\ &= \frac{9.6866W}{12V} \\ &= 0.8072A \end{aligned} \tag{3.24}$$

The maximum current that id drawn from a battery is $0.4843A$ to be supplied to the motors.

Finally, the capacity (C) of the battery pack required can be estimated using the equation 3.25:

$$\begin{aligned} C &= I * t \\ &= 0.8072 * 1 \\ &= 0.8072Ah \\ &= 0.8072 * 8 \\ &= 3.2288Ah \end{aligned} \tag{3.25}$$

With a $3.2Ah$ battery the motors will be able to run the mobile platform for 1hr without recharging.

3.7.2 Implementation

Having calculated the torque required from the DC motor in Section 3.7, a geared DC motor that met all the specified conditions was chosen. The particular motor, shown in Figure 3.21 is a 12V, 300rpm and 0.8629Nm motor that has enough torque to move a $20kg$ payload. The motor also coincides with the dimensions listed when designing for the wheel frame in section 3.4.1 as it has a diameter of $25mm$ and a total length of $50mm$

Figure 3.21: Geared DC Motor

This motor torque is also less than the torque determined for the power transmission system in section 3.5.1. This means that the belt drives considered can transmit the power from the DC motor.

3.7.3 Design Changes

The original plan was to apply geared DC motors for both drive and steering functions. However, a realisation was made that DC motors would not provide feedback data on the exact position of the shaft, information that was crucial in controlling the direction of the platform. For this purpose, an encoded DC motor or a standard stepper motor were the ideal choices. However, the encoded DC motor was difficult to acquire locally, mostly due to empty stores or blatant overpriced quotations. On the other hand, stepper motors were easy to acquire, even from second-hand shops, a choice that proved financially sound.

A stepper motor of the same specifications as the DC motor selected in Section 3.7 was purchased for direction control. This meant there was a total of four geared DC motors for drive, and at least two stepper motors for direction control.

Having changed to a different motor altogether, there was concern that the motor driver modules selected for the platform in Section 3.8 would be unable to control the stepper motor. However, this was not the case because the drivers could each support one stepper motor meaning that the motor control design did not have to change.

Figure 3.22: Stepper Motor Selected

3.8 Motor Control

3.8.1 Design

Motor control is achieved using a motor driver module. Motor direction control is achieved using an H-bridge circuit whereas speed control is achieved using Pulse Width Modulation (PWM) Some of the design considerations that were made when choosing a motor driver were:

i. Ability to both control speed and rotations

ii. The higher the number of motor outputs the better

iii. The operating voltage should be inclusive of our motor voltage of 12V.

iv. The higher the efficiency the better. Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) controlled drivers have a higher efficiency that Bipolar Junction Transistor (BJT).

v. A small form factor would be better

vi. Maximum current it can supply to the motors should be approximately 1A needed to generate our required torque of $0.37Nm$

Several motor drivers were considered, including the L293D circuit. However, The Satima S2 motor driver, a custom driver based on DRV880 that can be used to drive either 2 bidirectional or 4 unidirectional DC motors, was best suited for this application. This is because it can operate a 12V motor voltage, can supply up to a maximum of 3A per channel and High-Noise-Immunity Inputs. Furthermore, it is MOSFET controlled making it have higher efficiency compared to the BJT-powered L293D.

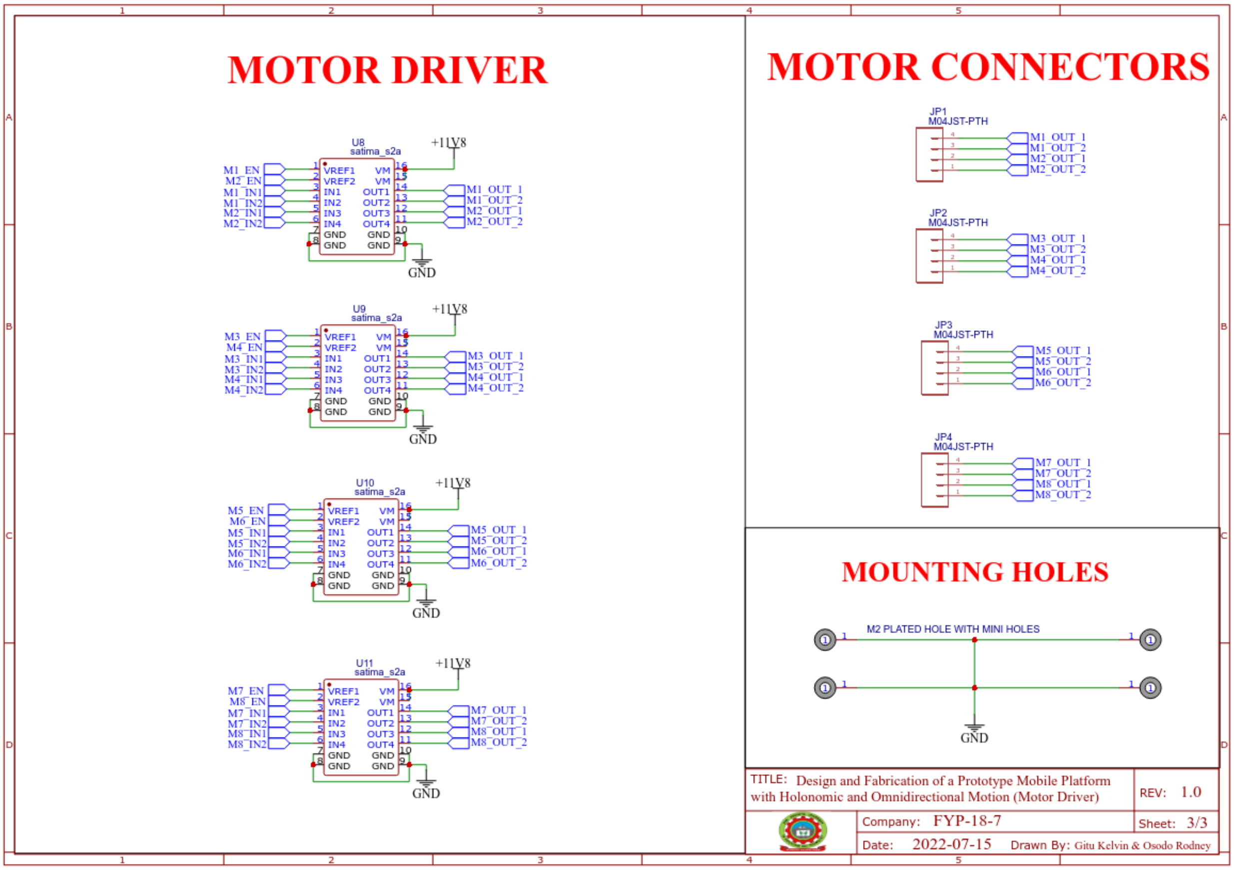

Figure 3.23: Motor Driver Schematic

Figure 3.23 shows the Motor Driver schematic, which is a part of the Mobile Platform. There are 8 motors controlled by 4 motor drivers which can be able to control 2 motors per motor driver. The Connectors are JST connectors as they are strong and reliable. The mounting holes are connected to the ground as they will be screwed on to the platform. The schematic was designed using the open-end software EasyEDA.

Once the schematics were designed, the actual PCB in Figure 3.25 that would host the circuit for motor control was also designed and simulated. The same software, EasyEDA was used for this function.

3.8.2 Fabrication

The satima motor driver in Figure 3.24 and the PCB in Figure 3.26 were manufactured based on their individual scematics. The choice was made to use PCB companies such as Gearbox or JLPCB as the components would require complex fabrication techniques that could not be achieved manually. For this case, JLPCB was the manufacturer of choice. All that had to be done was send the relevant Gerber files generated from the design processs to the manufacturer and pay for the service. A Gerber file is an open ASCII vector format file that contains information on each physical board layer of your PCB design [17]. Circuit board objects, like copper traces, vias, pads, solder mask and silkscreen images, are all represented by a flash or draw code, and defined by a series of vector coordinates. These files are used by PCB manufacturers to translate the details of your design into the physical properties of the PCB. The Gerber files are generated by the PCB design software, in this case, EasyEDA.

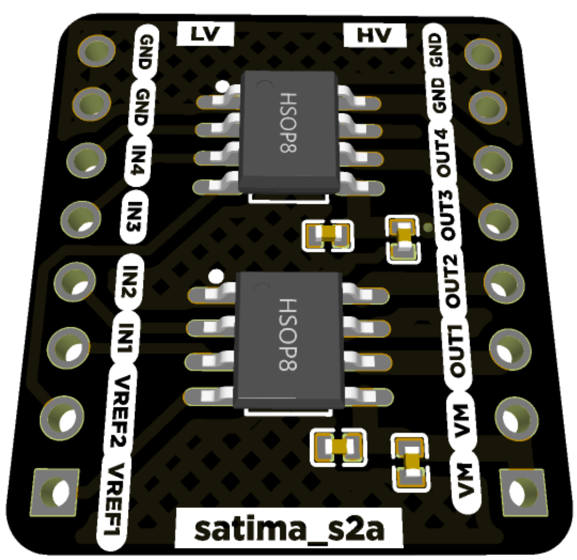

Figure 3.24: Satima Motor Driver

3.9 Platform Control Electronics

This represents the brain of the mobile platform and is responsible for converting user input to motor rotation and translational values. The main compute platform is responsible for controlling the motors individually to achieve holonomic control. The main components of the platform control are: the main microcontroller, power supply, and the Wi-Fi client. The schematic designs in Figure 3.25 were developed using EasyEDA software.

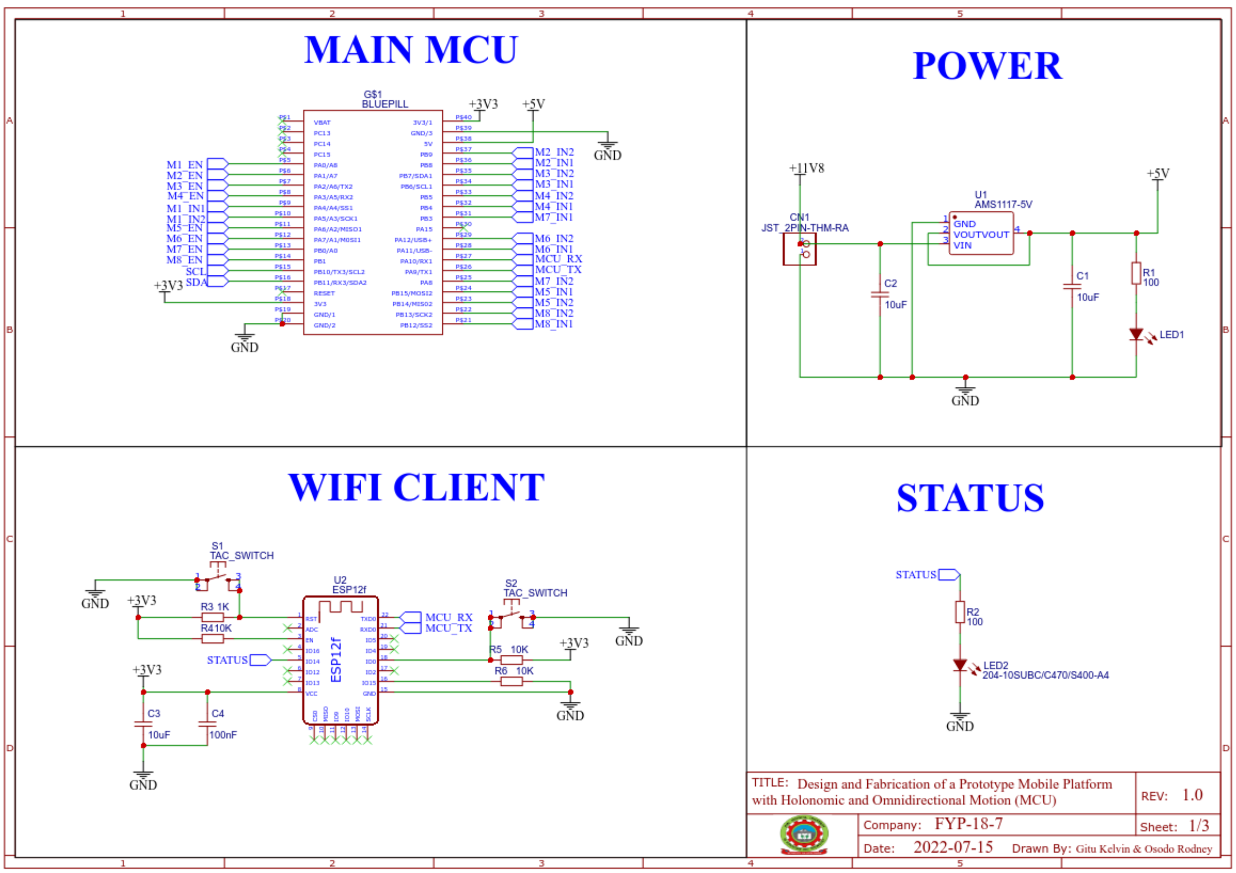

Figure 3.25: Mobile Platform Main Schematic View

The considerations that went into selecting the microcontroller were:

i It should be compatible with all auxilliary components including the motor and the inertial measuring sensor ii It should have on board features such as integrated Wi-Fi support and USB port

iii It should have enough processing power to reduce latency during operations such as wireless communication.

iv Its memory should be enough to accommodate the written program with all of its functionality.

v It should have the desired number of GPIO pins.

The STM32 and Arduino microcontrollers were considered as they are the most common and prevalent in the market. The STM32 microcontroller, more specifically STM32F103C8T6 was chosen as main Microcontroller Unit (MCU), and the main deciding factor was the number of pins on the MCU. It has 40 pins which would comfortably accommodate the more than 24 pins required to operate eight DC motors.

For the Wi-Fi client, the ESP-12f was chosen. This module supports the standard IEEE802.11 b/g/n protocol, a complete TCP/IP protocol stack. It adds networking capabilities to existing devices and can be used to build separate network controllers. It is also highly cost effective compared to other modules such as ESP32.

The motor driver schematics in Figure 3.23 and the platform control schematics in Figure 3.25 were incorporated into one circuit and used to generate the main PCB in Figure 3.25.

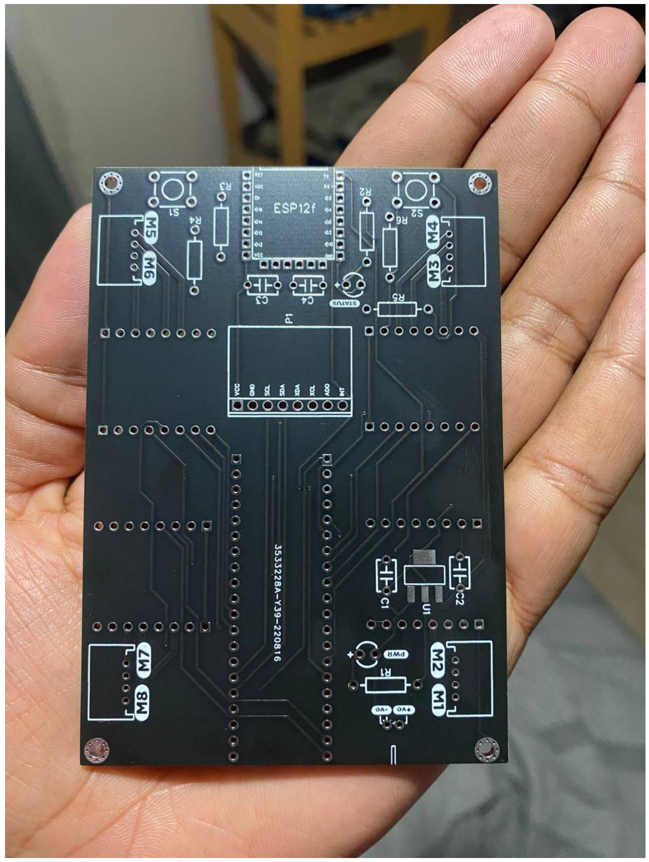

Figure 3.26: Main PCB

Once the motor drivers, microcontroller and Wi-Fi client were acquired, they were assembled onto the main PCB in Figure 3.26 to produce an assemblage of electronics shown in Figure 3.27.

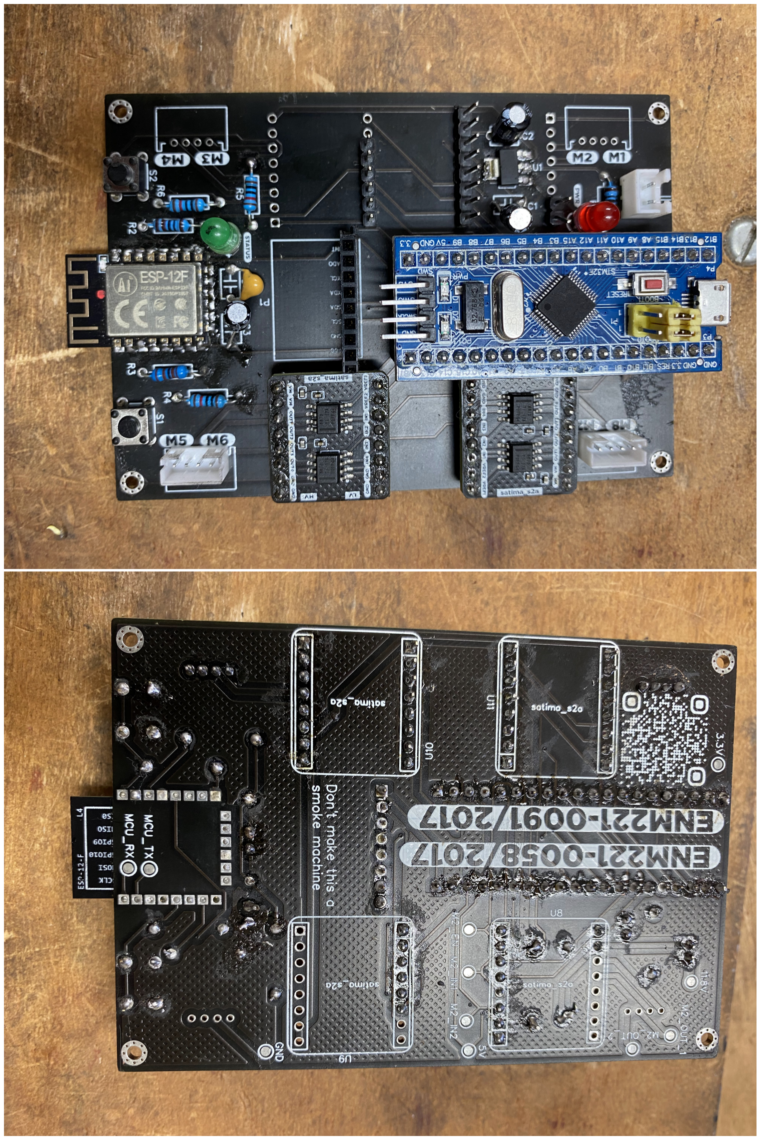

Figure 3.27: Platform PCB Assembly

In order to operate the mobile platform for at least an hour, a high capacity (greater than 900mAH) power source that can be recharged was the desired supply for the platform. Looking across the market, the 18650 Lithium Ion Battery 2200mAh 3.7V in Figure 3.28 was selected as most suitable for the job. This power supply was integrated into the main circuit as shown in Figure 3.25.

Figure 3.28: Lithium Ion Battery

For the sensory unit, the goal was to measure the acceleration and orientation of the mobile platform. For this, an Inertial Measurement Unit (IMU) was considered. An IMU, is an electronic device that measures and reports acceleration, orientation, angular rates, and other gravitational forces. It is composed of 3 accelerometers, 3 gyroscopes, and depending on the heading requirement 3 magnetometers. That is to say, one per axis for each of the three vehicle axes: roll, pitch, and yaw.

There are different types of IMU sensors [18]: the one based on FOG (Fiber Optic Gyroscope), the RLG IMUs (Ring Laser Gyroscope), and lastly, IMU based on MEMS technology (Micro Electro-Mechanical Systems). This technology allows lower costs and low power requirements while ensuring performance. MEMS-based systems therefore combine high performance and ultra-low power in a smaller unit.

The schematic developed for the sensory unit was used to incorporate the sensor into the other electronic components.

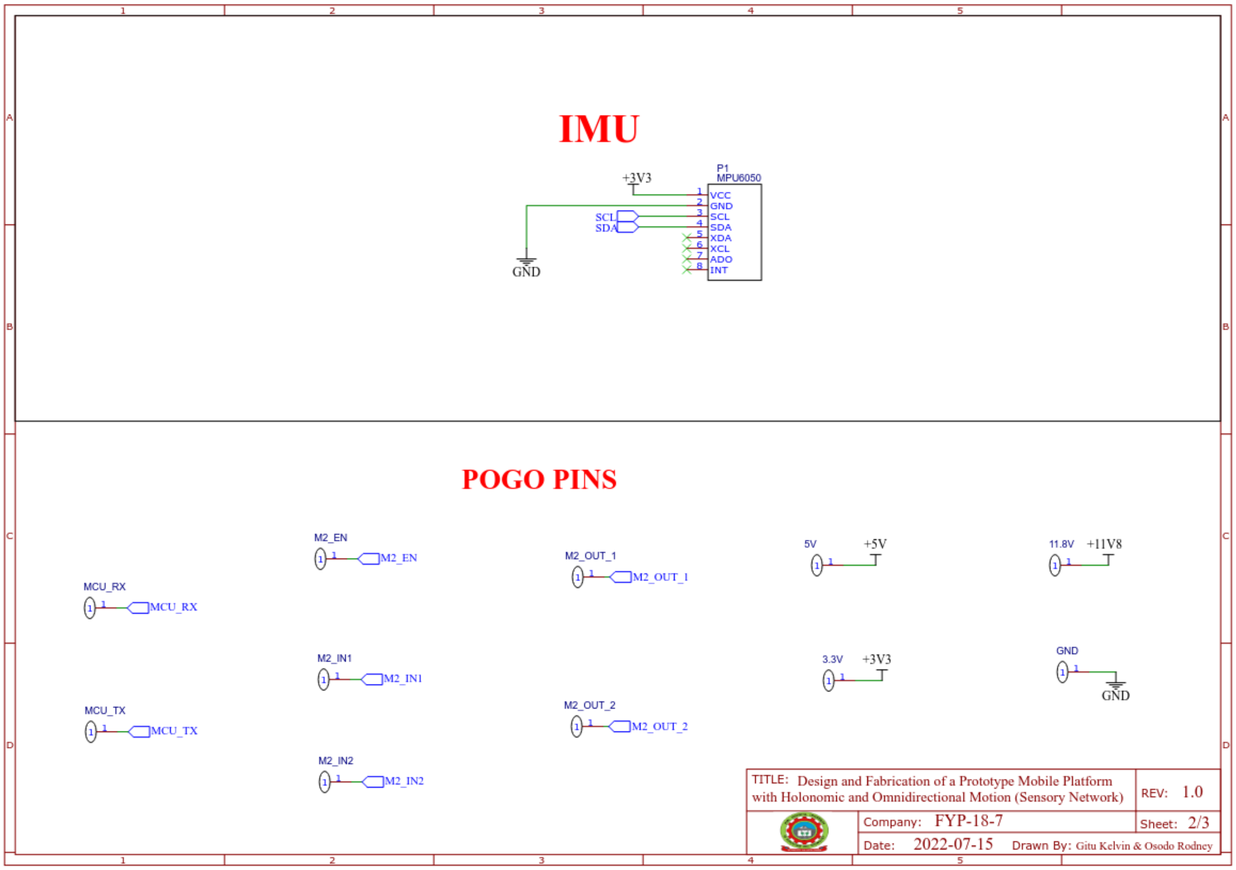

Figure 3.29: Mobile Platform sensory schematic

The IMU selected for this particular application is the MPU6050 sensor module which is a complete 6-axis Motion Tracking Device. It combines 3-axis Gyroscope, 3-axis Accelerometer and Digital Motion Processor all in small package [19]. It also has additional feature of on-chip temperature sensor. This module is shown in Figure 3.30 and was acquired off-the-shelf. The number of modules that this application required were two. One was assembled onto the main platform PCB in Figure 3.27 while the other was assembled onto the hand motion controller PCB in Figure **??**.

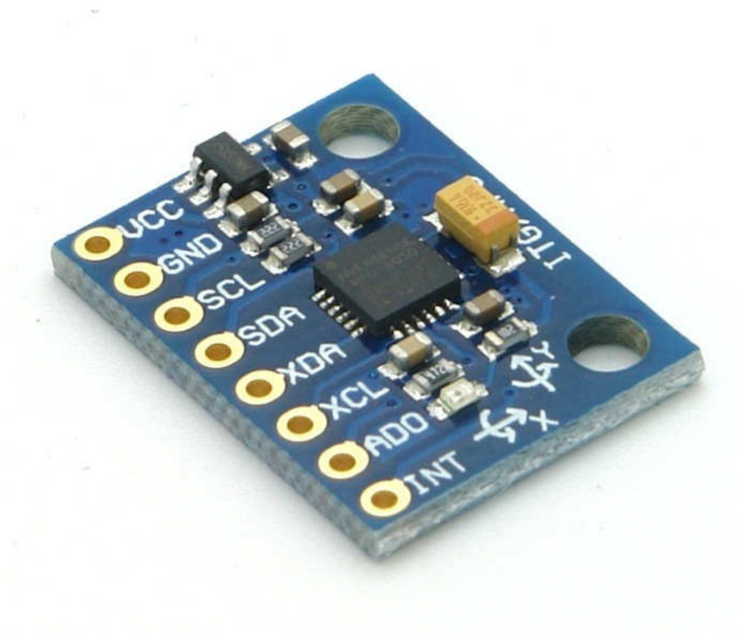

Figure 3.30: MPU6050 Sensor Module

3.10 Remote Control Clients

3.10.1 Design

APIs are code snippets that allow software applications to communicate in a common language. Web APIs enable client applications to access third-party data and seamlessly integrate it wherever and whenever it is needed, providing unrivalled data processing efficiencies and cost savings.

The goal of this project was to implement robot control using an API. This would ensure integrating different clients as shown in Figure 3.31.

More specifically, a mobile application and hand motion controller device would be the two control actions used for the platform.

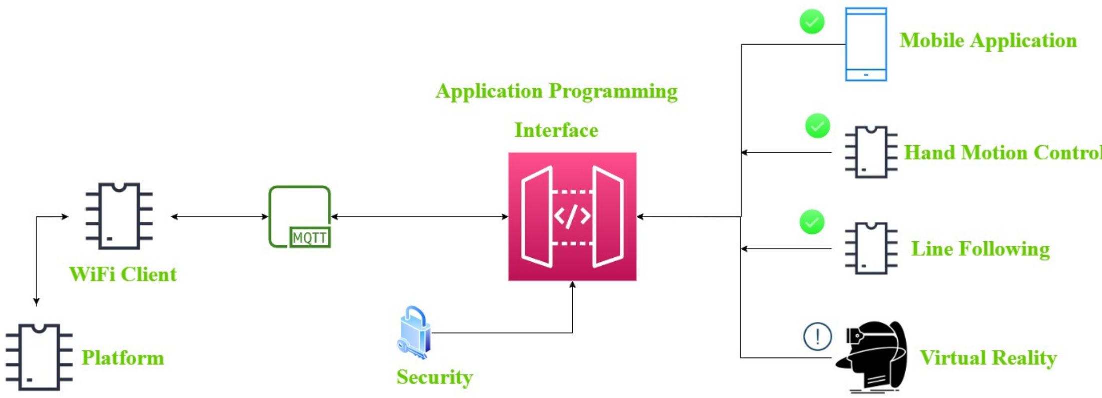

Figure 3.31: Mobile Platform Control Architecture

The hand-motion controller is a hardware client that maps hand motions to actual commands that are sent to the mobile platform. The hand motion device is made up of an IMU sensor in Figure 3.30 that would detect various hand motions. The Central Processing Unit (CPU) interprets the motions and transmits the commands via a Wi-Fi client to the mobile platform microcontroller.

The schematic for the hand motion device in Figure 3.32 was developed using EasyEDA software. The main components of the device are the Wi-Fi client that also acts as the MCU, power supply, a programmer, and the IMU sensor.

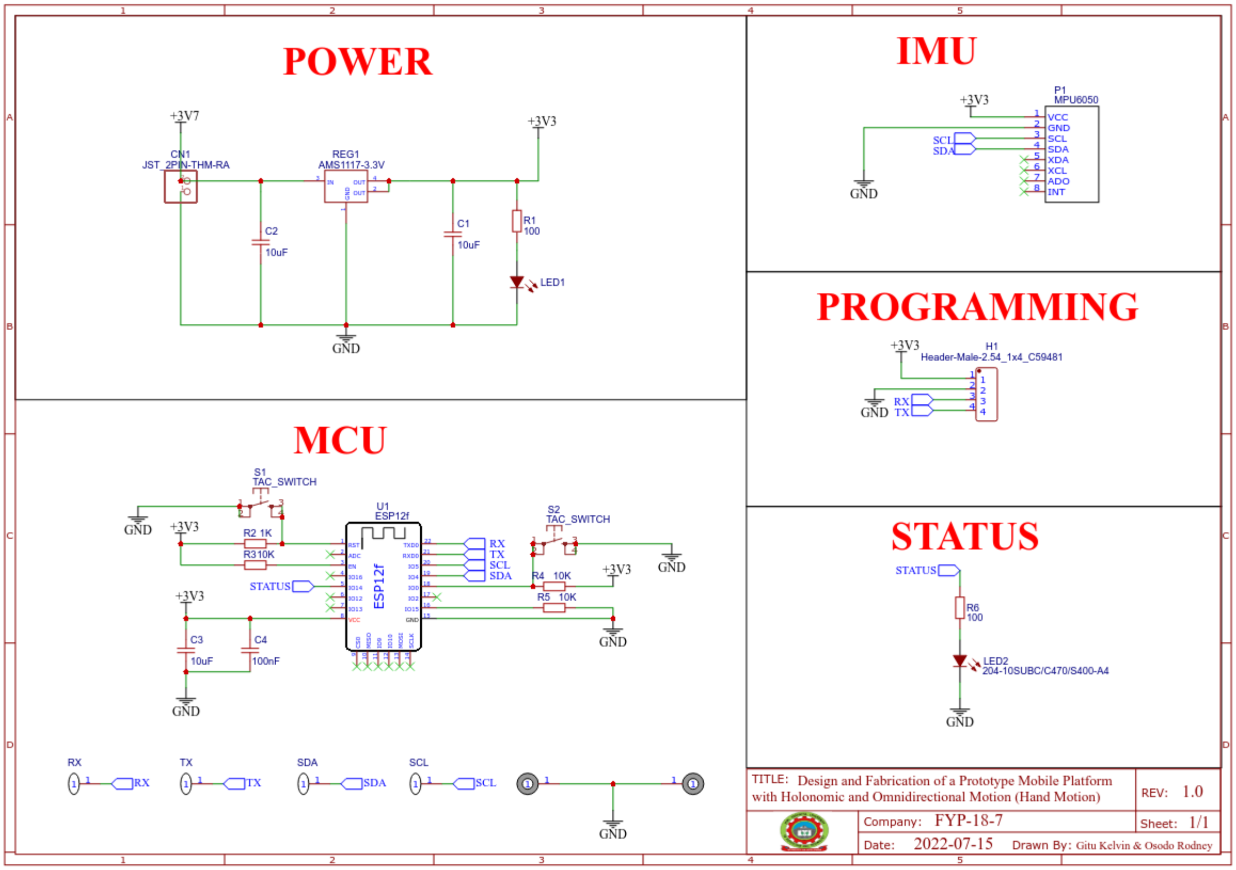

Figure 3.32: Hand Motion Schematic

For the mobile application client, software would be used to map inputs from the application to actual commands that would in turn be sent to the mobile platform. Several development tools were considered, including React native, Ionic, and Xamaric but ultimately Flutter seemed like the best platform for a number of reasons:

i. Flutter used a simple implementation of the dart language which would be easy to learn and integrate

ii. Flutter could create multi-platform applications on a single code-base. That means applications that run on Android, Windows and iOS could be created using on code-base implementation.

iii. Flutter apps are relatively fast

3.10.2 Fabrication and Implementation

With Mainflux, the robustness of our API is much increased. This is because, from our initial consideration, we wanted to build a multi protocol architecture. For instance, when we publish data using one protocol, we can receive it using another protocol. This is fundamental to increasing the robustness of our core API. Since we have different clients, we can either publish or subscribe data depending on the protocol that best suits the client.

1. Mobile application - Web socket and Hypertext Transfer Protocol (HTTP)
2. Hand motion controller - Message Queuing Telemetry Transport (MQTT)
3. Wifi Client - MQTT

In this case, when we publish data using the mobile application using HTTP, we can receive the same message using an MQTT subscriber. MQTT is a lightweight publish-subscribe messaging protocol that is commonly used in the Internet of Things (IoT) for communication between devices.

In an IoT system, MQTT is used to establish a communication channel between devices, allowing them to exchange data and messages with each other. This allows devices to share information and coordinate their actions, enabling the IoT system to function as a whole.

One of the key benefits of MQTT is its low overhead and high efficiency. The protocol uses a simple and compact message format, which allows for efficient data transfer even over low-bandwidth or unreliable networks. This makes it well-suited for IoT applications, where devices often have limited resources and may be connected through challenging networks.

Another advantage of MQTT is its flexibility. The protocol supports different messaging patterns, such as publish-subscribe, request-response, and push-pull. This allows it to be used in a wide range of IoT scenarios and applications, such as device-to-device communication, remote monitoring, and control.

Overall, MQTT is an important component of the IoT ecosystem, providing a reliable and efficient communication channel for devices to exchange data and messages.

Since we have three clients we create three things using the mainflux backend. These three things will be connected to one channel so that when the message is published to that channel any listening client can be able to receive the message. Mainflux provides support for both authorization and authentication.

Authorization refers to the process of determining whether a client has access to a certain resource or operation. In Mainflux, authorization is implemented using Access Control Lists (ACL) with the help of Keto as its main ACL engine, which specifies the permissions that a client has to access a particular resource. For example, an ACL may grant thing permission to read data from a specific channel or to control a particular device.

Authentication, on the other hand, refers to the process of verifying the identity of a thing. In Mainflux, authentication is implemented using JSON Web Token (JWT), which are digitally signed tokens that contain information about the thing. When a thing attempts to access a resource, Mainflux verifies the JWT to confirm its identity before granting access.

Overall, Mainflux provides support for both authorization and authentication to ensure that things are only able to access the resources and perform the operations that they are permitted to. This helps to protect the security and integrity of the IoT system.

The hand motion device was fabricated manually, which was different from other PCBs as depicted in Sections 3.8 and 3.9. The procedure for this process is described in detail in Section 6.4 and the result is depicted in Figure 3.33.

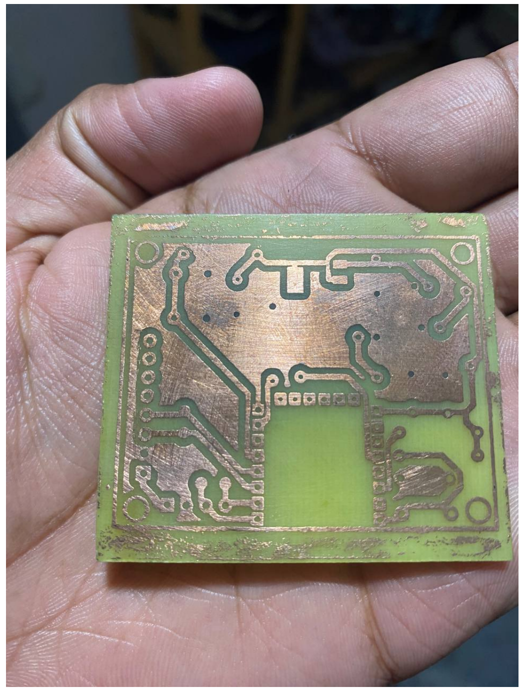

Figure 3.33: Hand Motion Device PCB

The Wi-Fi client, IMU sensor and other components were soldered onto the hand motion device PCB using a soldering gun and wire.

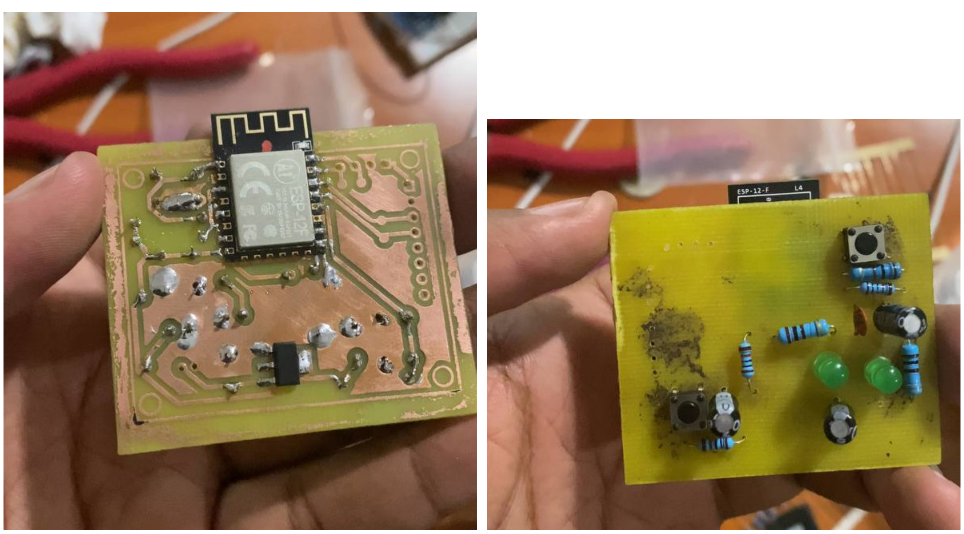

Figure 3.34: Assembled Hand Motion Device PCB

For the mobile application, implementation was done using various software tools. A code editor, Visual Studio Code was used to write dart code for the application. Another editor, Android Studio provided an emulator on which to edit the application in real-time. This ensured that any changes could be seen during active development. Flutter's official documentation was used as a guide, especially where challenges arose. Figure 3.35 is a representation of some of the pages that were developed using the code in Section 6.6

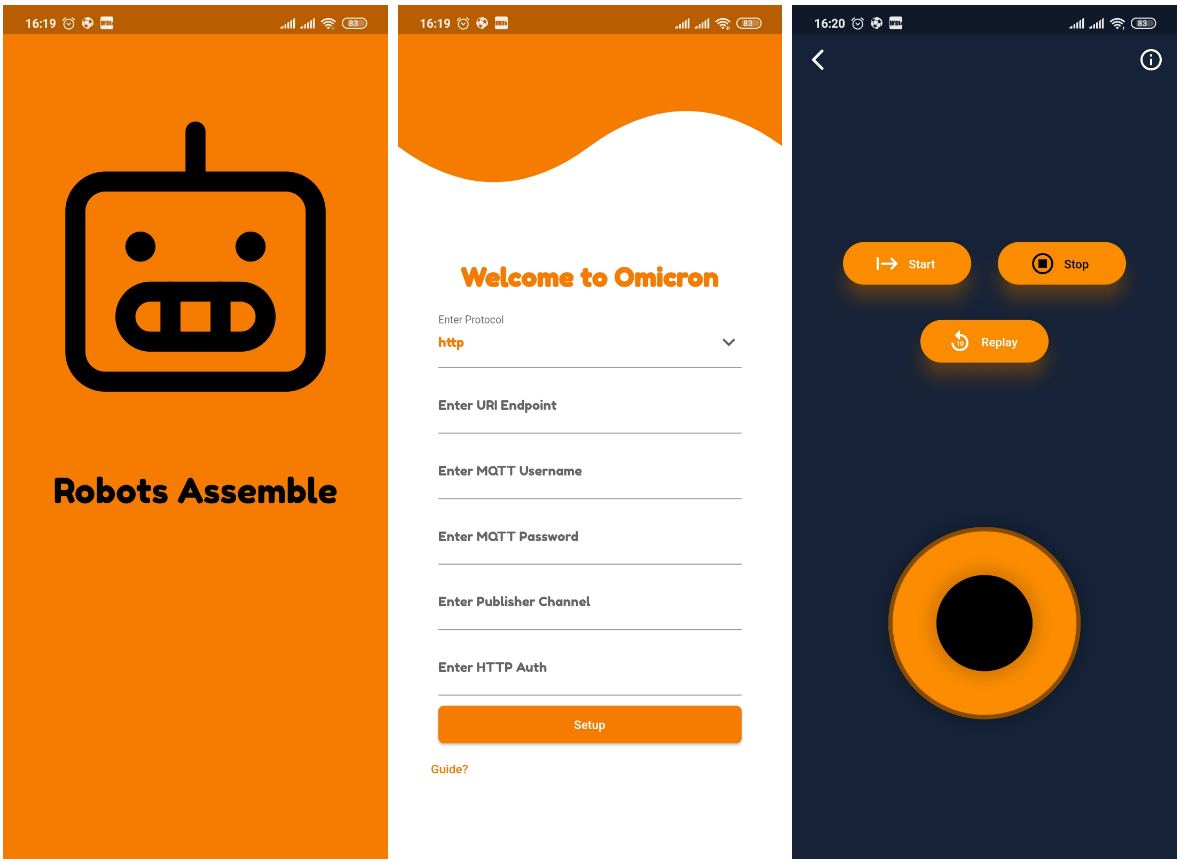

Figure 3.35: Flutter App Pages

4 Results and Discussion

4.1 Results

The design process yielded the final assembly design in Figures 4.1 and 4.2. The fabrication process on the other hand yielded the assembled mobile platform in Figure 4.3 and Figure 4.4.

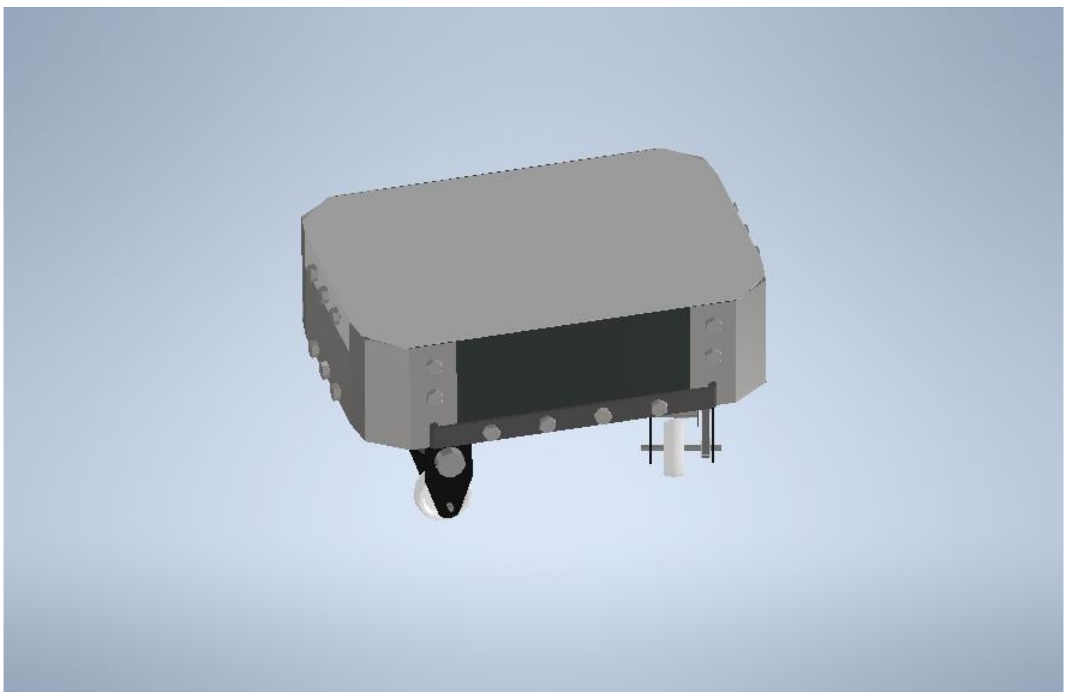

Figure 4.1: 3D Design

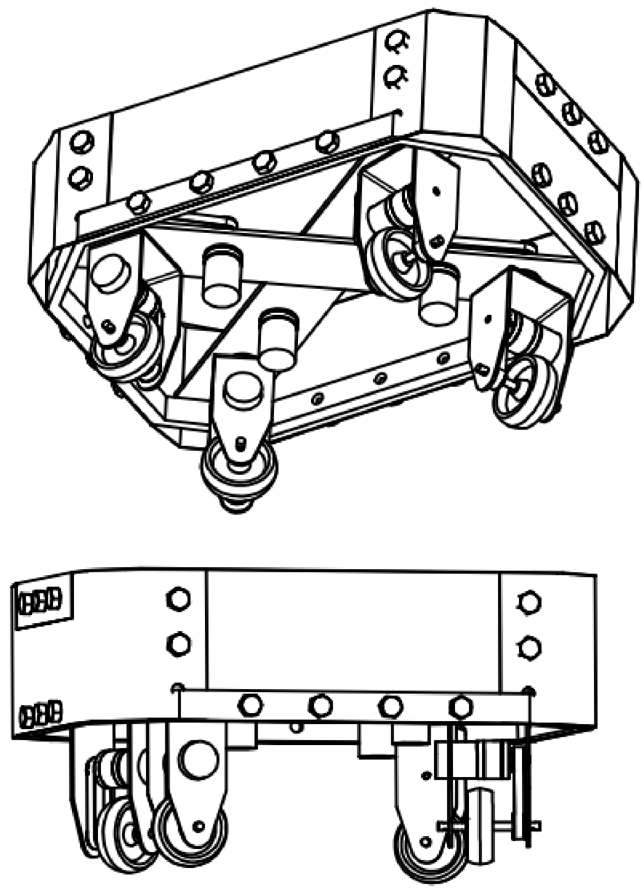

Figure 4.2: Assembly Drawing

Figure 4.3: Fabricated Assembly with Open Top

Figure 4.4: Fabricated Platform

After several experiments and tests, sending data between the mobile platform and the control clients (mobile application and hand motion control device) was confirmed. The data received by the mobile platform was for yaw and pitch values. This experiment was conducted by simulating PWM signals on an oscilloscope as shown in Figure 4.5, signals that would control the DC motor speed.

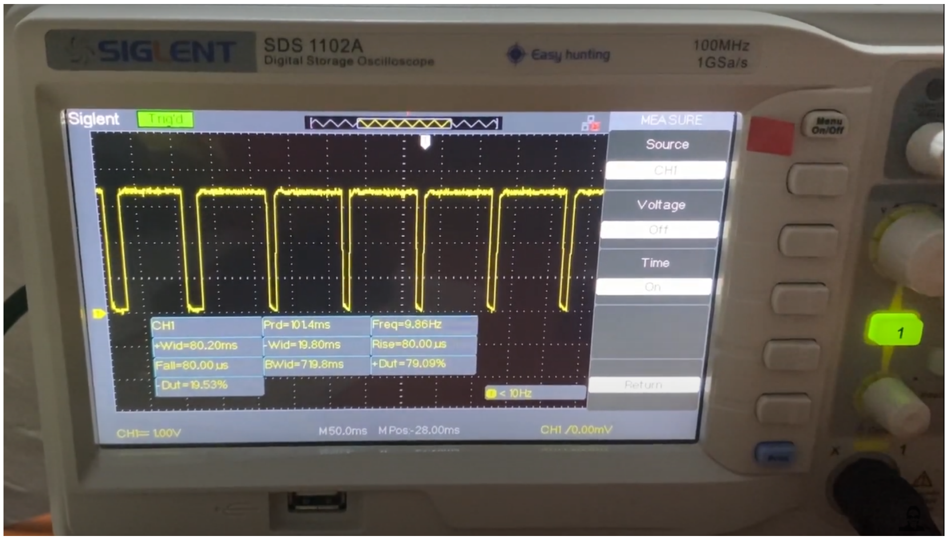

Figure 4.5: PWM Signals Generated using Transmitted Data

Once data transmission was simulated, the next step was driving the mobile platform remotely. To do this, a pre-defined trajectory was determined in order to test the orientation and stability of the mobile platform. The platform followed the path as expected but veered off the path a few times due to misalignment arising from the fabrication process. The trajectory path was set up to ensure omnidirectional and holonomic movements could be achieved. The path is shown in Figure 4.6 and the resultant path followed by the mobile platform is shown in Figure 4.7. The comparison between desired path and actual path is shown in Figure 4.8

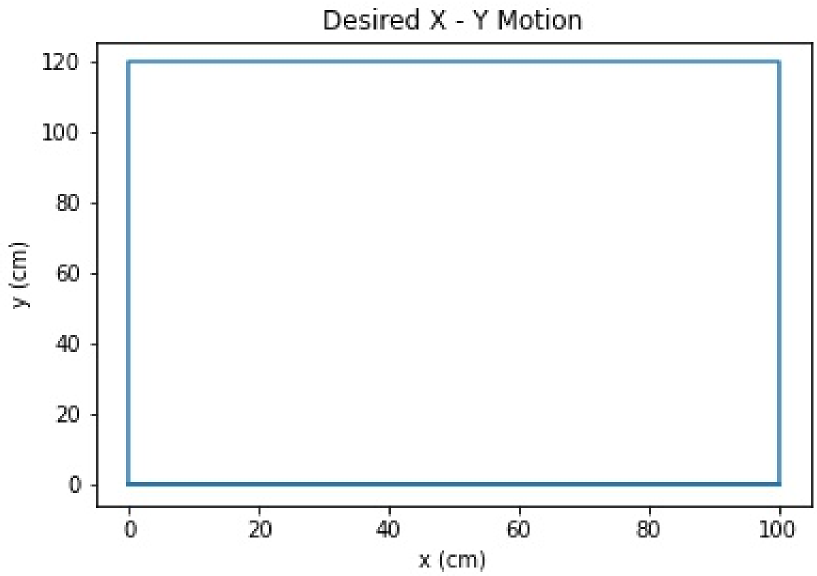

Figure 4.6: Desired Path

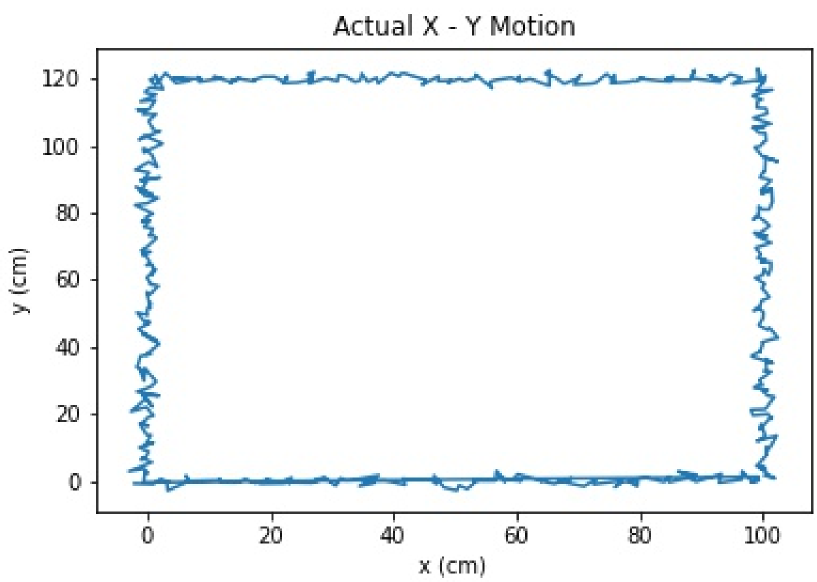

Figure 4.7: Actual Path

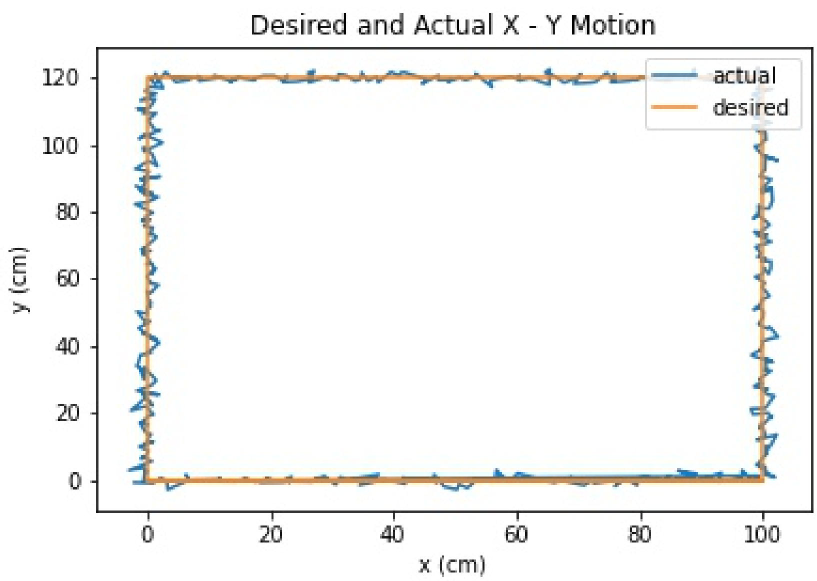

Figure 4.8: Desired and Actual Path

From the Figure 4.8 it it clear the platform is able to achieve holonomic and omnidirectional motion. With a little bit of tuning to reduce the misalignment, the platform can be able to move in the desired trajectory.

Other parameters, such as time to run vs velocity of the platform was measured and recorded in Table 4.1.

Table 4.1: Time and Acceleration under Different Payloads

Duration (min)	Velocity (m/s)
5	0.5 m/s
10	0.5 m/s
15	0.4 m/s
20	0.3 m/s
25	0 m/s

From Table 4.1, we were not able to achieve the $44mins$ duration we had planned to achieve. This is due to the factor that we purchased a stepper motor for directional motion rather than a DC motor which consumes more power.

4.2 Discussion

The results of the design and fabrication of the prototype mobile platform with holonomic and omnidirectional motion are as follows:

1. The mobile platform was tested in various scenarios, including moving in straight lines, turning, and moving in circular paths. It was found that the platform was not able to move smoothly and accurately in any direction, with the speed and direction being easily controlled using the mobile application and hand motion control device.

2. The mobile platform was able to carry a payload of up to 10kg without any issues, demonstrating its versatility and potential use in various applications such as material handling and transportation.

3. The mobile platform was found to be energy efficient, with the DC motors consuming minimal power even when operating at high speeds.

Overall, the results of this project show that it is possible to design and fabricate a prototype mobile platform with holonomic and omnidirectional motion using caster wheels and motors, and that this type of platform has the potential for various applications in the industry. The results showcased, show that the mobile platform was fabricated to a large extent as conceived in the design process. Furthermore, transmission of data between the clients through the channel as envisioned in Section 3.10 was achieved as proven by the generation of PWM signals which drive the DC motors in Figure 4.5.

This data was used to drive the mobile platform along a predetermined path but from Figure 4.8, it was clear that there were misalignments that interfered with the velocity and ultimately the orientation of the mobile platform. These misalignments came about when the wheel frame in Figure 3.12 was being bent using the manual bending machine. A lot of estimations had to be made during the metal sheet bending process, which ultimately made the final product less like the design.

5 Conclusion

Holonomic and omnidirectional motion can offer several benefits to mobile robots. Holonomic movements, which are inherently omnidirectional, allow a mobile robot to move in any direction without having to change its orientation.

One disadvantage of rectilinear motion is that the robot can only move in a straight line, making it difficult to navigate around obstacles or turn corners. In contrast, this mobile platform allows the robot to move in any direction without having to change its orientation, making it more maneuverable and better suited for navigating complex environments.

There are also some potential challenges to incorporating holonomic and omnidirectional motion into mobile robots. One challenge is the additional complexity of the design, as it requires more wheels and may require more advanced control algorithms to coordinate the movement of these wheels. Additionally, the cost of implementing holonomic and omnidirectional motion may be higher due to the increased number of wheels required.

The shortcomings that arise from mobile robots having rectilinear motion similar to conventional automobiles were presented in this report. A proposal was made to incorporate holonomic and omnidirectional motion into mobile robots and finally,a prototype of the holonomic and omnidirectional mobile robot was designed and fabricated.

In conclusion, the design and fabrication of the prototype mobile platform with holonomic and omnidirectional motion was a successful and promising project. The results of this process matched all the objectives listed in Section 1.3 that guided the project. Two of the three expected outcomes were met as follows:

i. A fully operational mobile platform with a chassis and a body was fabricated

ii. This mobile platform was made to exhibit omnidirectional and holonomic motion

The third expected outcome which involved controlling the platform remotely and unmanned using a mobile application and a hand motion control device fell short due to failure in data transmission. Data in the form of yaw and pitch values was generated using a joystick on the mobile application and used to drive a single motor as in Figure 4.5 but transmission troubles curtailed the final objective. This prompted the following recommendations on future research work:

i. Development of novel algorithms for motion planning and control of omnidirectional mobile robots

ii. Evaluation of the control challenges associated with holonomic and omnidirectional motion in mobile platforms

However, there were some challenges that were encountered during the project. One of the main challenges was instability, as the platform was prone to tipping over when moving at high speeds or carrying a heavy payload. This issue can be partially addressed by carefully calculating the dimensions and weight distribution of the platform, but further improvements could be made by adding stability features such as gyroscopes or counterweights.

Despite seemingly achieving all the objectives, the process was full of shortcomings that made the results fail to meet the desired standards. For instance, challenges arose due to old machines, and outdated machining processes. The next step would ideally be having more modern fabrication equipment and tools.

Overall, the design and fabrication of the prototype mobile platform with holonomic and omnidirectional motion was a successful and promising project, but there are still some challenges that need to be addressed in order to fully realise the potential of this type of platform. Future research could focus on improving the stability and range of the platform, as well as exploring additional applications and potential improvements to the design.

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6 APPENDICES

6.1 Time Plan

Table 6.1: Semester 1 Time-plan

	SEMESTER 1										
Week	1	2	3	4	5	6	7	8	9	10	11
Project Proposal		■	■	■							
Continuous Presentation					■	■	■	■	■	■	■
Literature Review						■	■	■	■	■	■
Mechanical Design							■	■	■	■	
Electrical Design							■	■	■	■	
Software Design									■	■	■
Material Acquisition											■

Table 6.2: Semester 2 Time-plan

	SEMESTER 2													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Continuous Presentation	■	■	■	■	■	■	■	■	■					
Literature Review	■	■	■	■	■									
Material Acquisition	■	■												
Mechanical Fabrication		■	■	■	■									
Electrical Fabrication			■	■	■	■								
Software Fabrication				■	■	■	■	■	■					
Assembly						■	■	■	■	■				
Testing						■	■	■	■	■	■	■		
Demonstration										■	■	■	■	■

6.2 Budget

Table 6.3: Cost Budget

No.	Item	Quantity	Supplier	Unit Cost	Total cost
1	Satima S2 Motor driver	4	Pixel Electric	500	2000
2	STM32F103C8T6	1	Nerokas	1000	1000
3	MPU-6050	1	Nerokas	260	260
4	Esp 12 F	2	Nerokas	300	600
5	Passive components	1	Pixel Electric	1000	1000
6	PCB	2		500	1000
7	18650 Lithium Ion Battery	5	Pixel Electric	350	1750
8	DC motor	8	Pixel Electric	1100	8800
9	Motor Bracket	8	Pixel Electric	300	2400
10	Motor shaft and couplings	4	Pixel Electric	200	800
11	Bearing	4	Hardware	100	400
12	V-belt pulley	16	Pixel Electric	150	2400
13	Belt	8	Hardware	200	1600
14	Castor Wheels	4	Nerokas	200	800
15	Steel rods	5	Hardware	60	300
16	Aluminium Sheet	1	Hardware	600	600
17	Fasteners	1	Hardware	500	500
18	Miscalleneous	1		2600	2600
				TOTAL	28810

Table 6.4: Power Budget

Component	Voltage (V)	Current (mA)	No. of Components	Power (W)
MPU6050	3.3	4.68	1	0.015444
ESp32	3.3	480	1	1.584
Stm32	3.3	360	1	1.188
Led	3.3	120	2	0.792
DC motor	12	360	4	34.56
Stepper motor	12	450	2	10.8
Motor driver	5	43.2	1	0.216
				49.155444

6.3 PCB Designs

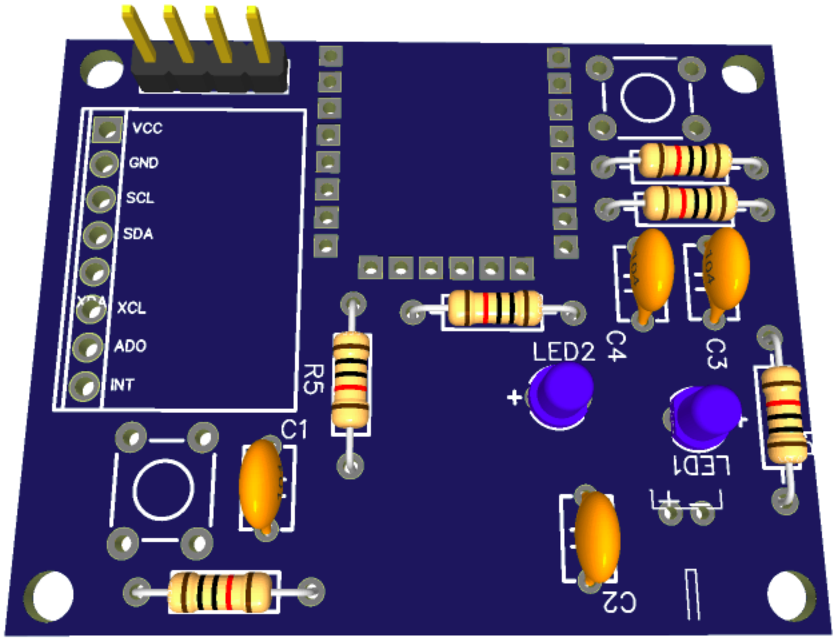

Figure 6.1: Hand Motion Top view of PCB

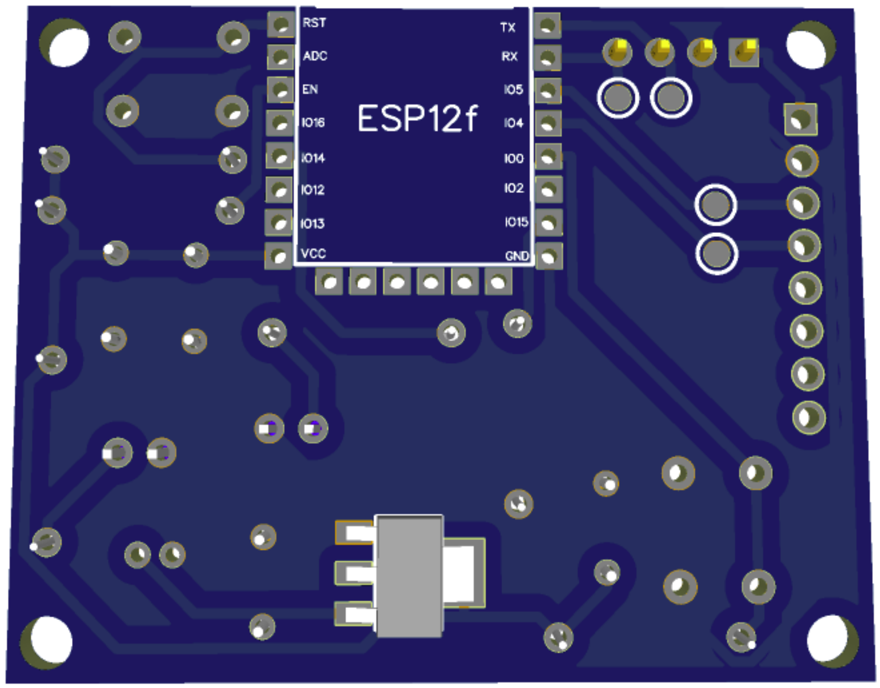

Figure 6.2: Hand Motion Bottom view of PCB

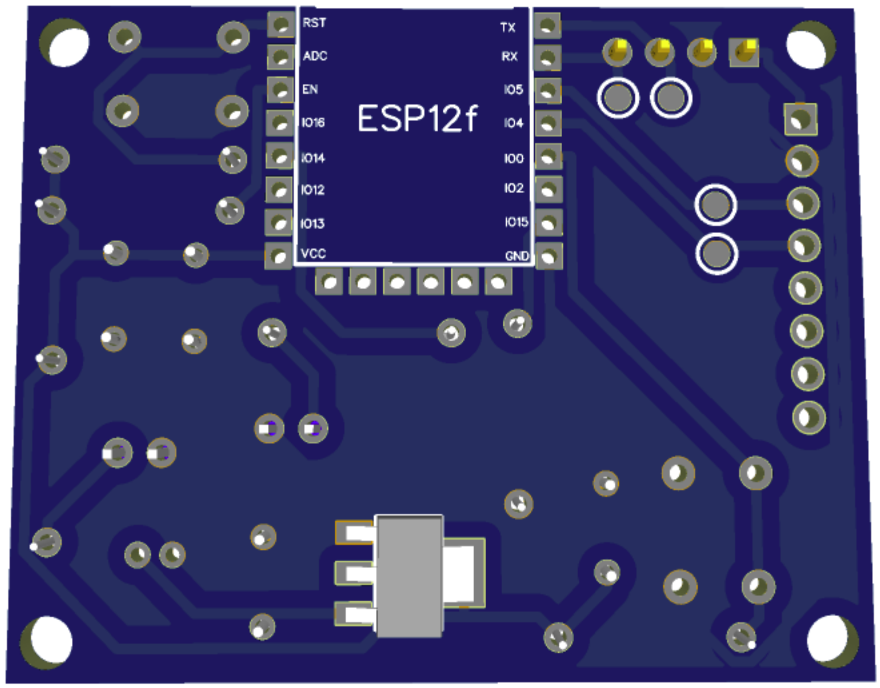

Figure 6.3: Hand Motion Fabricated PCB

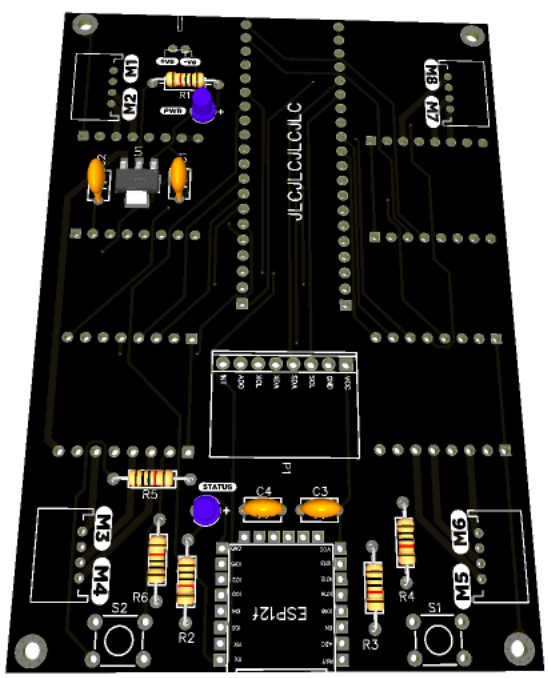

Figure 6.4: Mobile Platform top view

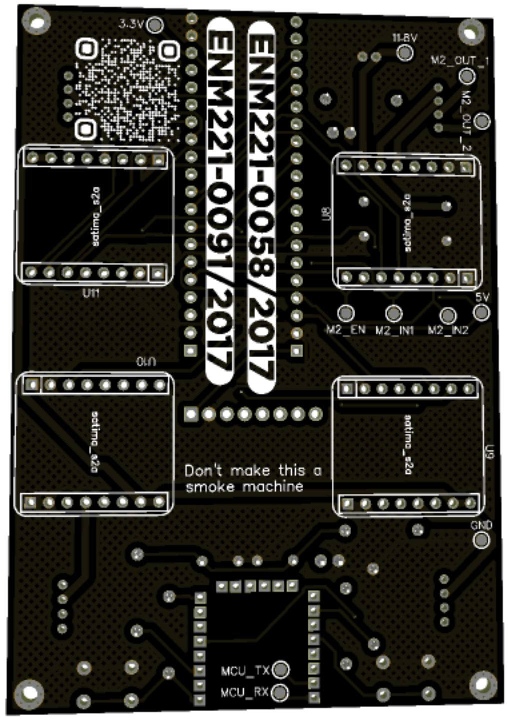

Figure 6.5: Mobile Platform bottom view

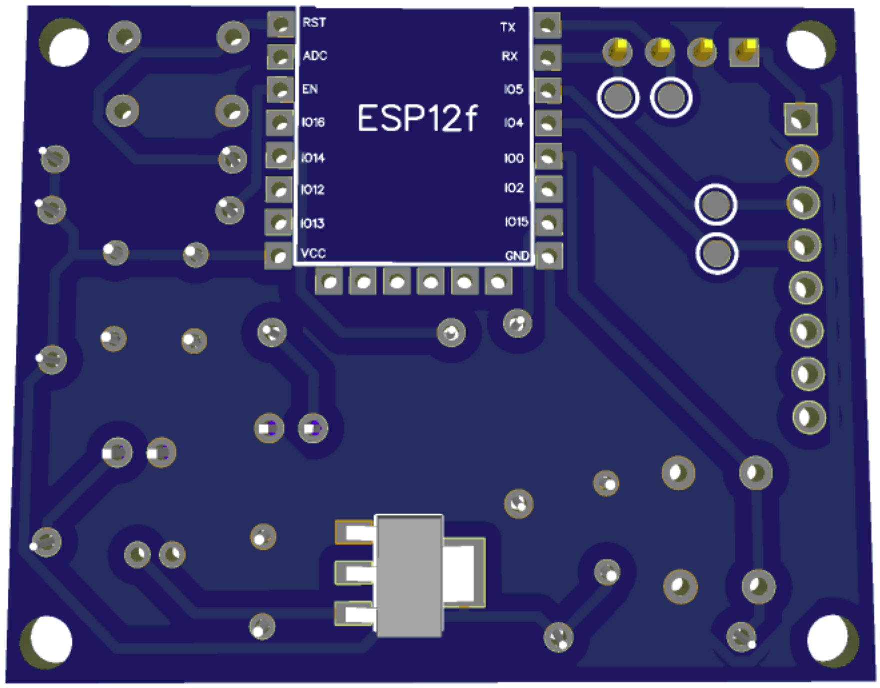

Figure 6.6: Mobile Platform Fabricated PCB

6.4 PCB Manual Fabrication Process

1. Print out the bottom layer onto the shiny side of the glossy paper. The copper pads and tracks should be black
2. Sand the copper plate so there is a rough surface for the design to stick to when transferred
3. Wash the copper with some water and rubbing alcohol and let it dry
4. Cut out the designs and place them face down on the copper
5. Run the copper plate with the design face down through a laminator or iron box 5-7 times until the plate is hot
6. After running the plate through a laminator or iron place the plate into a cold bath and agitate until the paper floats of

7. Place the PCB into the etching solution and agitate for 25-30 minutes or until all the copper has dissolved around the design

8. Once all the copper is gone rinse it in the water bath, let it dry and use rubbing alcohol to whip off the ink transferred onto the PCB

9. Drill the holes for DIP components and also mounting holes

10. Start by placing SMD components and solder them either by hot air gun or hand soldering

11. Solder DIP components by hand soldering

6.5 Production Plan

Table 6.5: Production plan

Production Plan					
Week	**Tasks/Activities**	**Material Required**	**Special Equipment**	**Concurrent Activities**	**Remarks**
1	Presentation	N/A	N/A	N/A	Done
2	-Project production feasibility test with Technician -Material Acquisition -Hand Motion PCB etching process -Mobile Platform PCB delivery and testing	Copper clad	N/A	Mobile App UI development	Completed
3	Mechanical Fabrication commences for both the body and chassis. - Metal sheet cutting for the body - Metal sheet folding for the body and wheel shell - Metal Sheet drilling for the chassis	Glalvanised Iron Sheet Metal	- Drill bits - Drilling Machining - Hack saw	Mobile App development Procure electrical components and mechanical parts for power transmission	Primary Activities Done Concurrent Activities Done
4	Mechanical Assembly of the different parts: - Join wheel shell to the top shaft - Join the chassis to each other - Join chassis to outframe - Assemble the body with the chassis	Mild Steel Rod Nuts and Bolts	Gas WeldingMIG Welding	Assemble Mobile Platform PCB Drive motors using motor driver and test workability Clean parts from rust	Primary Activities Done Concurrent Activities Done
5	Electrical Tests: - Drive the motors independently - Get gesture signals from hand motion controller	-DC motors -Stepper Motor -Fully Assembled Hand Motion Controller -Assembled Mobile Platform	Oscilloscope Multimeter Signal generator	Backend Application (Build) - Send message using MQTT and receive it using MQTT and vice versa - Send message using Web Socket and Receive using MQTT and vice versa - Send message using HTTP and receive it using MQTT and vice versa	Primary Activities Done Concurrent Activities Done
6	Assemble the motors to the platform together with the transmission system	N/A	N/A	Backend Application Deploy	Primary Activities Done Concurrent Activities Done
7	- Write Mobile Platform Code for holonomic and omnidirectional motions - Drive the Mobile Platform with static code inside the Microcontroller	N/A	N/A	Mobile App development	Primary Activities Done Concurrent Activities Done
8	Drive the Mobile Platform using Mobile Applications	N/A	N/A	N/A	
9	Drive the Mobile Platform using Hand Motion Controller	N/A	N/A	Drive the Mobile Platform using Mobile Applications	
10	Paint the Mobile Platform	Paint	Spray painter	Package the PCBs and Production Code to maintain industry standards	
11	Drive the Platform continuously to increase durability	N/A	N/A	Conference talk at DroidCon Regarding our Project	
12	Drive the Platform continuously to increase durability	N/A	N/A	Tech Expo presentations	

6.6 Production Code

6.6.1 Mobile Platform

The code we developed for this research is a complex and innovative solution that leverages advanced algorithms and data structures to achieve accurate and efficient results. It has been carefully documented and tested, and it can be found here [20]. This includes the mobileplatform code which is responsible for driving the platform, wificlient code responsible to receiving MQTT data from WiFi and the hand motion controller.

6.6.2 Flutter

The flutter code is quite lengthy and complex and can be found here [21].