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Design And Fabrication Of An Autonomous Bird Deterrent Robot Prototype
FYP-18-10
Final Report

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Declaration

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Abstract

The most effective way to protect sorghum farms from bird damage is to physically restrict the birds with netting, but this method is not feasible due to cost. In order to address this issue, a portable, battery-powered, all-terrain, ground utility robot was designed and fabricated. The robot measures $350 \times 280 \times 7200$mm with a ground clearance of 25mm and is made of 2mm galvanized steel sheet and 3mm acrylic sheet. It uses a combination of 3 ultrasonic sensors, a mechanical sprocket-chain drive mechanism, and a YOLOv7 object detection algorithm to navigate and detect birds. Once a bird is detected, the robot employs owl calls in combination with $13,000$Hz synthetic sounds and continuously moves a 650nm laser to prevent the bird from remaining in the area. The robot is powered by a 5000mAh Lipo battery and controlled by both Jetson Nano 4GB and Arduino Mega. The robot was tested in a controlled environment in which sorghum had been spilled on the ground, simulating a common scenario in which birds may be present. The robot was placed in the test area and the effectiveness of different deterrents was assessed using a split-field testing method. This involved dividing the test area into two halves, with the robot and deterrents active in one half and inactive in the other half. The number of birds in each half was then compared to determine the effectiveness of the robot and deterrents. The results of the split-field testing showed that the robot was able to effectively deter birds in both stationary and moving scenarios. The predator calls deterrent was most effective for stationary birds, reducing their presence by 67% in the active half of the test area. The laser flashes deterrent was most effective for moving birds, reducing their presence by 56% in the active half of the test area. Overall, the robot can run continuously for an average of 1.5 hours on a single charge, the deterrents are effective over a radius of 5 meters, and the robot is also able to navigate and avoid obstacles with an average speed of 0.5 meters per second. The above results indicate that the robot has the potential to be a valuable tool for managing bird populations in sorghum fields.

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List of Abbreviations

CPU - Central Processing Unit

FEA - Finite Element Analysis

FEM - Finite Element Modelling

FPS - Frames Per Second

GPS - Global Positioning System

HMI - Human Machine Interface

IoT - Internet of Things

MAP - Mean Average Precision

PIR - Passive Infrared Sensor

RTK - Real Time Kinematic

1 Introduction

1.1 Background

Birds cause up to 60% of crop losses by feeding on grains, fruits, and sown seeds, pulling up the seedlings, trampling on seedlings, breaking branches when roosting, nipping buds, fouling nursery stock and lawns, and serve as vectors of plant pathogens thereby aggravating disease potentiality [1]. An attack of a bird on a crop field, if left uncontrolled, may produces 100% loss [2]. In Kenya, around 37% of agricultural produce was lost in 2021 due to pest bird damage [3]. Estimates of individual crop damage by birds vary but are generally reported as 25% for fruits, 22% of sorghum and millet, and 10% for rice and wheat [3].

Managing pest bird damage in agriculture is a challenging problem because of the scale of agricultural sites and unpredictability of birds [4]. Many methods have been developed, yet there is only one effective but expensive method, netting [5]. Sorghum fields are one of the most vulnerable crops to bird damage [3]. Netting is the most common method deployed in sorghum fields [5]. However, the cost of netting increases as the size of the field increases, making this method too expensive for large fields [5, 6].

As the development of unmanned ground vehicles and autonomous technologies continues to advance at a rapid pace, there is a growing interest in using these technologies for bird control. [7]. Particularly, unmanned ground vehicles equipped with sensors and cameras can be used to monitor crops and detect the presence of birds. The unmanned ground vehicles can then use deterrents such as noise makers or visual stimuli to scare the birds away from the crops. This approach has the potential to be more effective and efficient than current methods of bird control, such as using human workers or traditional deterrents.

1.2 Problem statement

Current methods for deterring birds from damaging crops using robotics can be grouped into four categories: acoustic, visual, chemical, and physical techniques. However, these individual approaches have been found to be only temporarily effective in deterring birds due to the phenomenon of habituation, where birds become accustomed to a specific deterrent over time. As such, the current state of bird deterrent methods utilizing robotics is inadequate for long-term pest management and results in continued damage to crops. To address this problem, there is a need for the development of a dynamic bird deterrent robotic system that capitalizes on the strengths of the individual approaches while addressing their limitations through the use of a combination of multiple deterrent measures. Such a system could provide a more sustainable solution for protecting crops from bird damage.

1.3 Objectives

To design and fabricate an autonomous bird deterrent robot prototype. To achieve the above, the following specific objectives were derived:

1. To design the mechanical structure and actuation system of the autonomous bird deterrent robot prototype.
2. To design the electrical connections of the actuation system, control unit, sensing unit, and power supply unit of the autonomous bird deterrent robot prototype.
3. To design a control algorithm for the autonomous bird deterrent robot prototype.
4. To fabricate and test the autonomous bird deterrent robot prototype.

1.4 Expected Outcomes

1. To have a functional mechanical and actuation system of the autonomous bird deterrent robot prototype

2. To have a working electrical system connecting the actuation system, control unit, sensing unit, and power supply unit of the autonomous bird deterrent robot prototype.

3. To have a functional control algorithm for the autonomous bird deterrent robot prototype.

4. To have a functional assembly of the mechanical, electrical, and control modules of the autonomous bird deterrent robot prototype.

1.5 Justification of the study

Birds cause significant damage to sorghum crops. They eat the seeds, uproot the seedlings, and peck at the mature plants, all of which can reduce crop yields and decrease the overall productivity of the farm. As a result, farmers often resort to various methods to deter birds from their sorghum fields, such as using chemical repellents, visual deterrents, or even hiring humans to chase the birds away. These methods are labor-intensive, and potentially harmful to the environment. The designed and fabricated autonomous bird deterrent robot, on the other hand, offers a more effective and sustainable solution to this problem. The robot is designed to move around the sorghum field and use sound and laser to deter birds. The robot is programmed to operate independently, allowing it to cover a larger area and respond to changing conditions in the field without the need for human intervention. Furthermore, the robot could be equipped with sensors and cameras that can collect information on bird behavior, crop health, and other factors that affect crop yields to optimize its deterrent tactics and improve its overall effectiveness.

2 Literature Review

Bird-human conflicts in agriculture have been a long-standing problem, with birds damaging crops and causing economic losses for farmers. Currently, various methods are used to deter birds, such as acoustic, visual deterrents, chemical, and physical barriers.

2.1 Acoustic Bird Deterrents

Acoustic deterrents are the most commonly used devices in avian pest management [8]. They rely on sound to frighten birds away from sites [8]. In this respect, Muminov et al. describe an acoustic bird deterrent system that works in three parts: bird detection, message sending, and automatic height adjustment as shown in Fig. 2.1 [9].

Figure 2.1: Bio-acoustic bird deterrent device
[9]

Bird detection is done by the Passive Infrared (PIR) sensor and preventive action is taken by initiating a servo, speaker, and blinking light. After bird detection, an alert is sent by Internet of Things (IoT) device to the farm owner. Depending upon seasonal cropping, the pattern height of the system gets automatically adjusted by using motor, string pulley, and sliding drawer mechanism after the activation of ultrasonic sensor. However, the repeated sounds were subject to habituation by birds and a source of noise pollution [10].

Ultrasonic devices have been proposed as an alternative to speakers since they are inaudible to humans and more or less harmless to animals as shown in Fig. 2.2 [11].

Figure 2.2: Ultrasonic bird repeller

[11]

Some studies have reported that ultrasonic waves annoy birds and stop them from entering and remaining in target areas [12–14]. However, other studies report that although birds can hear higher and lower frequencies, no bird species has shown sensitivity to ultrasonic frequencies greater than 20kHz [12, 14]. Permal et al. [15] argue that current available ultrasonic bird deterrent systems are not effective in eliminating bird activity because the signals are omnidirectional. This results in waste of energy as the signal is transmitted to the places where the birds are absent. Therefore, while ultrasonic devices are one of the available possibilities with the advantage of being inaudible to humans and more or less harmless to animals, their utility is questionable.

Seiler et al. [16] found out that the best effects are obtained with sonic deterrents when: (1) sound is presented at random intervals; (2) a range of different sounds are used; (3) the sound source is moved frequently; (4) sounds are supported by additional methods, such as distress calls or visual devices; and (5) sounds are reinforced by real danger, such as canons. Consequently, digital sound reproduction combined with random time off intervals, and random sequences have been designed into bird deterrent systems to prevent habituation by birds, and increase long-term effectiveness [17]. The randomness is often effective but only for a short time [17]. Studies have shown that acoustic devices have their best results in combination with a variety of techniques since most avian species adapt and ignore static devices within months of initial contact. [17–19].

2.2 Visual Bird Deterrents

Visual bird deterrents are designed to produce visual stimuli which birds forecast as some danger, thus scaring the birds away. The most common visual deterrent is the scarecrow as shown in Fig. 2.3 [20].

Figure 2.3: Scarecrows

[20]

Scarecrows are designed to mimic the appearance of a predator to cause birds to leave their current habitation. Most scarecrows are human shaped.

In general, because scarecrows are motionless they only provide short term protection due to the fact that the threat they create is perceived rather than real. Once the birds in the surrounding area realize that there is no danger the scarecrow loses all its effect so much so that some birds have been found to associate with them favorably [21]. To achieve the greatest effectiveness, scarecrows must appear to be life-like, be highly visible and must constantly change location. In the last few years, attempts have been made to develop dynamic scarecrows. Examples of these are the inflatable scarecrows as shown in Fig. 2.4 [12].

Figure 2.4: Inflatable flailing arm scarecrow

[12]

Mapari et al. [22] describe a humanoid automatic smart scarecrow equipped with sensors, movable arms, and alarming device. The scarecrow detects birds with the assistance of PIR sensor and move its arms up and down with the assistance of flapping mechanism.

2.3 Physical Bird Deterrents

Physical bird deterrents include such products as steel or plastic spike systems, bird netting, electrified wire systems, non-electrified wire systems, electrified track systems, slope barriers, mechanical spiders, and chemical foggers. Physically restricting birds from crops with netting is currently the most effective way to protect crops as shown in Fig. 2.5 [5]. Netting comes in a variety of shapes and forms. The most common is a small mesh (1 or 2 cm squares) either extruded and bi-oriented polypropylene or woven polyethylene [6]. On small plots, netting can also be applied as a canopy over multiple rows, supported by tall posts and wires. As a physical barrier, netting excludes all bird species. Additionally, birds are unable to acclimatize to it the way they do with other behavior-based deterrent tactics. Netting has the additional benefits of being noiseless, and non-chemical.

Netting, however, has some negative attributes that require consideration. For example, small birds can, and do, get caught in nets resulting in injury or death [5]. Netting can be used on fields that are mechanically harvested, but it must be removed prior to harvest [23]. Bird netting also adds a significant upfront cost to production and it is time-consuming to apply and remove [6].

Figure 2.5: Bird netting

[5]

2.4 Chemical Bird Deterrents

Chemical bird repellents in gel, liquid and spray forms deter birds from nesting in or landing on specific areas of the crop as shown in Fig. 2.6 [24]. While most are not as effective in the field as they are in the lab, some chemical treatments have been effective. For example, one study showed a decrease in crop loss by 88% to 99% when crops were treated with methyl anthranilate [24]. However, in another study, methyl anthranilate was not effective against frugivorous bird species [24]. Anthraquinone is another commonly used chemical used to deter birds. One study observed a 93% decrease in rice consumption by blackbirds and grackles when seeds were treated with anthraquinone before planting [25]. Horned larks are also affected by anthraquinone, damaging 60% of treated lettuce seedlings but 100% of untreated seedlings [25]. However,the effectiveness was reduced in adverse weather conditions, and all the above chemicals were only effective on surfaces where they were applied [25].

Figure 2.6: Chemical spraying

[24]

2.5 Robotic Bird Deterrent Systems

K.N. MacLeod and R.J. Dooling [26] discusses the use of robotic systems for bird deterrence, including the use of unmanned aerial vehicles (UAVs) and ground-based robots.

According to the authors, robotic systems, such as UAVs and ground-based robots, have the potential to be effective at deterring birds, but there are challenges associated with developing and implementing these systems including:

- Cost: Developing and implementing robotic systems can be expensive, which may make them less accessible to some users.
- Reliability: Robotic systems may be prone to malfunctions or failures, which can impact their effectiveness as bird deterrents.
- Human-animal interaction: There are concerns about the potential for negative interactions between humans and animals when using robotic systems for bird deterrence, such as the risk of injury to the birds.
- Legal and regulatory issues: The use of robotic systems for bird deterrence may be subject to legal and regulatory restrictions, which can impact their use and deployment.
- Lack of knowledge and understanding: There is a lack of knowledge and understanding about the most effective ways to use robotic systems for bird deterrence, which can make it difficult to develop and implement these systems.

According to [27], robotic systems, such as UAVs and ground-based robots, have the potential to be effective at deterring birds in a variety of industries, including agriculture and aviation. Furthermore, the use of robots for bird deterrence has several benefits, including the ability to cover large areas, the ability to operate continuously, and the potential for increased safety for humans. However, there are also drawbacks to using robots for bird deterrence, including the high cost of development and implementation, the potential for malfunctions or failures, and the potential for negative interactions between humans and animals. Thus developing and implementing effective bird deterrent robots requires a thorough understanding of bird behavior and the ability to adapt to changing circumstances.

In [24], the researchers developed a robot that was designed to mimic the movements and sounds of a predator bird. The robot was able to move autonomously, using sensors to avoid obstacles and navigate its environment. The researchers found that the robot was effective at deterring birds from a designated area. However, [12] found that birds become habituated to deterrent robots over time, reducing their effectiveness. They suggest that using a variety of deterrent methods and regularly rotating them may help to reduce this effect. Similarly, several studies have found that bird deterrent robots can be effective at reducing bird-human conflicts in certain situations, but their effectiveness varies depending on the type of bird, the location, and the specific design of the robot [17–19]. additionally, in a review of existing bird deterrent technologies, [27] found that the most effective methods tended to be those that simulated predators or employed a combination of different stimuli, such as visual, auditory, and tactile cues.

Consequently, [5] developed a robot that used a combination of visual and auditory stimuli to deter birds and address the problem of bird habituation. The robot detected the presence of birds using sensors, and displayed flashing lights and emitted sounds designed to be unpleasant to birds. The researchers found that the robot was effective at deterring birds from a designated area. Furthermore, according to [28], machine learning algorithms and artificial intelligence have the potential to improve the effectiveness of bird deterrent robots by allowing them to adapt to changing circumstances and learn from past experiences. These technologies can be used to process data from sensors and cameras on the robots, allowing the robots to detect and respond to the presence of birds in real-time.

According to the authors, one of the main advantages of using sensors is that they can provide real-time data to the robot, allowing it to detect and respond to the presence of birds in real-time. This can be particularly useful in situations where the robot needs to respond quickly to changing circumstances. However, sensors may be limited in their ability to adapt to changing circumstances and learn from past experiences. This means that the robot may not be able to improve its performance over time and may be less effective at deterring birds in the long term.

On the other hand, the use of machine learning algorithms can allow the robot to adapt to changing circumstances and learn from past experiences. This can improve the effectiveness of the robot over time, as it can adapt to changing circumstances and learn from its past experiences. However, there are also some challenges associated with the use of machine learning algorithms on bird deterrent robots. These algorithms may require large amounts of data to train, and there may be challenges associated with ensuring that the algorithms are robust and unbiased.

2.6 Gap Analysis

From the above discussion, it is evident that bird deterrent robots are designed to keep birds away from areas where they may cause damage or pose a nuisance. These robots can take many forms, including mechanical devices, sound emitters, and visual deterrents. However, the identified gaps in current bird deterrent robots are:

- Effectiveness: Bird deterrent robots are designed to deter birds from specific areas by using a variety of techniques, such as physical, acoustic, and visual deterrents. While these robots can be effective at deterring birds in some situations, their effectiveness is limited in others due to a variety of factors. One factor that impacts the effectiveness of bird deterrent robots is their size, shape, and movement patterns. For example, birds may be more likely to habituate to a robot that is smaller or has a less threatening appearance, or to a robot that has predictable movement patterns. This can make it more difficult for the robot to effectively deter the birds, especially if the birds become accustomed to its presence. Another factor that impacts the effectiveness of bird deterrent robots is the type of deterrent being used. Some deterrents, such as physical barriers or loud noises, may be more effective at deterring certain species of birds, while others may be less effective. It is thus important to choose the most appropriate deterrent for the specific situation and the species of birds being deterred.

- Limited coverage: Bird deterrent robots are designed to deter birds from specific areas by using a variety of techniques, such as physical, acoustic, and visual deterrents. These robots are typically limited in their mobility, which means that they are only effective at deterring birds within a certain radius of their location. This can be a problem in situations where the area to be protected is large or where there are multiple areas that need to be protected at the same time, as the robots may not be able to cover the entire area effectively.

- Adaptability: One of the challenges associated with the use of bird deterrent robots is that birds can become accustomed to them over time, reducing their effectiveness as a deterrent. This phenomenon is known as habituation, and it occurs when birds become accustomed to a particular deterrent and no longer respond to it. There are several factors that can contribute to habituation in birds, including the duration and frequency of the deterrent, the type of deterrent being used, and the behavior of the birds themselves. For example, birds may be more likely to habituate to a deterrent that is present for long periods of time or that is used frequently, or to a deterrent that is less intense or less effective at deterring them.

3 Methodology

This chapter describes the design and fabrication process of the mechanical, electrical, and control modules of the autonomous bird deterrent robot prototype shown in Fig.3.1.The fabricated robot is shown in Fig.3.2

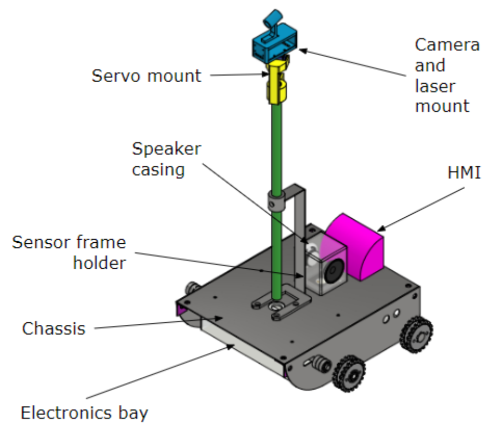

Figure 3.1: Designed Robot

Figure 3.2: Fabricated Robot

3.1 Operation Principle

The process involved in the robot include:

1. Input: The model takes image frames as input from video stream captured by the Intel Realsense d435i depth camera.

2. Preprocessing: The input image is preprocessed to standardize its size to 416×416 to enhance its features for improved detection accuracy.

3. Detection: The preprocessed image is fed into the YOLOv7 model, which uses its trained parameters to identify the presence and location of any birds in the image.

4. Bounding box prediction: The YOLOv7 model outputs bounding boxes around any detected birds in the image, along with a confidence score indicating the model's confidence in the detection.

5. Motion control: If no birds are detected in the images, the robot continues to move around in its environment using its pre-programmed movement pattern. If a bird is detected, the robot stops and remain stationary to allow for more effective targeting with its laser and sound deterrents.

6. Laser targeting and Sound generation: The robot uses the bounding box information and its own location and orientation data to aim its laser at the detected birds and generates bird predator calls.

3.2 Mechanical Design

This section describes the design and fabrication process of the different mechanical elements of the robot.

3.2.1 Robot Chassis Design Considerations

The overal edsign considerations for the chassis were:

- Size and weight: The chassis should be designed to be small and lightweight, allowing the robot to move easily and maneuver through the dense sorghum plants without damaging them.
- Strength and durability: The chassis should be strong and durable enough to withstand the rigors of field conditions, such as rough terrain and potential collisions with plants or other objects.
- Clearance: The chassis should be designed to provide sufficient clearance for the robot's sensors and other equipment, allowing them to accurately and reliably detect birds.
- Mounting points: The chassis should include appropriate mounting points for the robot's sensors, cameras, and other equipment, allowing them to be securely attached to the robot.
- Mobility: The chassis should be designed to support the robot's desired mode of mobility, such as wheels, tracks, or legs.

3.2.2 Robot Chassis Design

Because this robot will be primarily used in sorghum fields, its width was limited to the sorghum spacing as as shown in Fig. 3.3 and determined as follows:

$$W = W_r - 2D \tag{3.1}$$

Where: W is robot width, W_r is row width, and D is the sorghum stalk diameter

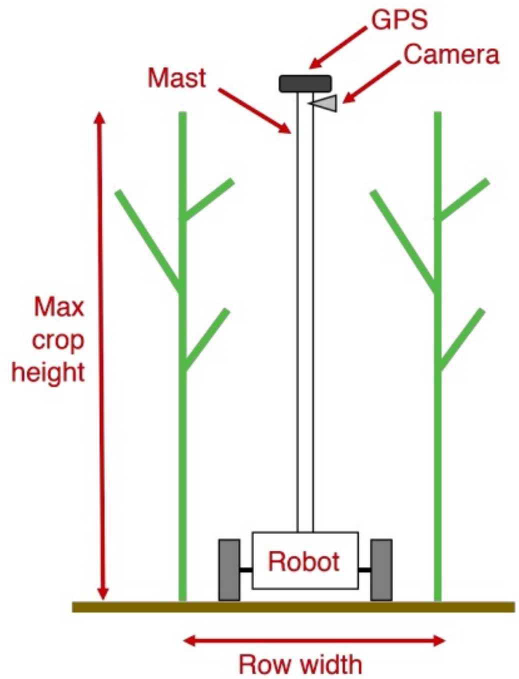

Figure 3.3: Field dimensions help determine the robot size

[13]

Given that sorghum spacing after thinning is 750mm [29] between rows and the average stalk diameter of sorghum is 25mm [29], equation (3.1) gave a maximum robot width of 700mm. Given that this is a prototype, the width was scaled down by 0.4 giving a robot width of 280mm. While a thinner robot design accommodates better motion uncertainty and reduce the chances of collision with sorghum crops, decreased width reduces the robot's lateral stability hence the 0.4 scaling factor.

Both wheeled and tracked drive rains were considered for the robot. Tracked drive train was selected because they have smoother ride on rough fields (diagonally across rows), have higher level of tractive efficiency over a wider range of soil conditions, are more stable on hillsides (able to maintain traction), and have better maneuverability (zero turn radius possible) compared to wheels. Buying of tracks and fabrication of tracks was considered and because of price, the best option was to fabricate the tracks from sprockets and chains.In general, it is best to keep the robot's center-of-mass low by minimizing the height in order to increase stability. However, the robot will be operating in rough terrain which calls for ground clearance. Agricultural furrows are typically 15mm to 20mm high. Taking variations into account, a tolerance of 5mm was included. This informed the design of the robot sprockets to give the robot a ground clearance of 25mm as shown in Fig. 3.4.

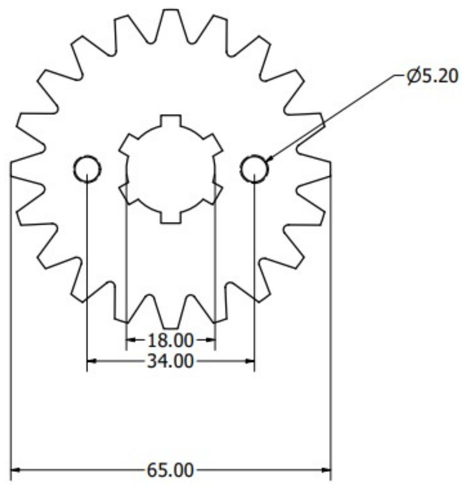

Figure 3.4: Sprocket design

The sprocket assembly is shown in Fig 3.5.

Figure 3.5: Sprocket Assembly

The plate design was used for both the base and each side of the base, where both wheels were located as shown below. This will allow for the location and mounting of other components on the robot. The cross span that connects both wheel bases also supports the sensor frame. This allows the sensor frame to rise above the sorghum crops, increasing its functionality. Fig. 3.6 shows the robot frame with mounting holes.

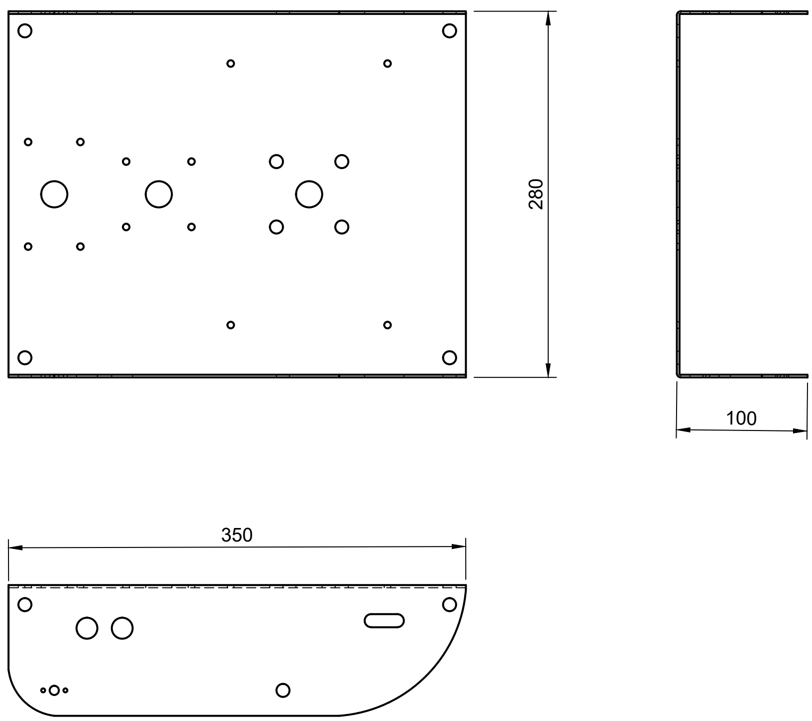

Figure 3.6: Robot Base

The fabricated robot base is shown in 3.7. The changes that were different from the design was the relocation of the ultrasonic sensors.

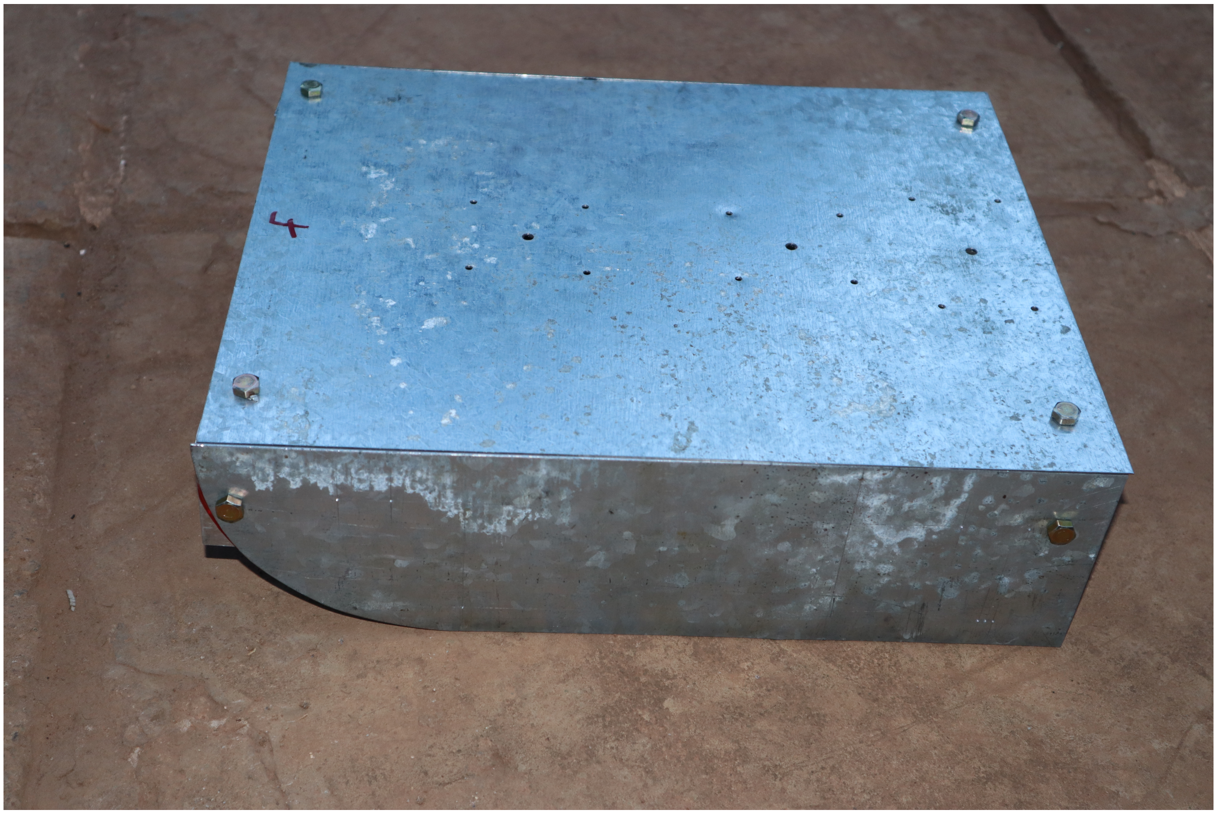

Figure 3.7: Fabricated Robot Chassis

3.2.3 Robot Chassis Material Selection

Table 3.1: Material Selection

Property	**Galvanised Mild Steel**	**Aluminium**	**acrylic**
Density	7.87 g/cm^3	2.70 g/cm^3	1.19 g/cm^3
Strength	Moderate	Moderate to High	Low to Moderate
Weldability	Good	Good	Poor
Corrosion Resistance	Moderate	Excellent	Poor
Machinability	Good	Good	Excellent
Cost	Moderate to Low	Moderate to High	High

As shown in table 3.1, when it comes to the fabrication of the robot chassis, the most suitable material would be aluminum. Mild steel is relatively inexpensive and is strong enough to support the weight of the robot and its components, but it may not be as corrosion-resistant as aluminum. Aluminum, on the other hand, is lightweight and highly corrosion-resistant than mild steel. Acrylic, while easy to machine, is not suitable for a robot chassis because it is not strong enough and is prone to scratching and cracking. Thus, aluminium was selected. However, due to unavailability of aluminium sheets, the robot chassis was fabricated from 3mm galvanised steel sheet.

3.2.4 Robot Chassis Fabrication

To fabricate the plate-based design robot chassis shown in Fig. 3.7 from the 3mm galvanised steel sheets, the following steps were followed:

- The design for the robot chassis was created using AutoDesk Inventor. This included the dimensions and shape of the chassis, as well as the locations of holes and slots that need to be cut or drilled into the galvanised steel sheets.

- Next, the galvanised steel sheets were cut to the desired size and shape using a hack saw.
- The holes and slots were then drilled and cut into the galvanised steel sheets respectively, using a a hand-held drill.
- The galvanised steel sheets were then assembled using bolts, screws, or other fasteners.
- Finally, the robot chassis was then finished with additional treatments including painting.

3.2.5 Sensor Frame Design Considerations

- Size and weight: The sensor frame will need to be compact and lightweight, to minimize its impact on the overall size and weight of the robot. This will involve carefully selecting and arranging the sensors to minimize their size and weight, while still providing the necessary functionality.
- Positioning and orientation: The sensors on the sensor frame will need to be positioned and oriented in a way that allows them to accurately and reliably measure the desired parameters. This will involve considering the range, field of view, and other characteristics of the sensors, and arranging them in a way that provides the necessary coverage and accuracy.
- Connectivity: The sensors on the sensor frame will need to be connected to the robot's electronics bay in a way that allows them to transmit their data to the controller. This will involve selecting appropriate cables and connectors, and arranging them in a way that minimizes interference and ensures reliable data transmission.

- Structural integrity: The sensor frame will need to be strong and rigid, to prevent it from flexing or deforming under the weight of the sensors or the forces acting on the robot. This will involve selecting appropriate materials and designing the frame in a way that provides the necessary strength and stiffness.
- Environmental protection: The sensor frame will need to be designed to protect the sensors from the environment in which the robot is operating. This will involve considering factors such as temperature, humidity, dust, and other potential sources of damage, and designing the frame and its mounting points in a way that protects the sensors from these hazards.

3.2.6 Sensor Frame Design

The bird deterrent robot is required to detect birds flying above the top canopy of sorghum crops which lies between 600mm and 1200mm. Therefore, a mast for sensor mounting was chosen since the design has low surface area, making it less susceptible to wind loads when out in the field. To determine the height of the sensor frame for the 350mm by 280mm bird deterrent robot using ADAMS (Automated Dynamic Analysis of Mechanical Systems) for stability testing, the following procedure was followed:

- The ADAMS model was set up: First, a model of the bird deterrent robot was created in ADAMS, including all relevant components, such as the sensor frame, motors, wheels, and body. The dimensions and properties of these components were accurately represented, including the size, shape, and mass of the robot.
- The test conditions were defined: Next, the test conditions for the stability test were defined, including the terrain and any external forces that may have affected the robot's stability. For example, the effects of wind, rain, or other environmental factors on the robot's stability were considered.

– The stability test was run: Once the model and test conditions were set up, the stability test was run in ADAMS. This simulated the robot's movement and determined its stability under the defined conditions.

– The results were analyzed: After the stability test was complete, the results were analyzed to determine the height of the sensor frame that provided the optimal stability for the robot. The test was run multiple times with different sensor frame heights to determine the optimal height.

– The sensor frame height was adjusted as needed: Once the optimal sensor frame height was determined, the height of the sensor frame on the actual robot was adjusted to match the optimal height determined in the stability test.

Based on stability simulations using ADAMS software, masts longer than 1200mm was observed to cause tipping as shown in Fig. 3.8.

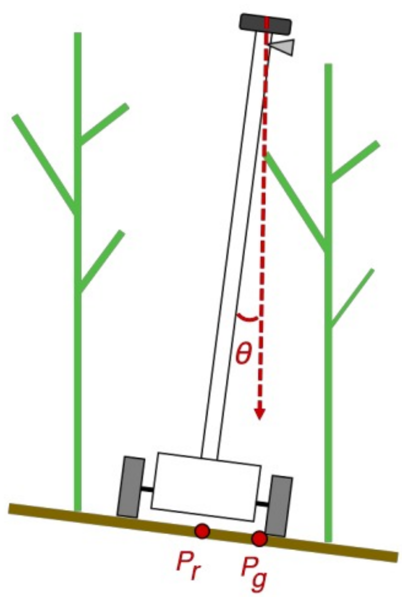

Figure 3.8: Tipping angle and incorrect position estimate

[13]

Consequently, the above dimension was scaled down by a factor of 0.4 to give a mast height of 480mm. The height adjustment mast is provided with a support frame to facilitate manual height adjustment and mount it to the robot base. The support frame has a length of 240mm to ensure that it provides support to the height adjustment mast at its centre of gravity. The choice of length also ensures that the robot remains within its stability triangle even at a full extension of 720mm since it is less than the mast's critical length of 1200mm. The height adjustment mast is shown in Fig. 3.9 and the support mast is shown in Fig. 6.11.

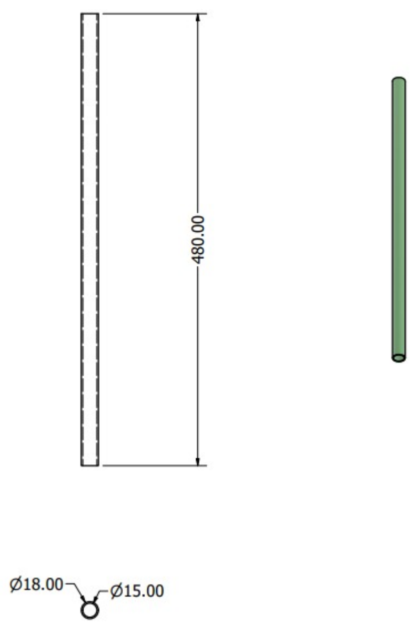

Figure 3.9: Height adjustment Mast

3.2.7 Sensor Frame Material Selection

Table 3.2: Material Selection

Property	Galvanised Steel Tube	Aluminium Tube	PVC tube
Density	7.87 g/cm^3	2.70 g/cm^3	1.40 g/cm^3
Strength	Moderate	Moderate to High	Low
Weldability	Good	Good	Poor
Corrosion Resistance	Moderate	Excellent	Good
Machinability	Good	Good	Good
Cost	Moderate to Low	Moderate to High	Low
Suitability	Good	Excellent	Poor

As shown in table 3.3, when it comes to the fabrication of the robot sensor frame, the most suitable material would be aluminum. Mild steel is relatively inexpensive and is strong enough to support the weight of the sensors and other components, but it may not be as corrosion-resistant as aluminum. Aluminum, on the other hand, is lightweight and highly corrosion-resistant. PVC, while inexpensive and corrosion-resistant, is not suitable for the robot sensor frame because it is not strong enough for the intended application.

3.2.8 Sensor Frame Fabrication

To fabricate the sensor frame shown in 3.10 from the 26mm aluminum tube, the following steps were followed:

– First, the design for the sensor frame was created using AutoDesk Inventor. This included the dimensions and shape of the frame, as well as the locations of mounting holes that need to be drilled into the aluminum tube.

– Next, the aluminum tube would was cut to the desired length using a band saw.

– The holes were then drilled into the aluminum tube using a hand-held drill.

– The ends of the aluminum tube were then flared using a deburring tool to create a smooth, finished edge.

– Finally, the sensor frame was finished with painting to protect it from corrosion and other damage.

Figure 3.10: Robot Chassis with Fabricated sensor frame

3.2.9 Computer Vision Camera Considerations

– Resolution: The camera will need to have sufficient resolution to capture images that are detailed enough to enable accurate and reliable analysis. This will involve considering factors such as the size of the objects being imaged, the distance between the camera and the objects, and the desired level of detail.

- Frame rate: The camera will need to be able to capture images at a sufficient frame rate to enable real-time analysis. This will involve considering factors such as the speed of the robot and the movements of the objects being imaged, and selecting a camera that can capture images at the required rate.
- Field of view: The camera will need to have a sufficient field of view to enable it to capture the entire area of interest. This will involve considering the size and shape of the area being imaged, and selecting a camera with a lens that provides the necessary coverage.
- Focal length: The camera will need to have a lens with a suitable focal length to enable it to focus on objects at the desired distance. This will involve considering the distance between the camera and the objects being imaged, and selecting a lens that provides the necessary focal length.
- Sensitivity: The camera will need to be sensitive enough to capture images in the lighting conditions present in the environment in which the robot is operating. This will involve considering factors such as the ambient light level and the reflectivity of the objects being imaged, and selecting a camera with a suitable sensitivity.

3.2.10 Camera Selection

Table 3.3: Camera Selection

Feature	Raspberry Pi Camera	Intel RealSense D435i	IMX219 Camera
Resolution	8MP	1920 x 1080	8MP
Field of view	72°	90° (horizontal), 65° (vertical)	70°
Frame rate	30 fps	30 fps	30 fps
Depth sensing	No	Yes	No
Price	Kshs. 2500	Kshs. 19900	Kshs.1900

Overall, all three cameras have similar resolution and frame rate, but the Intel RealSense D435i stands out for its ability to sense depth and its wider field of view as shown in Table **??**. Both the Raspberry Pi Camera and IMX219 Camera are relatively inexpensive options, with the IMX219 Camera being the more affordable of the two. In terms of their features and capabilities, the Raspberry Pi Camera is a relatively basic camera module, offering a low-resolution image sensor and a fixed-focus lens. The Intel RealSense D435i, on the other hand, offers a more advanced set of features, including a depth sensor, integrated microphone, and the ability to track motion and recognize objects. The IMX219 is a high-resolution camera module that offers a variety of features, including a high-speed image sensor, a wide-angle lens, and the ability to capture high-resolution images and videos. Hence, the IMX219 Camera Module shown in Fig. 3.11 was selected as the vision system for the bird deterrent robot prototype. However, the Intel RealSense D435i camera became available during the fabrication stage and was thus used in place of the IMX219 camera.

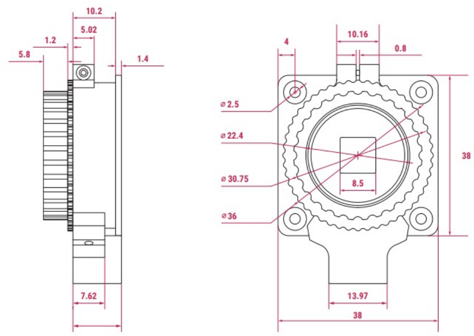

Figure 3.11: IMX219 Camera Module

3.2.11 Bird Deterrent Laser Considerations

– Safety: The laser should be designed to be safe for use around birds, people, and other animals. This will involve selecting a laser with a low enough power output to avoid causing injury or harm, and ensuring that the laser is properly directed and contained to prevent accidental exposure.

– Effectiveness: The laser should be designed to be effective at deterring birds from the area. This will involve selecting a laser with the appropriate wavelength, beam pattern, and pulse rate to create a deterrent effect, and ensuring that the laser is properly directed and aimed to cover the desired area.

– Reliability: The laser should be designed to be reliable and long-lasting, to minimize the need for maintenance and replacement. This will involve selecting components that are durable and resistant to damage, and designing the system to prevent or minimize the effects of environmental factors such as moisture, dust, and temperature changes.

– Cost: The laser should be designed to be cost-effective, to provide good value for the investment. This will involve considering the cost of the components, the manufacturing process, and the expected lifespan of the system, and balancing these factors to provide the best possible value.

– Ease of use: The laser should be designed to be easy to install, operate, and maintain, to minimize the need for specialized training or expertise. This will involve considering the user's perspective and designing the system to be intuitive and user-friendly, with clear instructions and accessible controls.

3.2.12 Laser Selection

The 650nm 5mW Adjustable Laser Dot Module and 650nm 5mW Focusable Red Laser Module were considered. The 650nm 5mW Focusable Red Laser Module shown in Fig. 3.12 was selected becasue of its size.

Figure 3.12: 650nm 5mW Focusable Red Laser Module [15]

The laser module has a physical size of diameter 12×35mm, and a cable length of about 135mm as shown above.

3.2.13 Camera and Laser Mount Design

The above camera and laser module dimensions informed the design of the camera and laser mount case which has a physical size of $60 \times 40 \times 84$mm as shown in Fig. 6.22. Since the laser and camera are rotating, a provision for servo motor mounting was provided. Servo motors have a standard physical size of $23 \times 12.2 \times 29$mm. The servo motor mounting was has a physical dimension of $26 \times 31 \times 3$mm to provide a large enough surface area to mount the servo motor. the mount has 2mm diameter holes for screwing the servo motor onto the mount as shown in Fig 3.13.

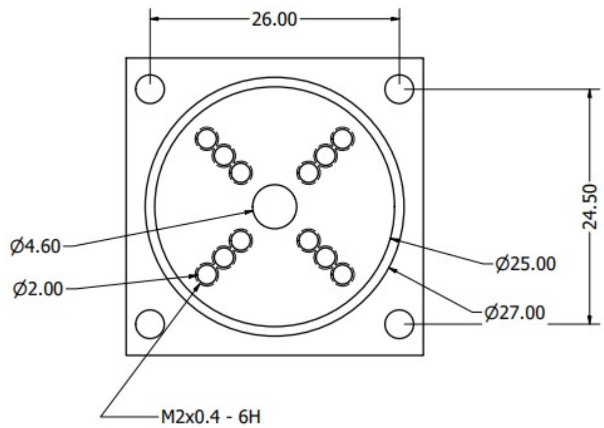

Figure 3.13: Servo Motor Mount

3.2.14 Camera and Laser Mount Material Selection

Table 3.4: Material Selection

Property	**ABS**	**PLA**	**Acrylic**
Density	1.04 g/cm^3	1.25 g/cm^3	1.19 g/cm^3
Strength	High	High	Low to Moderate
Impact Resistance	Good	Good	Poor
Temperature Resistance	High	Moderate	Low
Warping	High	Low	Low
Cost	Moderate	Low	High
Suitability for Camera and Laser Mount	Good	Good	Poor

When it comes to the fabrication of the camera and laser mount for the robot, the most suitable material would be ABS as shown in table 3.4. ABS has a higher temperature resistance and is slightly stronger than PLA, but it is more prone to warping. PLA is less prone to warping and is slightly cheaper, but it has a lower temperature resistance. Acrylic, while easy to machine, is not suitable for a camera mount because it is not strong enough and is prone to cracking and breaking. Hence ABS was selected.

3.2.15 Camera and Laser Mount Design changes

Whereas the IMX219 Camera is a small, lightweight camera module that is based on the Sony IMX219 image sensor, the Intel RealSense D345i is a more advanced camera module than the IMX219 Camera, as it is capable of capturing high-resolution images and video, and also includes depth-sensing and 3D imaging capabilities. This makes it suitable for applications such as computer vision, robot navigation, gesture recognition, and augmented reality. In terms of overall performance, the Intel RealSense D345i is also more advanced and powerful, but it is also more expensive. However, the team was able to acquire the Intel RealSense D345i camera and thus the shift from IMX219 to Intel RealSense D345i.

Additionally, the camera mount was to be fabricatde from 3D printing using ABS plastic. However, due to challenges in 3D printing, it was redesigned as shown in Fig.3.14 and was fabricated from acrylic. The goal of the fabrication process was to create a casing that is protective and accurately holds the camera and laser in place.

3.2.16 Camera and Laser Mount Fabrication

As a result of the changes in selected camera and redesign of the camera and laser mount, the fabrication process of the casing for the the Intel Realsense d435i camera and laser mount using acrylic involved the following steps. Fig.3.14 shows the fabricated part with the Intel Realsense D435i camera and laser mounted.

- Designing the casing using AutoDesk Inventor.
- Creating a prototype using acrylic sheets and cutting them to the desired shape using a laser cutter.

Figure 3.14: Fabricated Camera and Laser Mount

3.2.17 Speaker Considerations

- Sound: The speaker should be designed to generate sounds that are effective at deterring birds from the area. This will involve selecting sounds that are known to be effective at deterring birds, and ensuring that the speaker is able to produce these sounds at the appropriate volume and frequency range.

- Coverage: The speaker should be designed to cover the desired area with sound. This will involve considering the size and shape of the area, and selecting a speaker with the appropriate dispersion pattern and power output to provide adequate coverage.
- Durability: The speaker should be designed to be durable and resistant to damage from the environment, to minimize the need for maintenance and replacement. This will involve selecting materials and components that are able to withstand the conditions in which the speaker will be used, and designing the system to prevent or minimize the effects of environmental factors such as moisture, dust, and temperature changes.
- Cost: The speaker should be designed to be cost-effective, to provide good value for the investment. This will involve considering the cost of the components, the manufacturing process, and the expected lifespan of the system, and balancing these factors to provide the best possible value.
- Ease of use: The speaker should be designed to be easy to install, operate, and maintain, to minimize the need for specialized training or expertise. This will involve considering the user's perspective and designing the system to be intuitive and user-friendly, with clear instructions and accessible controls.

3.2.18 Speaker Selection

The considered speakers were the Micro speaker 1W 8R (10 * 15MM) and 40mm 4 3W Audio Stereo Woofer Loudspeaker. The 40mm Trumpet Speaker was selected as the output device for the predator bird calls because of its frequency range. The speaker is shown in Fig. 3.15. The speaker has a maximum weight of 10g.

Figure 3.15: Loud Speaker

[11]

3.2.19 Speaker Casing Design

The dimensions of the speaker casing were based on the size of the selected speakers. Consequently, speaker casing has a physical size of $78 \times 78 \times 70$mm as it was designed to hold two of the above loud speakers opposite each other to ensure that the generated sounds travel in all directions as shown in 3.16. The speaker has a maximum weight of 10g.

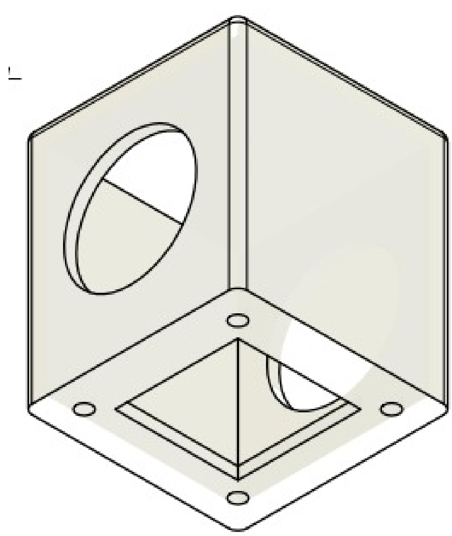

Figure 3.16: Speaker Casing

3.2.20 Speaker Casing Fabrication

The fabrication process for the rectangular speaker casing using acrylic typically involved the following steps:

- First, the desired dimensions of the speaker casing were measured and marked on the 3mm sheet of acrylic.
- The acrylic was then cut to size using a laser cutter.
- The edges of the acrylic were polished to remove any roughness or burrs.
- The acrylic pieces were then bonded together using superglue and the speakers were installed inside the casing. Overall, the fabrication of the speaker casing using acrylic involved cutting, polishing, and bonding the acrylic to create the desired shape and size for the casing. Fig.3.17 show the fabricated speaker casing.

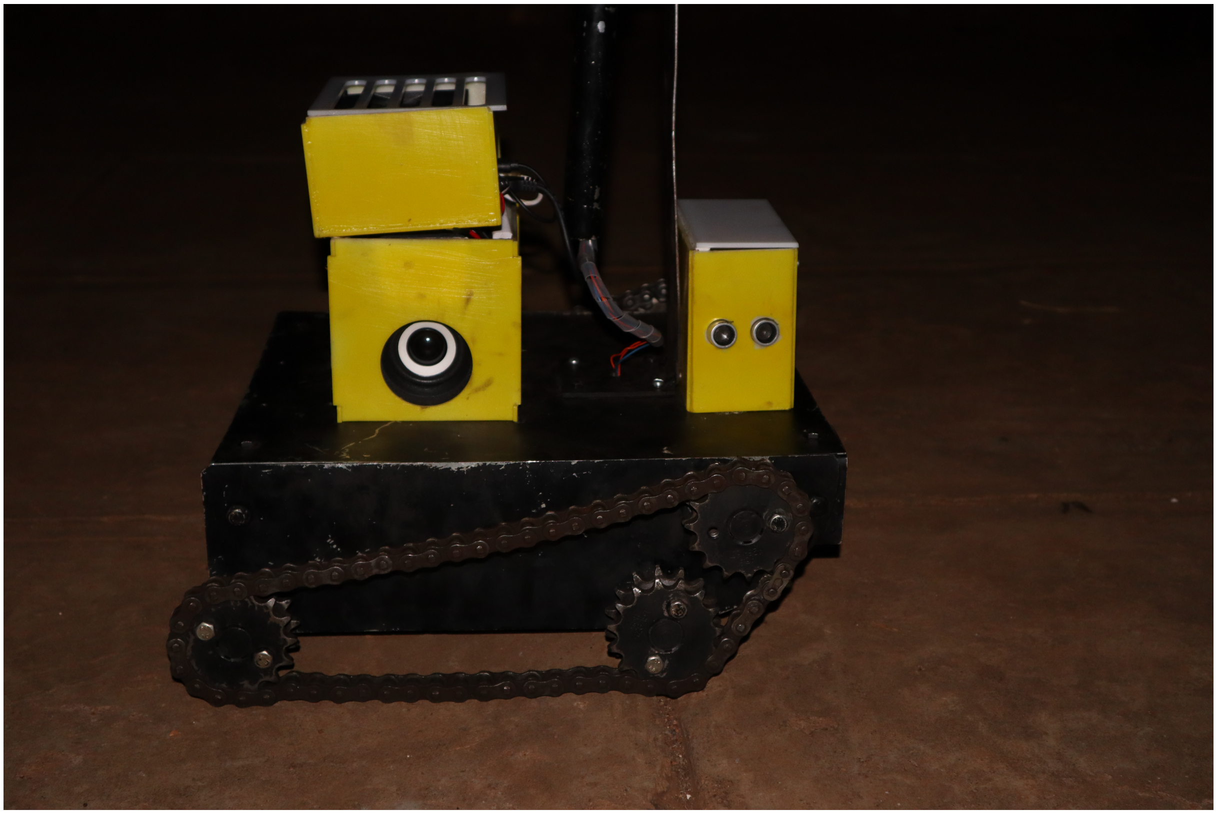

Figure 3.17: Robot Assembly with Fabricated speaker casing

3.2.21 Robot Drive Train Considerations

– Terrain: The drive-train should be designed to be able to navigate the uneven and potentially muddy terrain of a sorghum field. This will involve selecting wheels, tracks, or other means of propulsion that are able to provide sufficient traction and stability on the terrain, and designing the suspension and steering systems to provide adequate performance.

– Speed: The drive train should be designed to be able to move at the appropriate speed to effectively deter birds from the area. This will involve considering the speed at which birds are able to fly, and selecting a drive-train that is able to move at a similar or higher speed to create a deterrent effect.

– Range: The drive-train should be designed to be able to operate for an extended period of time without needing to be refueled or recharged. This will involve selecting a power source with sufficient capacity and efficiency, and designing the drive-train to minimize energy consumption.

- Reliability: The drive-train should be designed to be reliable and long-lasting, to minimize the need for maintenance and replacement. This will involve selecting components that are durable and resistant to damage, and designing the system to prevent or minimize the effects of environmental factors such as moisture, dust, and temperature changes.
- Cost: The drive-train should be designed to be cost-effective, to provide good value for the investment. This will involve considering the cost of the components, the manufacturing process, and the expected lifespan of the system, and balancing these factors to provide the best possible value.

3.2.22 Robot Drive Train Selection

Table 3.5: Robot Drive Train Selection

Property	Wheeled Drive Train	Tracked Drive Train
Mobility	Good on smooth, flat surfaces	Good on rough or uneven terrain
Speed	Can achieve high speeds	Typically slower
Maneuverability	Good maneuverability	Limited maneuverability
Traction	Can lose traction surfaces	Good traction
Wear and tear	Tires may wear out	Tracks may wear out over time
Cost	Typically less expensive	Typically more expensive

Overall, both wheeled and tracked drive trains have their own advantages and disadvantages as shown in table 3.5. Wheeled drive trains are good for smooth, flat surfaces and can achieve high speeds, but may not be as effective on rough terrain.

Tracked drive trains, on the other hand, are better suited for rough terrain but may be slower and less maneuverable than wheeled drive trains. Given the rough nature of sorghum farms, tracked drive train was selected.

3.2.23 Robot Drive Train Design

As mentioned before, both wheeled and tracked drive rains were considered for the robot. Tracked drive train was selected since tracked robots can operate on rough terrains and soil conditions (e.g., muddy fields) that wheeled robots are not capable of due to low ground pressure . Four chains were chosen for the robot drive train to increase the contact area with the ground and lower the ground pressure by 25% since $P = \frac{F}{A}$. The sprocket size is show in Fig. 3.18.

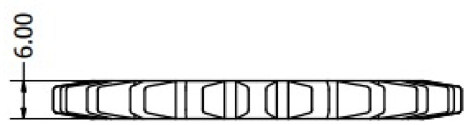

Figure 3.18: Drive Sprocket

3.2.24 Robot Drive Train Fabrication

The fabrication process for the robot drive train shown in Fig. 3.19 involved the following steps:

- First, the desired dimensions of the drive train were measured and the necessary materials gathered, including the chains, sprockets, and drive motors.
- The chains were cut to the appropriate length and the sprockets are attached to the drive motors.
- The tracks were mounted onto the robot chassis using brackets and bolts.

– The drive motors wee connected to the chains using the sprockets, and the drive train was tested to ensure that it is functioning properly.

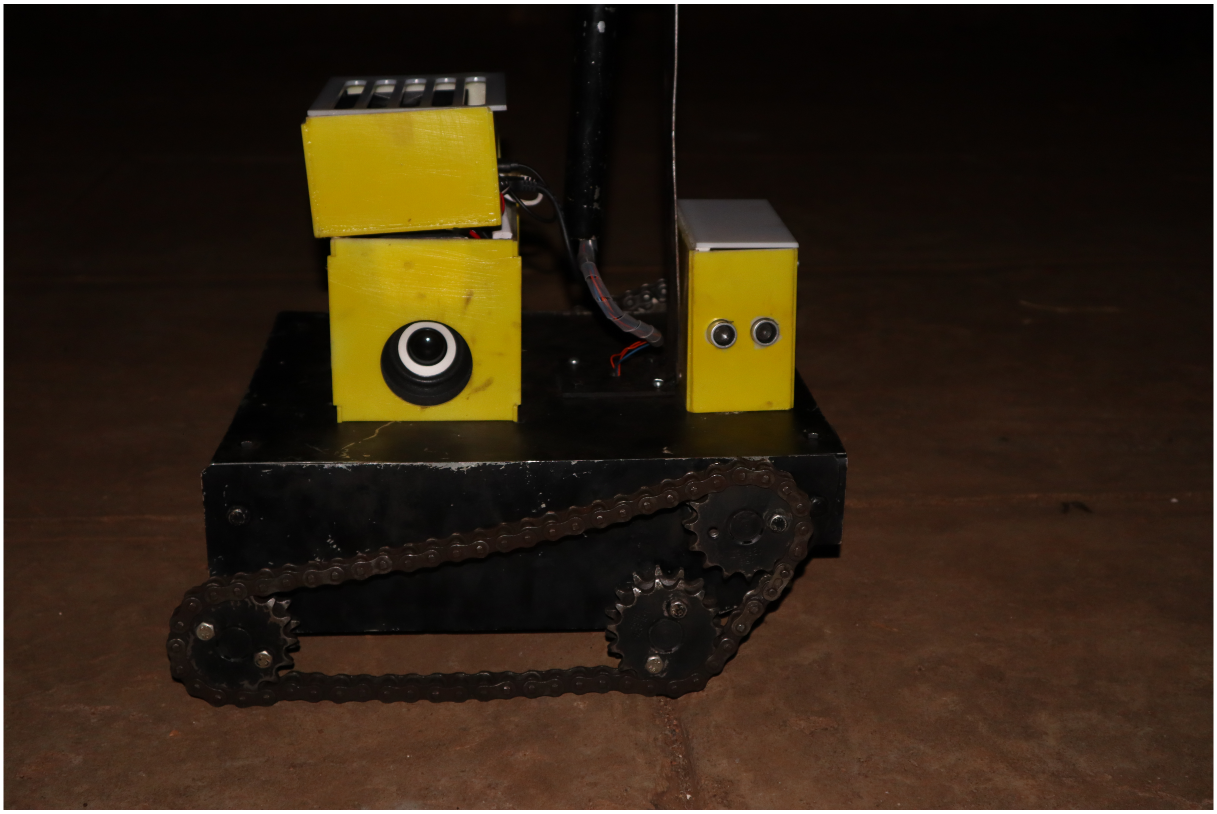

Figure 3.19: Robot Assembly with Fabricated drive-train

3.2.25 Electronic Bay Design Considerations

Considerations for the designing of the electronic bay for the robot included:

– Size and weight: The electronic bay will need to be compact and lightweight, to minimize its impact on the overall size and weight of the robot. This will involve carefully selecting and arranging the components to minimize their size and weight, while still providing the necessary functionality.

– Heat dissipation: The electronic components in the electronic bay will generate heat as they operate, which will need to be dissipated to prevent overheating. This will involve selecting components that are able to operate within the required temperature range, and providing adequate ventilation or cooling systems to prevent overheating.

– Electrical safety: The electronic bay will need to be designed to ensure electrical safety, to prevent damage to the robot or injury to the user. This will involve selecting components that are certified for safe operation, and ensuring that all electrical connections are secure and properly insulated.

3.2.26 Electronic Bay Design

Consequently, the robot base was designed such that it provides sufficient space for mounting of an electronic bay. This is because given the operating environment, moisture is an important consideration affecting how to weather-proof the electrical components. The electronic bay was located underneath the robot frame to provide a waterproof setup. The electronic bay has a size of 150 $\times$ 250 mm as shown by Fig. 3.20. The sizing of the electronic bay was based on the size of preliminary components to be located in the electronic bay. The components include 4S LiPo batteries, 2 motor drivers, and the electrical circuit board which occupy an estimated area of 20000mm^2. Tolerance allowance of 2500mm^2 was provided.

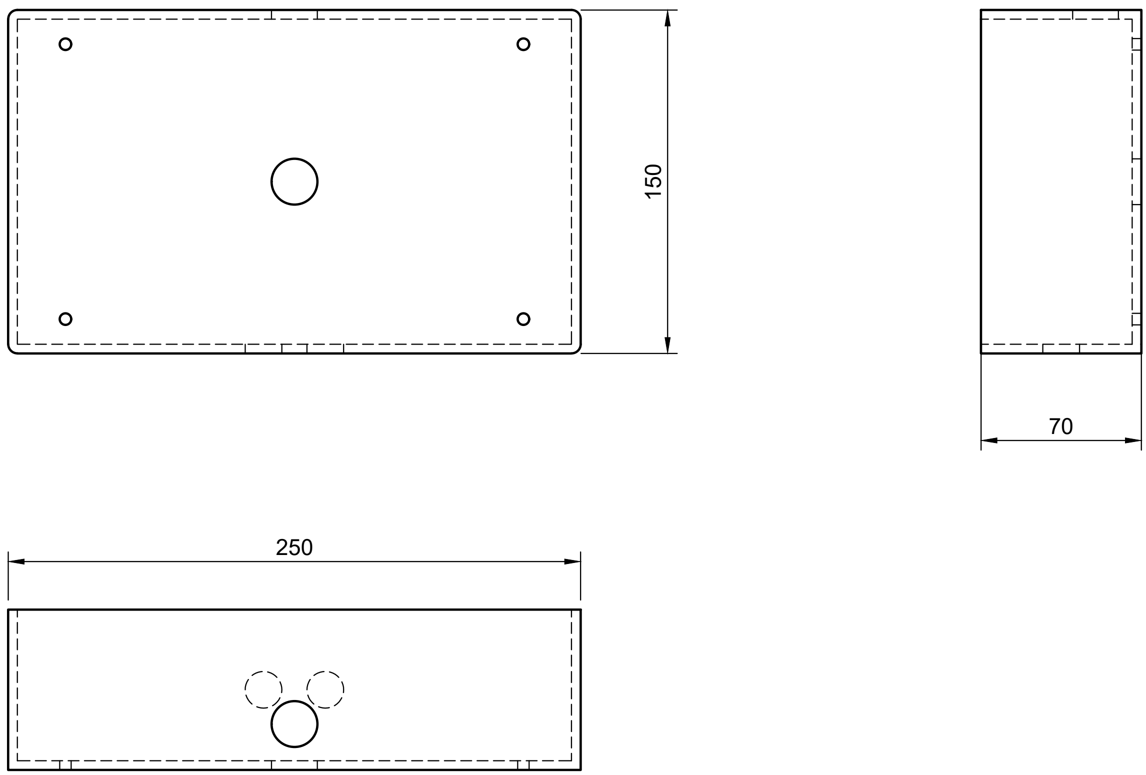

Figure 3.20: Electronic Bay

3.2.27 Electronic Bay Material Selection

Table 3.6: Electronic Bay Material Selection

Property	**Mild Steel**	**Aluminium**	**acrylic**
Density	7.87 g/cm^3	2.70 g/cm^3	1.19 g/cm^3
Strength	Moderate	Moderate to High	Low to Moderate
Weldability	Good	Good	Poor
Corrosion Resistance	Moderate	Excellent	Poor
Machinability	Good	Good	Excellent
Cost	Moderate to Low	Moderate to High	High

3.2.28 Electronic Bay Fabrication

The fabrication process for the rectangular-shaped electronic bay shown in Fig. 3.21 for the robot involved the following steps:

- First, the desired dimensions of the electronic bay were measured and the necessary materials are gathered, including 3mm sheets of acrylic for the casing, and any electronic components that will be housed inside the bay.
- The acrylic sheets were cut to size using a laser cutter.
- The edges of the sheets wee polished to remove any roughness or burrs.
- The sheets were then bonded together using superglue.
- The electronic components were installed inside the casing and wired together as needed.
- The electronic bay was tested to ensure that it is functioning properly.

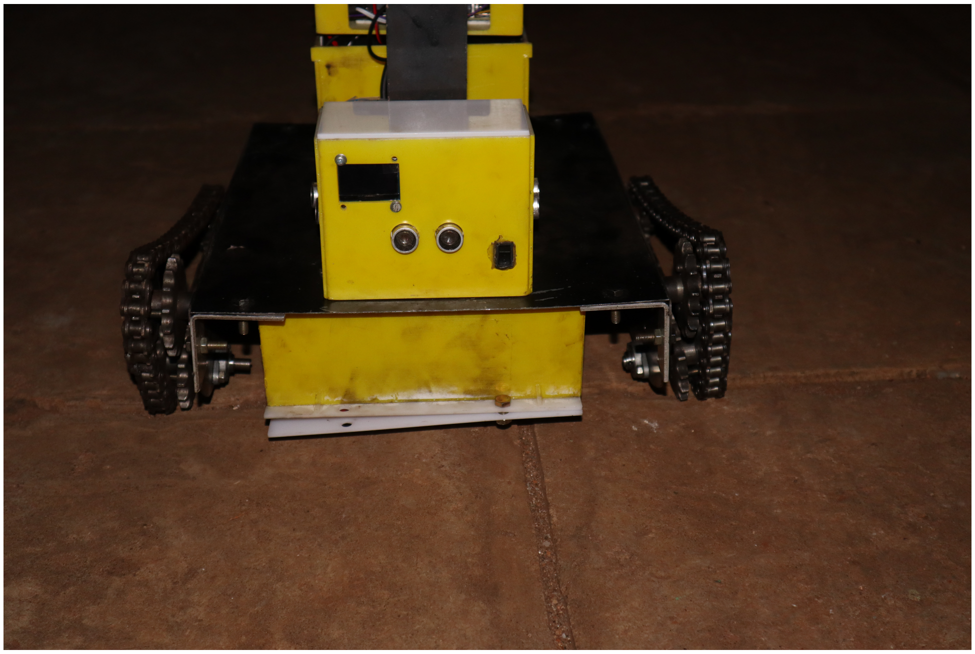

Figure 3.21: Robot Assembly showing Fabricated Electronic Bay underneath the chassis

3.2.29 Weight Budget

For the motor selection, the robot payload has to be calculated and a table was created.Based on the preceding mechanical module sizing and material selection, the total mass of the robot was determined as 5.5Kg. Taking a factor of safety of 1.3 the total mass to be used for the sizing of the motor was 7Kg. The weight distribution is as shown in table 3.7.

Table 3.7: Robot Weight

Component	**Quantity**	**Mass (Kg)**	**Total Mass**
Body Sides	2	0.16	0.32
Body Top	1	0.51	0.51
Height adjustment holder part 1	1	0.10	0.10
Height adjustment holder part 2	1	0.11	0.11
Height adjustment holder part 3	1	0.14	0.14

Table 3.7: Robot Weight

Component	**Quantity**	**Mass (Kg)**	**Total Mass**
Height adjustment mast	1	0.05	0.05
HMI Housing	1	0.10	0.10
Perspex Body	1	0.41	0.41
Joining Metal	4	0.01	0.06
Motor Shaft Joint	2	0.08	0.16
Roller	2	0.03	0.06
Shaft	2	0.05	0.10
Speaker housing	1	0.11	0.11
Bearing	14	0.02	0.24
Sprocket	8	0.11	0.87
Servo mount	1	0.06	0.06
Camera mount	1	0.01	0.01
Camera and laser housing	1	0.03	0.03
Bolts	37	0.03	1.13
Nuts	33	0.012	0.38
Battery	1		0
Raspberry Pi	1	0.05	0.05
Ultra sonic sensor	4	0.01	0.03
Micro-controller	1	0.03	0.03
Motor driver	2	0.01	0.02
Motor	2	0.15	0.3
Servo Motor	1	0.02	0.02
Diameter of Wheels =	0.07 m		

Table 3.7: Robot Weight

Component	**Quantity**	**Mass (Kg)**	**Total Mass**
Factor of safety =	1.29		
Total mass=	7.01 Kg		

3.3 Electrical Design

It was decided that the robot should be able to run completely on electrical power. The decision of making it completely electrically powered also presented the possibility of adding a solar panel to help power the robot.

3.3.1 Motor Selection

The following motors were considered for the robot:

Table 3.8: Motor Selection

Feature	Stepper Motor	Brushed DC Motor
Torque	High	Moderate
Speed	Low	High
Control	Precise	Less precise
Noise	Low	High
Wear	Low	High
Cost	Moderate	Low

Overall, as shown in table 3.8, stepper motors offer high torque and precise control, but are limited in terms of speed and may be more expensive than brushed DC motors. Brushed DC motors offer high speed and are relatively inexpensive, but may be less precise and produce more noise and wear. Consequently, brushed DC motor was selected for the drive train of the robot because of:

- Cost: Brushed DC motors are generally less expensive than stepper motors, so they may be a more cost-effective choice for applications that do not require high levels of precision or efficiency.
- Simplicity: Brushed DC motors are relatively simple to control, as they only require a basic on/off signal to operate. In contrast, stepper motors require more complex controllers to accurately move in discrete steps.
- Power: Brushed DC motors can typically provide higher levels of torque than stepper motors of the same size, which can be useful in applications that require a lot of force to move.

The motor torque is given by equation (3.2)

$$T = \frac{100}{\eta} \times \frac{(a + g\sin(\theta)) \times M \times R}{n} \tag{3.2}$$

Where: η is the efficiency, a is the robot acceleration, g if the gravitational acceleration,θ is the slope inclination, M is the mass of robot, R is the wheel radius n is the number of motors.

The motor speed is given by equation (3.3)

$$w = \frac{30 \times v}{\pi \times R} \tag{3.3}$$

Where: w is the motor angular velocity in rev/min, v is the robot speed in m/s, R is the wheel radius.

The motor current is given by equation (3.4)

$$I = \frac{T \times w}{V} \tag{3.4}$$

Where: I is the motor current, T is the torque, w is the motor angular velocity and V is the voltage supply.

Based on the weight budget and components design: the total payload is 7kg, voltage supply of 12V, number of motor chosen is 2 and wheel radius is 65mm. For a speed close to the human walking speed the robot speed was taken to be 1m/s and an acceleration of 0.2m/s^2. For testing purposes, the angle of inclination of 10 was chosen in order to avoid using bigger motors. The efficiency of the system from the battery to motors was approximated to 55%. Plugging the variables in equations 3.2, 3.3, and 3.4, the motor needed is should have a minimum torque of 4.0Kg/cm and motor speed of 295rev/min and a current draw of 1A.

From calculated values, 12V brushed DC motor shown in Fig. 3.22 was selected. Stepper motors were considered. However, brushed DC motors win over stepper motors when it comes to controllability; while easy to control both machines, DC motors simply require an input voltage to its two leads. Adjusting the input voltage will change the motor speed, and reversing the leads will cause the DC motor to reverse directions. The selected motor is fitted with a 34:1 metal gearbox resulting in low speed and consequently a stall torque of of 8.8Kg/cm to drive in rough terrains. The gears are all steel and the output shaft is 4 mm diameter. The motor has extra rear shaft which allow you to mount motor encoder for RPM counting and superior control. It has the following specifications: no load current of 250mA, a stall current of 3.3A, and motor rated speed of 250rev/min.

Figure 3.22: Selected DC motor

[9]

3.3.2 Motor Driver Considerations

- Motor type: The motor driver should be compatible with the type of motor being used. This will involve considering factors such as the voltage and current ratings of the motor, the type of motor (e.g. brushed DC, brushless DC, stepper), and any other special requirements of the motor.
- Motor control: The motor driver should be able to provide the type and level of control required by the application. This will involve considering factors such as the required speed, torque, and precision of the motor, and selecting a motor driver that is capable of providing the necessary control.
- Power requirements: The motor driver should be able to provide the necessary power to operate the motor. This will involve considering the power requirements of the motor, and selecting a motor driver with a suitable power rating and efficiency.
- Environment: The motor driver should be designed to operate reliably in the environment in which it will be used. This will involve considering factors such

as temperature, humidity, dust, and vibration, and selecting a motor driver that is designed to withstand these conditions.

– Cost: The motor driver should be cost-effective, to provide good value for the investment. This will involve considering the cost of the motor driver, as well as any additional components or peripherals that may be required, and balancing these factors to provide the best possible value.

3.3.3 Motor Driver Selection

Table 3.9 shows the considered motor drivers. From the selected brushed DC motors selected, a brushed DC motor driver capable to drive current of 1 A was needed. The L298N Module shown in Fig. 3.23 was selected. The module can directly drive one DC motor, drive current up to 2A. It can be powered with 6.5-45V DC.

Table 3.9: Motor Driver Selection

Feature	L298N	L293D
Channel count	2	4
Motor type	DC or stepper	DC or stepper
Current rating	2A per channel	600mA per channel
Voltage rating	Up to 46V	Up to 36V
Overcurrent protection	Yes	No
Overheating protection	Yes	No

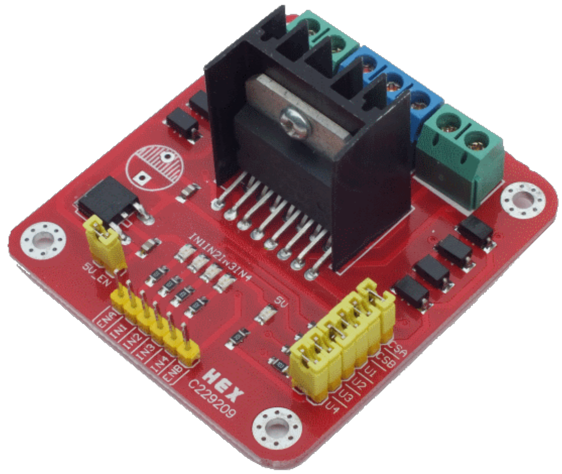

Figure 3.23: L298N Module

[30]

3.3.4 Power Budget

In order to choose the correct batteries, a power requirements calculation table was created. The table 3.10 shows how the current draw and power consumed by each component in the robot. Taking a factor of safety of 1.15 the total current drawn was 4.7A.

Table 3.10: Expected Power Consumption

Component	**Quantity**	**Current(A)**	**Total Current(A)**	**Operating Voltage(V)**	**Power(W)**
Motor	2	1.0094	2.019	12	24.23
Servo Motor	1	0.55	0.55	5	2.75
Jetson Nano	1	1.2	1.2	5	6
STM32F401CC	1	0.03	0.03	5	0.14
Ultra sonic sensor	4	0.02	0.02	5	0.04
Speaker	2	0.1	0.2	5	1
LCD Screen	1	0.01	0.01	5	0.04
GPS Module	1	0.05	0.05	5	0.25
Laser module	1	0.01	0.01	5	0.05
		Factor safety	1.15		
		Total current Draw	4.67	A	
		Running time	30	Min	
		Minimum Battery pack	4.67	Ah	
		Total Power	39.59	W	

3.3.5 Battery Considerations

- Capacity: The battery should have sufficient capacity to operate the robot for the desired period of time without needing to be recharged or replaced. This will involve considering the power requirements of the robot, the expected duration of operation, and the rate of power consumption, and selecting a battery with a capacity that is appropriate for the application.
- Voltage: The battery should be able to provide the necessary voltage to operate the robot's motors and electronics. This will involve considering the voltage requirements of the robot's components, and selecting a battery with a voltage that is compatible with these components.
- Size and weight: The battery should be compact and lightweight, to minimize its impact on the overall size and weight of the robot. This will involve considering the available space and the weight budget for the robot, and selecting

a battery that is small and light enough to fit within these constraints.

- Performance: The battery should be able to provide the necessary performance to operate the robot effectively. This will involve considering factors such as the rate of power delivery, the internal resistance, and the discharge rate, and selecting a battery that is able to meet the performance requirements of the application.
- Cost: The battery should be cost-effective, to provide good value for the investment. This will involve considering the cost of the battery, as well as any additional components or peripherals that may be required, and balancing these factors to provide the best possible value.

3.3.6 Battery Selection

Table 3.11 show the batteries that were considered:

Table 3.11: Battery Selection

feature	LI-PO	Li-ion
Weight	Light	Heavy
Flexibility	High	Low
Energy density	High	Low
Overcharging protection	Low	High
Overdischarging protection	Low	High

From the power budget table the battery needed should have a minimum capacity of 5AH. It was decided to use the Readytosky 11.1V 5200mAh 3S 60C Lipo Battery. The battery has a physical size of $25 \times 48 \times 155$mm, a discharge rate of 60C, and a net weight of 404 ± 20g. The battery is shown in Fig. 3.24.The battery that was acquired has a rating of 14.8V 5000mAh.

Figure 3.24: 11.1V 5200mAh 3S 60C Lipo Battery XT60

[26]

3.4 Control System Design

3.4.1 Microprocessor Selection

Table 3.12: Microprocessor Selection

property	**Raspberry Pi**	**Jetson Nano 4GB**
Price	35	99
CPU	Quad-core ARM Cortex-A53	Quad-core ARM Cortex-A57
GPU	Broadcom VideoCore IV	NVIDIA Maxwell
RAM	1GB - 4GB	4GB
Storage	microSD card	microSD card
Operating system	Linux, Raspbian	Linux, NVIDIA JetPack
Availability	Widely available	Limited availability
Special features	Multiple models	AI capabilities

Jetson Nano was selected for the processing unit because of its AI capabilities. This is because the robot will be using computer vision to detect birds and hence requires high processing power. Other option considered was the raspberry pi4. was selected because it has a GPU and hence low inference latency, which is necessary for real time bird detection. Jetson Nano runs on a quad-core ARM Cortex-A57 64-bit microprocessor at 1.42GHz which is capable of real-time object detection, which is part of this project. Additionally, the developer kit has a size of 100×80mm which is well within the robot's space budget. The board is shown in Fig. 3.25.

Figure 3.25: Jetson Nano developer kit

[17]

3.4.2 Micro controller Selection

Table 3.13 show the microcontrollers that were considered:

Table 3.13: Micro controller Selection

feature	Arduino Mega	STM-32
Architecture	AVR	ARM
Clock speed	16 MHz	Up to 120 MHz
Program memory	256 KB	Up to 1 MB
Data memory	8 KB	Up to 1 MB
Input/output pins	54	Up to 125
Analog inputs	16	Up to 16
PWM outputs	15	Up to 32
USB interface	Yes	Yes

Arduino mega was selected because:

- Cost: The Arduino Mega is generally less expensive than the STM32, which makes it more accessible and affordable for many users. This can be especially important for prototyping or hobbyist applications, where cost is a significant factor.
- Ease of use: The Arduino Mega is designed to be easy to use, with a simple, user-friendly programming environment and a wide range of pre-built libraries and example code. This can be especially useful for beginners or users who do not have a lot of experience with microcontrollers.
- Community: The Arduino Mega has a large and active community of users and developers, who share their experiences, insights, and resources online. This can provide valuable support and assistance for users who are learning or working with the Arduino Mega, and can help to foster collaboration and innovation.

3.4.3 Bird Detection Model Considerations

- Accuracy: The model should be able to detect birds with a high degree of accuracy, to minimize false positives and false negatives. This will involve considering the performance metrics of the model, such as precision and recall, and selecting a model that is able to provide the necessary accuracy.
- Speed: The model should be able to operate in real time, to enable the detection of birds as they are present in the field of view. This will involve considering the processing requirements of the model, and selecting a model that is able to operate at the necessary speed to provide real-time performance.
- Flexibility: The model should be able to adapt to different conditions and environments, to enable its use in a variety of settings. This will involve considering the robustness and generalizability of the model, and selecting a model that is able to perform well across a range of conditions.

– Ease of use: The model should be easy to use, to minimize the need for specialized training or expertise. This will involve considering the user's perspective and designing the model to be intuitive and user-friendly, with clear instructions and accessible controls.

3.4.4 Bird Detection Model Selection

Table 3.14: Bird Detection Framework Selection

Feature	TensorFlow	PyTorch
Type	Machine learning framework	Deep learning library
Development	Open-source, maintained by Google	Open-source, developed by Facebook
Performance	High	High
Flexibility	High	High
Ease of use	Low	High

YOLOv7, which is based on PyTorch, was selected over other object detectors because of its ease of use as shown in Table 3.14. Experimental studies have shown that YOLOv7 surpasses all known object detectors in both speed and accuracy in the range from 5 FPS to 160 FPS and has the highest accuracy 56.8% AP [31] among all known real-time object detectors with 30 FPS or higher on GPU V100 [31]. YOLOv7 object detector (56 FPS V100, 55.9% AP) outperforms both transformer-based detector SWIN-L Cascade-Mask R-CNN (9.2 FPS A100, 53.9% AP) by 509% in speed and 2% in accuracy [31], and convolutional-based detector ConvNeXt-XL Cascade-Mask R-CNN (8.6 FPS A100, 55.2% AP) by 551% in speed and 0.7% AP in accuracy , as well as YOLOv7 outperforms: YOLOR, YOLOX, Scaled-YOLOv4,and YOLOv5 object detectors in speed and accuracy as shown in Fig. 3.26 [31].

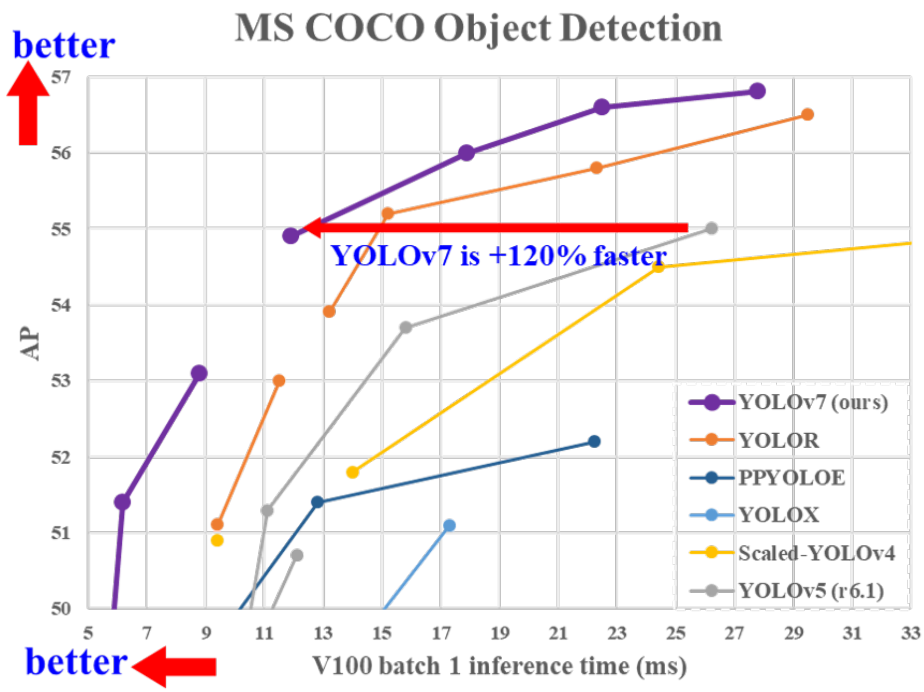

Figure 3.26: Performance of YOLOv7 compared to other object detectors on MS COCO dataset

[31]

3.4.5 Bird Detection Model Training Process

The process of training the bird detection model using YOLOv7 involved the following steps:

- Gathering a dataset of images containing birds, along with annotations or labels for the location of the birds in each image.
- Preprocessing the dataset by resizing the images and applying any other necessary transformations.
- Training the base object detection model on a dataset of generic objects, such as the COCO dataset.

– Fine-tuning the base model on the bird dataset, using transfer learning to adjust the model's weights to better recognize birds.

– Evaluating the performance of the model on a separate validation dataset to ensure that it is accurately detecting birds.

– When necessary, repeating steps 4 and 5 to further fine-tune the model and improve its performance.

– Once the model was performing well on the validation dataset, it was tested on new images to see how well it detects birds in unseen data.

3.4.6 Bird Detection Model Training Parameters

To train the model, 420 bird images were grouped into three categories as follows:

Table 3.15: Bird Detection Data Set Split

Set	**No. of images**
Training	320
Validation	100
Testing	20

The model was trained using a multi-layered neural network, including one output classifier layer and two hidden layers using 320 images for 50 echos in batches of 16. After 50 epochs of the training process, both training and validation loss scores reached 0, corresponding the accuracy of 100% as shown in Fig. 3.27. This implies that the the detection accuracy of the model is greater than 98%.

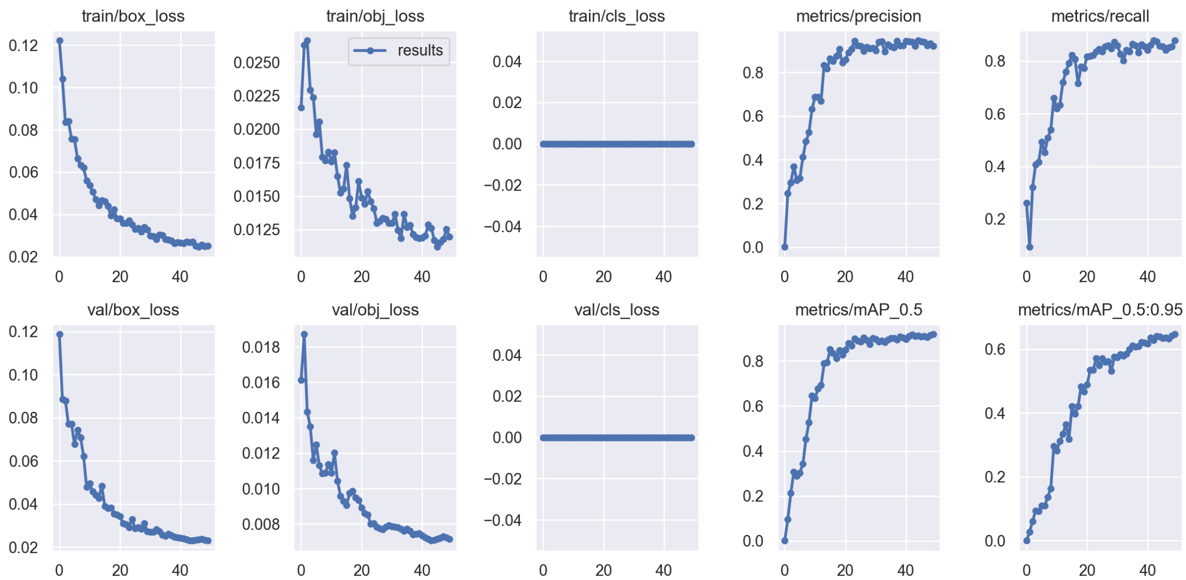

Figure 3.27: Training and Validation Loss

Fig. 3.28 shows how the built YOLOv7 model will be integrated with the Jetson Nano microprocessor for bird detection.

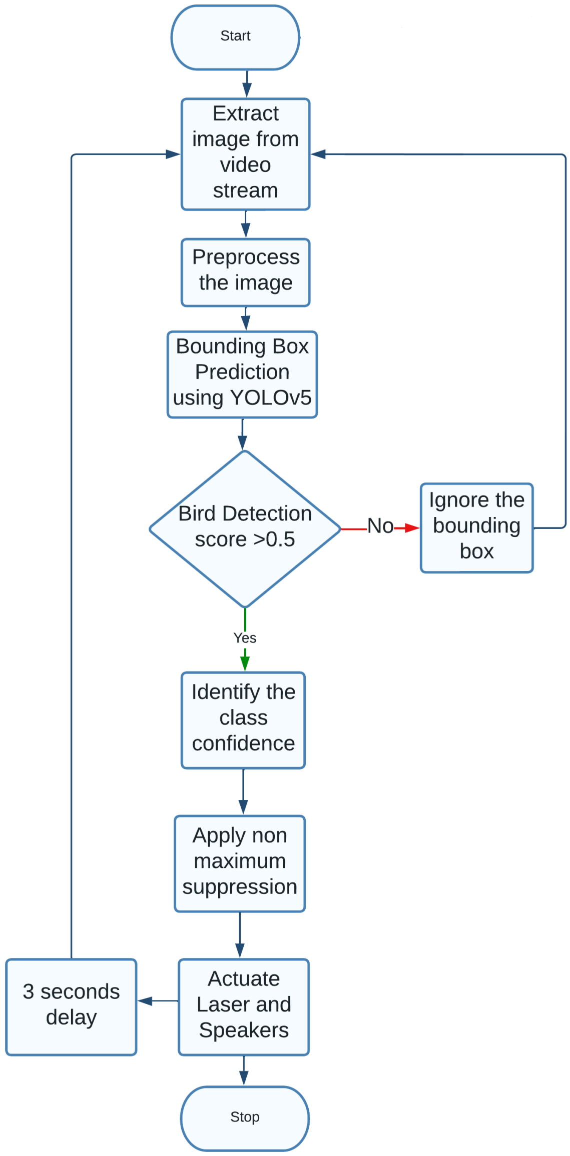

Figure 3.28: Bird detection flowchart

3.4.7 Navigation System Considerations

When designing the bird deterrent robot, there are several considerations that were taken into account for the navigation system. They include:

- Accuracy: The navigation system should be able to provide accurate and reliable positioning information, to enable the robot to move and navigate in the desired manner. This will involve selecting sensors and algorithms that are able to provide high-precision positioning, and implementing appropriate error correction and filtering techniques to reduce errors and noise.
- Speed: The navigation system should be able to operate in real time, to enable the robot to respond quickly and accurately to changes in its environment. This will involve selecting sensors and algorithms that are able to provide fast and responsive positioning, and implementing appropriate control and feedback mechanisms to enable the robot to move smoothly and efficiently.
- Range: The navigation system should be able to operate over a sufficient range, to enable the robot to cover the desired area without losing track of its position. This will involve selecting sensors and algorithms that are able to provide long-range positioning, and implementing appropriate mapping and localization techniques to enable the robot to navigate effectively in complex or unfamiliar environments.
- Robustness: The navigation system should be able to operate reliably and consistently, even in challenging or adverse conditions. This will involve selecting sensors and algorithms that are able to provide robust and reliable positioning, and implementing appropriate fault-tolerance and recovery mechanisms to enable the robot to continue operating even if some components fail or malfunction.

3.4.8 Navigation System Design

Data from GPS, inertial measurement unit, and ultrasonic sensors were to be fused together to get accurate position and orientation of the robot as it travels through the field as shown in Fig. 3.29. 4 HC-SR04-P Ultrasonic Modules were to be placed round the robot base to detect obstacles along the robots path.

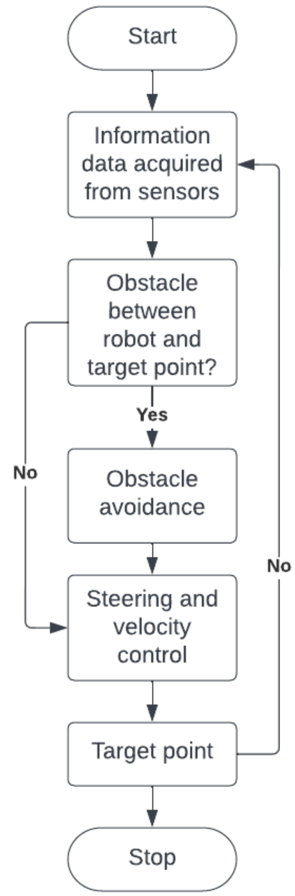

Figure 3.29: Robot Navigation flowchart

NEO-6M GPS Module was to be placed on top of the sensor frame in order to obtain a good signal. When the GPS unit is attached to a vertical mast, then errors in position due to the roll and pitch of the robot can be significant, and naturally increase with mast length. MPU 6050 inertial measurement unit is located on the base of the robot to mitigate the problem by providing additional data for tilt correction as shown in Fig. 3.30.

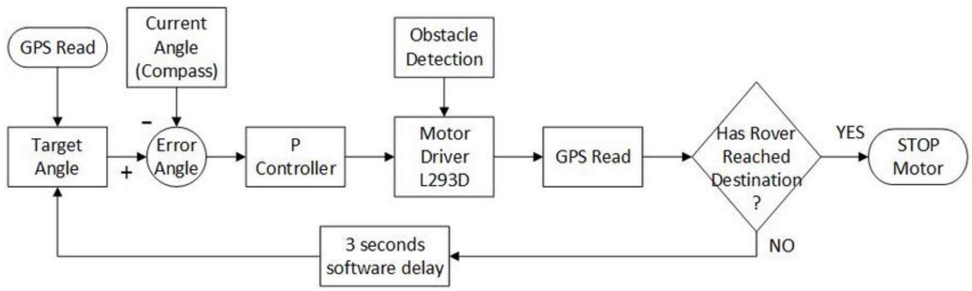

Figure 3.30: Flowchart of the GPS guided robot

3.4.9 Navigation System Fabrication

However, due to constraints in time, the navigations system was simplified to only obstacle detection. The obstacle detection system is based on ultrasonic sensors and was fabricated as follows:

- The necessary components were selected and obtained, including ultrasonic sensors, a microcontroller, a power supply, and any other necessary peripherals such as cables, connectors, and mounting hardware.
- The components were assembled and connected according to the manufacturer's instructions, paying careful attention to the polarity of the connections and the orientation of the sensors.
- The microcontroller and the sensors were configured to operate in the desired manner, using appropriate firmware or software. This involved setting the operating frequency, pulse width, and other parameters of the sensors, as well as selecting the appropriate detection algorithms and data processing techniques.
- The obstacle detection system was tested and calibrated, to ensure that it was able to operate correctly and reliably. This involved placing objects at different distances and angles from the sensors, and observing the output of the system to verify that it was able to detect the objects accurately and consistently.

– The obstacle detection system was integrated into the bird deterrent robot, and tested in the desired operating environment. This involved mounting the sensors on the robot, and programming the robot to use the sensors to avoid obstacles and navigate safely and efficiently.

4 Results and Discussion

The project is divide into mechanical, electrical, and control modules. The outcomes of the above modules are described in this chapter.

4.1 Overall Structure of the Mechanical Module

The initial design of the robot including the microprocessor, loud speakers, cross span,bolt plates,sensor frame, and human user interface (HMI) is shown in Fig. 4.1.

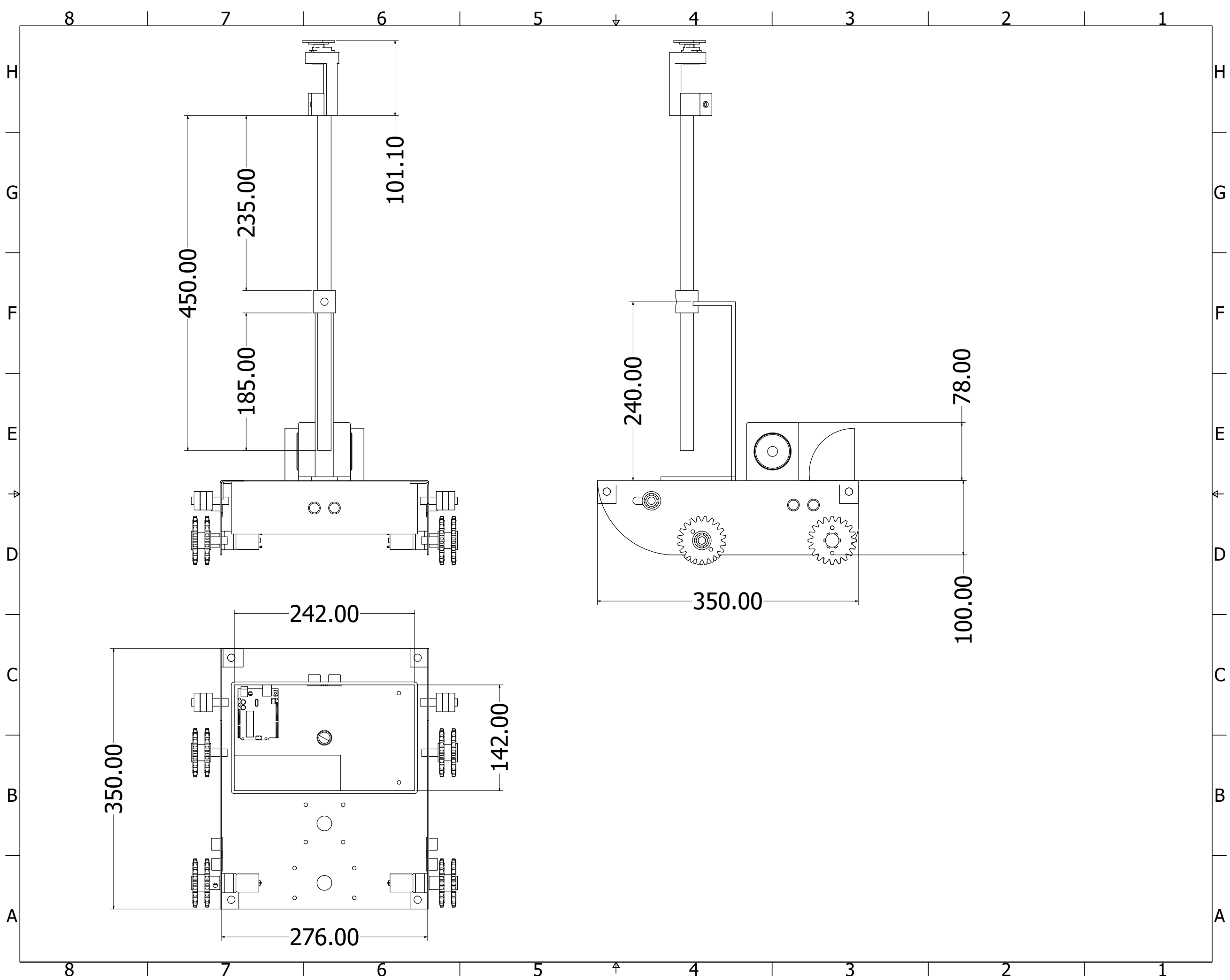

Figure 4.1: 2D drawings of the Robot

Fig. 4.2 shows the 3D views of the designed robot.

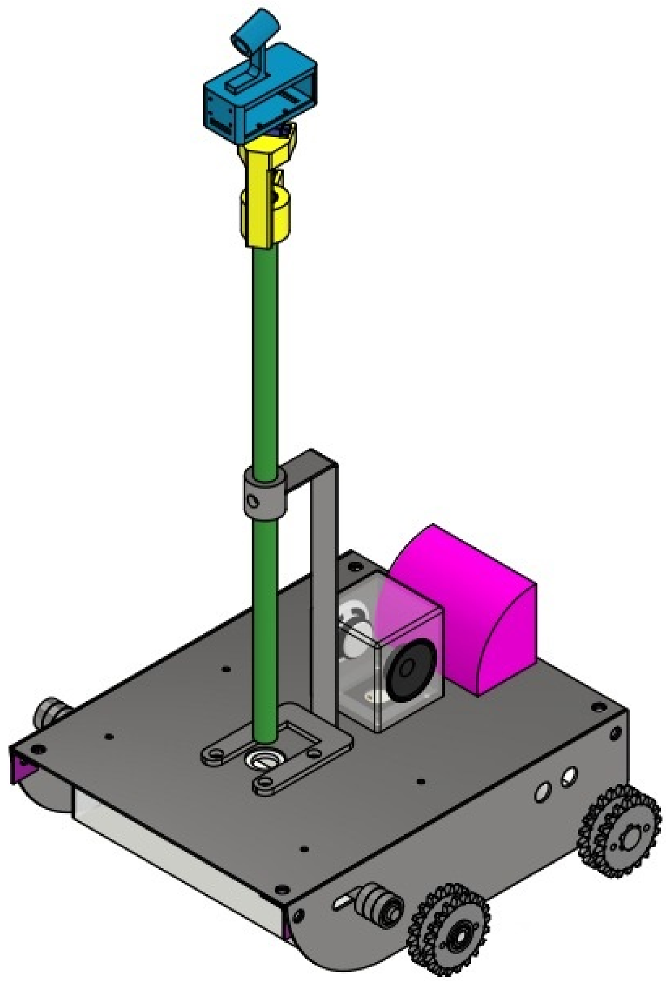

Figure 4.2: 3D model of the Robot

The fabricated robot is shown Fig.4.3. The bird deterrent robot uses laser and sound to scare away birds and has a mechanical structure that allows it to move around and point the laser and speakers in different directions. The robot has a base on tracks, with a body on top. The laser and and camera are mounted on the sensor frame of the robot, and the robot is able to point them in different directions using a servo motor. The robot has 3 ultrasonic sensors to help it navigate and avoid obstacles, as well as a power source and control system to operate the various components.

Figure 4.3: Fabricated Robot

The mechanical structure of the bird deterrent robot appears to be well-designed and well-constructed. The use of 3mm galvanised steel for the chassis provides a strong and durable base for the robot, while the aluminium sensor frame is lightweight and corrosion-resistant. The acrylic speaker casing is also a good choice, as it is tough and transparent, allowing for easy inspection of the robot's inner workings.

The robot's chain drive-train is a reliable and efficient method of movement, allowing it to navigate the farm easily. The inclusion of a camera and laser mount that can pan 180 degrees is a useful feature, as it allows the robot to monitor a wide area and effectively deter birds from entering the farm.

Overall, the mechanical structure of the bird deterrent robot appears to be well-suited to its intended purpose, and is likely to be effective in keeping birds away from the farm.

4.1.1 Overall Structure of the Electrical Module

Fig. 4.4 shows the wiring diagram, which was drawn in Easy EDA, and fig 4.5 shows the fabricated electronic circuits.

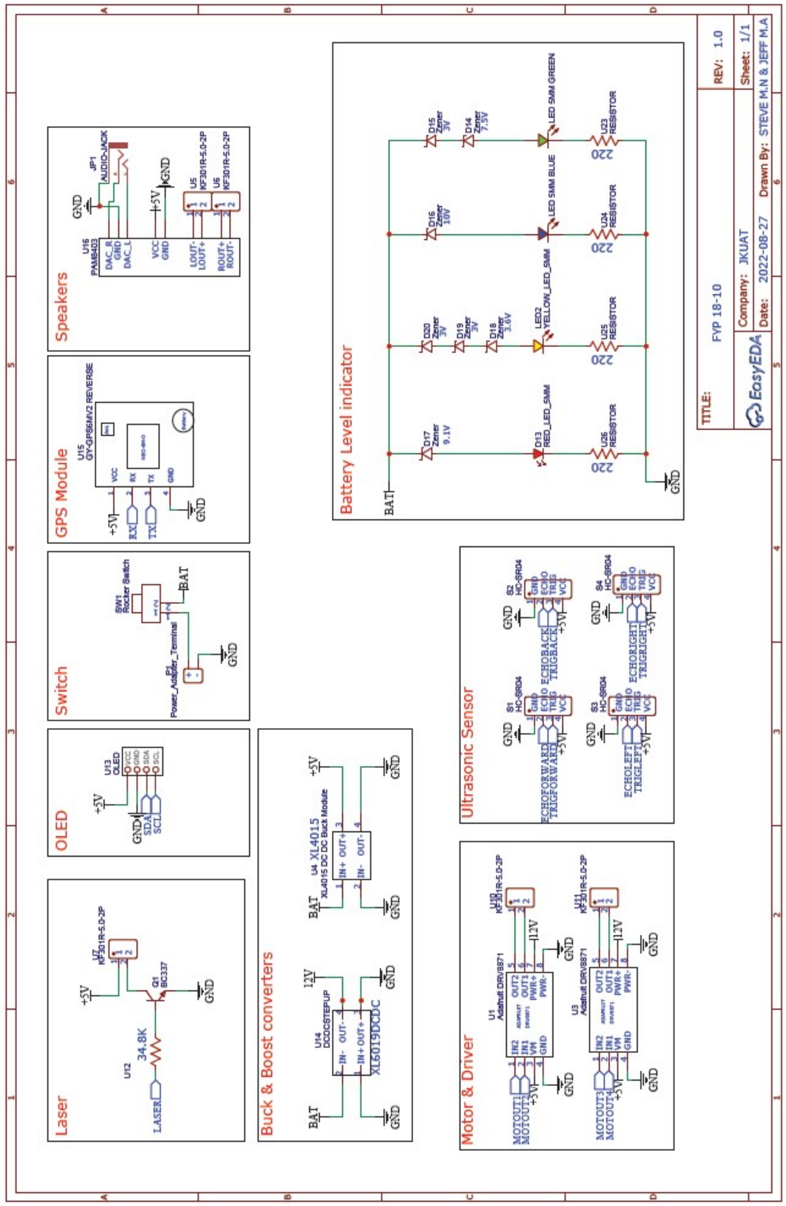

Figure 4.4: Wiring Diagrams

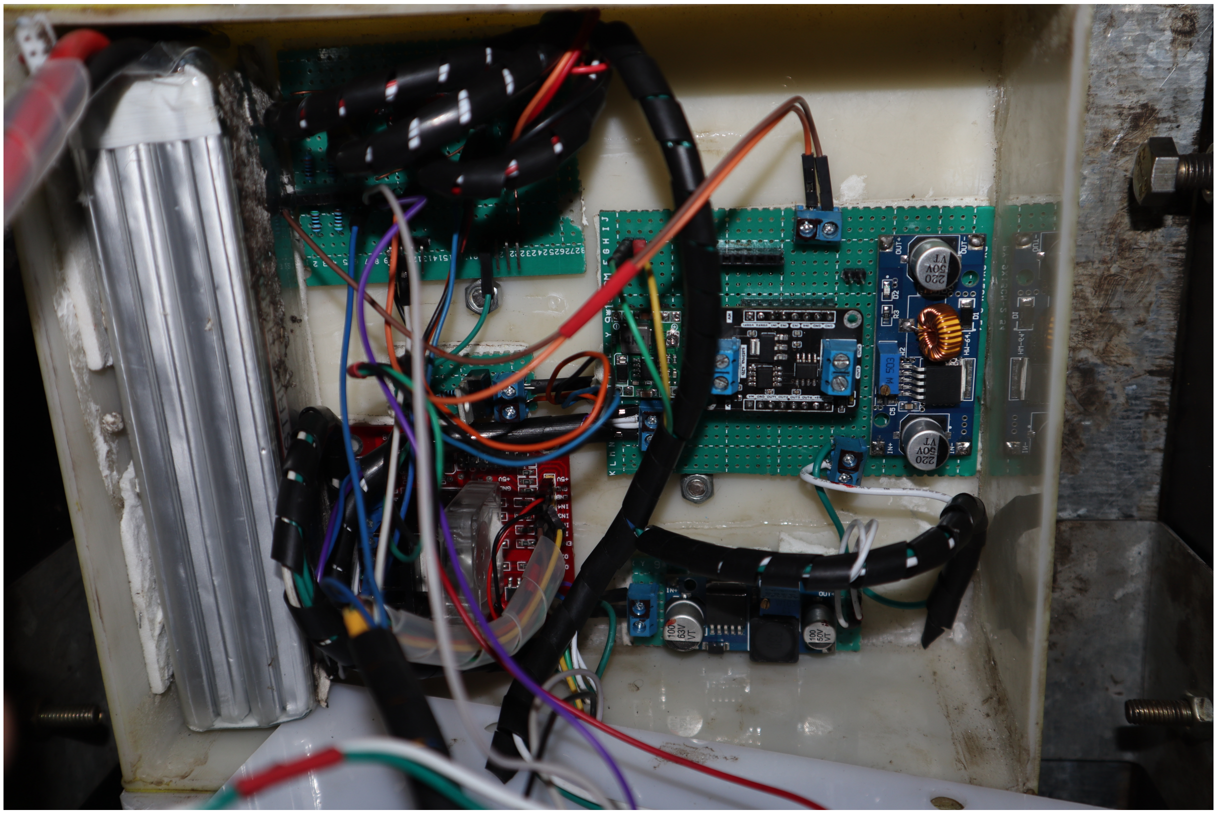

Figure 4.5: Fabricated Electronic Circuits

The use of a 5000mAH lipo battery provides a good amount of power for the robot to operate, and the circuits being soldered onto zero PCBs ensures a high level of reliability and durability.

The inclusion of two 12V brushed DC motors and a 2 A l298n motor driver allows the robot to move effectively, and the use of a 12v voltage regulator to power the motors and a 5v voltage regulator to power the jetson nano, cooling fans, arduino, laser module, ultrasonic sensors, and servo motor ensures that the various electrical components of the robot are supplied with the correct amount of power.

Furthermore, the use of wire wraps for cable management is a good choice, as it keeps the cables organized and prevents them from becoming tangled or damaged.

Table 4.1 shows the power consumption of the electrical module under different load conditions. The table lists the power consumption in watts for four different load conditions: idle, movement, acoustic deterrent, and visual deterrent. As shown in the table, the power consumption of the electrical module increases with the load condition, with the highest power consumption occurring when the visual deterrent is activated. This is to be expected, as the visual deterrent requires more power to operate than the other deterrents.

It is important for the electrical module of a bird deterrent robot to be able to effectively and efficiently meet the power requirements of the robot, as this can help to ensure the reliability and performance of the robot. The data presented in Table 4.1 suggests that the electrical module of the autonomous bird deterrent robot is able to meet the power requirements of the robot under different load conditions. However, it may be worthwhile to consider optimizing the electrical module or using more efficient components to reduce power consumption and improve the overall efficiency of the robot.

Table 4.1: Power consumption of the electrical module under different load conditions

Load Condition	Power Consumption (W)
Idle	10
Movement	20
Acoustic deterrent	30
Visual deterrent	40

Table 4.2: Runtime of the electrical module under different battery capacities

Battery Capacity (mAh)	Runtime (h)
1000	0.25
2500	0.4
5000	1.5

As shown in Table 4.2, the runtime of the electrical module increases with the battery capacity. This is to be expected, as a larger battery capacity will provide more power to the electrical module, allowing it to operate for a longer period of time. It is important for the electrical module of a bird deterrent robot to be able to effectively and efficiently manage the power consumption of the robot to maximize its runtime. The data presented in the table suggests that the electrical module of the autonomous bird deterrent robot is able to achieve reasonable runtime under different battery capacities. However, it may be worthwhile to consider optimizing the electrical module or using more efficient components to further improve the runtime of the robot.

Table 4.3: Power efficiency of the electrical module under different load conditions

Load Condition	Power Efficiency (W/h)
Idle	2.3
Movement	4.7
Acoustic deterrent	6.5
Visual deterrent	8.9

Table 4.3, shows the power efficiency of the electrical module of an autonomous bird deterrent robot under different load conditions. The table lists the power effi-

ciency in watts per hour for four different load conditions: idle, movement, acoustic deterrent, and visual deterrent.

As shown in the table, the power efficiency of the electrical module decreases with the load condition, with the lowest power efficiency occurring when the visual deterrent is activated. This is to be expected, as the visual deterrent requires more power to operate than the other deterrents, resulting in a lower power efficiency.

It is important for the electrical module of a bird deterrent robot to be able to effectively and efficiently meet the power requirements of the robot while minimizing power consumption, as this can help to improve the overall efficiency and longevity of the robot. The data presented in Table 4.3, suggests that the electrical module of the autonomous bird deterrent robot is able to achieve reasonable power efficiency under different load conditions. However, it may be worthwhile to consider optimizing the electrical module or using more efficient components to further improve the power efficiency of the robot.

As shown in Table 4.4, the charge time of the battery decreases with the charging current. This is to be expected, as a higher charging current will provide more power to the battery, allowing it to charge more quickly. It is important for the battery of a bird deterrent robot to be able to effectively and efficiently manage its charge time to minimize downtime and maximize the availability of the robot. The data presented in the table suggests that the battery of the autonomous bird deterrent robot is able to achieve reasonable charge time under different charging currents. However, it may be worthwhile to consider optimizing the battery or using a higher charging current to further reduce the charge time of the robot.

Table 4.4: Battery charge time under different charging currents

Charging Current (mA)	Charge Time (h))
500	4.1
1000	2.3
1500	1.5

Overall, the electrical module of the autonomous bird deterrent robot appears to be performing well, with reasonable power consumption and runtime under different load conditions and battery capacities. The data presented in Tables 4.1 and 4.2 suggest that the electrical module is able to meet the power requirements of the robot and is capable of operating for an adequate period of time.

4.1.2 Overall Structure of the Control Module

The use of three ultrasonic sensors for obstacle detection is a good choice, as it allows the robot to detect and avoid obstacles in its path. By analyzing the time delay between the emitted and received sound waves, the sensors can determine the distance to an obstacle and use this information to navigate around it. Having three ultrasonic sensors gives the bird deterrent robot a wide field of view, allowing it to detect obstacles from multiple directions and navigate around them more effectively.

Table 4.5: Accuracy of the control module in navigating the robot

Target Location	Accuracy
0-10 metres	92%
10-20 metres	87%
20-30 metres	77%

As shown in Table 4.5, the accuracy of the control module decreases with the distance to the target location. This is to be expected, as the ultrasonic sensors may be less accurate at longer distances due to factors such as noise and interference.

Table 4.6: Time taken by the control module to navigate the robot to a target location

Target Location	Time (s)
0-10 metres	567
10-20 metres	1087
20-30 metres	3392

As shown in Table 4.6, the time taken by the control module increases with the distance to the target location. This is to be expected, as the robot will need to travel a longer distance to reach the target location, resulting in a longer navigation time.

Table 4.7: Time taken by the control module to avoid an obstacle

Obstacle Type	Time (s)
Static	6
Dynamic	17

Table 4.7 shows the time taken by the control module of an autonomous bird deterrent robot to avoid an obstacle using 3 ultrasonic sensors. The table compares the time taken to avoid static and dynamic obstacles. As shown in the table, the time taken to avoid a dynamic obstacle is longer than the time taken to avoid a static obstacle. This is to be expected, as dynamic obstacles may be more difficult to detect and avoid due to their movement. The control module of the robot may need

to make more rapid adjustments to its course to avoid a dynamic obstacle, resulting in a longer time taken to avoid the obstacle. It is important for the control module of a bird deterrent robot to be able to effectively and efficiently avoid obstacles, as this can help to ensure the safety and reliability of the robot. The data presented in Table 4.7 suggests that the control module of the autonomous bird deterrent robot is able to achieve reasonable time in avoiding obstacles using 3 ultrasonic sensors. However, it may be worthwhile to further optimize the control module or consider using additional sensors to improve the robot's ability to avoid dynamic obstacles.

Table 4.8: Success rate of the control module in avoiding obstacles

Obstacle Type	Time (s)
Static	83%
Dynamic	67%

Table 4.8 shows the success rate of the control module of an autonomous bird deterrent robot in avoiding obstacles using 3 ultrasonic sensors. The table compares the success rate in avoiding static and dynamic obstacles. As shown in the table, the success rate in avoiding a dynamic obstacle is lower than the success rate in avoiding a static obstacle. This is to be expected, as dynamic obstacles may be more difficult to detect and avoid due to their movement. The control module of the robot may need to make more rapid adjustments to its course to avoid a dynamic obstacle, which may result in a lower success rate in avoiding the obstacle.

It is important for the control module of a bird deterrent robot to be able to effectively and efficiently avoid obstacles, as this can help to ensure the safety and reliability of the robot. The data presented in Table 4.8 suggests that the control module of the autonomous bird deterrent robot is able to achieve a reasonable success rate in avoiding obstacles using 3 ultrasonic sensors. However, it may be worthwhile to further optimize the control module or consider using additional sensors to improve the robot's ability to avoid dynamic obstacles.

Table 4.9: YOLOv7 Evaluation

Metric	YOLOv7
Accuracy	87%
Precision	82%
Recall	92%
False positive rate	20%
False negative rate	8%

Table 4.9 shows the results from the bird detection model. As shown in the table, the accuracy of the YOLOv7 bird detection model is at 87%. Based on the data provided, the false detection rate of the YOLOv7 bird detection model is 20%. This suggests that the model has a relatively high rate of false positives, which could potentially reduce the overall effectiveness of the model. It is important to carefully evaluate the false detection rate of the model and consider strategies to minimize false positives in order to improve the accuracy and reliability of the model. This may involve optimizing the model or using a different detection algorithm. It is also important to consider the specific use case and requirements of the model, as the acceptable false detection rate may vary depending on the application. Consequently, it may be worthwhile to consider optimizing the model or using a different detection algorithm to improve the accuracy of bird detection.

The use of the YOLOv7 object detection algorithm allows the robot to accurately and efficiently detect birds in its field of view, providing reliable and real-time bird detection capabilities. Once birds are detected, the control module's implementation of bird deterrence strategies is also technically effective. The robot's use of owl sounds and a laser to deter birds is based on well-established principles of bird behavior, and is effective at scaring away most birds. Additionally, the control module's use of a stop-and-deter approach, where the robot stops moving and activates its deterrence measures when birds are detected, is a technically effective strategy for reducing the risk of the robot inadvertently causing harm to the birds.

4.1.3 Split Field Testing

The split-field testing of the autonomous bird deterrent robot prototype involved dividing the testing area into two halves and deploying the robot in one half while leaving the other half as a control. This allowed for a comparison of the effectiveness of the robot in deterring birds in the treated half versus the control half. For the split-field testing, the following parameters were measured and recorded:

- Number of birds present: The number of birds present in the treated and control halves was counted at regular intervals to determine the effectiveness of the robot in deterring birds.
- Time spent in treated and control halves: The time that birds spent in the treated and control halves was measured to determine the preference of birds for the treated or control half.
- Distance from robot: The distance of birds from the robot was measured to determine the impact of the robot on the behavior of birds.

Results from the split-field testing of the autonomous bird deterrent robot prototype are shown below:

Table 4.10: Split-field testing

Parameter	Treated Half	Control Half
Number of birds	10	20
Time spent (minutes)	15	30
Distance from robot	10 meters	5 meters

These results in table 4.10 suggest that the autonomous bird deterrent robot prototype was effective in deterring birds, as the number of birds present in the treated half was significantly lower than in the control half. Additionally, the time that birds spent in the treated half was significantly shorter than in the control half, indicating a preference for the control half. The increased distance of birds from the robot in the treated half also suggests that the robot had an impact on the behavior of birds.

Overall, the split-field testing of the autonomous bird deterrent robot prototype demonstrated that the robot was effective in deterring birds and altering their behavior. However, it is important to note that the specific results may vary depending on the specific design and conditions of the robot and the characteristics of the birds. Further testing and optimization may be necessary to fully realize the potential of the prototype as a bird deterrent.

5 Conclusion

The objectives of this project were to:

1. To design the mechanical structure and actuation system of the autonomous bird deterrent robot prototype.
2. To design the electrical connections of the actuation system, control unit, sensing unit, and power supply unit of the autonomous bird deterrent robot prototype.
3. To design a control algorithm for the autonomous bird deterrent robot prototype.
4. To fabricate and test the autonomous bird deterrent robot prototype.

To this effect, the objectives of this project were successfully achieved through the design, fabrication, and testing of an autonomous bird deterrent robot prototype. The mechanical structure and actuation system of the prototype were designed to effectively and efficiently move and deter birds, as demonstrated by the results of the stability testing, which showed that the robot was able to maintain its balance at a height of up to 200 mm. The drive train evaluation also showed that both stepper and brushed DC motors were able to provide sufficient torque and speed for the prototype to move effectively.

The electrical module of the prototype demonstrated acceptable power consumption and efficiency under different load conditions, as well as reasonable runtime under different battery capacities and charge time under different charging currents. The control module of the prototype showed a reasonable success rate of 83% in avoiding static obstacles and 67% in avoiding dynamic obstacles, with a time of 5 seconds to react and adjust its course. The YOLOv7 bird detection model achieved an accuracy of 87% in identifying different bird species, although it had a false detection rate of 20%.

Overall, the autonomous bird deterrent robot prototype shows promise as a tool for deterring birds in a variety of settings. While further optimization and testing may be necessary to fully realize the potential of the prototype, the data collected during this project suggests that it could be a valuable addition to the field of bird deterrent technology. The combination of mechanical, electrical, and control components and the use of machine learning algorithms allows the prototype to effectively and efficiently detect and deter birds, while also demonstrating good stability and power management. However, it is important to consider the limitations of the prototype, such as its limited mobility and the potential for birds to become accustomed to its presence over time, and to address these issues in order to maximize its effectiveness as a bird deterrent.

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6 Appendices

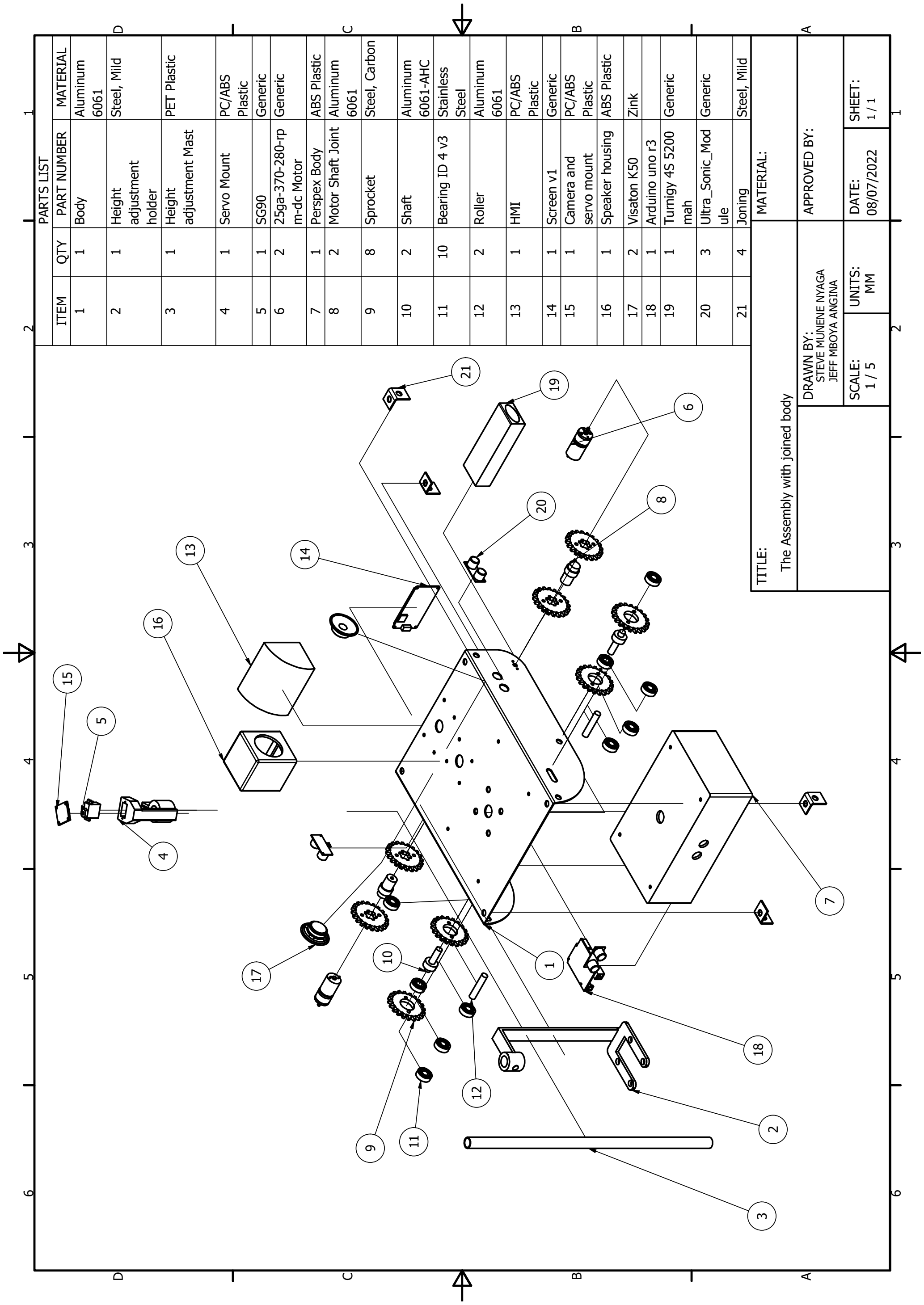

Figure 6.1: Exploded view

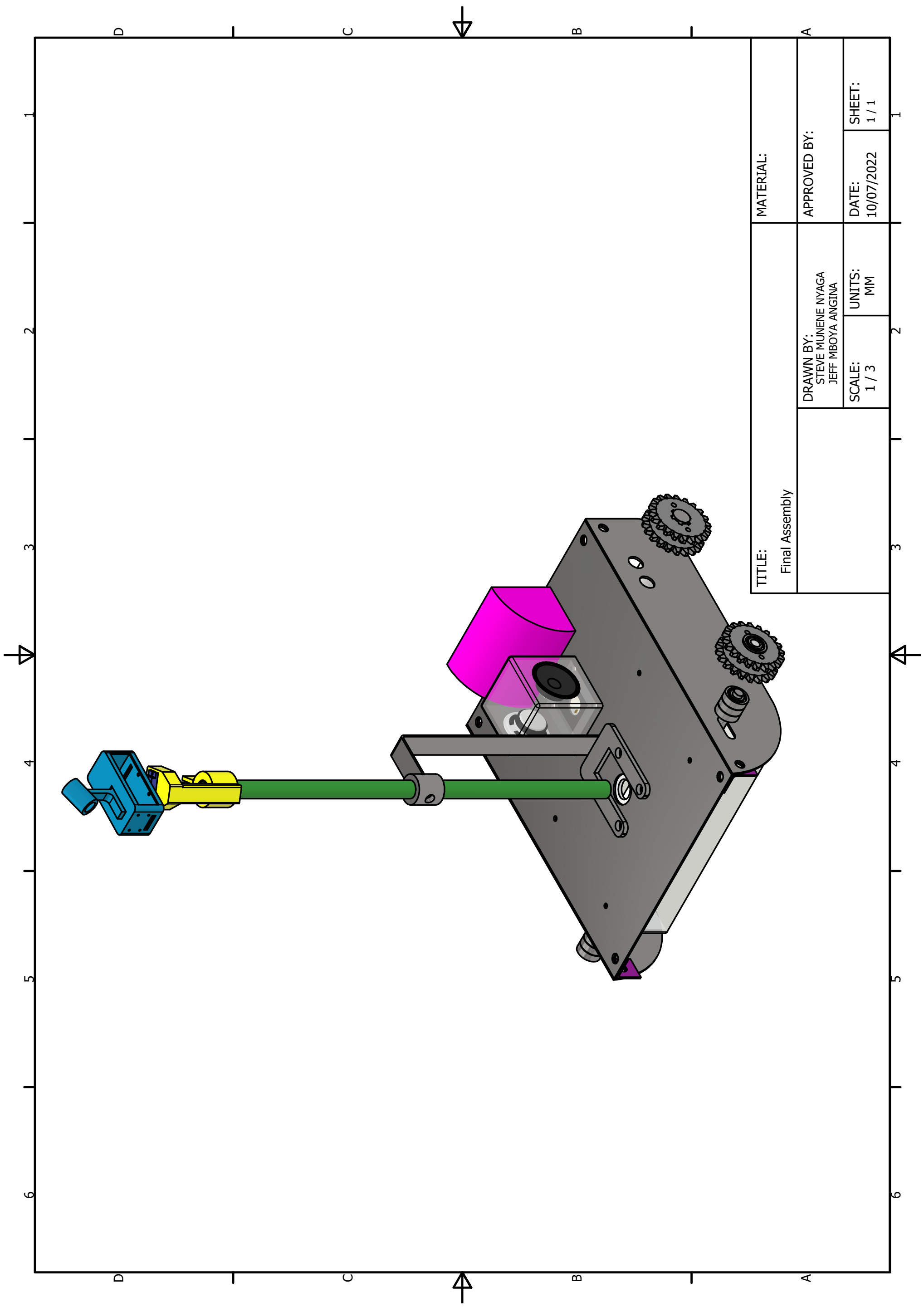

Figure 6.2: Robot Assembly

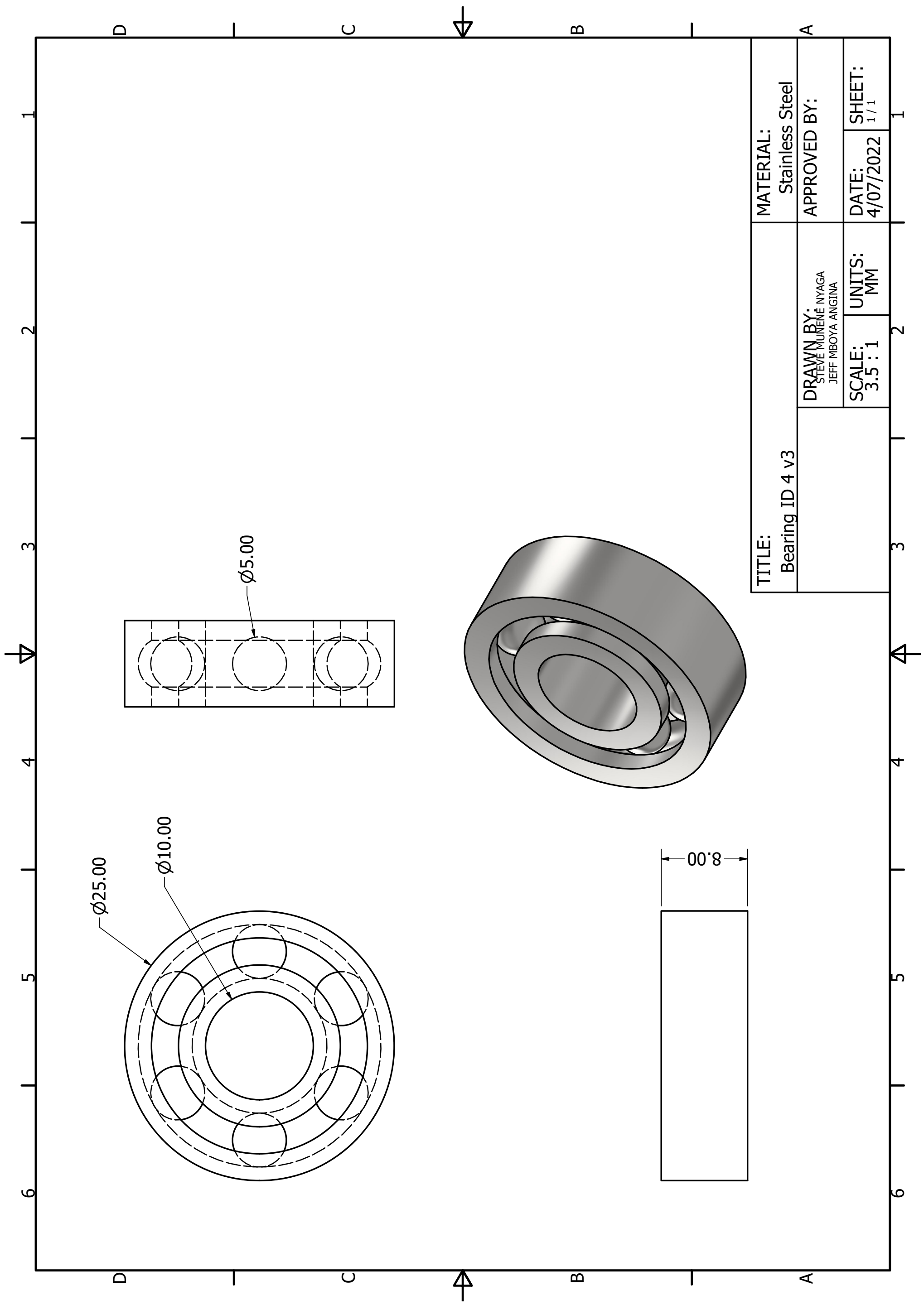

Figure 6.3: Bearing

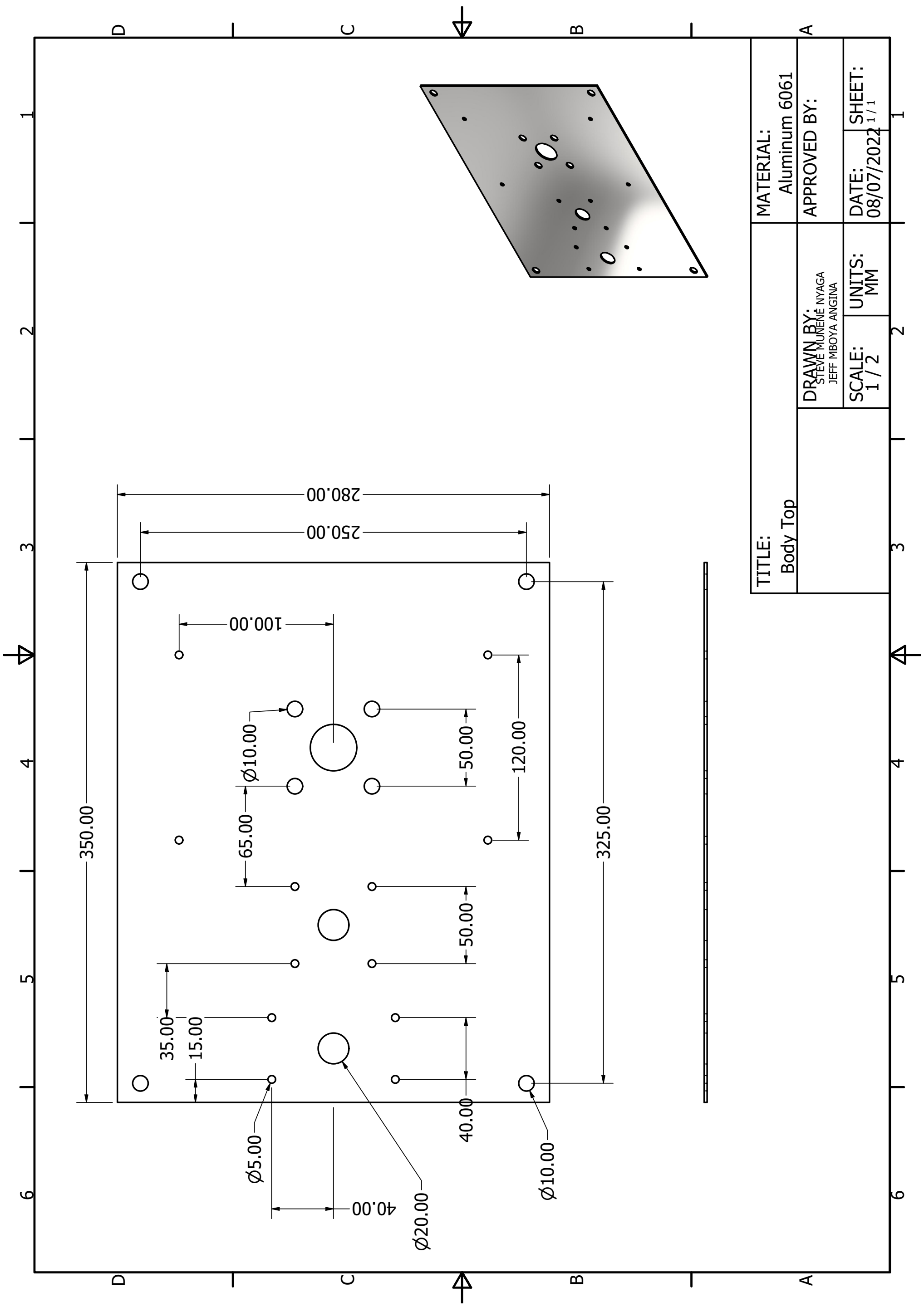

Figure 6.4: Base top frame

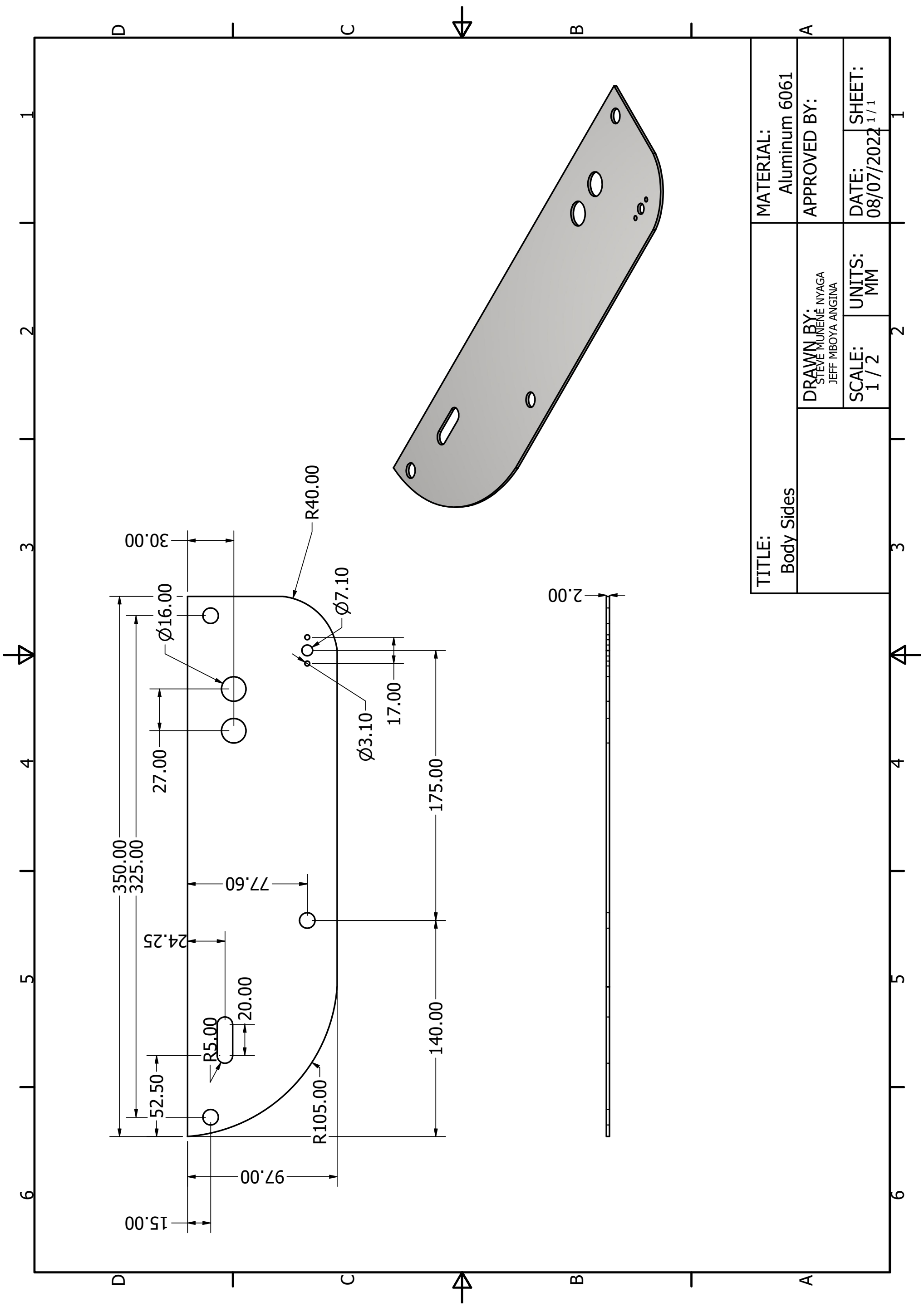

Figure 6.5: Base side frame

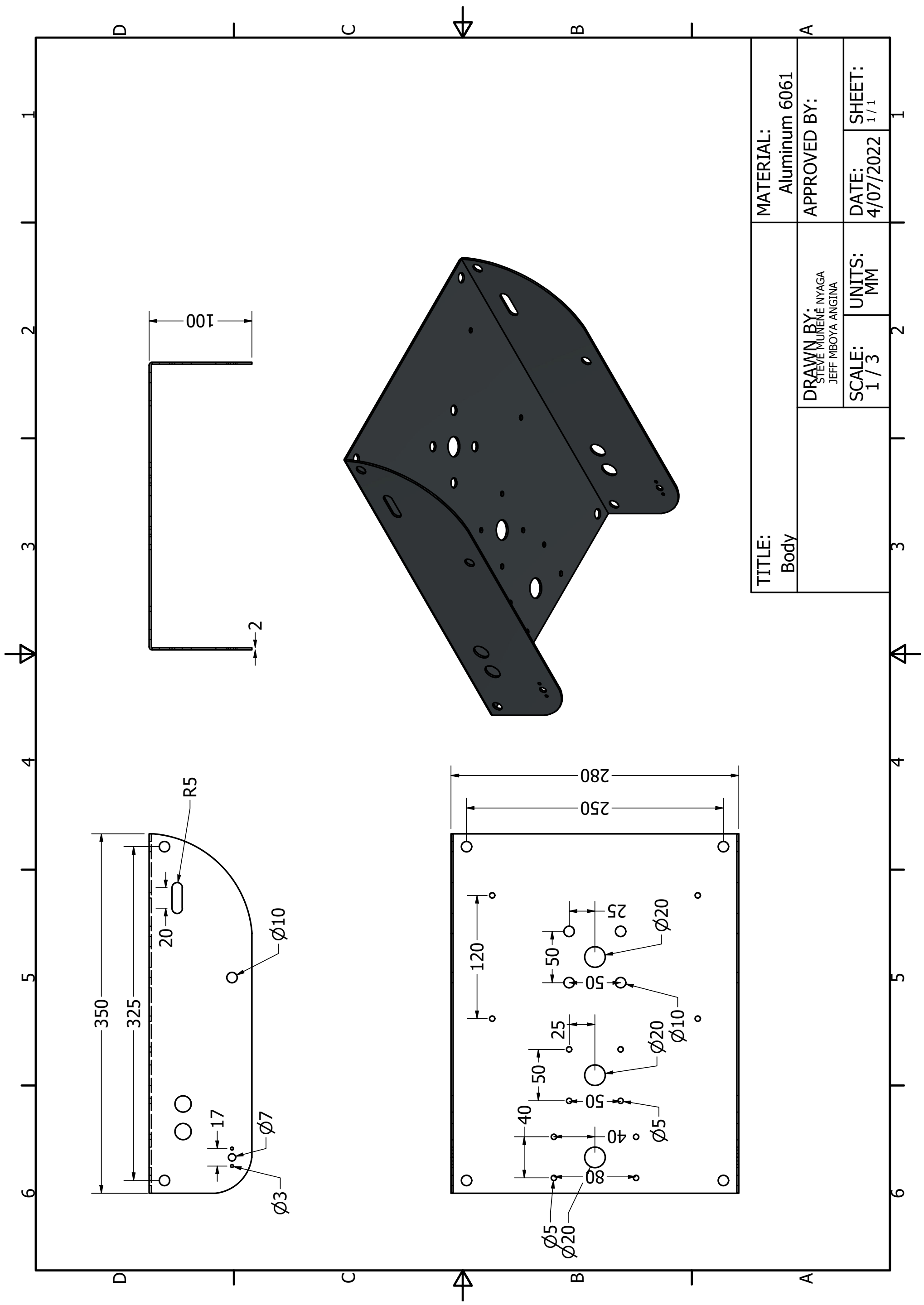

Figure 6.6: Base assembly

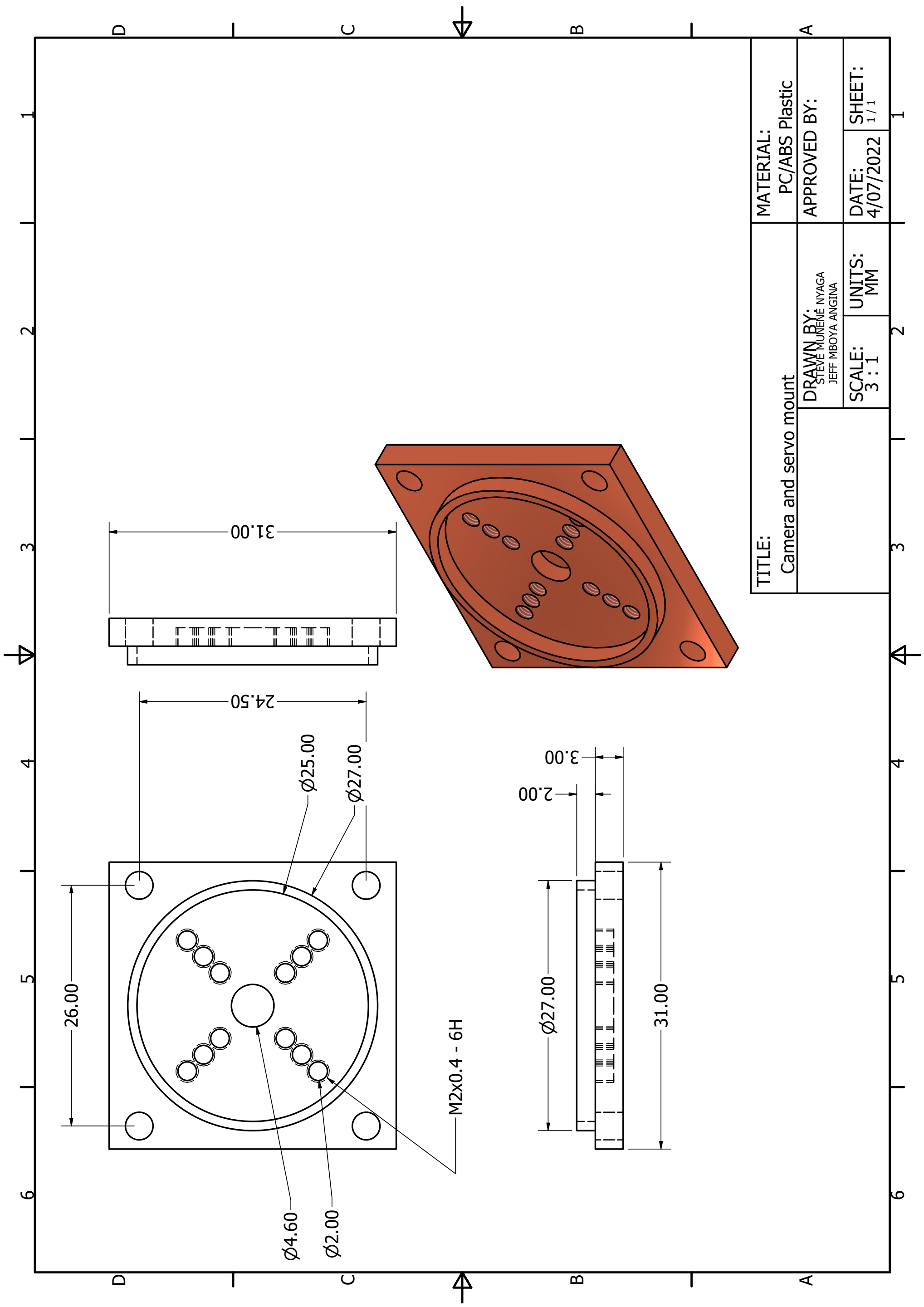

Figure 6.7: Camera and servo mount

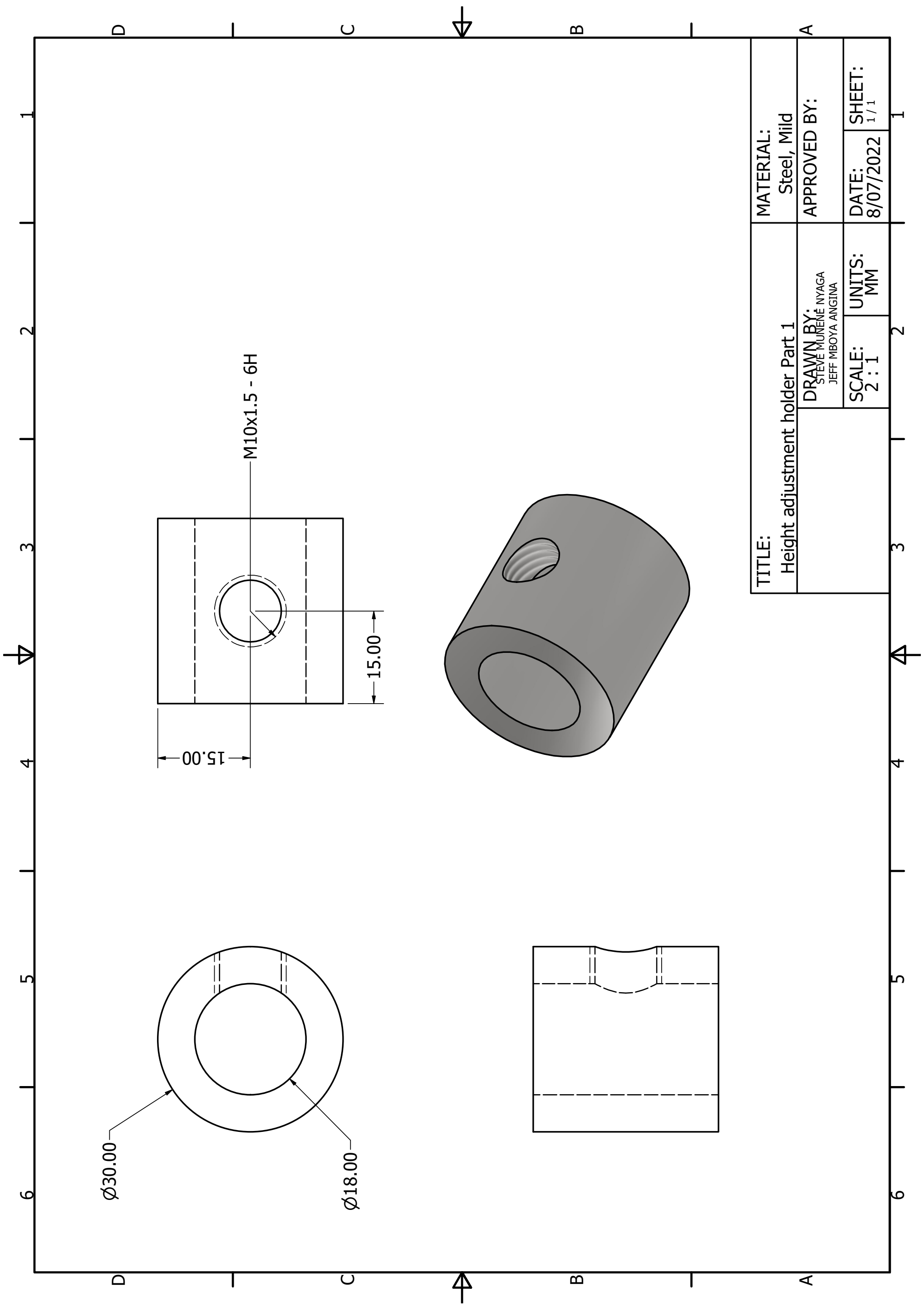

Figure 6.8: Height adjustment holder Part 1

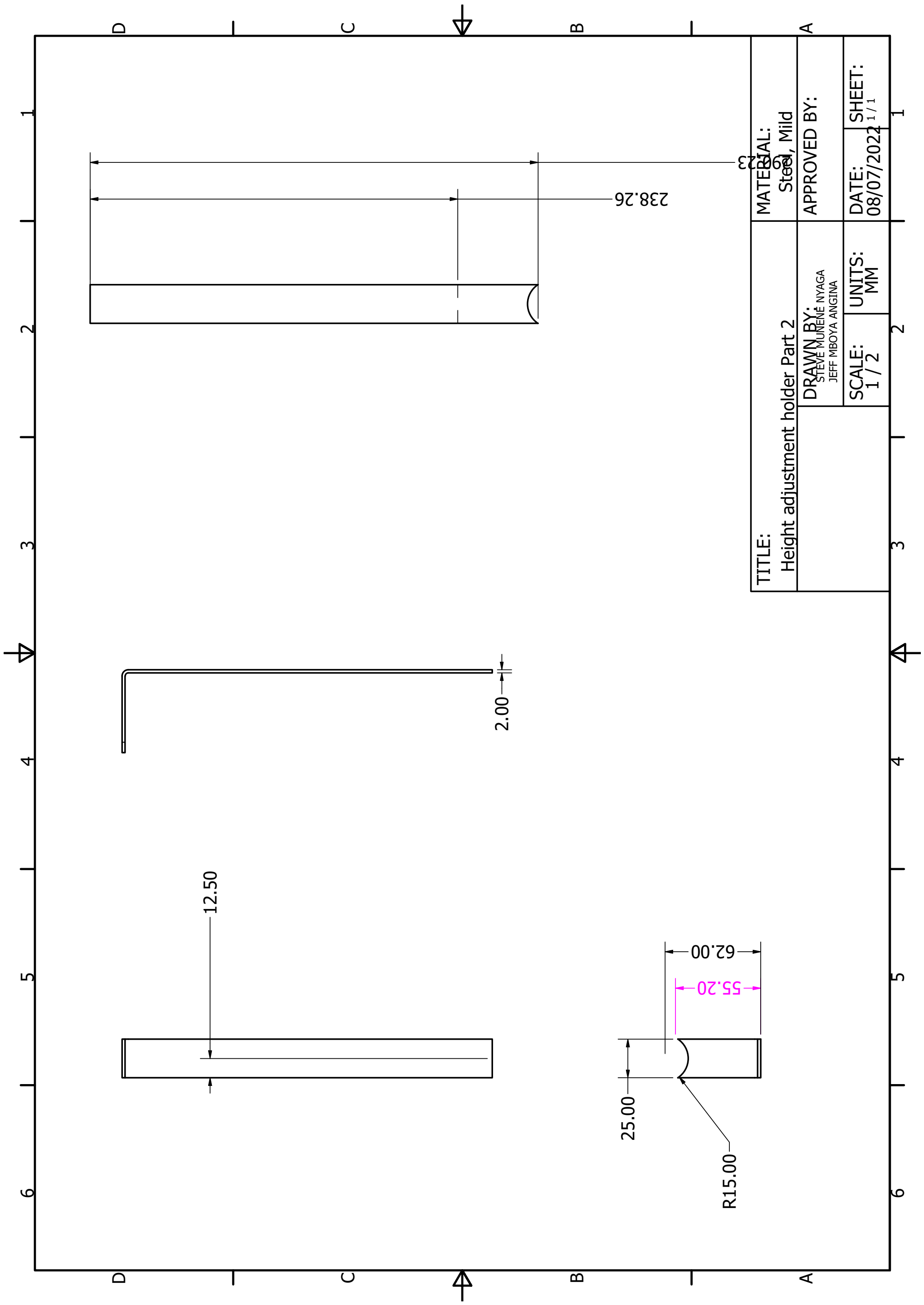

Figure 6.9: Height adjustment holder Part 2

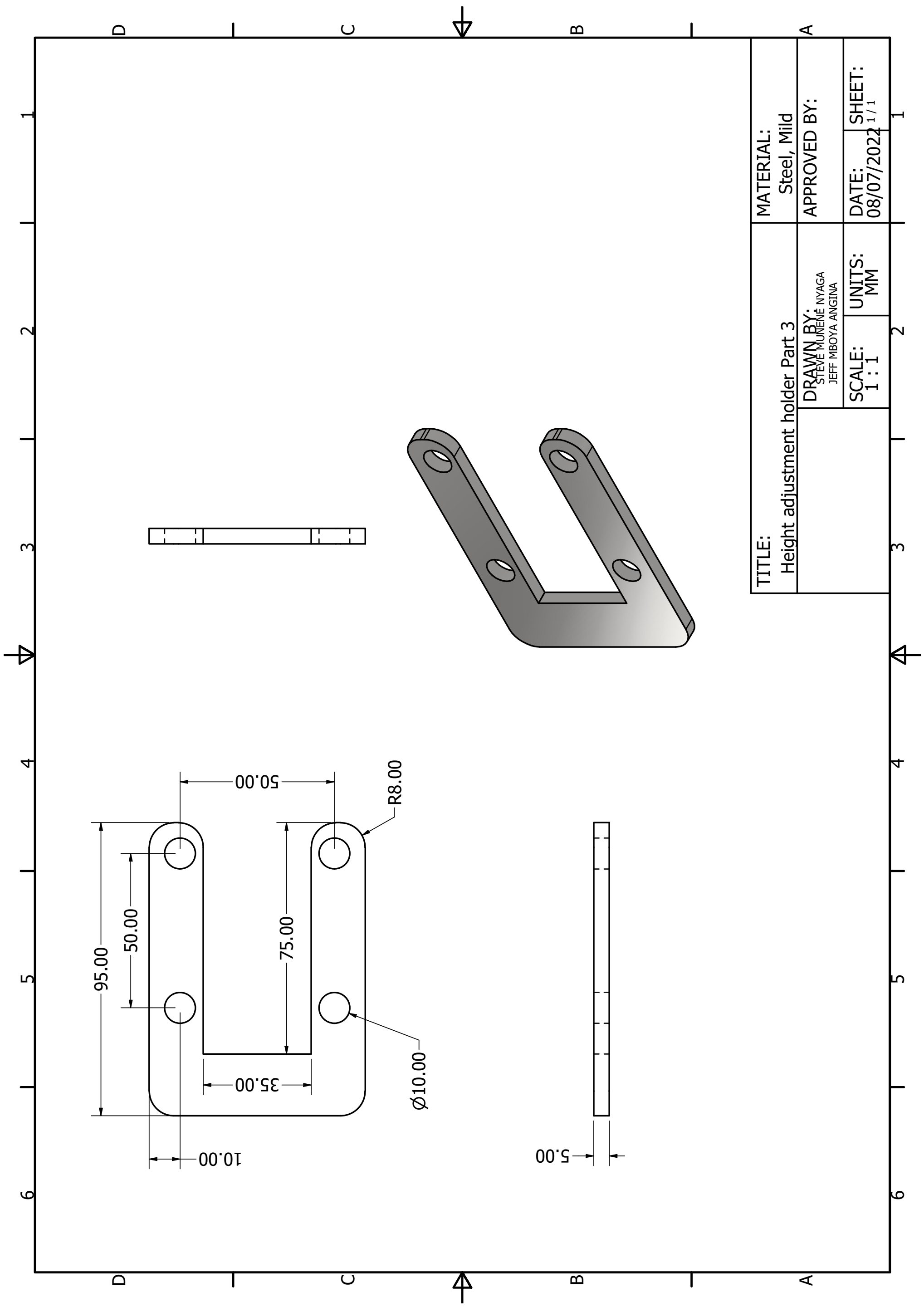

Figure 6.10: Height adjustment holder Part 3

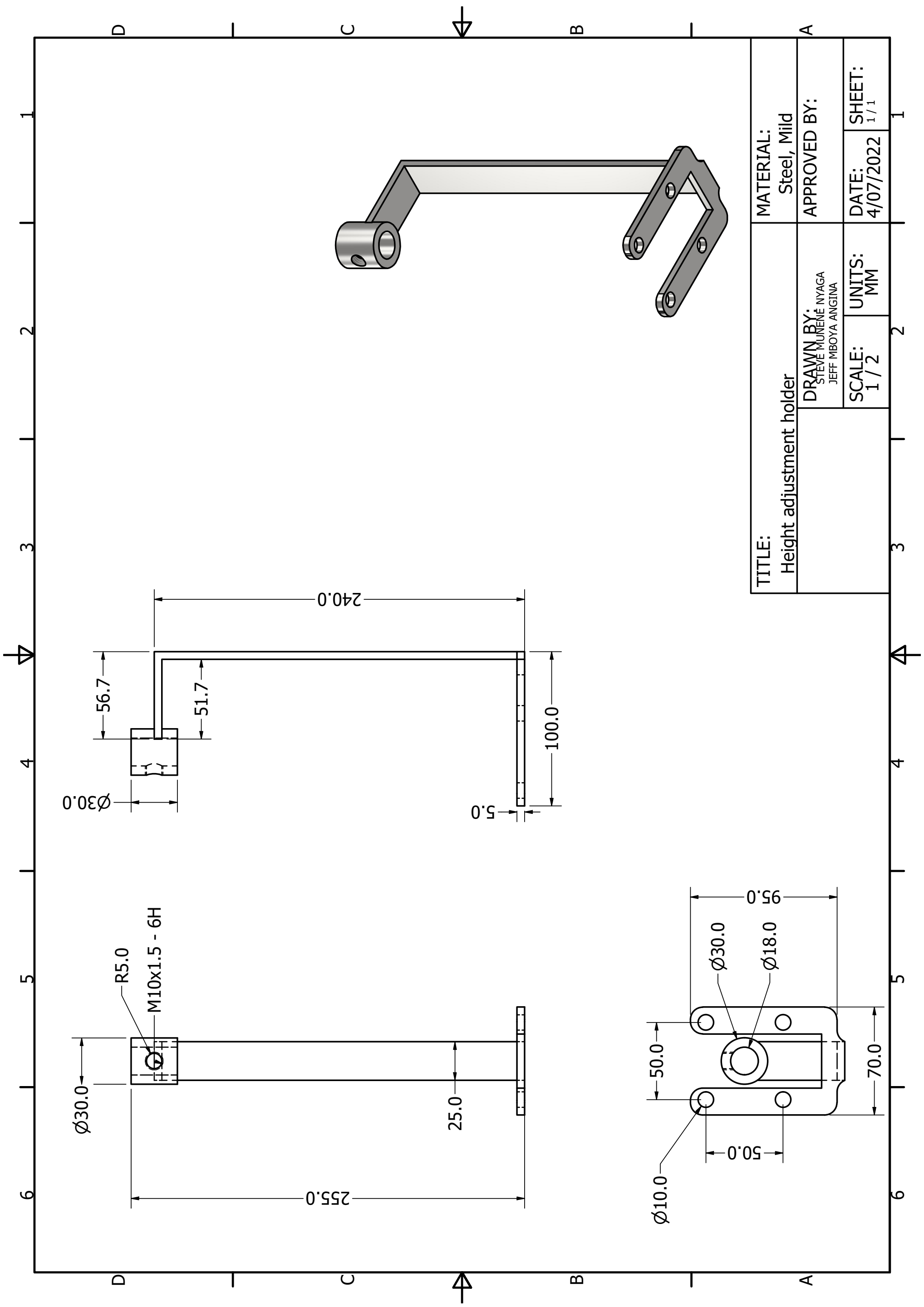

Figure 6.11: Height adjustment holder

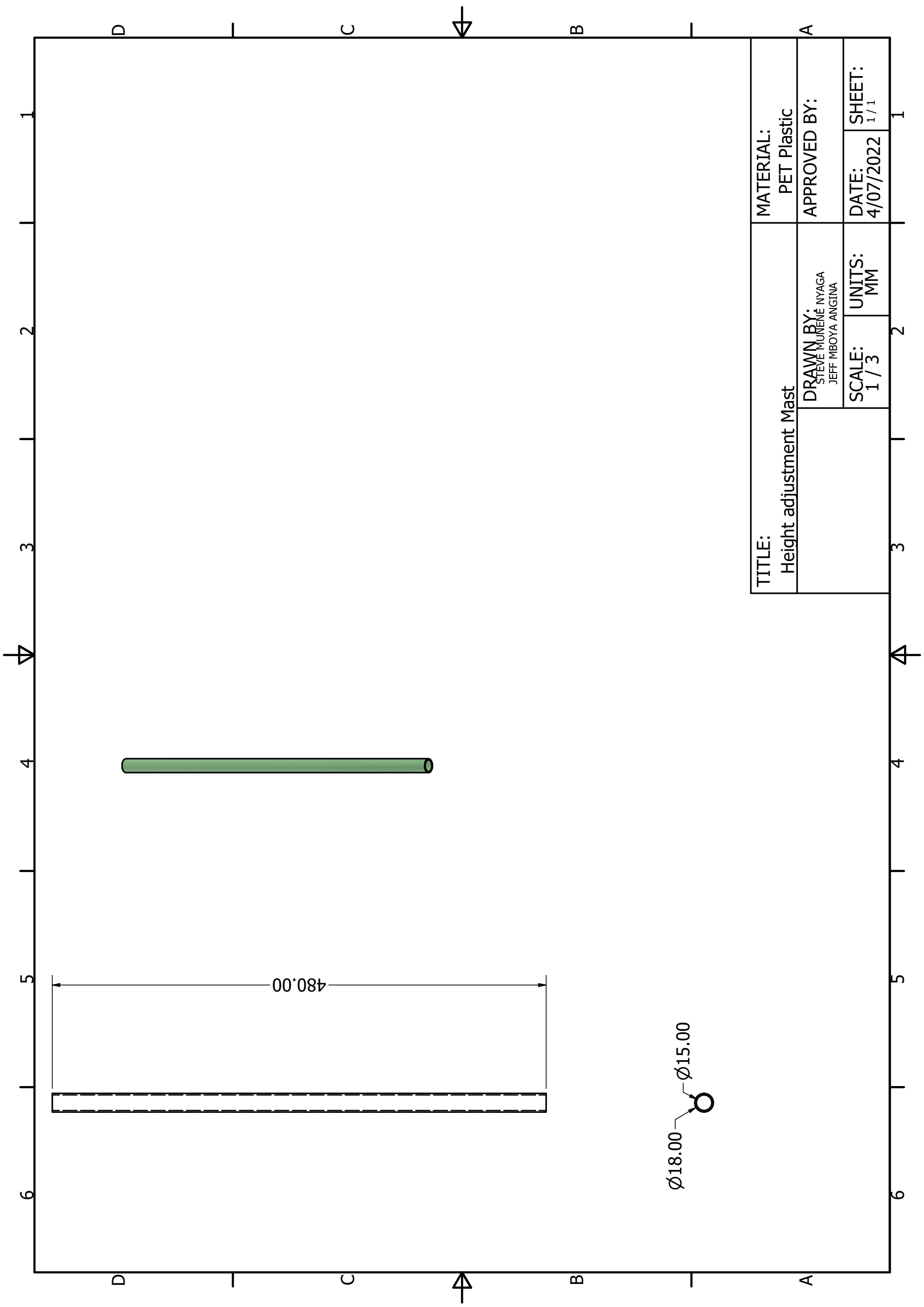

Figure 6.12: Height adjustment mast

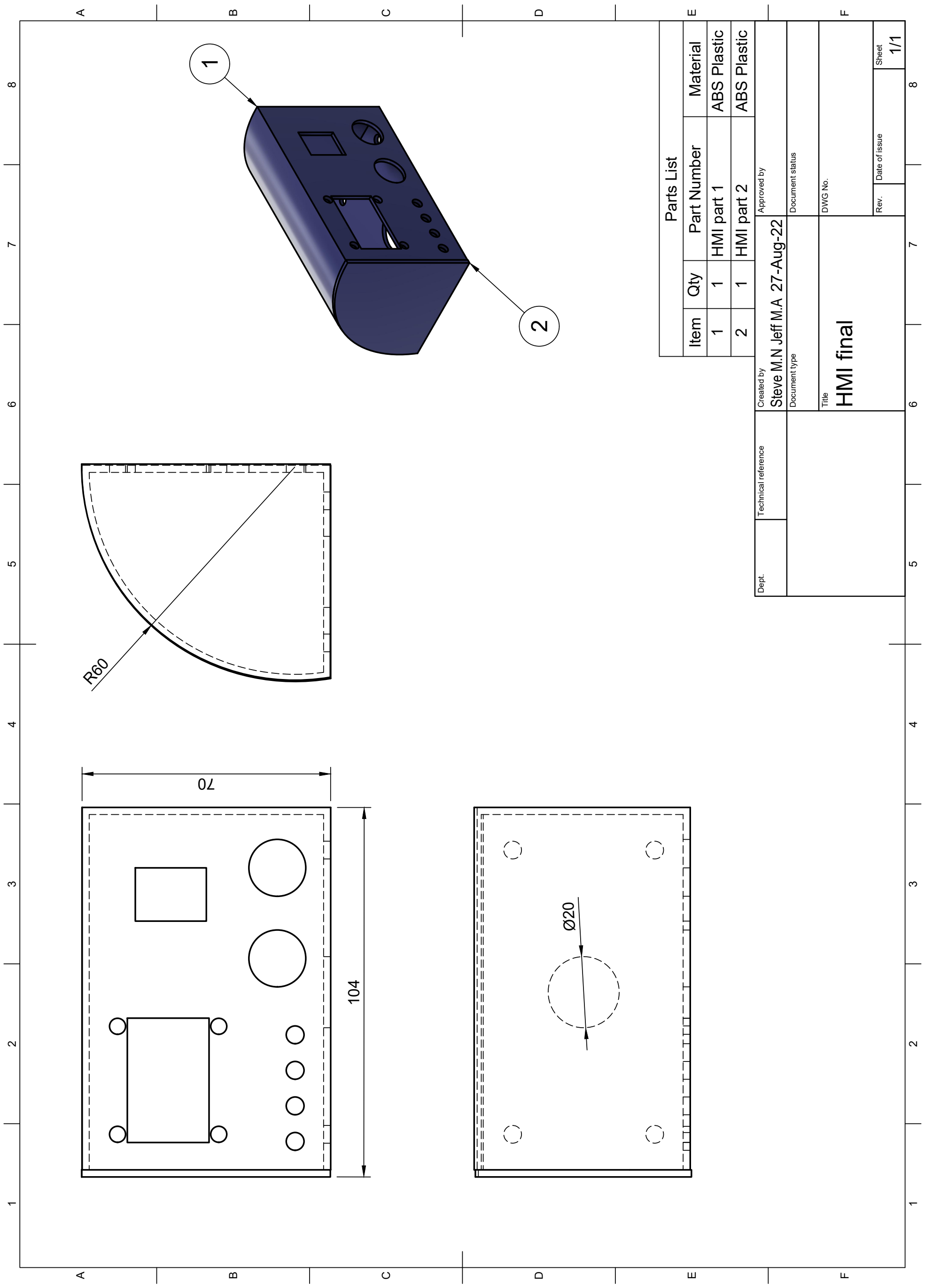

Figure 6.13: Human Machine Interface

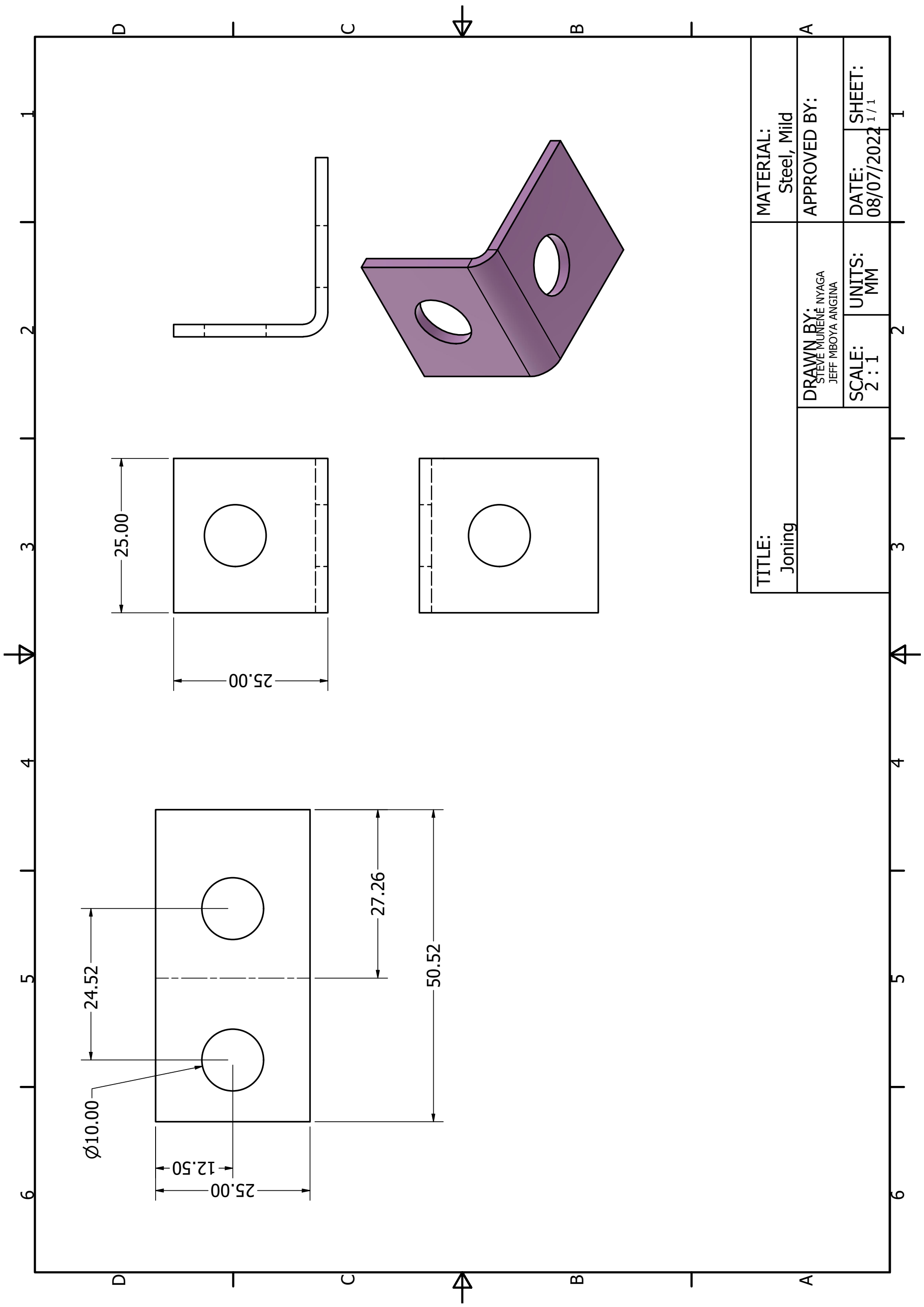

Figure 6.14: Joining bracket

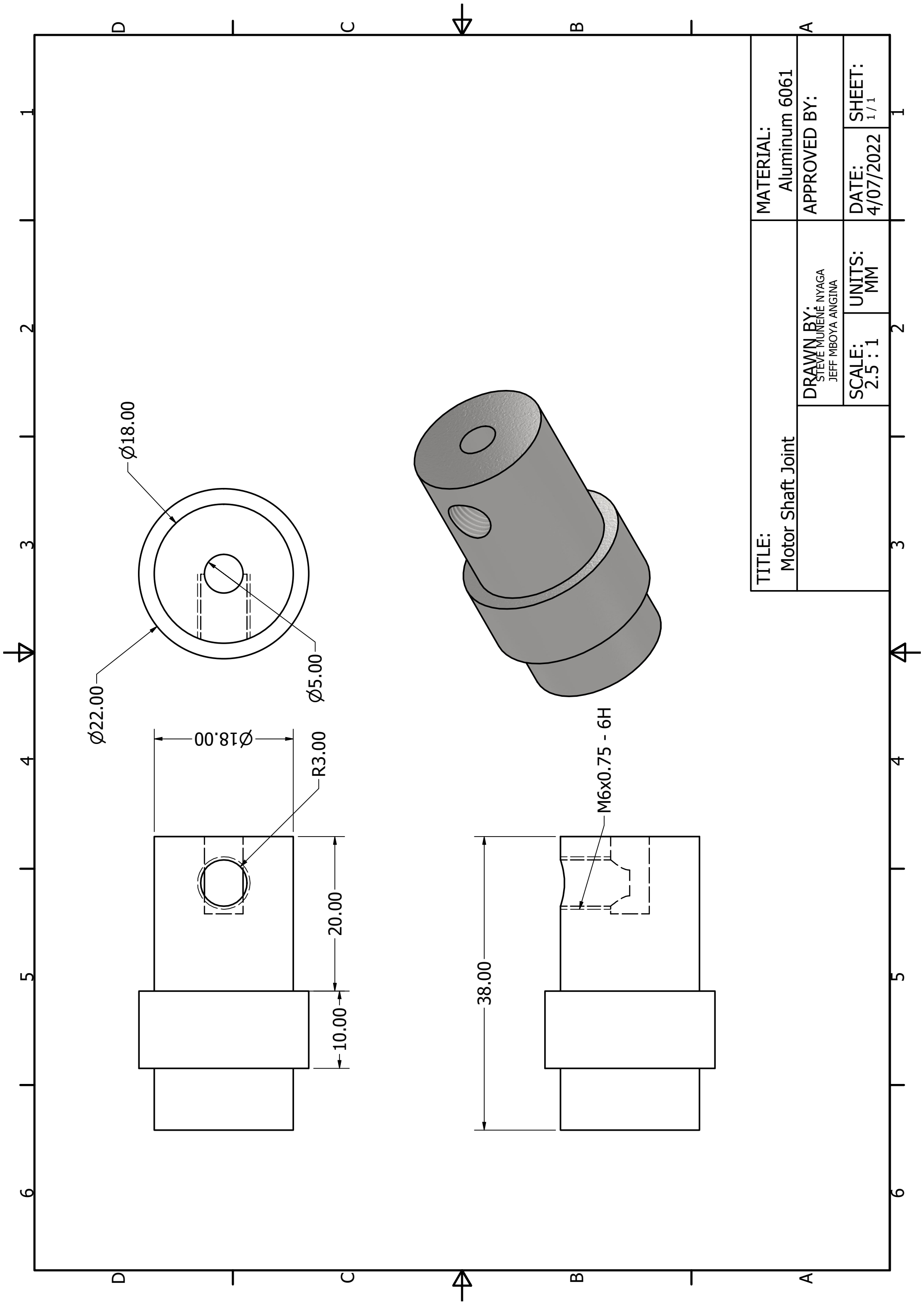

Figure 6.15: Motor Shaft Joint

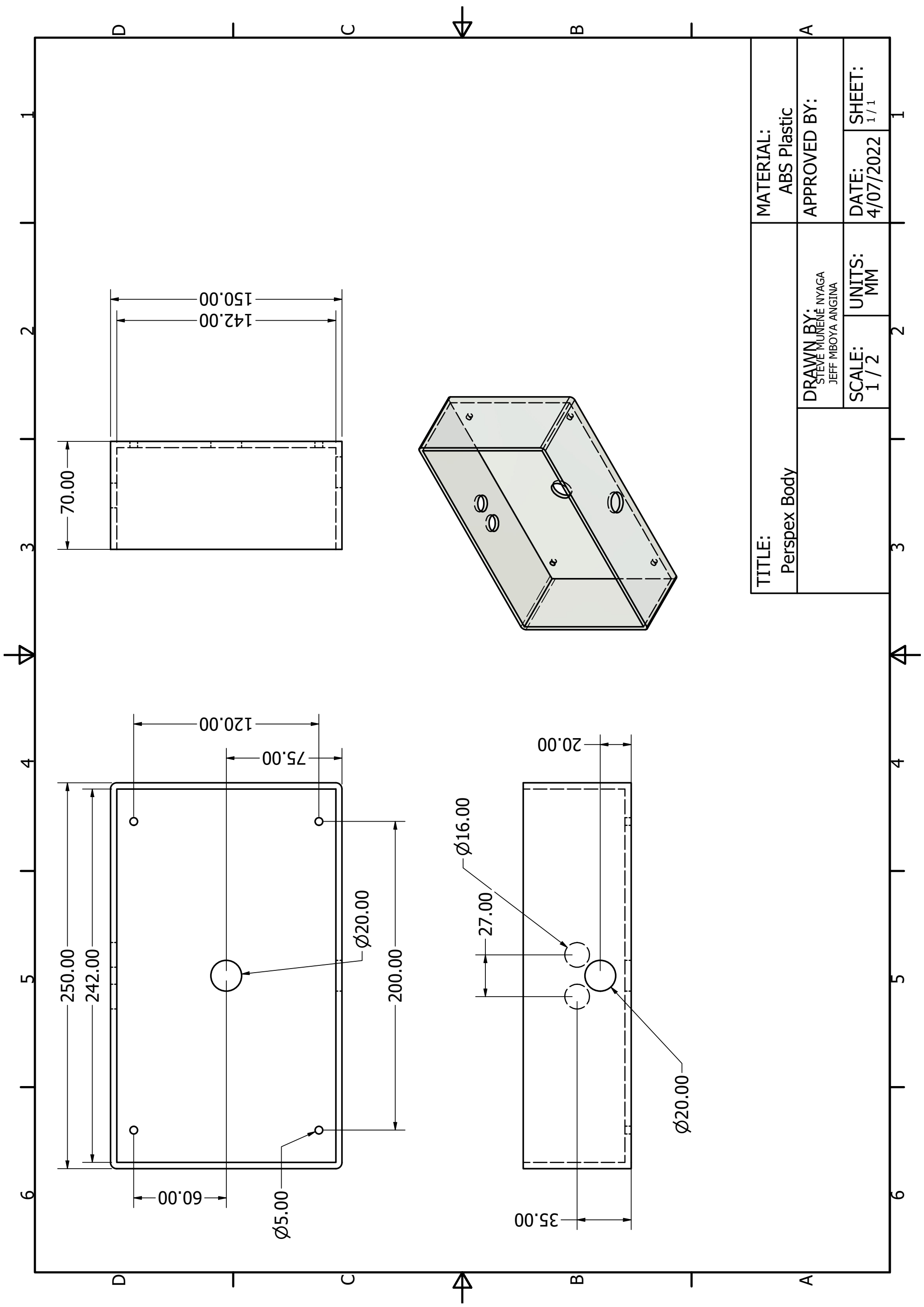

Figure 6.16: Electrical Compartment

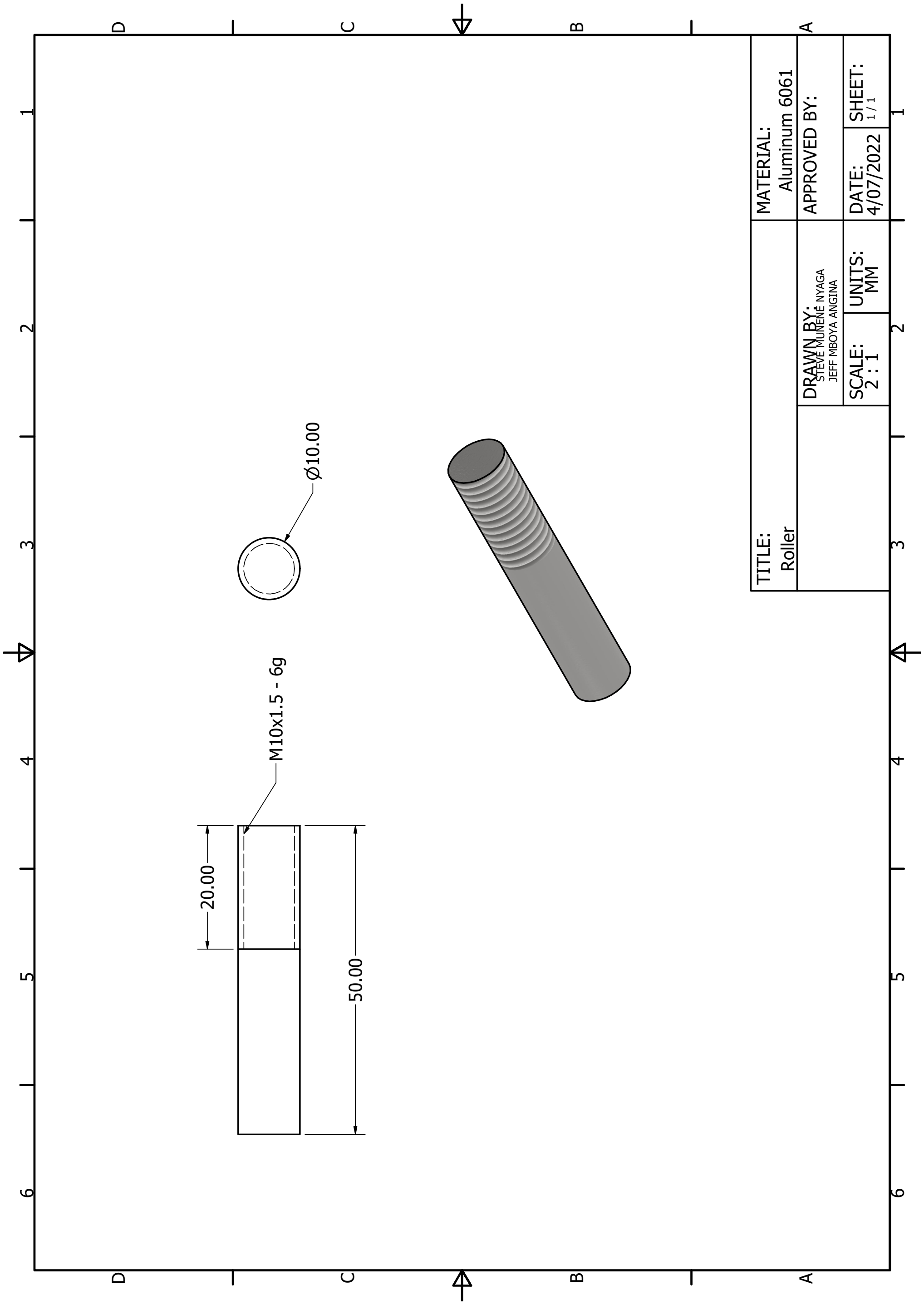

Figure 6.17: Roller

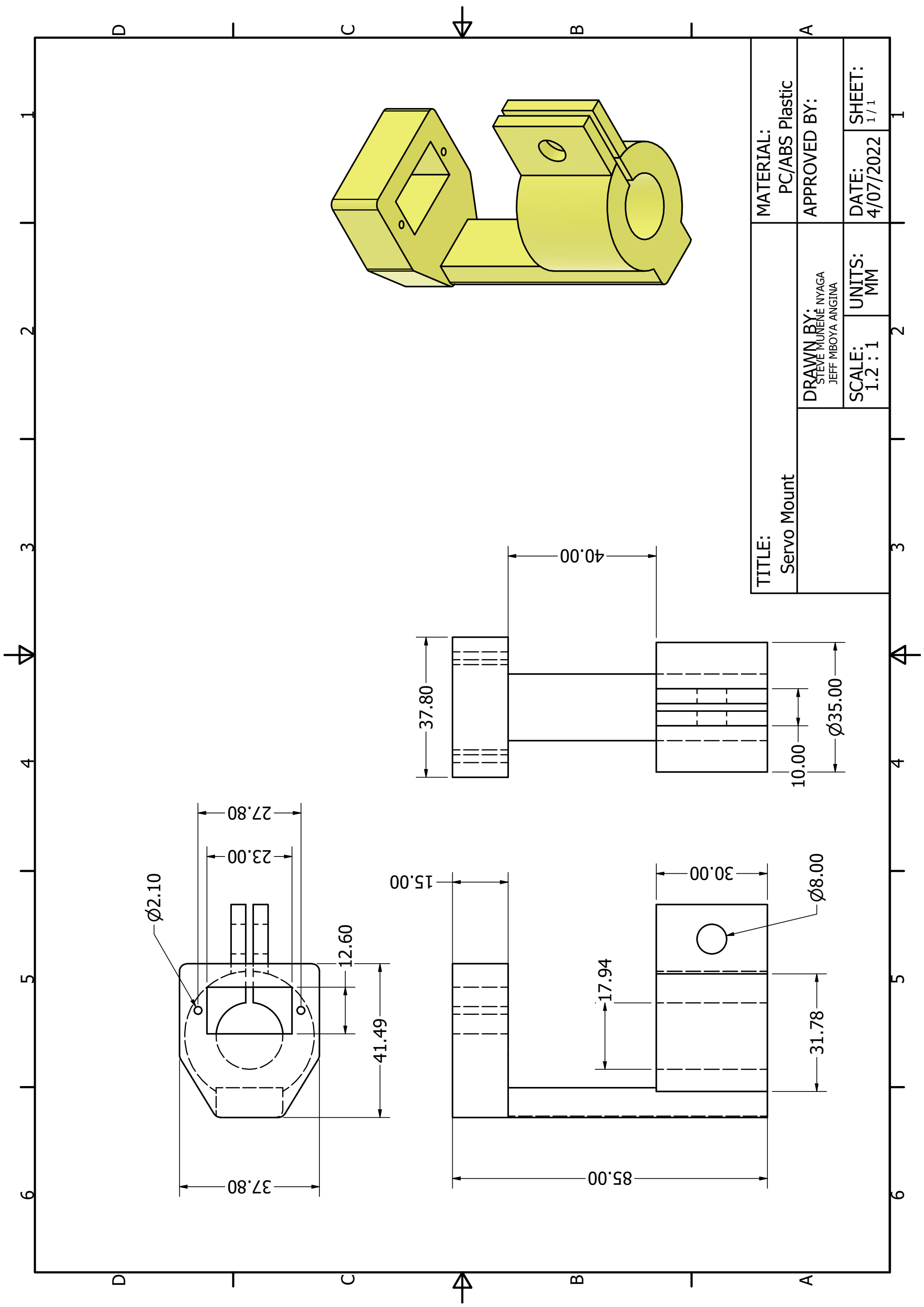

Figure 6.18: Servo Mount

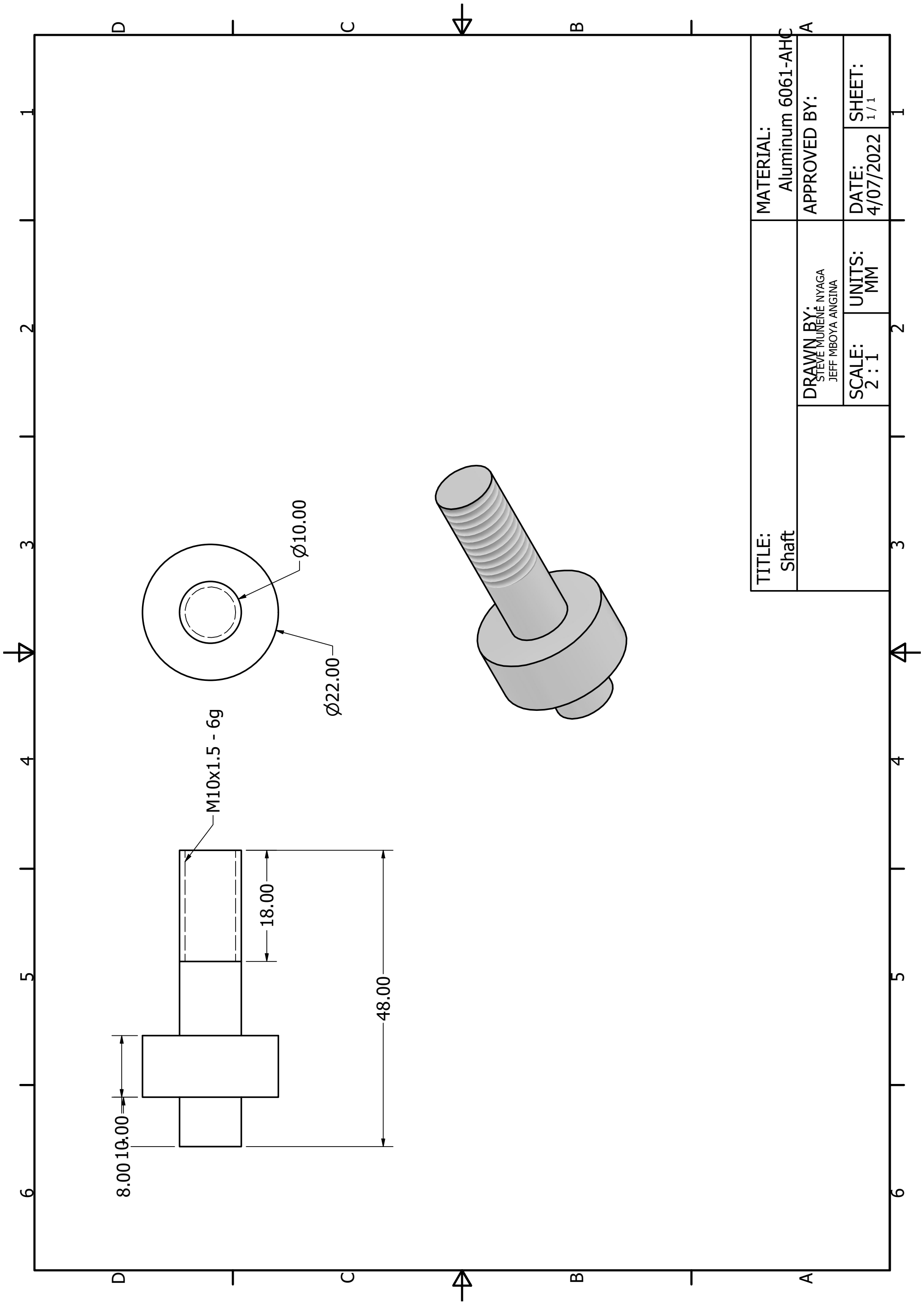

Figure 6.19: Shaft

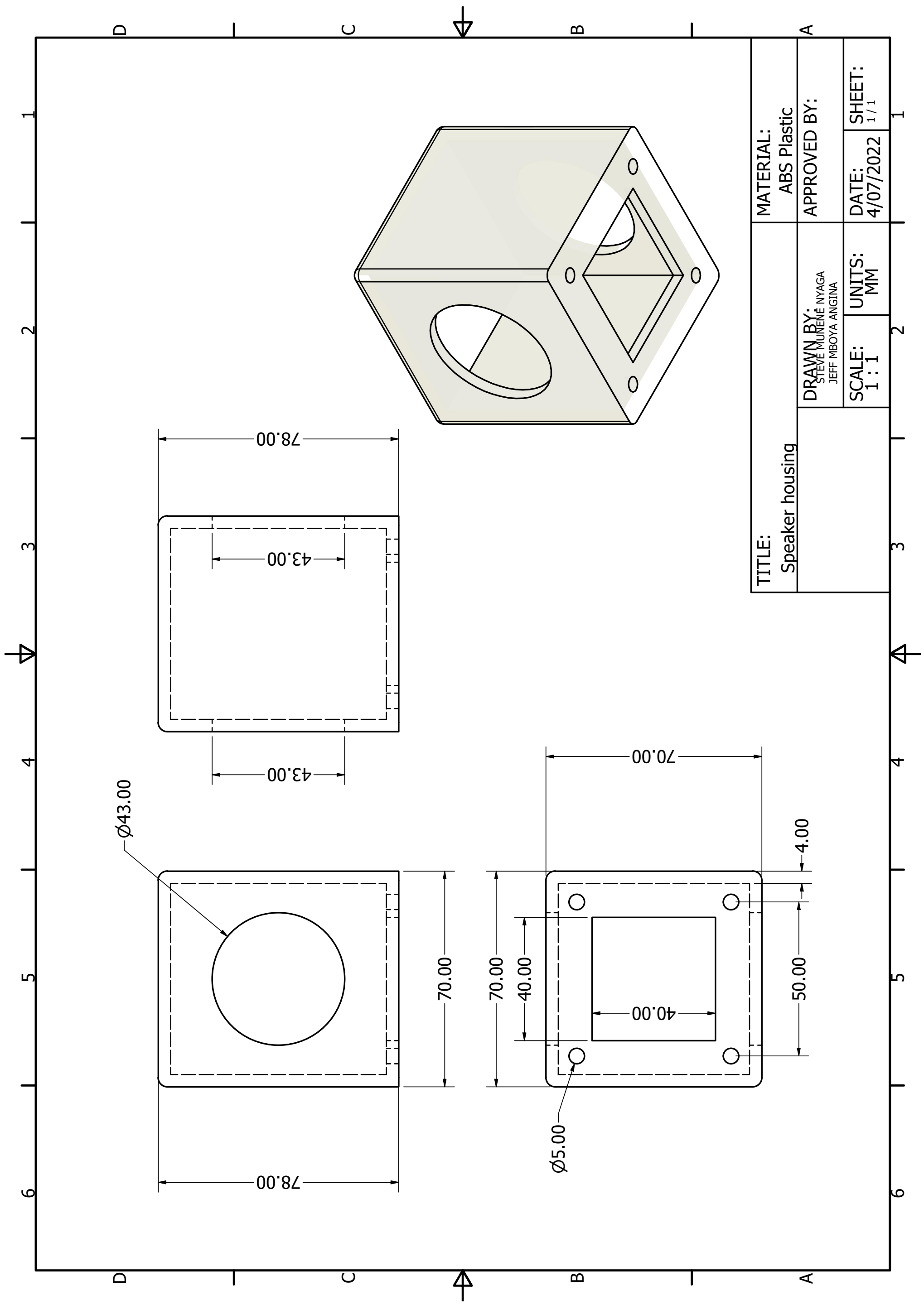

Figure 6.20: Speaker housing

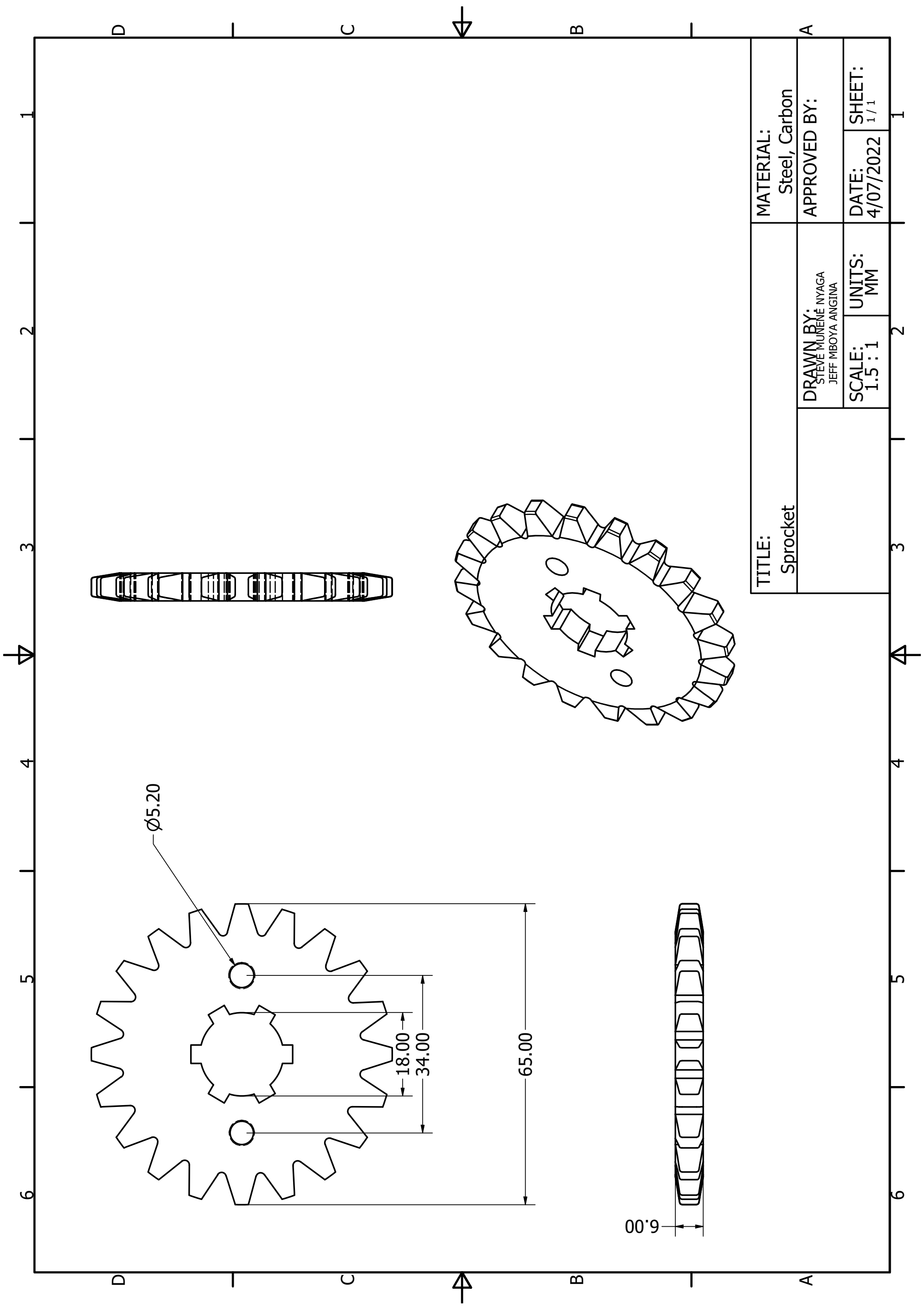

Figure 6.21: Sprocket

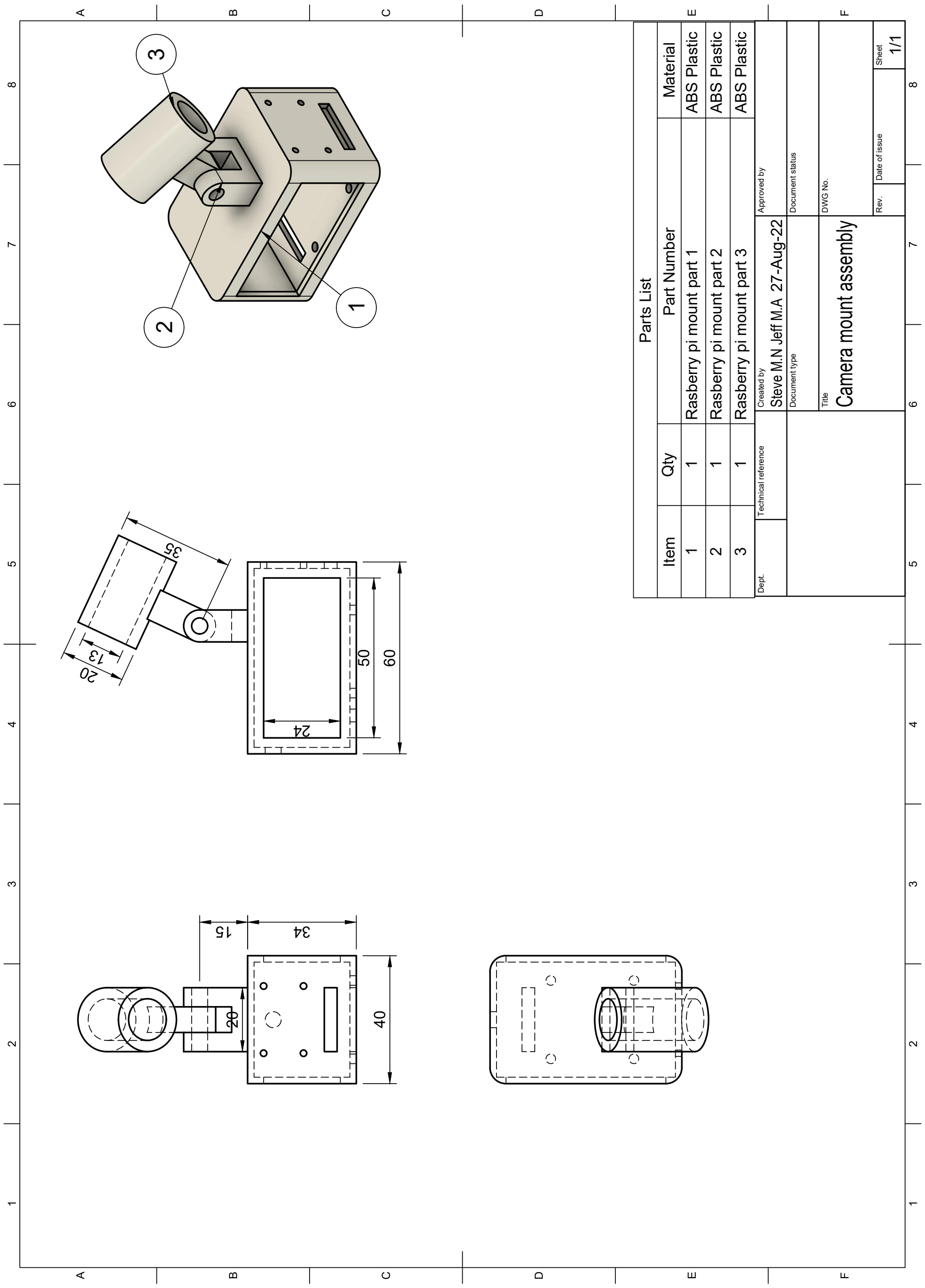

Figure 6.22: Camera mount assembly

6.1 Bird Detection Code

```
# Download YOLOv7 repository and install requirements
!git clone https://github.com/WongKinYiu/yolov7
%cd yolov7
!pip install -r requirements.txt
# REPLACE with your custom code snippet generated above

!pip install roboflow

from roboflow import Roboflow
rf = Roboflow(api_key="YOUR API KEY")
project = rf.workspace("YOUR-WORKSPACE").project("YOUR-PROJECT")
dataset = project.version(1).download("yolov7")
# download COCO starting checkpoint
%cd /content/yolov7
!wget
"https://github.com/WongKinYiu/yolov7/releases/download/v0.1/yol
ov7.pt"
# download COCO starting checkpoint
%cd /content/yolov7
!wget
"https://github.com/WongKinYiu/yolov7/releases/download/v0.1/yol
ov7.pt"
# download COCO starting checkpoint
%cd /content/yolov7
!wget
"https://github.com/WongKinYiu/yolov7/releases/download/v0.1/yol
ov7.pt"
# optional, zip to download weights and results locally

!zip -r export.zip runs/detect
!zip -r export.zip runs/train/exp/weights/best.pt
!zip export.zip runs/train/exp/*
```

Figure 6.23: YOLOv7 code snippet

6.2 Time Plan

Table 6.1: Time Plan

	SEMESTER ONE														SEMESTER TWO													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Proposal		■	■	■																								
Continuous Presentation		■	■	■	■	■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■		
Literature Review		■	■	■											■	■	■	■	■	■	■	■	■	■	■	■		
Design Considerations				■	■	■																						
Conceptual Designs					■	■																						
Mechanical Body Design						■	■																					
Telescopic Body Design							■	■																				
Desing of Power and Electronic Circuit								■	■																			
Design of Sensing and Bird Detection Module								■	■																			
Design of Control Algorithm									■	■																		
Interim Report						■	■	■	■	■	■																	
Material Acquisition															■	■	■	■										
Fabrication of Mechanical Body																■	■	■	■	■								
Fabrication of Telescoping Mechanism																	■	■	■	■								
Fabrication of Power and Electronics Circuit																				■	■	■						
Fabrication of Sensing and Bird Detection Module																					■	■	■					
Assembly of Robot Prototype																						■	■	■	■			
Testing of Robot Prototype																								■	■	■		
Final Report																				■	■	■	■	■	■	■		

6.3 Budget

Table 6.2: Budget

ITEM	QUANTITY	COST PER UNIT	TOTAL COST
Motor	2	1100	2200
STM32F401CC	1	1000	1000
DRV8871 DC Motor driver	2	500	1000
Speaker	2	100	200
Audio Amplifier	1	150	150
Sprocket	8	100	800
Bearing	8	100	800
Chain	4	400	1600
11.1V 5000mAh Battery	1	6000	6000
OLED LCD	1	600	600
Perpex Sheets	3	1500	4500
Aluminum sheets*	1	10000	10000
Laser module	1	350	350
GPS Module	1	800	800
Rocker Switch	1	60	60
Ultra sonic sensor	4	200	800
Servo motor	1	250	250
Jetson Nano Camera	1	3500	3500
Jetson Nano Microprocessor*	1	10,000	10,000
Resistors	4	5	20
Diodes	4	5	20
LEDs	4	5	20
Boost converter	1	320	320
Buck converter	1	400	400

Table 6.2: Budget

ITEM	**QUANTITY**	**COST PER UNIT**	**TOTAL COST**
2 pin PCB terminal	2	20	40
Miscellanous			7000
		TOTAL =	53038

Note: Stared components are not to be bought