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Design and Fabrication of a model of an automated coffee berry sorting machine

FYP 20-16

(Final Year Project Report)

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Declaration

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Abstract

This project presents the design and fabrication of a model of an automated coffee berry sorting machine, to improve the precision and efficiency of sorting in coffee production. The machine is equipped with an image-based detection system and air ejection mechanisms, operating under the control of a Raspberry Pi 3 computer. The primary function of the system is to distinguish between ripe, unripe, overripe, and dried up coffee berries based on their colour by utilizing image processing techniques.

The machine's architecture includes a vibrating conveyor system to ensure consistent flow of coffee berries, a chute for better alignment of berries and an object detection and tracking system that ensures continuous monitoring of individual berries as they progress through the sorting process. This tracking capability is critical for the precise activation of air ejectors that eject unwanted berries.

This project delivers a sorting solution that reduces manual intervention, thereby improving consistency in coffee quality production. By automating the sorting process, the machine not only improves operational efficiency but also enhances the overall economic viability of coffee production.

Contents

List of Figures

1 Introduction

1.1 Background

The global coffee industry is a significant contributor to the economies of many developing countries. It supports millions of smallholder farmers worldwide. Coffee production involves several critical stages, from cultivation and harvesting to processing and packaging. One of the most challenging and labor-intensive stages in the coffee value chain is the sorting of coffee berries. Traditionally, the sorting of coffee berries has been done manually, relying on the visual inspection skills of the workers to identify and separate the berries according to ripeness, size, and defects. This manual process is time-consuming, inconsistent, and often costly, leading to variability in coffee quality and increased operational expenses.

Manual sorting methods are susceptible to human error and fatigue, which can result in misclassification of berries, thereby affecting the overall quality of the final product. Additionally, the labor-intensive nature of manual sorting limits scalability and efficiency, especially during peak harvest seasons when labor shortages are common. These challenges underscore the need for an automated solution that can perform sorting tasks more accurately, consistently, and efficiently.

Technological advancements in machine learning, computer vision and robotics present new opportunities to address these challenges. Automated sorting systems equipped with high-resolution cameras and sophisticated image processing algorithms can analyze the physical characteristics of coffee berries with high precision. Machine learning models can be trained to recognize subtle differences in berry appearance, enabling the accurate classification of berries based on predefined criteria. Furthermore, robotic handling systems can sort berries at high speeds without causing damage, ensuring a gentle and efficient sorting process.

Implementing an automated coffee berry sorting machine offers numerous benefits. First, it enhances the quality of coffee by ensuring that only the best quality berries are selected for processing. Second, it increases operational efficiency by reducing the time and labor required for sorting. Third, it lowers costs associated with manual labor and reduces the likelihood of human error. Finally, it provides a scalable solution that can be adapted to various sizes of coffee production operations, from smallholder farms to large industrial facilities.

Several pilot studies and prototype developments have demonstrated the potential of automated sorting technologies in the agricultural sector. For instance, similar technologies have been successfully implemented in sorting other fruits and vegetables, providing valuable insights and a foundation for the development of a coffee-specific solution. However, the unique characteristics of coffee berries, such as their size, shape, and color variations, as shown in figure 1.1, necessitate a tailored approach to design an effective automated sorting system.

This engineering proposal outlines the design and development of an automated coffee berry sorting machine, leveraging current technologies to deliver a high-performance solution tailored to the needs of coffee producers. By addressing the limitations of manual sorting and harnessing the power of automation, this project aims to revolutionize the coffee sorting process, enhancing product quality, operational efficiency, and overall sustainability in the coffee industry.

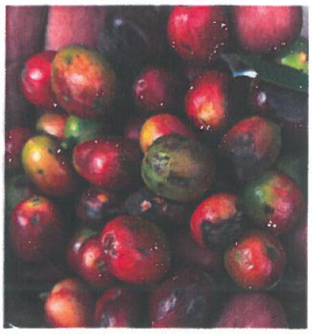


Figure 1.1: Harvested coffee berry variation

1.2 Problem statement

The global coffee industry prioritizes delivering a consistently high-quality coffee product to consumers. However, a significant obstacle prevents this,traditional manual coffee berry sorting methods. While these methods provide a baseline level of quality control, they are affected by various limitations. Human error, a major factor, which can be attributed to fatigue, inconsistent lighting conditions and individual sorting variations. This variability in sorting practices ultimately leads to inconsistencies in the final coffee product, potentially impacting flavor profiles and ultimately, the consumer experience.

Both Large-scale and small-scale coffee producers are particularly affected by these inefficiencies. The labor-intensive nature of manual sorting significantly limits processing speed and efficiency, especially during periods of high harvest volumes. This bottleneck creates logistical challenges and hinders overall production capacity. Additionally, producers face significant operational costs due to the reliance on manual labor. Furthermore, the potential for human error during sorting can result in product waste, further impacting profitability.

These limitations highlight the need for a more robust and reliable solution within the coffee industry. An innovative approach to coffee berry sorting is crucial to ensure consistent coffee quality throughout the supply chain. By improving processing efficiency and minimizing human error, this new technology can positively impact producers, roasters, and ultimately, the coffee-loving consumer. Moreover, consistent quality control can incentives sustainable practices by offering premium prices for high-quality coffee berries, encouraging farmers to invest in methods that enhance bean quality.

1.3 Objectives

Main Objective

- To develop an automated coffee berry sorting machine to improve consistency and accuracy in sorting coffee berries.

Specific Objectives:

1. To design and fabricate a mechanical system for the coffee berry sorting machine
2. To design and fabricate an electrical system for the coffee berry sorting machine
3. To develop a control system to sort coffee berries
4. To test the automated coffee berry sorting machine

1.3.1 Justification

The coffee berry sorting project is essential for improving the efficiency and quality of coffee production. By automating the sorting process, producers can ensure a consistent selection of high-quality berries, reducing human error and labor costs. This automation improves productivity and profitability while minimizing waste, contributing to sustainability efforts. With advanced technologies such as machine learning and computer vision, the system can adapt to varying characteristics of the berry, ensuring long-term effectiveness. Overall, this project positions coffee producers to meet increasing market demands, maintain competitive advantage and support sustainable agricultural practices at reduced costs.

2 Literature Review

The differentiation of coffee berries based on ripeness is crucial in ensuring the quality of the final coffee product.[1].Harvested coffee berries are usually in a mixture as in figure 2.1

Figure 2.1: Harvested Batch

Ripe coffee berries, which are typically red in colour, are preferred for high-quality coffee production and are most suitable for wet processing methods. These berries contain optimal levels of sugars and acids, contributing significantly to the flavor profile of the coffee. The wet method, which involves pulping, fermenting, and washing the berries, is ideal for ripe berries because of their softer texture and higher moisture content. This method enhances the clarity and brightness of the coffee's flavor, making it a preferred choice for premium coffee. On the other hand, unripe and overripe berries are often harder to pulp using mechanized pulping machine 2.3 and are more commonly processed using dry methods. Unripe berries, which are green or yellowish, lack the necessary sugars and acids for high-quality coffee and tend to produce astringent and bitter flavors. Note that these berries are firmer, which makes them difficult to process using the wet method[2]. As a result, they are usually dried whole, a process that requires less handling and can still produce drinkable, though often lower-quality, coffee[1].

Figure 2.2: ripe, unripe, overripe and defective

Overripe berries, which may range from dark red to black, also pose challenges for wet processing due to their softer, sometimes damaged texture. These berries are more prone to fermentation, which can lead to undesirable flavors. It is emphasized that the dry method, where berries are dried with their pulp intact, is more appropriate for these overripe berries, as it reduces the risk of spoilage during processing.

Defective berries, including those that are moldy, insect-damaged, or diseased, are generally unsuitable for wet processing due to the risk of contaminating the fermentation tanks. It is suggested, that these berries are better suited for dry processing, where they can be sorted and removed more effectively after drying.

Given these distinctions, automated sorting systems must be capable of not only differentiating between ripe, unripe, and overripe berries but also recognizing the appropriate processing method for each category. Studies have shown that advanced image processing techniques, combined with color analysis, can effectively classify berries based on ripeness and determine their suitability for either wet or dry processing[3].

Figure 2.3: Mechanized pulping machine

2.1 Challenges of Traditional Sorting Methods:

Traditional manual coffee berry sorting, as shown in figure2.4, has been a long-standing practice in coffee production, but several studies have identified inherent challenges that limit its efficiency and ability to maintain consistent coffee quality. Despite serving its purpose for generations, this method faces issues that hinder the overall productivity and quality control of coffee processing.

One of the most prominent challenges associated with manual sorting is its labor-intensive nature. Research indicates that manual sorting requires a large workforce, making it not only expensive but also unsustainable for larger coffee producers who aim to scale up their operations [4] . The process is physically demanding, and workers are often required to maintain a high level of focus for extended periods, which can lead to fatigue. This physical exhaustion can directly impact the accuracy and speed of the sorting process, further increasing labor costs and reducing overall efficiency.

Another significant issue is the risk of human error. Human sorters, especially when fatigued, are prone to mistakes, leading to defects being overlooked or inconsistencies in sorting criteria. Over time, this variability can result in undesirable berries slipping through, ultimately affecting the quality of the coffee produced [5]. The reliance on human judgment introduces a level of unpredictability that makes it difficult to maintain consistent quality across different batches.

The limited throughput of manual sorting methods has also been highlighted as a considerable bottleneck in the production process. Studies have shown that the speed of sorting is inherently constrained by human capabilities, making it challenging to keep up with the demands of large-scale operations [1]. This restriction often results in delays within the coffee production process, hindering the ability of producers to meet market demands efficiently.

These limitations highlight the need for more efficient and consistent sorting methods, driving interest in automated solutions that can address these issues and improve overall coffee quality.

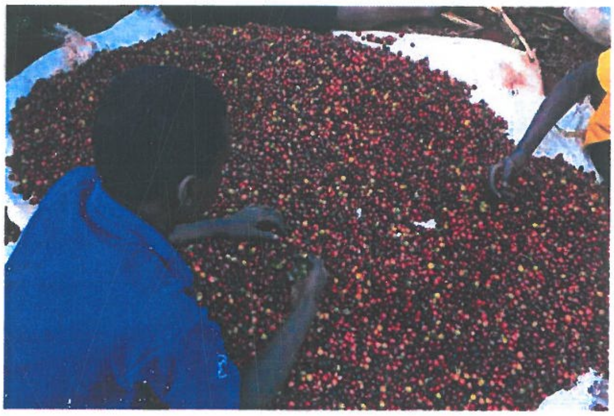


Figure 2.4: Manual sorting

2.2 Advantages of automated coffee berry sorting over traditional methods

Recent advancements in agricultural technology, particularly in the field of automated sorting systems such as in figure2.5, have significantly impacted the coffee industry. Automated coffee berry sorting has emerged as a more efficient and precise alternative to traditional manual sorting methods. Numerous studies and reports have highlighted the advantages of automation, which address many of the limitations of human labor in coffee berry sorting .

One of the most significant benefits of automated sorting is its ability to increase efficiency. According to various studies, automation reduces the reliance on manual labor, which not only minimizes labor costs but also eliminates the limitations associated with a human workforce, such as fatigue and variability in performance. Machines, once programmed, can operate continuously without breaks, leading to a higher throughput and fewer delays in the overall processing chain [1]. The ability to maintain a constant speed and avoid stoppages due to labor shortages or worker fatigue makes automation highly valuable in large-scale coffee production.

Another key advantage is the consistency provided by automated vision systems. Manual sorting is inherently subjective, as workers may apply varying criteria based on personal judgment and experience. This variability can lead to inconsistencies in the quality of sorted coffee berries, particularly across different batches. Automated systems, on the other hand, employ machine vision technology that applies predefined, objective criteria uniformly, ensuring consistent sorting results[4]. As a result, automation reduces human error and enhances the overall reliability of the sorting process.

Accuracy is also a critical factor in coffee sorting, particularly when it comes to detecting defects and determining ripeness. Research shows that automated systems, driven by advanced algorithms, outperform human workers in this aspect. For example, machine learning models integrated into these systems can detect subtle variations in berry ripeness and defects that may not be apparent to the naked eye. As a result, automated systems can channel a higher percentage of high-quality berries into the processing stage, improving the overall quality of the final coffee product [5].

Additionally, data collection capabilities are a growing area of interest in automated systems. Many modern sorting machines are equipped with sensors and software that collect data on the size, color, and other characteristics of the berries during the sorting process. This data can be used to refine sorting algorithms, improve quality control, and even inform decisions related to crop management and processing techniques. By leveraging this data, producers can optimize their sorting operations and achieve higher quality and efficiency [1].

Overall,these benefits highlight the growing role of automation in modern coffee berry sorting and its potential to transform traditional coffee processing methods.

Figure 2.5: Modern sorting machines

2.3 Separation methods

Various separation methods have been developed and refined for coffee berry sorting, with the aim of improving efficiency, accuracy, and minimizing damage to the berries. This section reviews the primary methods used in automated coffee berry sorting, focusing on air jet systems, ejector plates, and diverter systems, highlighting their mechanisms, advantages, and limitations.

2.3.1 Air Jet System

The air jet system is one of the most commonly used methods for separating coffee berries based on image analysis. In this technique, compressed air jets are strategically positioned above a feeder mechanism, and an image analysis system triggers these jets to eject unwanted berries into a separate collection bin, as shown in figure 2.6 when they are identified as defective [4]

According to recent studies, the air jet system is highly efficient, capable of handling large volumes of berries at high speeds with minimal damage to the desirable berries. This makes it suitable for high-throughput sorting operations where maintaining berry integrity is crucial [4]

Despite its efficiency, the air jet system requires precise calibration to avoid accidentally ejecting good berries, as the force of the air jets can potentially disrupt nearby berries if not properly controlled.

2.3.2 Ejector Plates

The ejector plate system employs electromagnetic valves or ejector plates are then activated to push unwanted berries off the main sorting path into a separate collection bin [4].

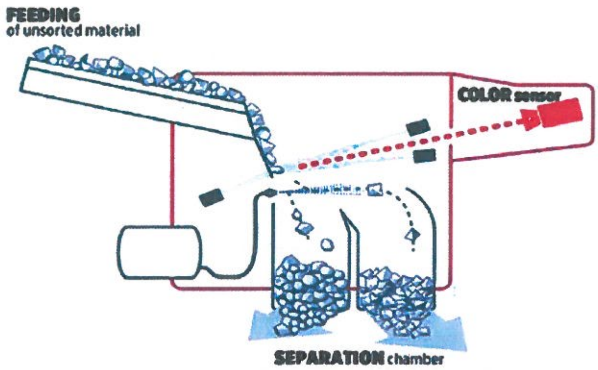


Figure 2.6: example of an air ejection system

Ejector plates offer more direct control over the movement of objects, providing precise and targeted removal or redirection of undesirable berries. Unlike the air jet system, this method requires less infrastructure, such as air compressors, making it more cost-effective in terms of equipment requirements.

However, ejector plate systems are typically more complex and expensive than other methods, given their reliance on mechanical components. Additionally, there is a risk of damaging the berries if the ejection mechanisms are not accurately calibrated, as the physical impact can cause bruising or other forms of damage, especially in delicate berries [6].Figure 2.7 shows ejector plate with the ejector rods

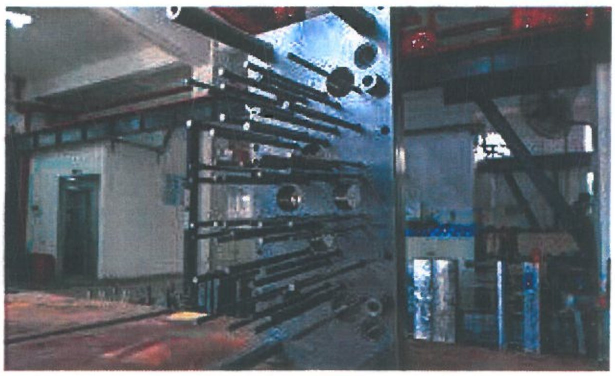


Figure 2.7: ejector plate

2.3.3 Diverter systems

The diverter system in figure 2.8 uses diverters located at the bottom of the conveyor and are activated to momentarily change direction and deflect undesirable berries into a separate collection bin, while allowing good berries to continue along their path [7].

The diverter system is highly regarded for its ability to handle delicate berries, as it minimizes handling and mechanical contact, thereby reducing the risk of damage. Furthermore, this method can efficiently manage large volumes of berries at high speeds, making it suitable for high-capacity sorting operations .

However, the efficiency of diverter systems is somewhat limited by the motor reaction speed that controls the diverters. As a result, this method may not be as fast as air jet systems particularly when sorting larger quantities of berries in a short timeframe [4].

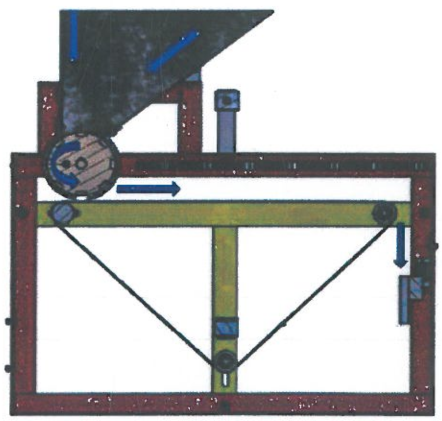


Figure 2.8: Diverter system

2.4 Classification methods

2.4.1 Color-Based Classification:

Color histogram analysis is a type of color based classification that works by quantifying the distribution of colors in an image through the creation of histograms for each color channel, typically red, green, and blue (RGB). This is done by loading the image and splitting it into its constituent color channels. Each channel is then divided into a fixed number of range, commonly corresponding to the range of pixel values (0-255 for 8-bit images). The intensity values of each pixel increment the count in the appropriate range, generating a histogram that represents the frequency of each color intensity. This results in three separate histograms that can be visualized to analyze the color composition of the image. The histograms are then compared to assess the similarity between images to facilitate color-based classification, however they do not capture the spatial arrangement of colors within the image [8].

2.4.2 Shape-Based Classification:

Contour detection is an image processing technique that identifies the boundaries of objects within an image, enabling shape recognition. The process begins with preprocessing the image, often converting it to grayscale and applying edge detection algorithms like the Canny edge detector to highlight significant edges. These detected edges are represented as points, which are then grouped to form continuous curves or contours that outline the shapes of the objects. Contours are typically extracted using algorithms such as the Moore-Neighbor tracing method, which follows edges to create closed loops around objects. This representation allows for shape analysis, making contour detection good for image classification.

2.4.3 Texture-Based Classification:

Local Binary Patterns (LBP) is a texture analysis technique used in image processing to describe the texture and patterns of an image in a simple yet efficient way. This involves examining each pixel in a grayscale image and comparing it with its surrounding pixels within a specified neighborhood, typically a 3x3 pixel matrix. Each neighboring pixel is assigned a binary value of 1 if it is greater than or equal to the center pixel, and

0 otherwise. These binary values are then combined to form a binary number, which is converted into a decimal value that replaces the original center pixel. The resulting LBP values capture local texture information and can be used to create a histogram that represents the texture features of the entire image.

2.4.4 Deep Learning-Based Classification:

It consists of multiple layers, including convolutional layers, pooling layers, and fully connected layers, that work together to automatically extract features from input images. The convolutional layers apply filters that slide over the image to capture local patterns, like edges and textures, creating feature maps that highlight important aspects of the image. Pooling layers then reduce the spatial dimensions of these feature maps, making the model more efficient and less sensitive to small changes in the input. Finally, the fully connected layers take the extracted features and perform the classification task. This architecture enables CNNs to effectively learn hierarchical representations of visual data, making them highly effective for tasks involving image classification

2.4.5 Pattern Recognition:

In this approach, the algorithm represents each image as a feature vector, capturing key characteristics like pixel intensity, color histograms or other extracted features. When a new image needs to be classified, KNN calculates the distance (commonly Euclidean distance) between the feature vector of the input image and those of the labeled images in the dataset. It then selects the 'K' closest images, where 'K' is a predefined integer, and assigns the input image to the most frequent class among these neighbors. KNN is intuitive and works well for smaller datasets, but it can be computationally intensive with large datasets, as it requires comparing each new image with all existing examples.

2.4.6 Multi spectral and Hyper-spectral Imaging:

Multispectral and hyperspectral imaging are advanced techniques used to capture images across multiple wavelengths beyond the visible spectrum, providing detailed information about the composition and characteristics of objects. Multispectral imaging captures data across a limited number of broad wavelength bands , such as visible, infrared, and ultraviolet, making it useful for internal structure coffee berry imaging. In contrast, hyperspectral imaging captures hundreds of narrow, continuous wavelength bands, allowing for a more detailed spectral signature of each pixel in the image. This high level of detail enables precise differentiation, making hyperspectral imaging valuable in coffee berry classification and quality control. While both techniques provide rich data for analysis, hyperspectral imaging offers a more comprehensive spectral profile, enabling more accurate identification and classification of objects .[9]

2.4.7 3D Object Classification:

3D Depth sensors capture the distance between the sensor and the berries, creating a depth map that reveals variations in surface contours and dimensions. This information is crucial for distinguishing between berries of different ripeness stages, as ripe and unripe berries often differ in size and shape. By combining depth data with color information, the classification process becomes more robust, enabling more precise sorting, even in challenging conditions where color variations alone may not be sufficient for accurate classification. [4]

2.5 GAP ANALYSIS:

Automated coffee berry sorting machines offer significant advantages over traditional manual methods. However, there are still some gaps that can be addressed through further research and development:

- Sorting Accuracy: Machine vision has improved sorting accuracy considerably, there is still room for improvement, since newer algorithms have been developed including use of machine learning algorithms.
- Gentle Berry Handling: While some methods minimize handling, there is still a potential for damage during sorting, especially with delicate coffee bean varieties. Development of improved sorting mechanisms with even gentler handling techniques, such as utilizing softer air jets or more sophisticated robotic grippers, could further reduce damage rates.
- Cost-Effectiveness for Small-Scale Producers:

  High-end automated sorting machines can be expensive e.g the HCS 2000 costs about $1980, potentially limiting accessibility for small-scale coffee producers. Research on developing more affordable and scalable sorting solutions specifically designed for smaller coffee farms would promote wider adoption of this technology

3 Methodology

This section focuses on the development of a coffee berry color sorting machine, designed to distinguish ripe berries from others, which are typically processed using the dry method. The machine utilizes a Raspberry Pi 3 computer board to control key components: four air ejectors, a vibrating conveyor, and an air compressor. This involves integrating a camera system to capture images of the coffee berries as they pass through the chute. These images are processed using image detection algorithm to determine the ripeness of each berry. Depending on the classification, air ejectors are triggered to separate the berries into different categories. .

3.1 DESIGN

3.2 Mechanical design consideration

1. Sorting Mechanism: The sorting mechanism must be capable of distinguishing between different berry ripeness states with high precision. This requires use of sensors and reliable actuators.
   Speed: The mechanism should operate at a speed that matches the desired throughput without compromising accuracy.
   Versatility: The system should be adaptable to different berry sizes and types, potentially through adjustable settings or interchangeable components.

2. Feeder System
   Consistency: The feeder must ensure a consistent flow of berries to the sorting mechanism, preventing clogs and ensuring uniform sorting.
   Gentleness: To avoid damaging the berries, the feeder system should handle them gently, minimizing drops or collisions.
   Capacity: The feeder should have sufficient capacity to handle the expected volume of berries without frequent refilling.

3. Linear feeder System

   Durability: The linear feeder must be durable and capable of continuous operation in a potentially dusty and humid environment.

   Smooth Operation: It should operate smoothly to avoid jostling the berries, which could affect sorting accuracy.

   Maintenance: Easy access for cleaning and maintenance is crucial to ensure long-term reliability and hygiene.

4. Material Selection

   Food-Grade Materials: All materials in contact with the berries should be food-grade, non-toxic, and corrosion-resistant.

   Durability: Components should be durable enough to withstand the operational environment, including exposure to moisture and potential abrasives like berry pulp and skin.

5. Sensor Integration

   Placement: Optimal placement of sensors to ensure accurate detection without interference.

6. Actuation Mechanism

   Reliability: Actuators must be reliable and capable of high-frequency operation without significant wear.

   Precision: Actuators should provide precise control to ensure accurate sorting and rejection of defective berries.

   Energy Efficiency: The system should be designed to minimize energy consumption while maintaining performance.

3.3 MECHANICAL MODULE

The mechanical module consists of:

- **Linear Vibrating Feeder**: This component is essential for ensuring a consistent and controlled flow of coffee berries to subsequent stages. The vibrating motion facilitates the smooth and uniform distribution of berries, minimizing blockages and ensuring a steady feed to the hopper.
- **Hopper**: The hopper serves as the initial storage unit for the coffee berries, allowing for bulk handling and ensuring a continuous supply to the vibrating feeder. Its design is optimized to prevent jamming and ensure smooth flow of berries into the chute.
- **Chute**: The chute channels the coffee berries from the hopper to the sorting area, guiding them with minimal disturbance. Its design ensures a smooth transition and accurate positioning of the berries for effective sorting.
- **Ejector Holder**: This component houses the air ejectors, which are responsible for sorting the berries based on their ripeness. The ejector holder is designed to securely position and precisely control the air jets, ensuring accurate ejection of undesired berries.
- **Camera Holder**: The camera holder is designed to mount and position the imaging system used for analyzing berry characteristics. Its adjustable design ensures optimal positioning for accurate image capture and analysis.
- **Frame**: The frame provides the structural support for all the components, ensuring stability and alignment throughout the sorting process. It is designed to withstand operational stresses and maintain precise alignment of the various mechanical parts.

3.3.1 Linear feeder Design:

Linear feeders are vital in transporting the coffee berries efficiently in a linear motion to subsequent stages. The choice of feeder significantly affects production performance, with vibrating feeders and belt feeders being two common types. Vibrating feeders use vibrations to move materials along a trough, effectively managing bulk materials, especially fine or granular products. In contrast, belt feeders utilize a continuous belt for transportation, providing smoother handling and accommodating larger, heavier items. Table 3.1 highlights their differences

Feature	Vibrating Feeder	Belt Feeder
Flow Control	Consistent and adjustable flow	Consistent flow, but less adjustable
Throughput	High throughput with controlled feed rate	High throughput, but flow rate is less precise
Durability	Robust and durable construction	Durable, but belts can wear out and need replacement
Cost	Moderate initial cost, lower long-term costs	Lower initial cost, potentially higher long-term maintenance costs e.g belts replacements
Initial setup	Requires precise tuning of vibration parameters	Easier and quicker to set up initially

Table 3.1: Feeder Comparison

Linear feeder Material: Selection of a food-grade vibrating feeder material suitable for handling coffee berries. Common options included PVC, polyurethane, Aluminium and stainless steel . Considering the material should be durable, easy to clean, resistant to wear and tear and handle vibrations. Based on these considerations stainless steed was found to be the best. It offers Higher rigidity, better vibration transmission and fatigue resistance compared to aluminium.

Feeder Trough Width: The width of the conveyor belt needs to be sufficient to accommodate the desired flow rate of berries while maintaining proper spacing for sorting. The final design for the feeder trough is a shown in figure 3.1 Our target was 500 g/min with each berry weighing 1-2 grams [10] maximum amount of berries will be 500 @ 1 g per berry. The Output per second becomes $\frac{500}{60}$ which is 8.33 berries/second.
Berries are elliptical in shape with the longer diameter growing as large as 20 mm. We added 10 mm extra to ensure proper flow, a safety factor of 1.5 for each berry column. The final width is: 30 mm x 4 = 120 mm
Feeder Speed: The speed of the feeder should be adjustable to match the processing capacity and ensure accurate sorting based on the capabilities of the machine vision system an inference time of 500 ms was considered at 8 berries per second hence 500 g/min on average.

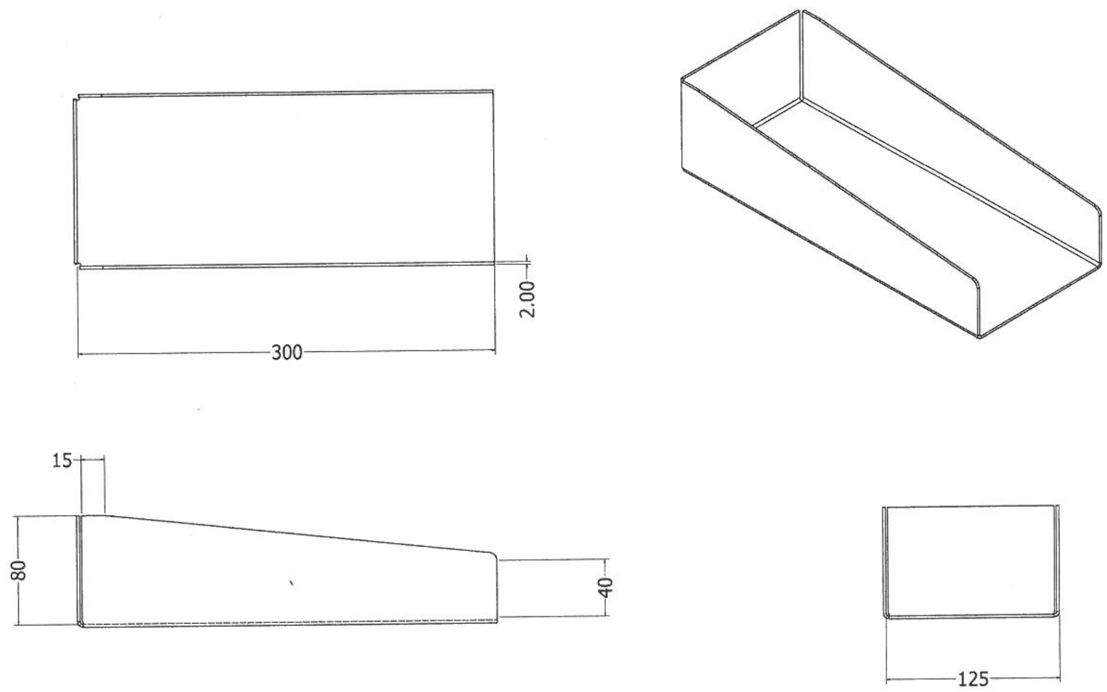


Figure 3.1: Feeder Trough

Drive System: We used a vibrating motor as the source of vibration It proved to be way more cost effective than electromagnet system[11].

Flat spring:mass of the coffee berry with the feeder channel is 1.0 kg Desired displacement 0.5 mm Desired flow rate 500 g/min Stainless steel elasticity 200 GPa In designing of the flat spring the stiffness of the spring is required and is given by:

$$k = \frac{3E.I}{L^3} \tag{3.1}$$

$$I = \frac{b.h^3}{12} \tag{3.2}$$

Where: k is the stiffness, I the moment of inertia for a rectangular cross section, b is the width, h is the thickness, L is the length and E is is the modulus of elasticity of stainless steel (200 GPa or 200,000 N/mm^2)

$I = \frac{0.12 \times 0.002}{12} = 8.333 \times 10^{-11}$

$k = \frac{3 \times 200 \times 10^9 \times 8.333 \times 10^{-11}}{0.153^3} = 13959.77 N/m$

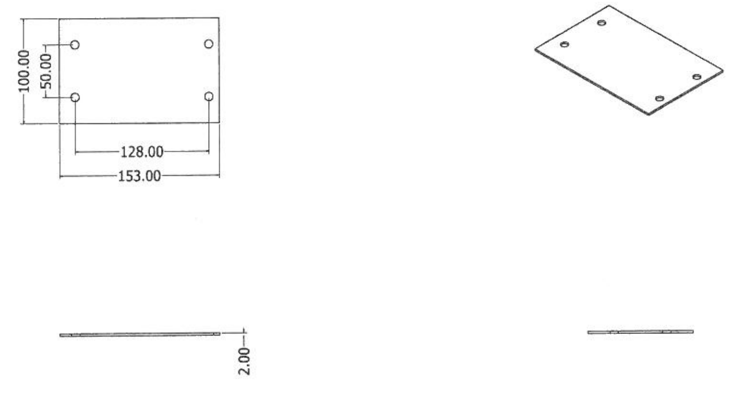


Figure 3.2: Flat Spring

Vibrating system

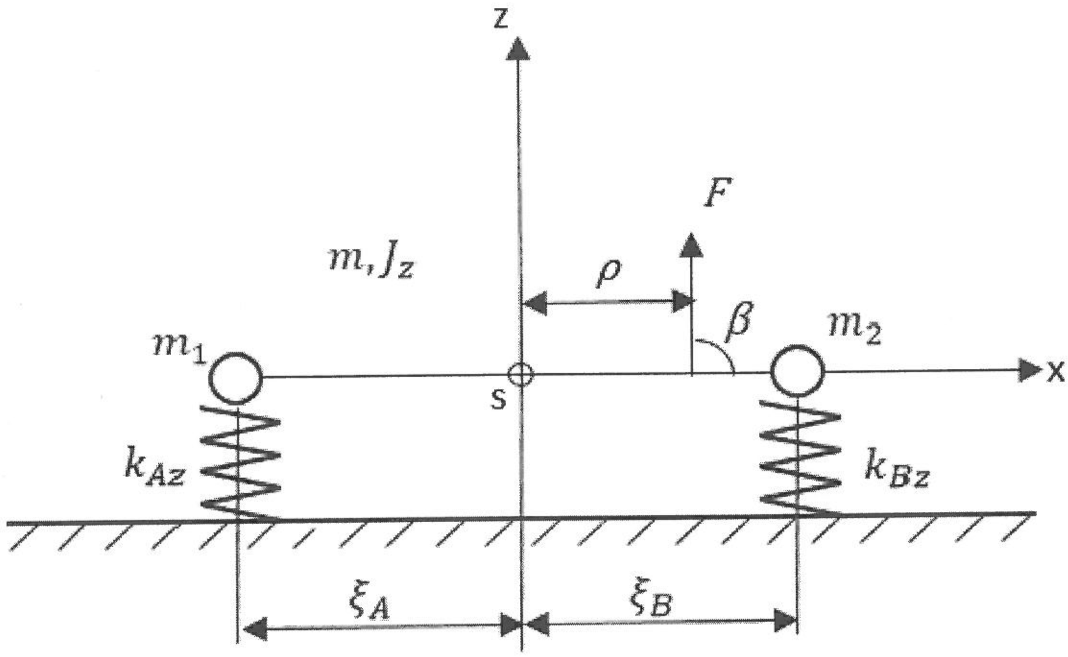


Figure 3.3: vibrating feeder math model

[12]

Our main requirements were the torque and the speed of the motor From the stiffness of the Vibrating feeder and using the math model as shown in figure 3.3 we calculated the resonant frequency of the structure

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{3.3}$$

$m = 1Kg$

For a spring system in parallel:

$$K_T = K_1 + K_2 \tag{3.4}$$

$K_T = 13960 + 13960 = 27920N/m$

The resonant frequency is given by: $\frac{1}{2\pi}\sqrt{\frac{27920}{1kg}} = 26.5936Hz$

At maximum feeding rate the motor rpm is given by:

$$f \times 60 = N_m \tag{3.5}$$

$26.5396 \times 60 = 1596rpm$

Feed rate at $500g/min$ which is $8.33g/s$

The average coffee berry density is at $1g/cm^3$ The amplitude desired is given by :

$$\sqrt[3]{8.33cm^3} \times \frac{1}{26.59366}$$

$A = 0.761mm$

at maximum displacement $A = A_0$

from $A = A_0 sin(wt)$[12]

$$A'' = -A_0 w^2 cos(wt) \tag{3.6}$$

$$maximumacceleration(a) = A_0 w^2 \tag{3.7}$$

$w = \frac{2\pi \times 1596}{60} = 167.132rad/sec$

$a = 0.000761 \times 167.132^2 = 21.257m/s^2$

$$Excitationforce(F_e) = m \times a \tag{3.8}$$

$$F_e = F_c(Centrifugalforce) \tag{3.9}$$

$$F_c = m_u e \frac{w^2}{1000}[13] \tag{3.10}$$

$$w = 2\pi f \tag{3.11}$$

$$eccentrictorque(M_u) = m_u e \tag{3.12}$$

$M_u = \frac{21257}{167.132}0.76909Nm$

A safety factor of 1.5 we went for a motor with at least 1Nm 2000 rpm

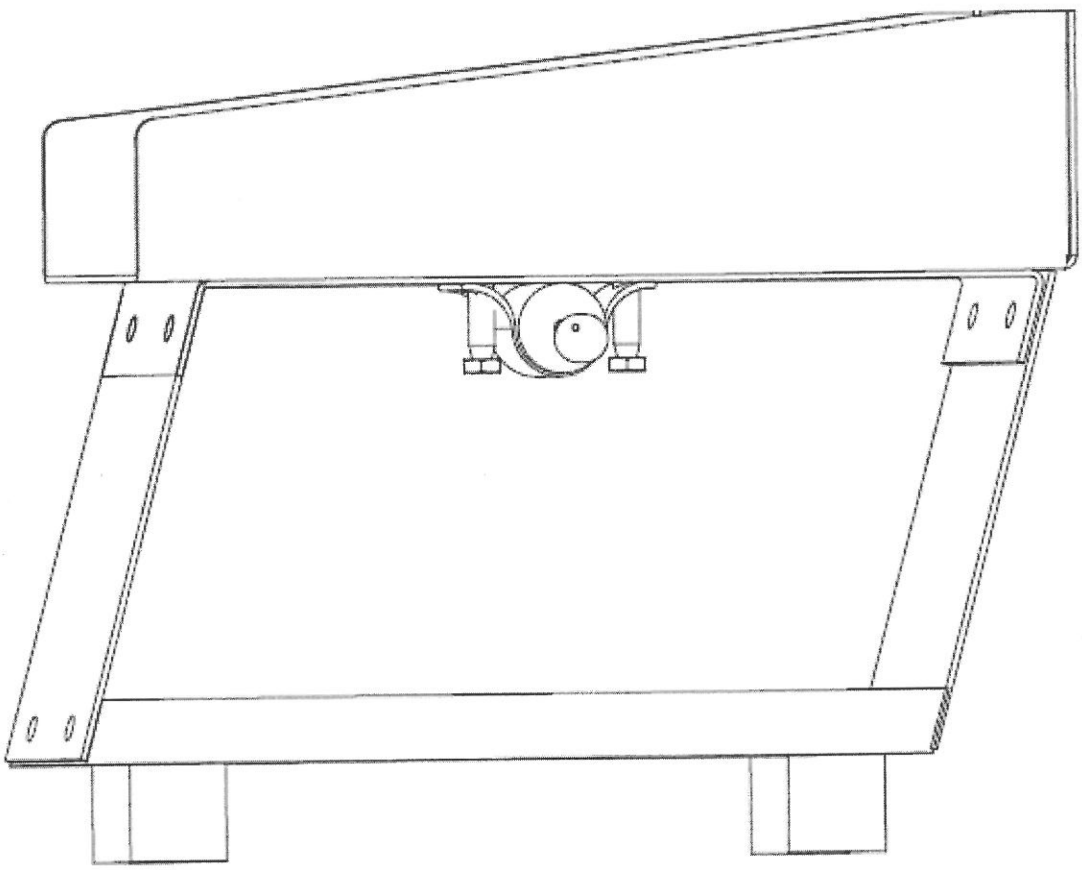


Figure 3.4: full assembly vibrating system

3.3.2 Hopper Design:

Hopper Capacity: Design the hopper to hold enough berries to maintain a continuous flow onto the feeder and hold a capacity of 5 Kg berries. opening diameter from hopper design standard for bulk materials should be :

$$4 \times w$$

Where: w is the maximum width of the material in this case 20mm height of the opening is [6] ;

$$\tfrac{1}{2}r$$

Where: r is the small diameter opening

An angle of 45 degrees the optimum angle for bulk flow hopper[6]

Volume for 5 kg coffee berries is approximately $5000cm^3$

Hopper Shape: Volume of bottom channel:

$$V = \pi r^2 h$$

- $r = 40mm$
- $h = 40mm$
- $V = 201cm^3$

A conical frustum is preferred since:

- **Flow Dynamics:** The sloping walls of a conical hopper facilitate smooth and continuous flow of materials, including round objects like coffee berries. The conical shape helps in creating a natural funneling effect, which can reduce the chances of clogging and ensure that materials flow consistently to the outlet.
- **Optimized for Round Objects:** The gradual slope of the conical shape is particularly effective for handling round objects like coffee berries. The design helps to channel the berries towards the center and into the outlet, reducing the risk of clogging and ensuring even distribution.

Volume of the conical frustum should be $4800cm^3$ to sum up to the $5000cm^3$ desired

$$V = \frac{1}{3}\pi h(R_1^2 + R_1R_2 + R_2^2)$$

Ratio for Proper Flow:

- Typical Range: The ratio R:r often falls between **2:1 and 4:1**. This means that the diameter of the larger base should be 2 to 4 times that of the smaller base to ensure good flow characteristics and prevent clogging[6].
- **Flow-ability:** A ratio within this range helps to create a smooth, consistent flow of materials, minimizing issues such as bridging and arching.

We went with 3 it being the median point hence base of 120 mm.
Hopper Angle being 45 degrees h became 120mm
Total volume of $2611.4cm^3$
Remaining volume approximately $2200cm^3$
R being 120mm at a height of 50mm we obtain the extra $2261cm^3$ to finish up the hopper design To control the flow of the berries an open and closing mechanism was developed for the hopper to regulate the flow of coffee berries into the sorting machine. The mechanism ensures a controlled and consistent release of berries, preventing clogging or overflow during the sorting process. This design involved integrating a motorized gate the system's , which adjusts the hopper's opening based on the sorting machine's operational requirements. This allows for an efficient and uninterrupted sorting process, ensuring that the berries are fed at an optimal rate. The design involved having the lid cover fully the hopper bottom opening and the attachment point for the motor.The final design is as shown in figure3.6 From the iproperties the mass of the plate is 0.093Kg and the centre of gravity is at 58.728mm. Torque required is $0.093Kg \times 5.8728cm = 0.5461704kgcm$.
Using a safety factor of 1.5 torque requirements for the motor is 0.819255.
Since the motor is to be used for positional control Servo motors and stepper motors were considered as positional control could be achieved without need for positional sensors.
However stepper motor required motor drivers which would increase the cost.
We finally settled with the SG90 Servo motor, It delivers 1.6 Kg cm of torque and 180

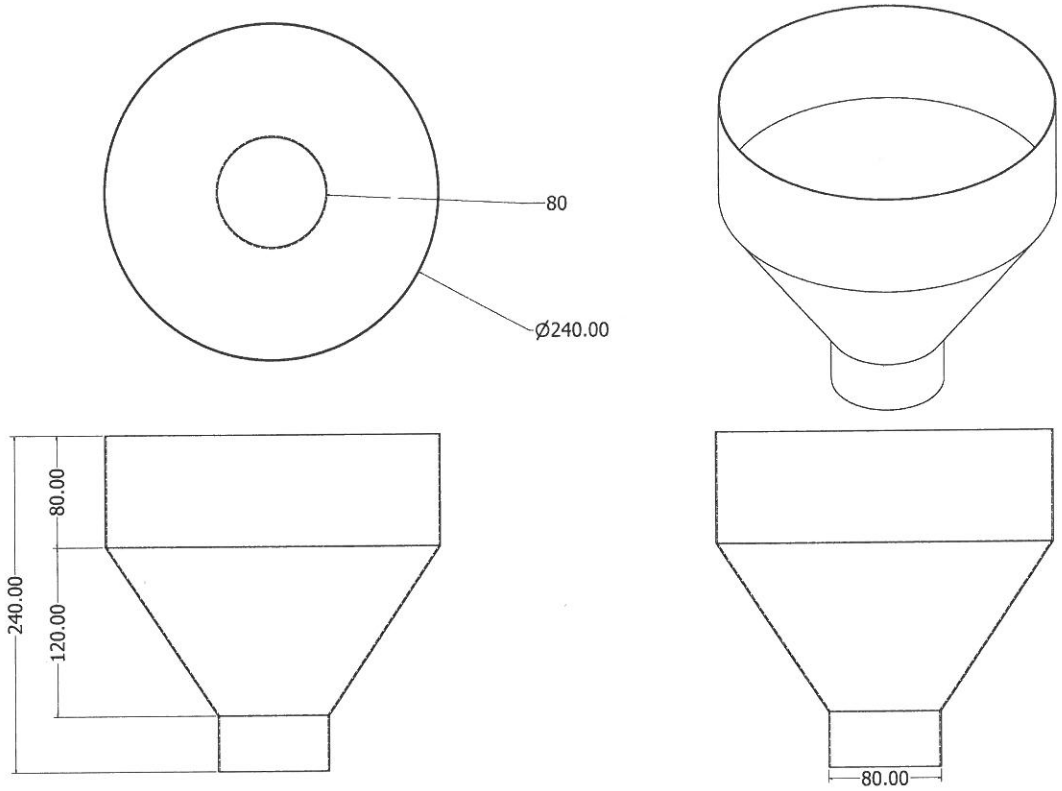


Figure 3.5: Hopper

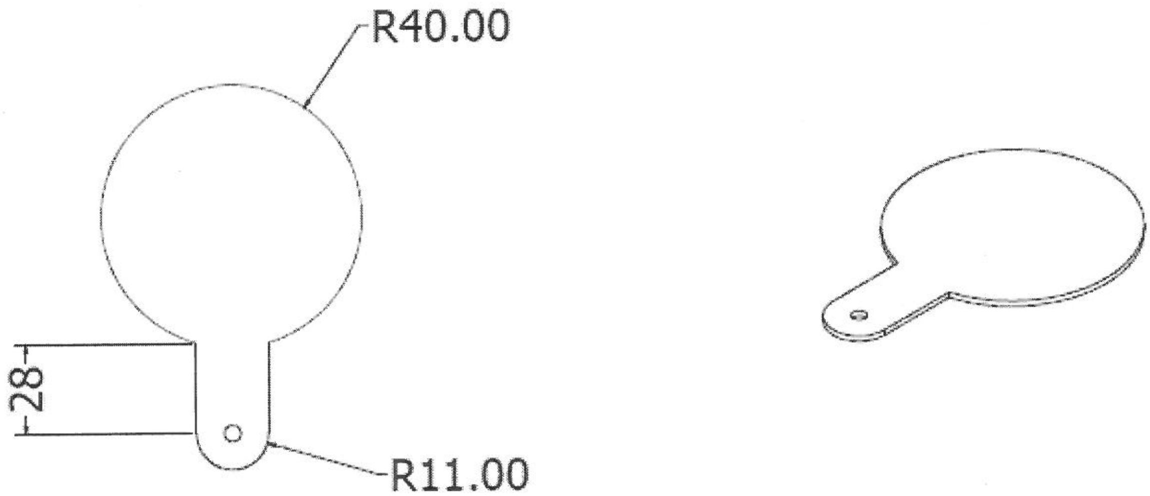


Figure 3.6: Hopper lid

degrees motion.It used PWM for positional control and is most cost effective.The final motor design is as show in figure 3.7

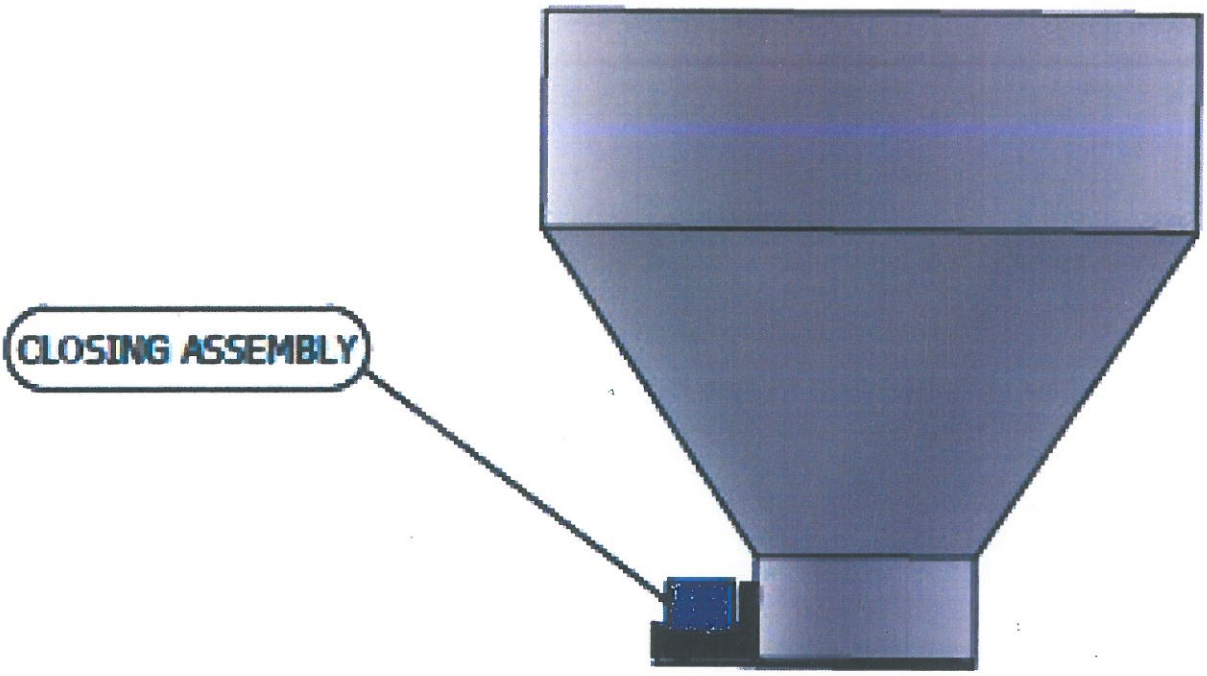


Figure 3.7: Hopper assembly

3.3.3 Chute Design:

Chute Shape: The chute was designed to channel berries from the feeder in a single layer and with minimal bumping. A tapered design with smooth transitions proved ideal. Channels were added to align the berries with the ejector system in four columns each 30mm wide.

Inclination Angle: The chute angle was set at 45 degrees to ensure maximum flow rate the angle will be adjustable to control the velocity of the berries depending on the imaging station performance

Chute length to width at a ratio of **2.5:1** give us the length of 300mm Figure 3.8 shows the final design for the chute.

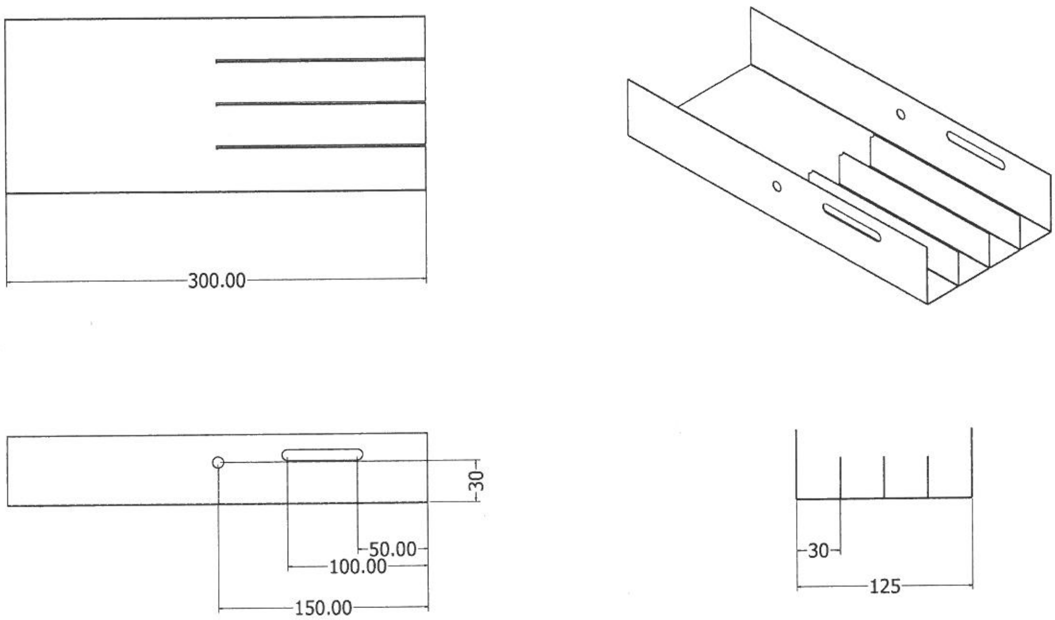


Figure 3.8: Chute

3.3.4 Integration and Assembly:

Frame Design: A sturdy frame was designed to support the Feeder, hopper, and chute assembly. The frame material Mild steel was used since it offered the strength and was cost effective.

Anglelines were used since they would be much easier to bolt them with other body components

Positioning and alignment of the hopper, chute, and feeder was done using trigonometric equations , mid point angle of 45 degrees initial points was used to enable adjustments in both directions for the chute .

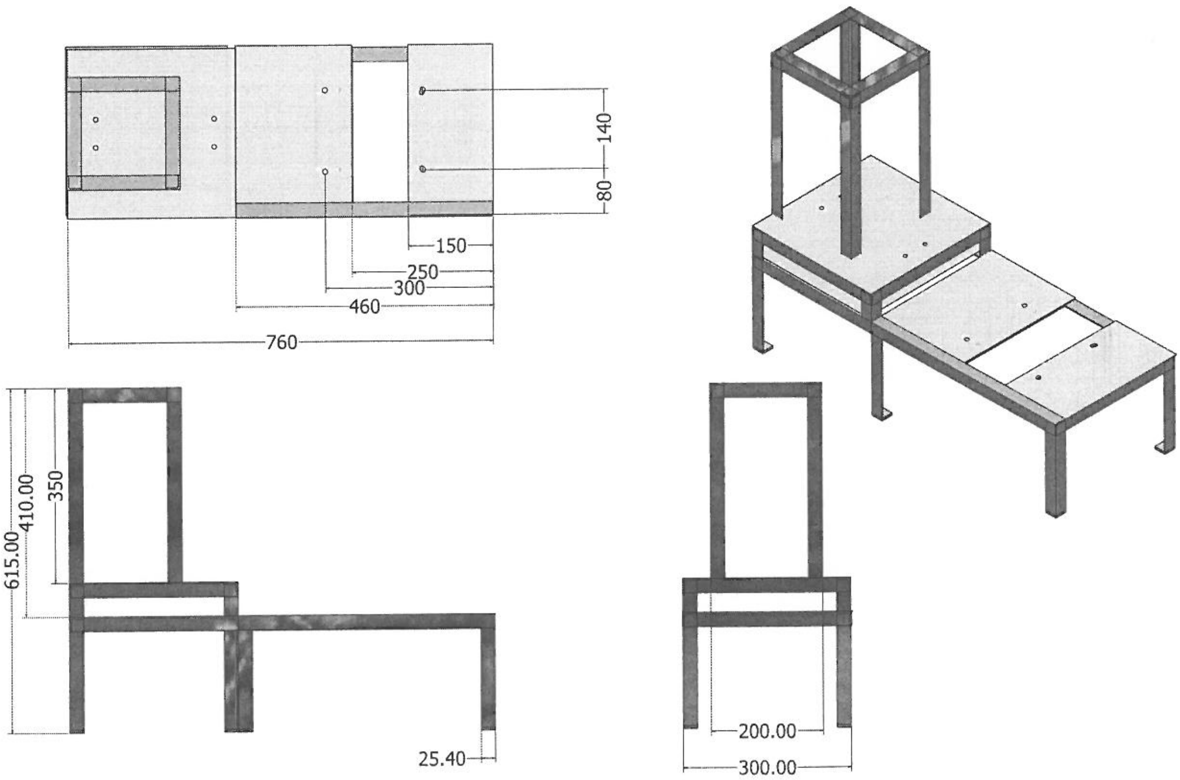


Figure 3.9: Main Frame

3.4 ELECTRICAL MODULE

3.4.1 Considerations

1. Control Systems :utilizes controllers for handling specific tasks such as sensor data processing and actuator control.

2. Sensors and Data Acquisition Type of Sensors: Selection of appropriate sensors for detecting berry quality, such as cameras. Data Processing: Use high-speed data processing units to handle large volumes of sensor data in real-time, ensuring swift and accurate sorting decisions.

3. Actuators and Motion Control Motor Selection: Choose suitable motors for linear vibrating feeder and other moving parts. Motor Drivers: Design or select appropriate motor drivers to control motor speed and direction accurately. LED's: Used to provide good vision for the optical sensor

4. Safety and Compliance Electrical Safety: Designing a circuit with proper insulation, grounding, and protection to prevent electrical hazards.

5. Environmental Considerations Temperature Control: Design for proper cooling and ventilation to prevent overheating of electrical components e.g the LEDs. Dust and Moisture Protection: Use enclosures and sealing to protect sensitive electronics from dust, moisture, and other environmental contaminants, such as the camera lens

6. Maintenance and Troubleshooting Diagnostics: Incorporate diagnostic tools and indicators (e.g., LEDs, display screens) to aid in troubleshooting and maintenance.

7. Power Supply and Distribution Power Requirements: Determine the total power requirements of the sorting machine, including all motors, sensors, actuators, and control systems. Voltage Levels: Ensure the design accommodates the appropriate voltage levels for different components, with proper isolation and protection.

3.4.2 Electrical Components

Raspberry Pi 3 Computer

- Equipped with a quad-core ARM Cortex-A53 CPU running at 1.2 GHz.
- Capable of running a Real time operating system and allows more complex computations and more simultaneous computation through multitasking.
- More suitable for tasks that require significant processing power, such as image processing, running machine learning models, and handling multiple tasks simultaneously.
- It cost effective compared to the newer models

Raspberry Pi camera V2

- High Resolution:8MP Provides high-resolution images (3280 x 2464 pixels), which are crucial for detailed image analysis and accurate sorting of coffee berries.
- Image Quality:Sony IMX219 Sensor: Equipped with a high-quality Sony sensor known for excellent image quality, color fidelity, and low-light performance. This ensures clear and sharp images, which are essential for distinguishing between different coffee berry colors and defects.
- High Frame Rate: Can capture 1080p video at 30 fps, 720p at 60 fps, and (640x480) at 90 fps. This is beneficial for real-time monitoring and processing, allowing for faster and more accurate sorting.
- Enhanced Sensitivity: The Sony IMX219 sensor offers good low-light performance, which can be beneficial in varying lighting conditions typically found in industrial environments

- Broad Software Support: Compatible with various software libraries and tools, such as OpenCV, which is widely used for computer vision tasks. The picamera library provides easy access to the camera's functionalities within Python, facilitating easier software development.
- Raspbian Compatibility: Fully supported by the Raspberry Pi OS, making setup and configuration straightforward.
- CSI Interface: Connects directly to the Raspberry Pi's CSI (Camera Serial Interface) port, ensuring efficient data transfer and seamless integration with the Raspberry Pi hardware and software

Air ejectors

Feature	Jianyin JYZ-3 Solenoid Valve	Air Ejector Sorters	ASCO 8210 Series Solenoid Valve	Parker 7321 Series Solenoid Valve
Cost	500 Ksh(each)	15,000(8 ejector assembly)	2000 Ksh each	2000 Ksh each
Switching Time	¡ 10 ms	4ms	¡ 15 ms	20 - 50 ms
Max Pressure	0 - 1 bar	1.5 bar	1 bar	1 bar
Power Consumption	6	50W	15 W	15 W
Operating Temperature	-5 to 80 °C	0 to 50 °C	-10 to 60 °C	-20 to 70 °C
Flow Rate	0.5 - 10 L/min	10 - 100 L/min	1 - 20 L/min	5 - 50 L/min

The recommended air pressure without damaging the coffee berries is 0.5 - 0.8 bars[4] We used the Jiayin JYZ-3 solenoid valve to act as our air ejectors. They were the cost effective solenoid valves that could handle over 0.8 bars

- Max working pressure 1bar
- Switching time 10ms
- 12v
- 0.5 A
- 6W

Air compressor

Since the absolute pressure is 0.8 bars above the atmospheric pressure (1bar).From Boyle's law: $P_1V_1 = P_2V_2$, we required approximately twice the operating pressure This is to cater for pressure loss after ejection to maintain pressure of the system.

$(0.8 \times 4) \times 2 = 6.4bars)$

Feature	**Ingco AAC 1408**	**Makita MP001G**	**Bostitch BTFP02012**	**DeWalt D55140**
Maximum Pressure	8 bar	8.3 bar	8 bar	8 bar
Voltage	12V	18V	12V	18V
Local Availability	Yes	No	No	No
Price	$40	$40	$50	$45

Table 3.2: Air compressor comparison

We therefore picked the INGCO AAC 1408 as it was cost effective and offered 8 bars.

- Operating voltage 12V
- Maximum current 10A
- Capacity 35L/min

Lighting

Lighting plays a crucial role in the coffee berry sorting system by enhancing the visibility and clarity of the berries' surface characteristics, such as color, texture, and ripeness. Proper lighting ensures that the imaging system, typically a camera, captures high-quality images that can be accurately analyzed by the sorting algorithm. Uniform and consistent lighting is essential for minimizing shadows, glare, and reflections, which could otherwise lead to incorrect sorting decisions LED strips proved to be the better option since they :

- Uniform Illumination: LED strips provide consistent and uniform light distribution across the entire area of interest due to multiple angle illumination. This uniformity is crucial for avoiding shadows and ensuring that each berry is evenly illuminated, which enhances the accuracy of image capture and analysis.
- Energy Efficiency: LEDs are highly energy-efficient, consuming less power while providing ample illumination. This efficiency is particularly beneficial in continuous operation environments like a sorting system, where lighting needs to be maintained for extended periods.
- Long Lifespan: LED strips have a long operational life compared to other lighting options, reducing the need for frequent replacements and maintenance. This longevity is advantageous in maintaining consistent performance over time.
- Low Heat Emission: LEDs emit very little heat, which helps in maintaining a stable operating environment for both the berries and the electronic components of the

sorting system. Excessive heat from other lighting options could interfere with other equipment e.g ejectors.

- Compact and Flexible Design: LED strips are compact and can be easily integrated into the sorting system's design, allowing for custom installations around the conveyor or hopper. Their flexibility in mounting positions makes them ideal for achieving optimal lighting angles and coverage.

On the LED strip length we went with 250 mm as it offered optimal coverage and it would also reduce our energy usage

- 5V
- 20mA per LED (12 LEDs)

Optoisolators and relay

For switching we considered reed switches optocoupler and transistors as they provided faster switching .Optocouplers proved better as they also protecting the microcontroller without extra cost or circuitry. A relay is also used to connect the Air compressor as the optoisolators cant handle 10A current

Motor selection

Criteria	DC Motor (Brushed)	DC Motor (Brushless)	Stepper Motor	AC Motor
Power Supply	5-48V DC	12-48V DC	5-24V DC	110-240V AC
Torque	Moderate to High	High	Low to Moderate	High
Speed Control	Easy (PWM)	Easy (PWM)	Motor drivers	Complex
Vibration Control	Moderate	High	Poor	Moderate
Efficiency	Moderate	High	Low	High
Cost	Low to Moderate	Moderate to High	Moderate	Low to Moderate
Durability	Moderate	High	Moderate	High
Maintenance	Requires more (brushes)	Low (no brushes)	Low	Low
Application Suitability	Good for simple designs	Best for high performance	Poor for continuous vibration	Good for industrial use

The DC motors are easier to control with no motor drivers required for speed control. Brushed DC motor are more affordable. We used RF-385 CE DC vibrating motor which comes with an eccentric load attached.

- Voltage 12V
- Power 6W
- 1 Nm
- Speed 3000rpm
- Current 0.5A
- No Load :0.042A at 3000 rpm

Power Supply

We went with a 12V 200W power supply to power Compressor, vibrating motor and the solenoid valves A separate a 5 V 25 W Power supply to power the Raspberry Pi 3 this reduces risk of damaging it.The table below shows specific and overall power consumption3.3

Component	Power Consumption
Raspberry Pi 3	5V 12.5W
Air ejectors	4@6W
Air compressor	12V 120W
LEDs	1.2W
VIB MOTOR	12V 6W
Optocouplers	48mW
Relay	700mW
SG90	2.5W
Total	167.38W

Table 3.3: Power consumption

3.5 SOFTWARE DESIGN

The system is divided into five main sections: Startup,input image pre-processing, object detection, object tracking, and ejection scheduling.

3.5.1 Startup

The process begins with the Startup sequence, which initializes the system:

- Start Compressor: The air compressor is activated, which powers the air ejectors responsible for separating undesired berries from the ripe ones.
- Clear Valves: All valves are cleared to ensure no blockages, allowing for smooth operation of the air ejectors.
- LED ON: The LED lights are turned on, providing consistent lighting conditions for the camera to capture clear images of the coffee berries.
- Camera Live Feed: The camera is activated to provide a live video feed of the berries moving along the conveyor.
- Vibrating Conveyor ON: The vibrating conveyor is turned on, ensuring the berries move consistently through the detection area.
- Video DATA: The video data captured by the camera is sent to the object detection system for analysis.

3.5.2 Input Image pre-processing

During implementation of the designed method as on the interim report, various challenges were faced mainly motion blur . This resulted in the implementation of other image processing technique to improve clarity of the frames processed and make it easier for detections to occur. The resulting algorithm 3.10 was added into the video Data stage:

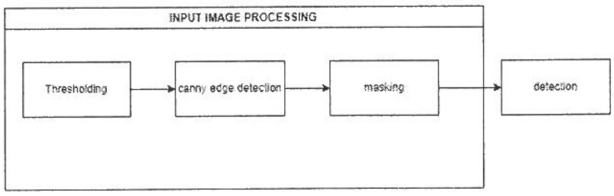


Figure 3.10: Input image pre-processing

This involved using thresholding to separate the background from the berries, canny edge detection to improve clarity and also isolate the useful regions with objects and those without and masking to overlay useful region with original frame.
This led to frames being much more easily detected

3.5.3 Object Detection

The Object Detection section is crucial for identifying the berries on the conveyor:

- YOLOv11n: This is a lightweight version of the YOLO (You Only Look Once) object detection algorithm is used, leveraging training data and weights to detect coffee berries in real-time[14].
- Detection: The system continuously processes the video data, identifying the coffee berries and classifying them based on the predefined categories.
- Object detected: This decision point determines whether an berry has been detected that requires ejection. If no berry is detected, the system continues to process the video feed. If an object is detected, the process moves to the Object Tracking section.

3.5.4 Object Tracking (deepSORT)

The Object Tracking section uses the deepSORT algorithm to track detected berries:

- Kalman Filter Object Estimation: The Kalman filter is employed to estimate the state of the detected object, predicting its future positions as it moves along the conveyor.
- Association Metrics: These metrics are used to associate the detected objects with existing tracks, ensuring that each berry is accurately tracked over time.
- Solve Assignment: This step resolves any conflicts in tracking assignments, ensuring that each track corresponds to a single berry.
- Update TrackID : The system updates the track IDs for all detected objects and removes any tracks for objects that are lost or no longer detected.
- Generate Tracking Results: The tracking results are generated, providing detailed information on each berry's position and movement.

3.5.5 Ejection Scheduling

The Ejection Scheduling section manages the timing and execution of the ejection process:

- Tracking Results: The tracking results from object tracking are used to determine the position of each berry on the conveyor.
- Get Berry ID / Ejector Row: The system identifies the berry by its ID and determines which ejector row is responsible for removing it.
- Calculate Time to Ejection: The system calculates the precise time at which the ejector should be triggered based on the berry's speed and position on the conveyor.
- Trigger Ejection: The ejector is activated at the calculated time, removing the undesired berry from the conveyor.
- Update Schedule: The ejection schedule is updated to reflect the recent ejection, ensuring the system is ready for the next berry

The Flowchart on figure 3.11 show the whole process.

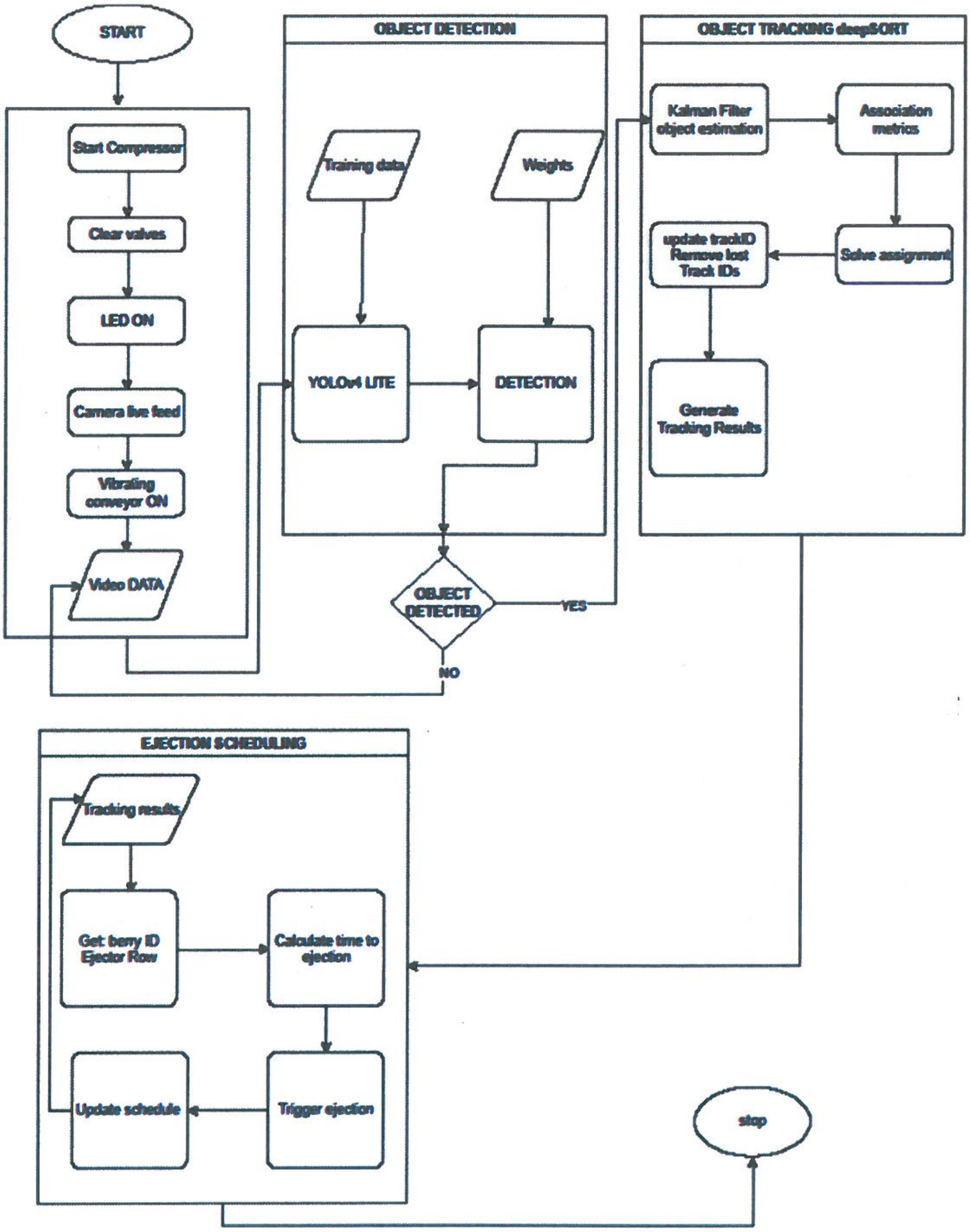


Figure 3.11: Flow chart

3.6 FABRICATION

This section focuses on the fabrication of the project

3.6.1 MECHANICAL MODULE

A major change from the design phase includes the use of mild steel over Stainless steel in the fabrication of the plates, vibrating feeder components and chute. This help lower our cost while maintain stiffness of the components. Oil based paints were used to prevent rusting while also being foodsafe.

Vibrating feeder fabrication This entailed fabrication of 2 flat springs, feeder trough, bottom plate and base plate.

Fabrication of the flat springs involved:

- Cutting of flat spring flat pattern using a hydraulic power shear
- Drilling the 4 , 5mm mounting holes
- Filing the edges
- Painting

Fabrication of the Feeder trough involved:

- Cutting the U channel flat pattern using a power shear
- Drilling the mounting holes
- Bending it using a sheet bending machine
- Cutting the backplate

- Welding the backplate to the U section
- Filing and Painting

Fabrication of the bottom Plate involved:

- Cutting the flat pattern
- Drilling the mounting holes
- Bending it to 15 degrees using manual sheet bender and a combination square protractor head

Fabrication of the base plate involve:

- Using a horizontal mill to to cut a 20 mm mild steel plate into 100 mm width
- A power hacksaw was oriented to cut 15 degrees and a length of 270 mm measured and cut
- The 4, 5 mm flat spring mounting holes were drilled
- The 4 , 5 mm anti-vibration pad mounting holes were drilled
- Mounting threads were added on the plate using M6 taps

The part were then assembled with respective M5 and M6 bolts and nuts with the final output being fig3.12.

Hopper fabrication This involved:

- Cutting the 2 cylindrical section flat patterns using a power shear
- Cutting the conical section using a laser machine

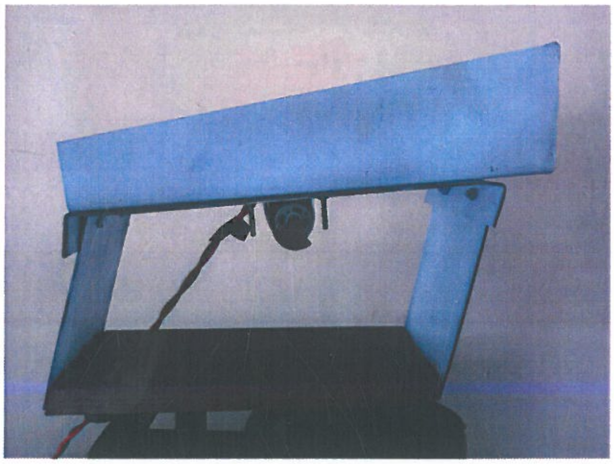


Figure 3.12: vibrating conveyor full assembly

- Cutting the opening/Closing motor mount with laser machine
- Rolling the 2 cylindrical sections and conical sections
- Welding the 4 sections together

The closing mechanism motor was mounted as shown in figure 3.13

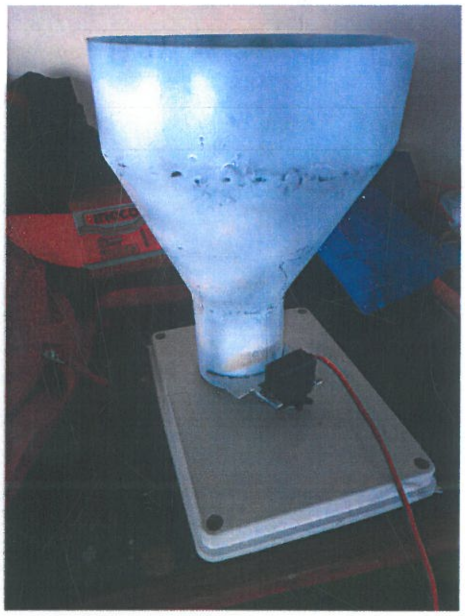


Figure 3.13: Hopper assembly

Chute assembly fabrication .

The fabricated chute assembly in figure 3.14 involved:

- Cutting the chute flat pattern with a power shear
- Cutting the mount flat pattern with a power shear
- Cutting the 3 alignment fins
- Drilling the mounting holes
- Cutting the adjustment slots using a cold chisel
- Filing the adjustment slots
- Bending the chute and chute mounts
- Welding the alignment fins onto the chute
- Assembling chute and chute mount with bolts and nuts

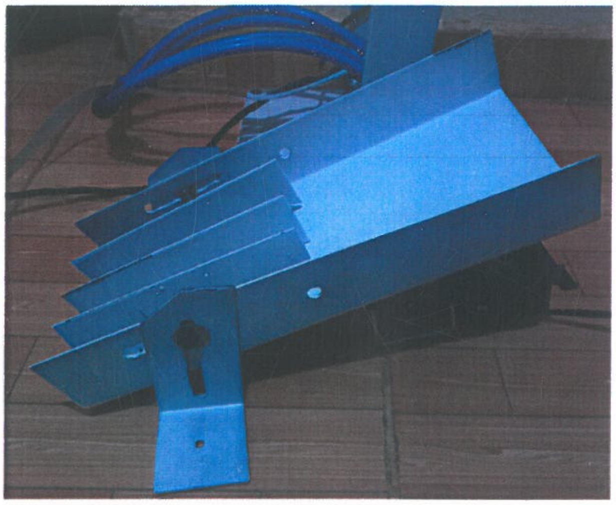


Figure 3.14: Chute assembly

Camera and ejector holder assembly fabrication This involved:

- Cutting the camera and ejector mount flat pattern using a power shear
- cutting the camera holder flat pattern using a laser machine
- Cutting a 50 mm by 50 mm angle line to 120 mm
- Cutting the an extra 120 mm using an angle grinder
- Cut it into 2 flat bars
- Welded to 1st angle line to form a U channel bar
- Divide the remaining bar into 2 an welded at the sides of the U channel
- Drilling an initial 8 mm hole for the ejectors
- Boring the holes with a 16 mm drill

The use of angle line for the ejector holder proved to be the most cost effective compared to 3d printing or milling a metal block The final result of the whole assembly is highlighted in figure3.15

Figure 3.15: Camera and ejector assembly

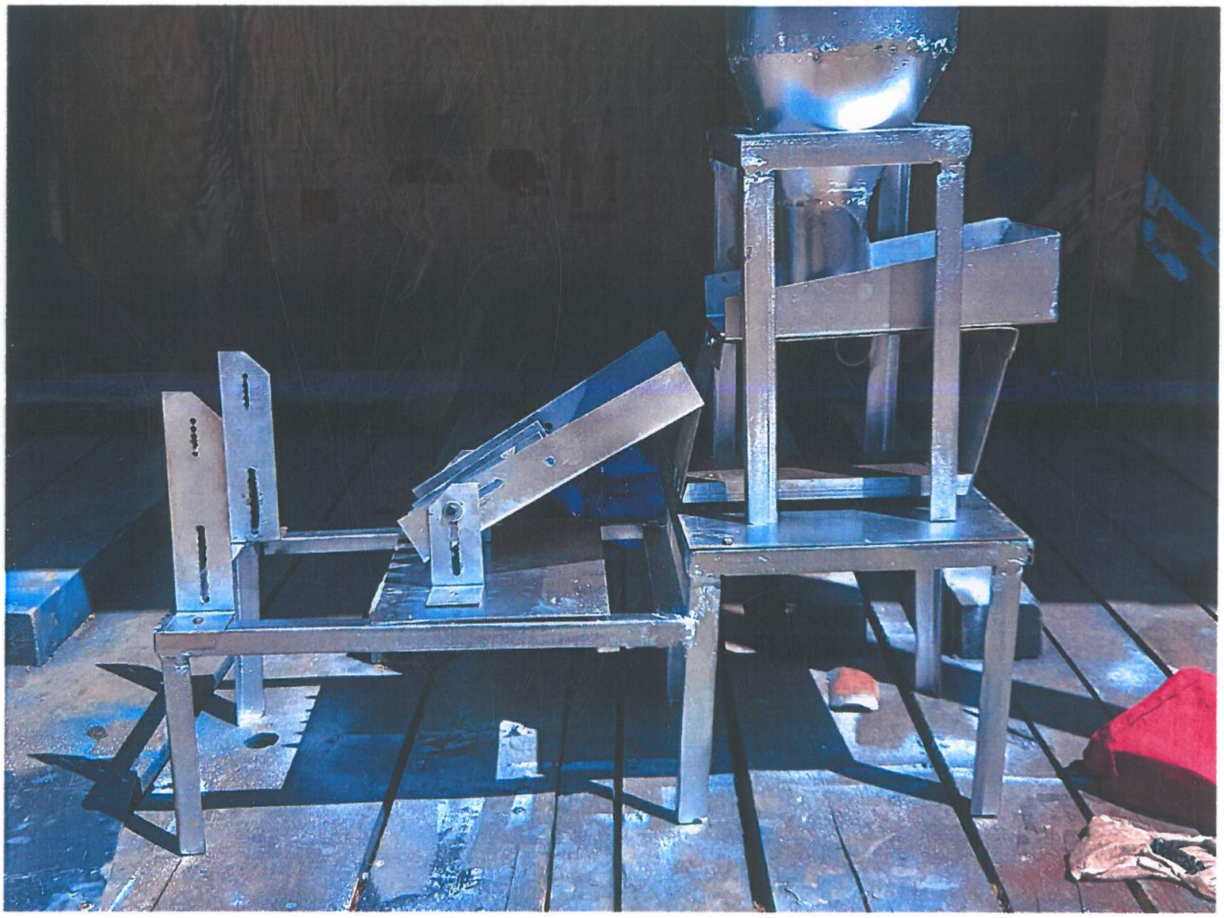


Figure 3.16: Fabricated mechanical assembly

Frame fabrication This included the frame skeleton and plates.The other components were mounted to form the mechanical structure in figure3.16 It involved:

- Cutting the mounting plates
- Drilling mounting holes on the plates
- Cutting the angle lines based on design
- Welding angle lines based on design
- Painting

3.6.2 ELECTRICAL MODULE

It mostly involved the fabrication of a High frequency switching circuit for the air ejectors. The other components were bought and wired up according to the design and as shown in figure3.17. Changes were made to the design due challenges in obtaining opto-couplers. For fast frequency switching we used npn transistors (PN222A), a diode to prevent back emf and 2 resisitor(base resistor 1K ohm and pull -down resistor 10K ohm).

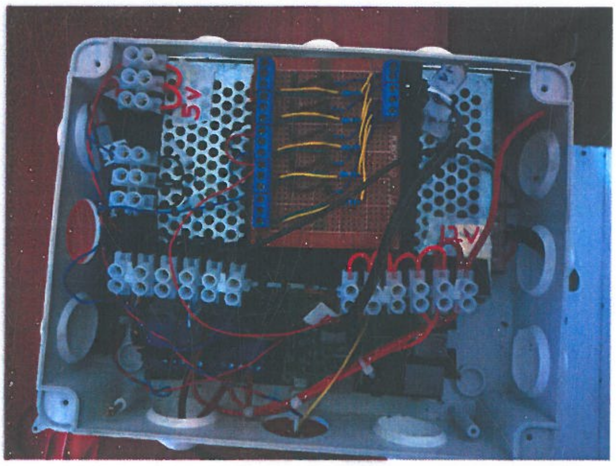


Figure 3.17: Electrical circuit fabrication

3.6.3 CONTROL MODULE

The control system for the coffee berry processing project was implemented using Python scripts running on a Raspberry Pi 3, with a focus on real-time coordination between components. The code utilized the GPIO library for controlling the solenoid air ejectors and the DC motor driving the vibrating conveyor. A trained YOLOv11n model, optimized and converted to TensorFlow Lite, handled berry classification through OpenCV-based image capture. The main control script employed multithreading to process camera frames, analyze berry ripeness, and calculate ejector activation timings simultaneously. Synchronization was achieved by calculating berry positions based frame position and timestamps, triggering the appropriate GPIO pins for ejector activation. A simple UI as in figure3.18 was also created to indicate the state of the berry sorting machine, control start and stop and also to display the camera view

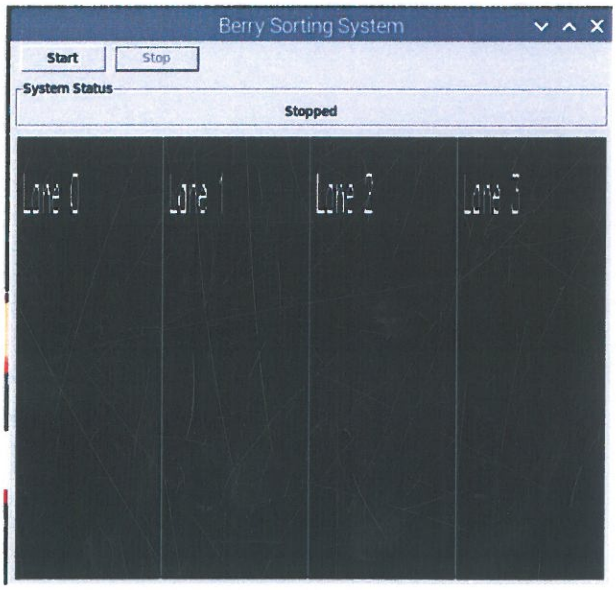


Figure 3.18: User Interface

4 RESULTS AND DISCUSSION

4.1 RESULTS

The coffee berry sorting machine was designed and fabricated to effectively separate ripe from unripe berries using a combination of a vibrating conveyor, a vision-based detection system, and air ejectors. The system layout includes four air ejectors positioned along the chute, controlled by a Raspberry Pi 3, to ensure efficient sorting.

4.1.1 Mechanical module

The final overall dimensions are 760 by 300 by 750 as shown in figures 4.1 and 4.2.
The air ejectors pressure is set at 5 bars at maximum.
The fabricated machine consists of 11 major component as show on the parts-list in figure4.3

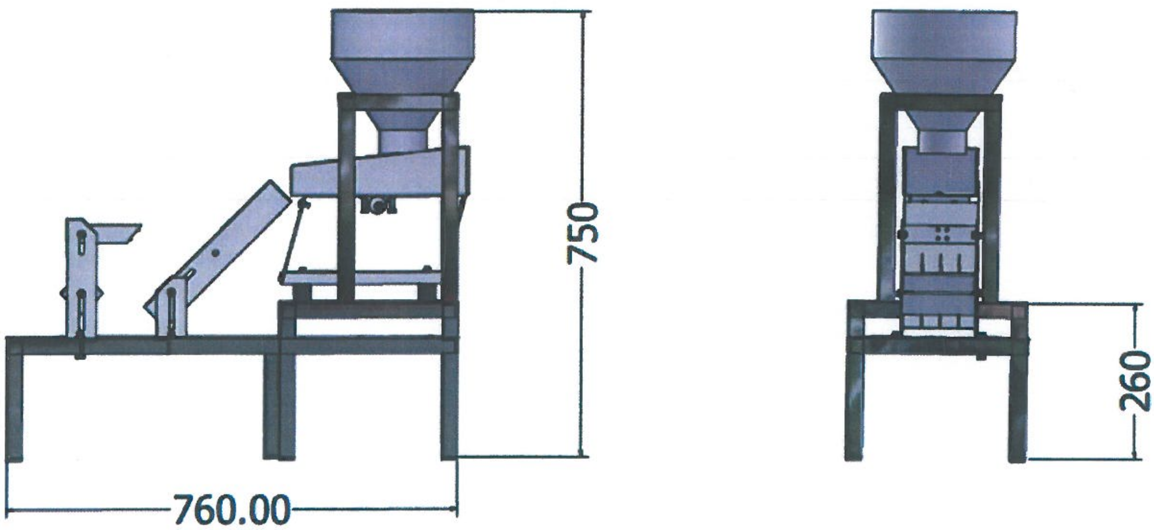


Figure 4.1: side views

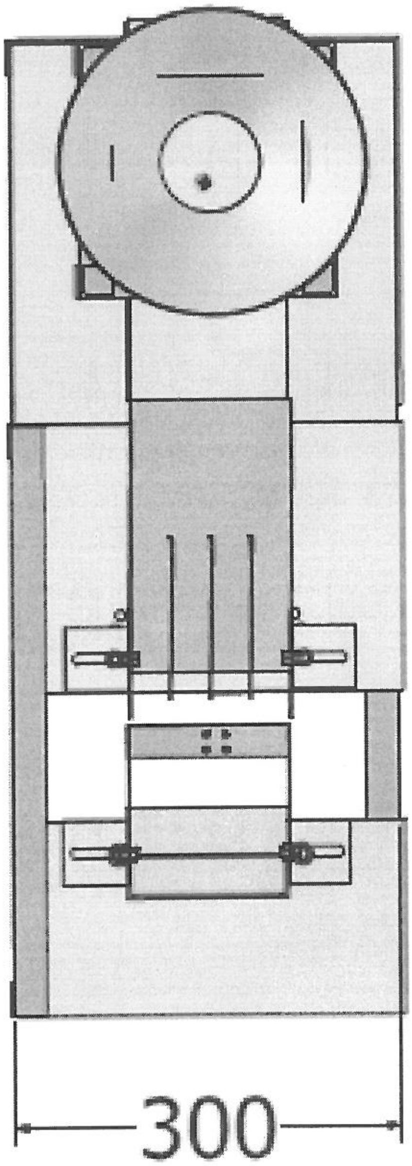
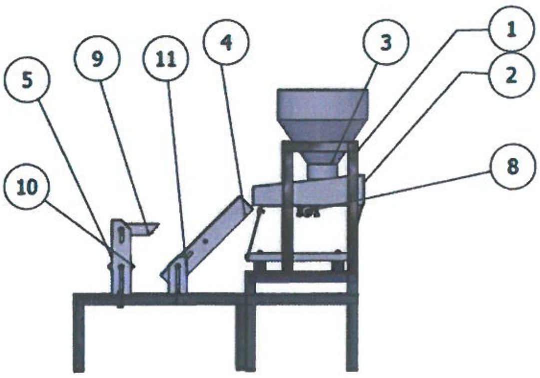


Figure 4.2: Top View



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1.000 mm	FRAME
2	1	FEEDER TROUGH
3	1	HOPPER1
4	1	CHUTE ASSEMBLY
5	1	CAMERA AND AIR MOUNT
8	1	VIBRATING MOTOR
9	1	CAMERA STAND
10	1	EJECTOR HOLDER
11	1	CHUTE MOUNT

Figure 4.3: Parts list

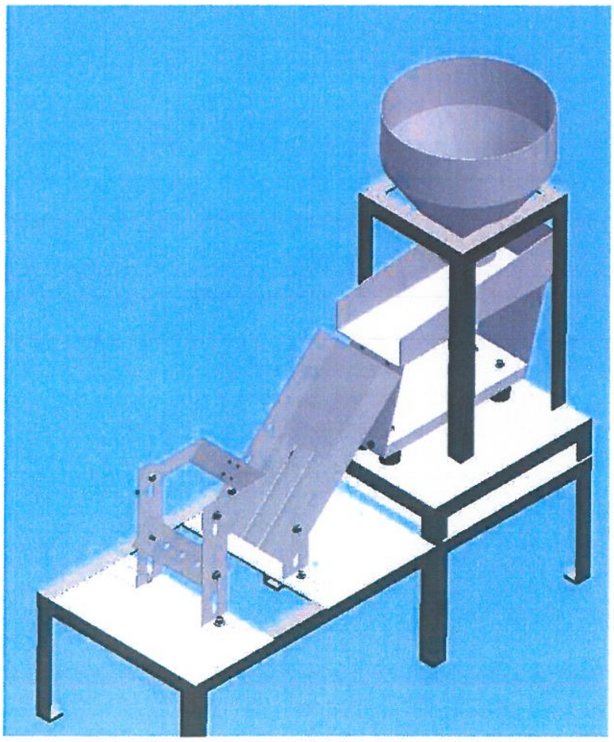


Figure 4.4: Main assembly model

Figure 4.5: final assembly

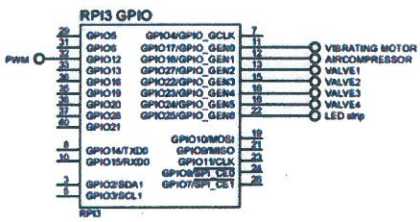


Figure 4.6: Pi pinout

4.1.2 Electrical module

The wiring for the electrical modes is as shown in figure4.7 with figure 4.8 showing connection ejectors with the RL circuit used to represent the 4 solenoid valves ,figure4.6shows the pinout of the raspberry pi 3 and figure4.10 from the optoisolators to the other electrical components and Servo motor connection. The fabricated ejector circuit is fabricated as shown in 4.9

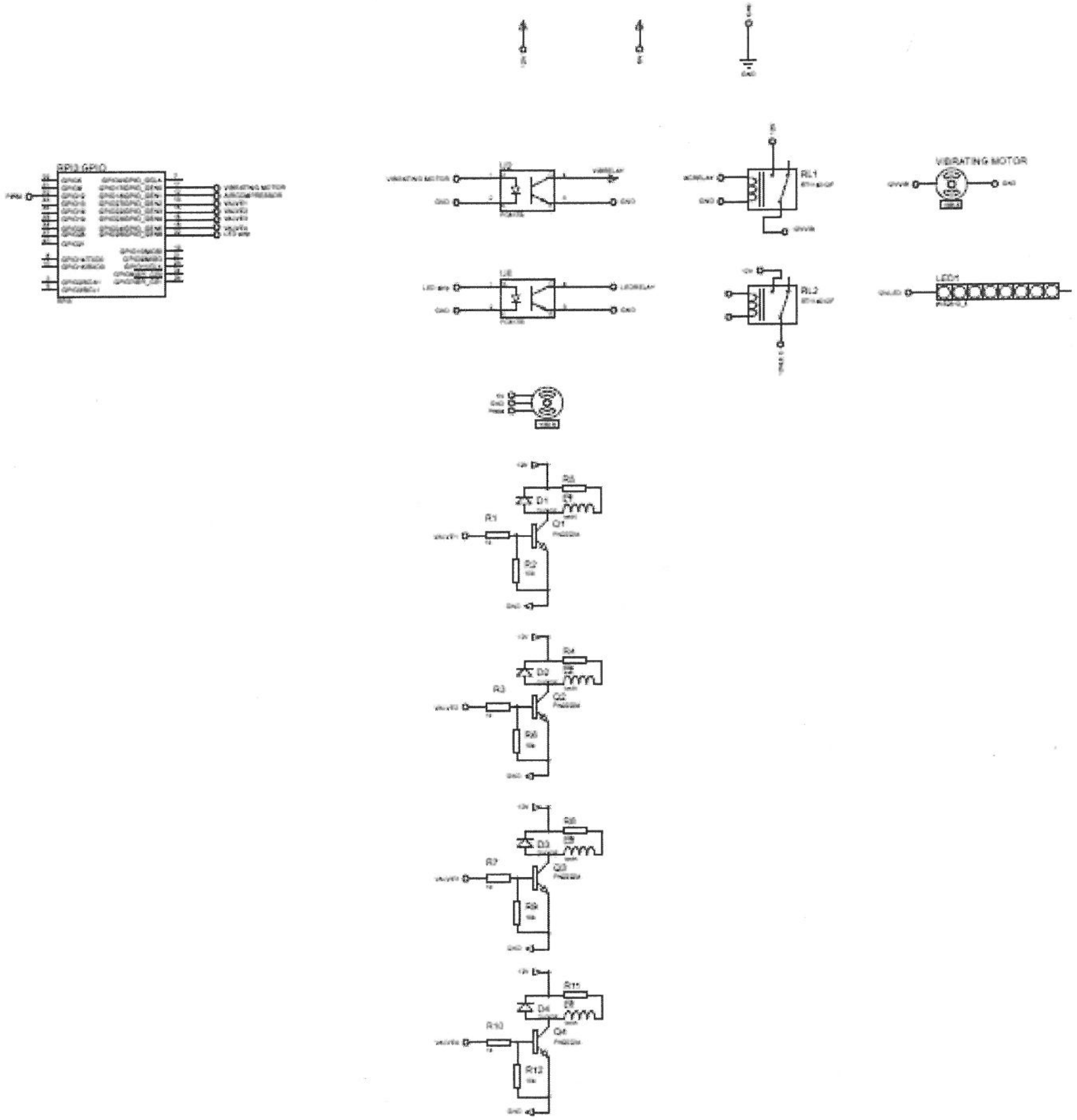


Figure 4.7: Electrical

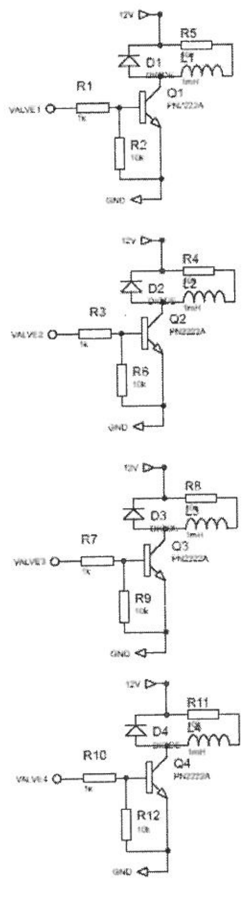


Figure 4.8: Ejector circuit

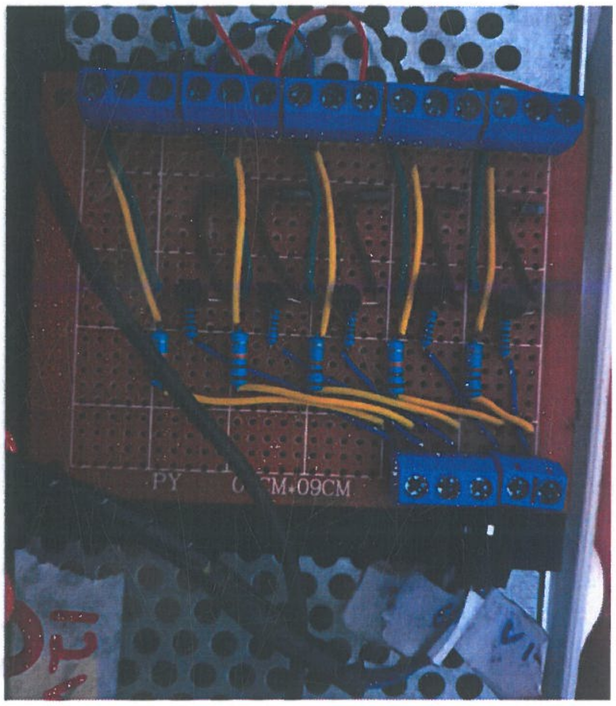


Figure 4.9: fabricated ejector circuit

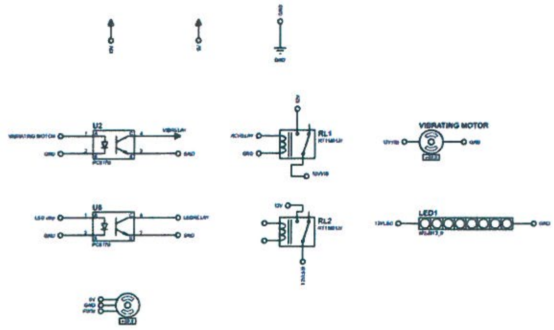


Figure 4.10: Pi to led,vibrating conveyor and servo

4.1.3 Control Module

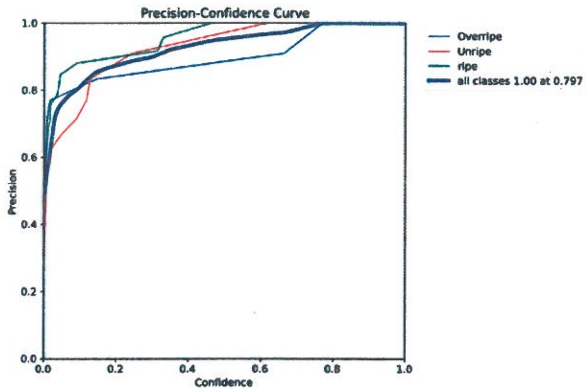


Figure 4.11: Precision data

Precision vs Confidence

- Precision measures how many of the objects the model detected are actually correct. A precision vs confidence graph is useful in setting the confidence scores
- The model is very good at minimizing false positives. When its sure an object is 80% is present, it's right 100% of the time. This high precision is important when you want to be confident that the detection's made by the model are correct.
- The precision across classes is also indicated in figure 4.11

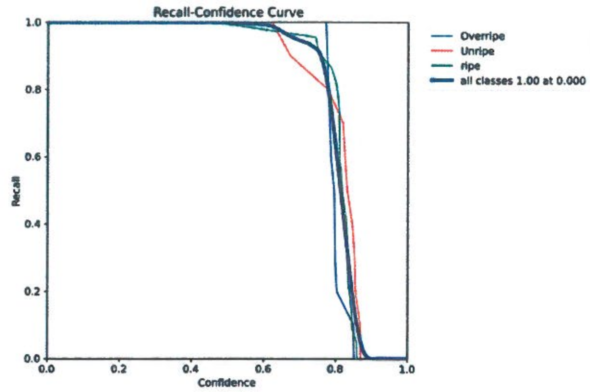


Figure 4.12: Recall data

Recall vs Confidence From figure 4.12high recall was achieve upto around 50% confidence whereby the recall started to drop meaning we were missing some true positives.

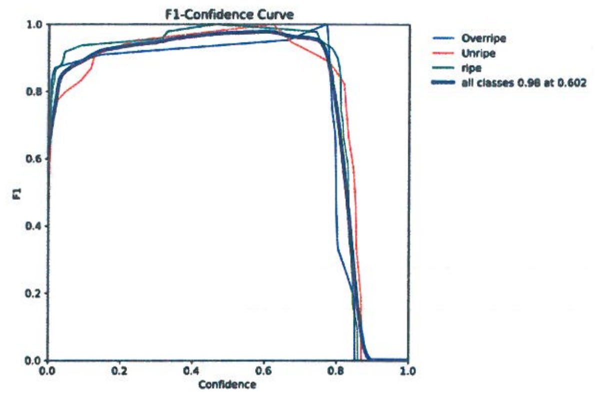


Figure 4.13: F1 score

F1 vs Confidence The F1 score combines both recall and precision. Our highest F1 score from figure 4.13, for all classes 98%, was achieved at 60.2% confidence threshold . This helped in setting the most optimum confidence threshold for our model

Achieved frame rates : From fig 4.14 we were able to achieve frame rates of about 1-1.9 frames per second with both the model detection and tracking running. This was closer to the 2 fps we had expected. However there was a lot of delay and inconsistency in processing which led to a lot of frame not being detected. Larger motion blur due to the high exposure time also led to difficulties in pre processing.

Other tests, in fig 4.15, were conducted. It included removing the tracking element

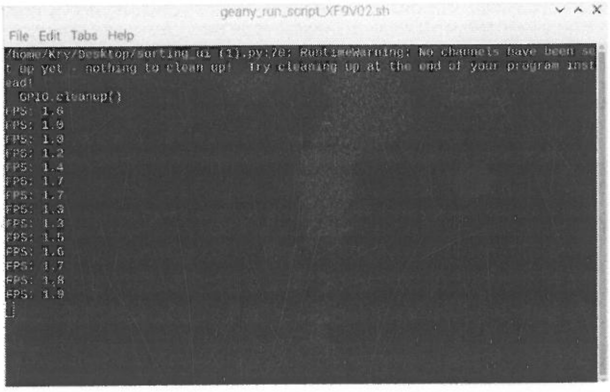


Figure 4.14: Object tracking enabled

deepSORT as the majority of the berries were being captured in only a single frame. Ejection was simply to be done based on timing.This led to the frames being processed hitting maximum of about 6 fps and not going below 2 fps .

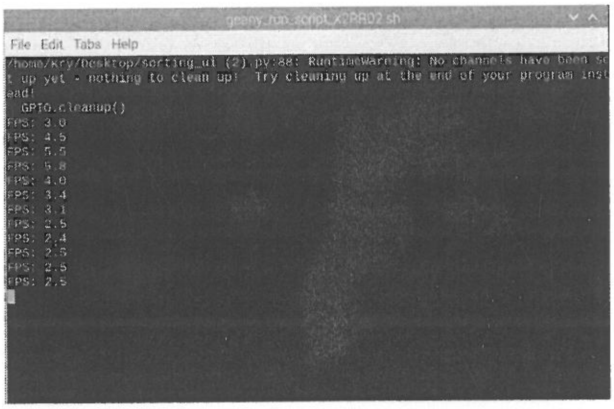


Figure 4.15: Tracking disabled

Final tests were done using the preprocessing and calculation of the color variations in isolated regions where by majority red is ripe, green unripe and purple to black ripe . From Fig 4.16Higher frames were achieved reaching a maximum of about 10 fps. The accuracy of the detections were however undetermined.

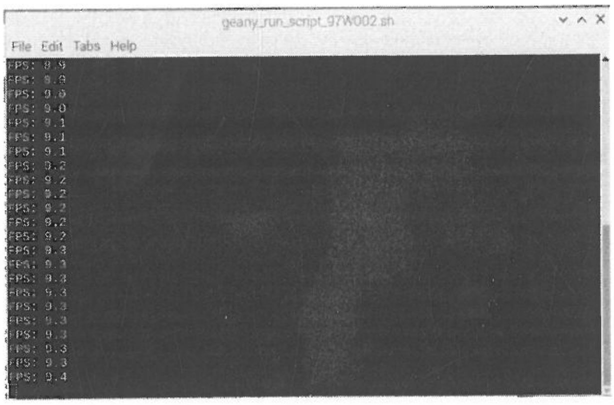


Figure 4.16: color intensity calculations

5 Conclusion

The design of the coffee berry sorting machine has yielded promising results that align closely with our objectives.We were able to design and fabricate a functional mechanical electrical and control module capable of sorting coffee berries based on their ripeness. These results demonstrate that the fabricated project could address the challenges of automated sorting, good berry flow to sorting station, berry detection and a functional ejection system.

Despite the successful implementation of the coffee berry sorting system, one significant challenge encountered was the limited processing speed of the Raspberry Pi 3 during real-time detection and classification. The constrained computational power occasionally led to delays in processing frames from the camera, which could affect the precise timing required for ejector activation. While optimization techniques such as TensorFlow Lite conversion and multithreading mitigated this issue to some extent, the system's performance highlighted the need for more powerful hardware or a co-processing unit to achieve higher throughput and ensure seamless operation in larger-scale applications. Future work could explore hardware acceleration like Ai accelerators to overcome these limitations

The coffee berry sorting project successfully demonstrated an automated approach to classifying and sorting coffee berries based on ripeness and processing methods. The integration of machine learning, real-time control, and mechanical systems resulted in a functional prototype capable of improving post-harvest efficiency

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6 Appendices

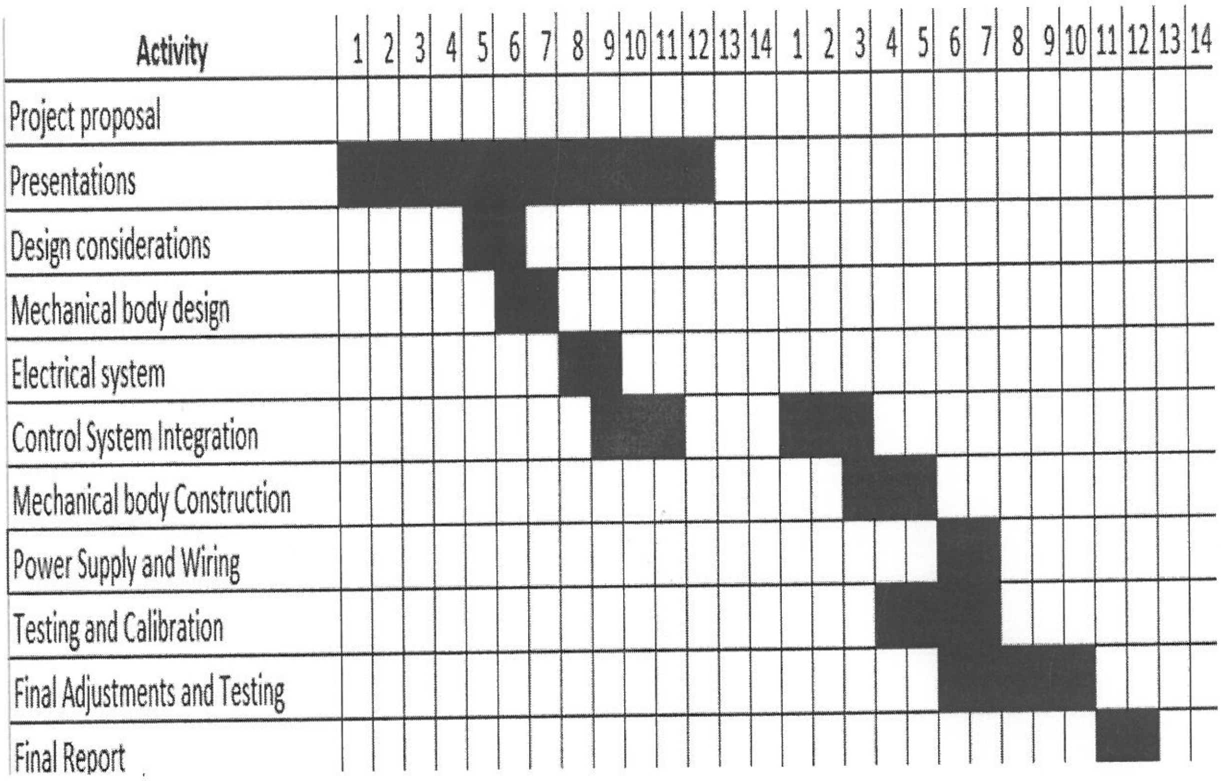

Figure 6.1: Time-Plan

Component	**Qty**	**Price**	Availability
Frame	6m	3000	Available
Raspberry Pi 3	1	8000	No
Camera	1	1500	No
Air ejectors	4	2500	No
Air Compressor	1	4500	Available
Sheet metal	1000 x 500 x 2	4000	No
Power supply	12V 200w & 5V 10W	5500	No
Bolts and nuts	M8 20	300	No
Vibrating motor	1	1500	No
Optoisolators	8	400	No
Relay	1	100	No
Cables, Tubes and LEDs		3000	No
SG90	1	500	Available
miscleneous		3000	No
TOTAL		37,800	29,900

Table 6.1: Budget

Week	Tasks	Materials required	Special equipment	Concurrent tasks	Status
1	Sourcing for coffee berries: Ask from: i) Sasini coffee mills ii) Mtaro coffee estate iii) Karunguru coffee estate		-	Model retraining	done
2	Making Corrections on the Interim report: i) Rephrasing the literature review ii) Correcting the Results section iii) Correct the grammatical errors	Interim report draft	-	Model retraining	done
3	Reviewing the mechanical design: i) Designing a closing/opening mechanism for the hopper		-		done
4	Sourcing for materials: Seeking available material within hardware's in juja and Thika		-	Model retraining and writing tracking algorithm	ongoing
5	Fabrication of chute and camera stand i) Cutting the chute flat pattern ii) Cut chute guides iii) Cut Chute bracket flat pattern iv) Cut camera mount flat pattern v) Cut camera bracket vi) Drill mounting holes 8mm for the chute and brackets vii) Drill 2mm holes for camera viii) Bend the parts and Weld guides on chute	2mm mild steel	Vertical drill Welding machine Angle grinder	Finalizing Model training and testing	Welding guides remaining
6	1. Fabrication of vibrating feeder i) Cutting the flat pattern of the feeder trough, bottom plate and flat springs ii) Drilling of holes 8mm iii) Bending the components	2mm mild steel	Drilling machine	Finalizing and Testing the object tracking Algorithm	ongoing

Figure 6.2: Production Plan

7	1. Fabrication of hopper i)Cutting of conical hopper section flat pattern ii)Rolling to shape iii)Cutting of the cylindrical section flat pattern iv)Welding the two sections to form hopper	2mm mild steel sheet	Pinch Roller Welding equipment	Optimization and testing of the Detection model	
8	Fabrication of motor mounts and ejector holder i) Cut flat pattern for motor mount ii) Machining the base plate iii) Machining ejector 1-4 manifold iv) 3D printing hopper closing mechanism motor mount v) 3D printing ejector holder	PLA filament Metal thread inserts Mild steel rod Aluminium plate	3D printer Soldering iron Milling machine Lathe machine	Calibrating the camera Writing Startup sequence code	
9	Fabrication of the Frame i)Cutting the sheet metal ii)Cutting the angle line iii) Drilling the mounting holes iv) Welding the angle line v) Polishing the welded joints	2mm stainless steel 1" x 1" angle line	Vertical drilling machine Welding machine Angle grinder	Assembling the vibrating feeder and testing and debugging startup code	
10	Assembling the mechanical and electrical module i)Assembling the mechanical module ii)Wiring the LED strip and motors iii)Testing the assembled components connections	Bolts and nuts, Wires. Motors Raspberry pi3 LED strip Silicon tubes Air compressor Hopper and vibrating feeder Optoisolators Soldering wire PCB board connectors Soldering board	Soldering kit	Fabricating the circuit board i) Soldering the Controller terminals to the Optoisolators. ii) Soldering the Components connection terminals iii) Testing the circuit	

Figure 6.3: Production plan

11	Testing and optimization of the control system	Mechanical and electrical module		Testing the air ejectors. Testing the vibrating motor and ejection software logic.	
12	Testing and optimization of the control system	Mechanical and electrical module			
13	Testing and optimization of the sorting system	Mechanical and electrical module			
14	Optimization of the system and final documentation				

Figure 6.4: Production plan

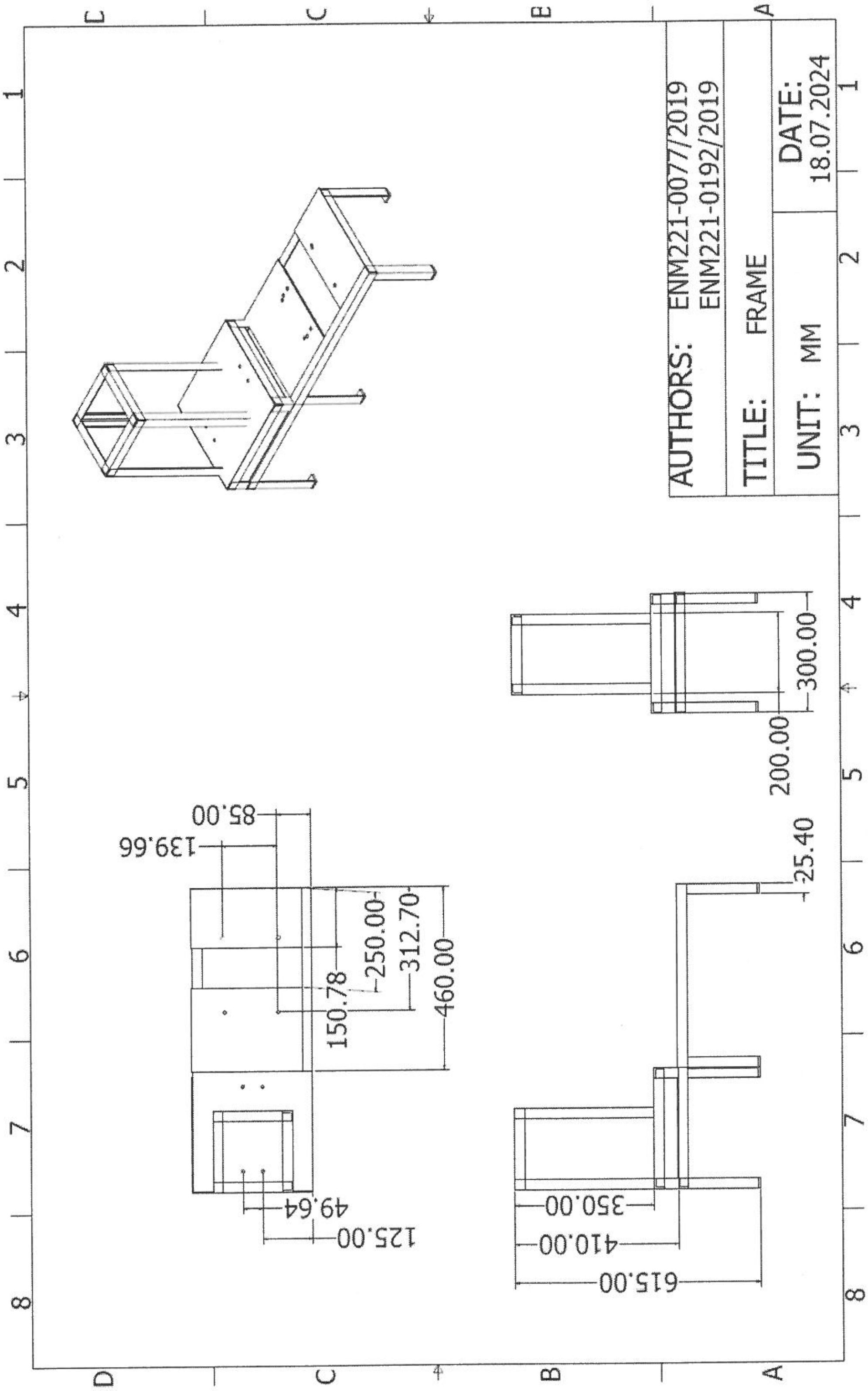

Figure 6.5: Frame

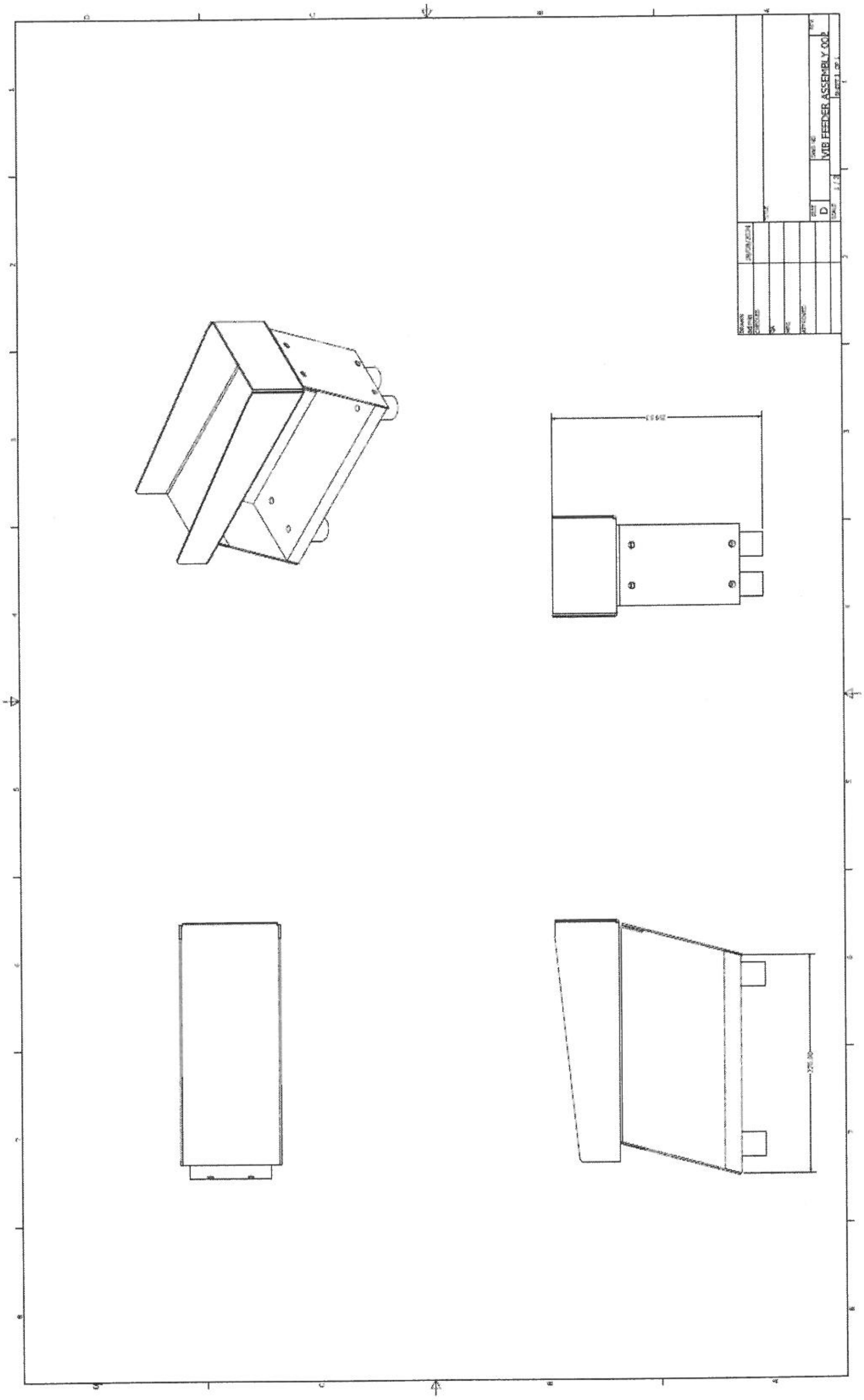

Figure 6.6: Vibration assembly

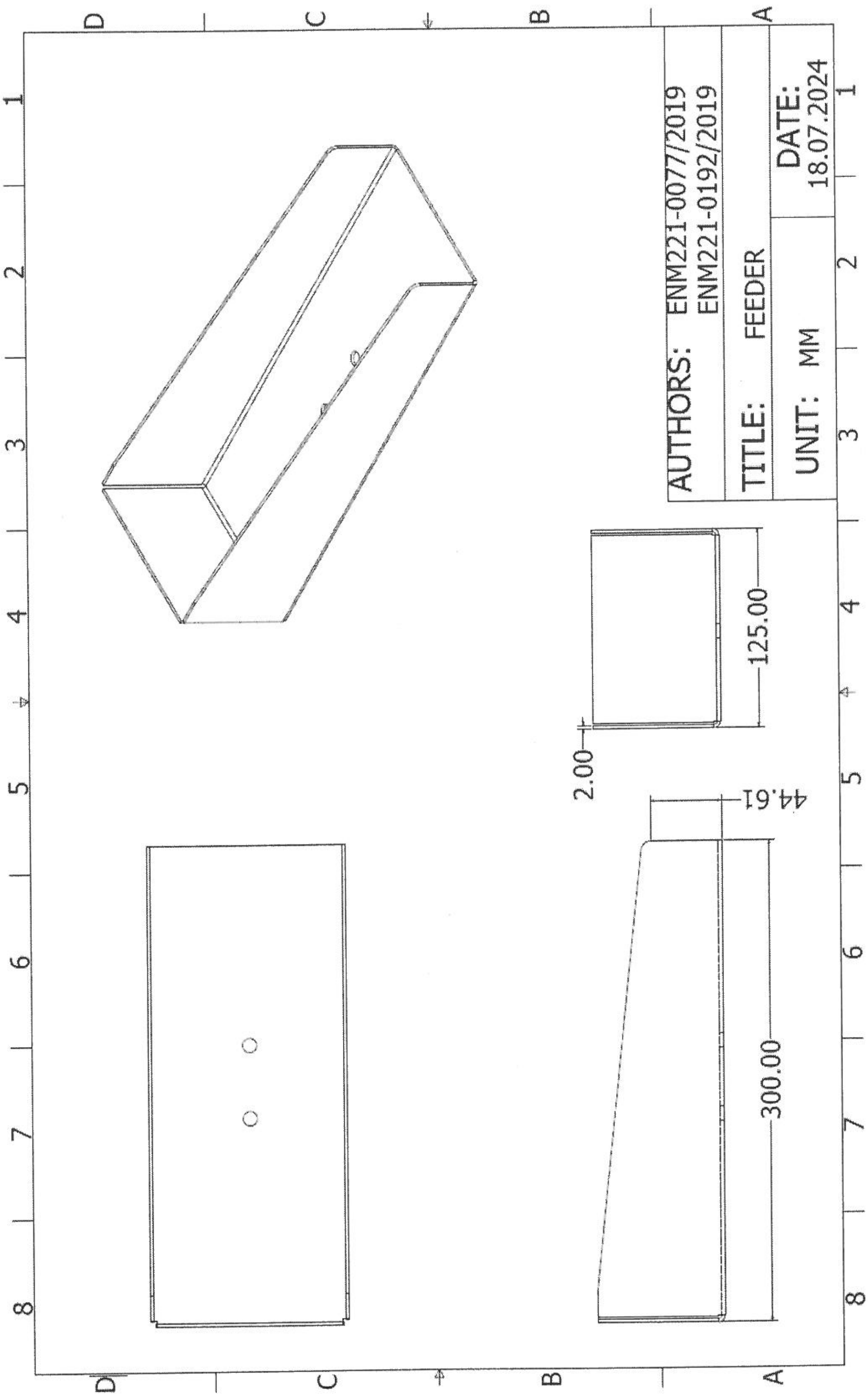

Figure 6.7: Feeder Trough

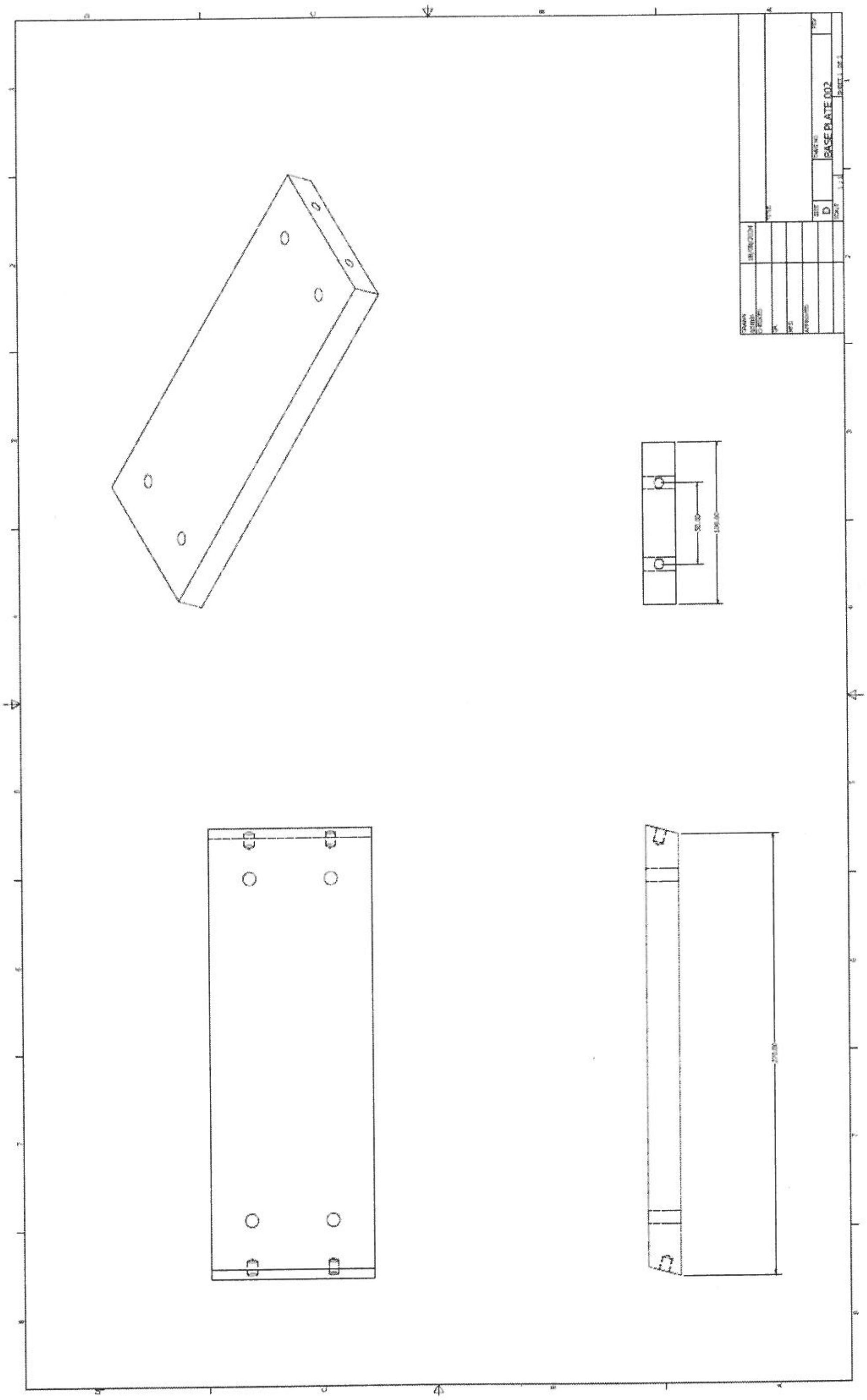

Figure 6.8: base plate

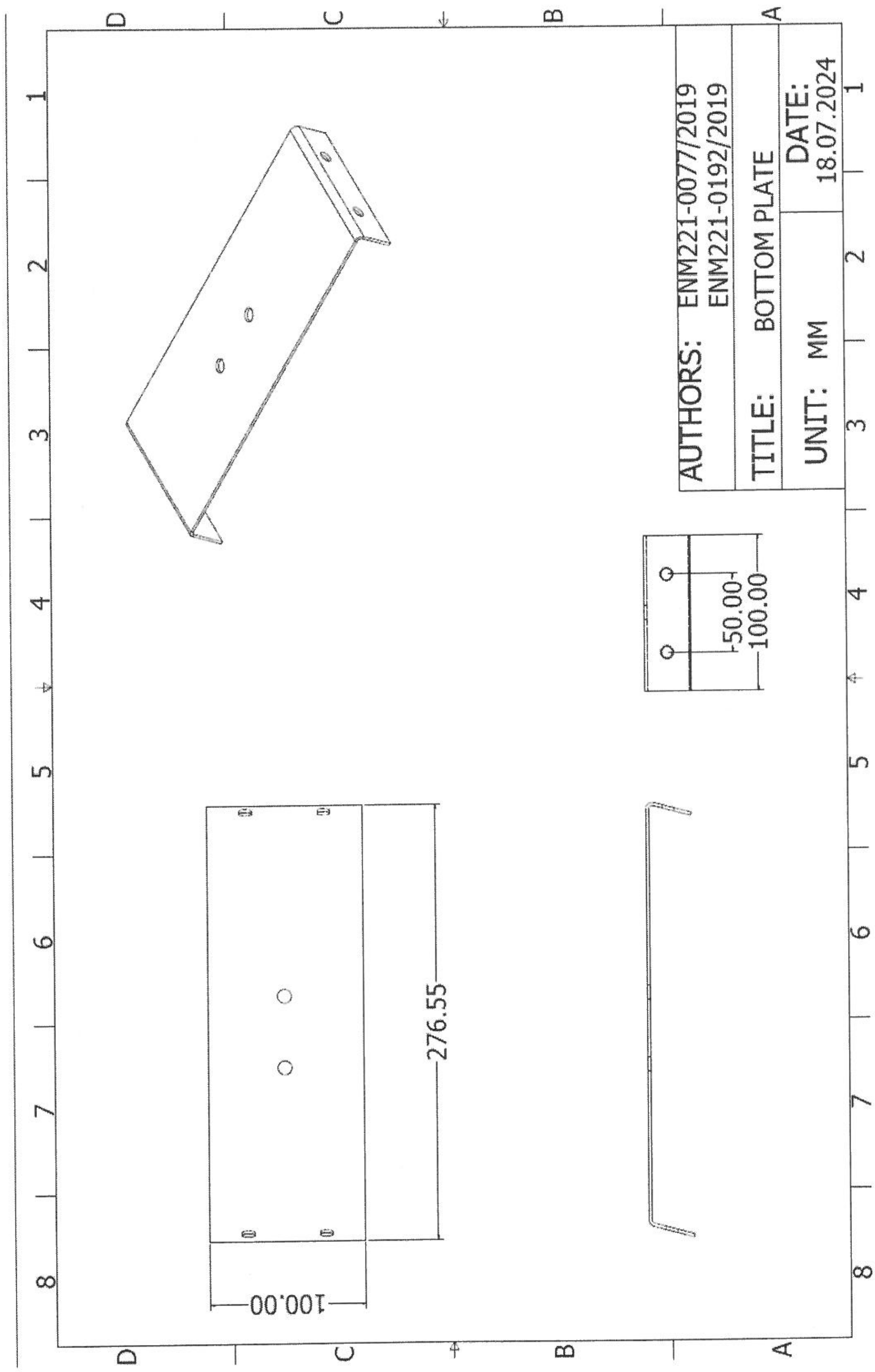

Figure 6.9: bottom plate

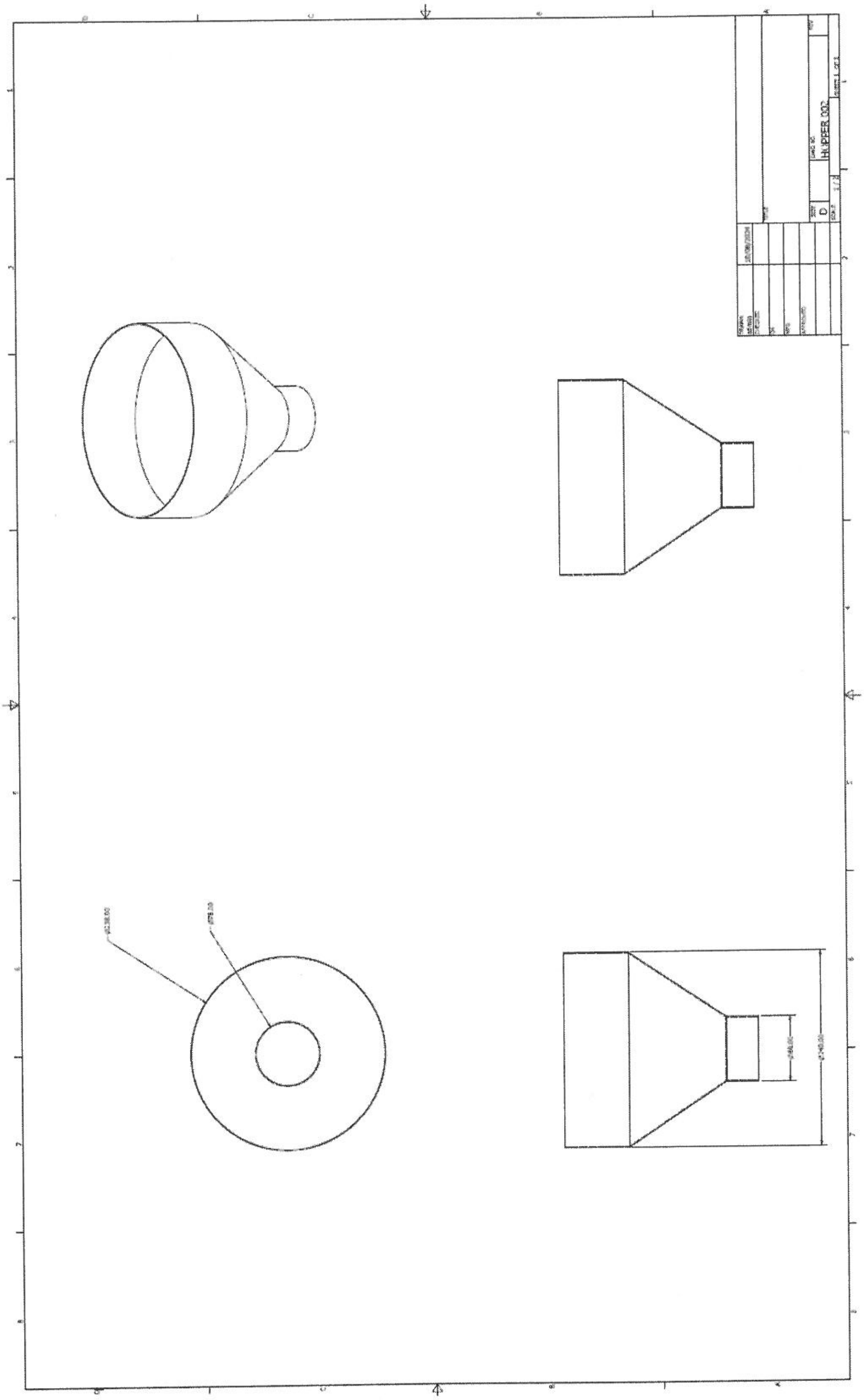

Figure 6.10: Hopper

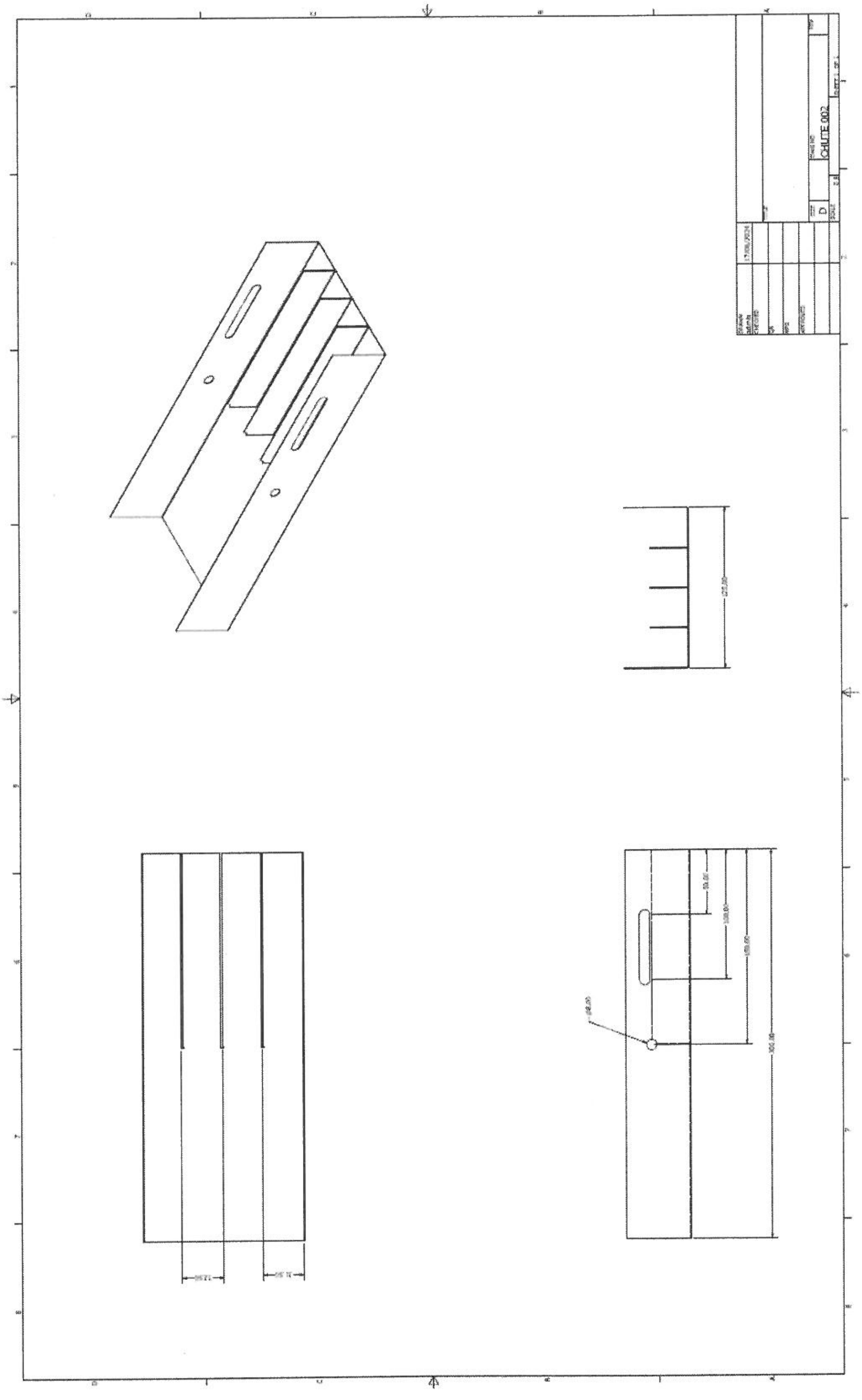

Figure 6.11: Chute

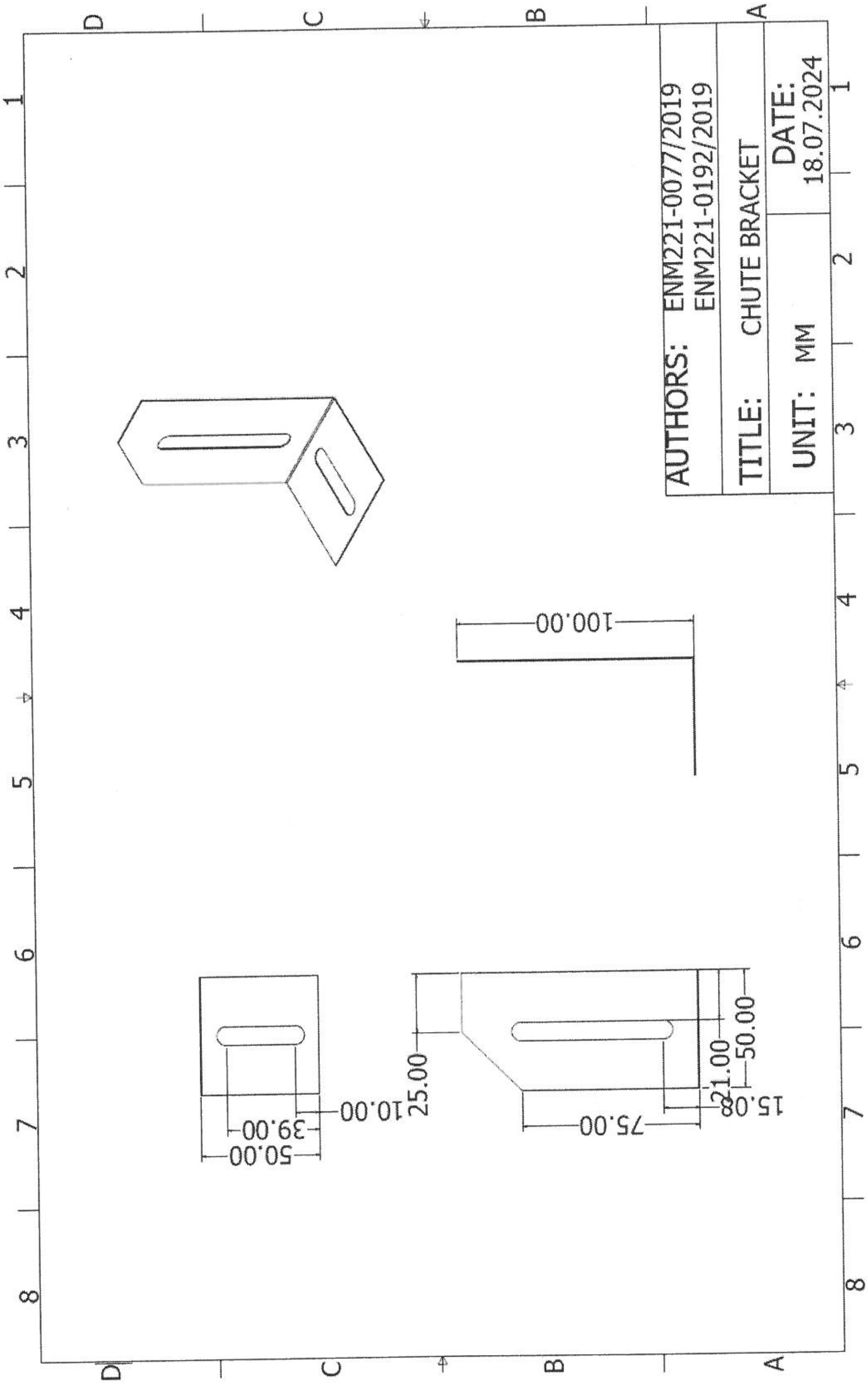

Figure 6.12: Chute bracket

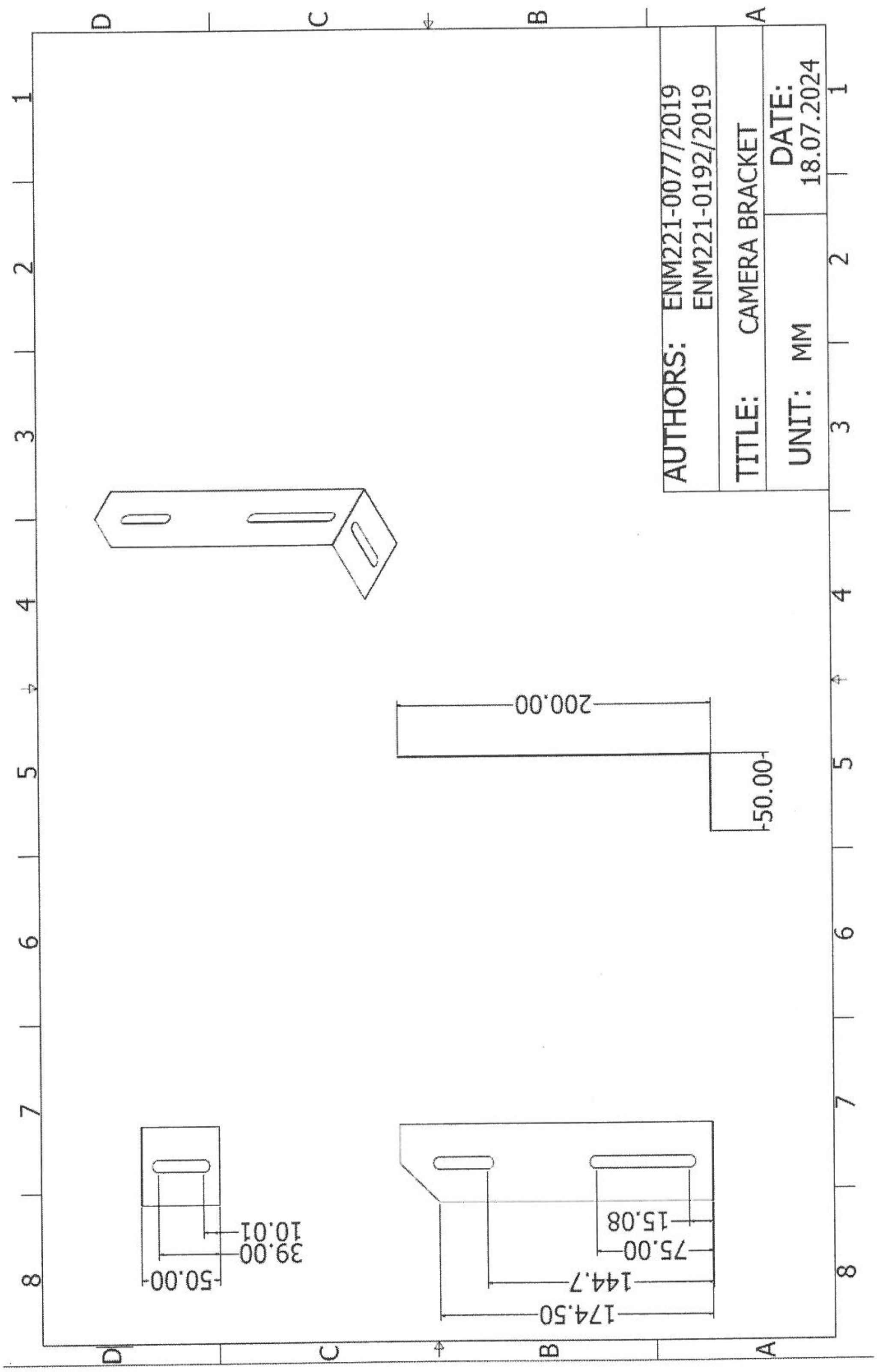

Figure 6.13: camera ejector stand

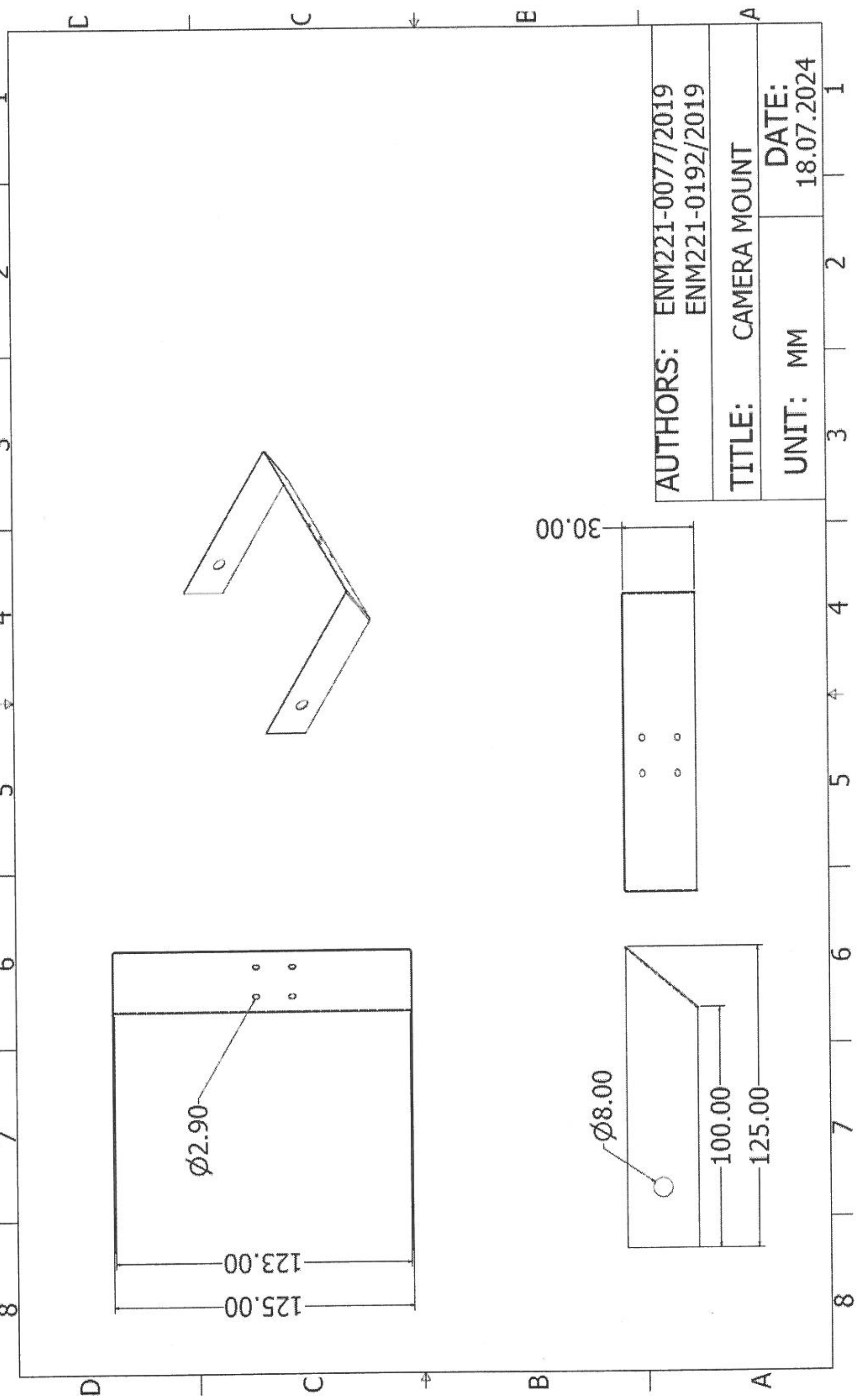

Figure 6.14: Camera holder

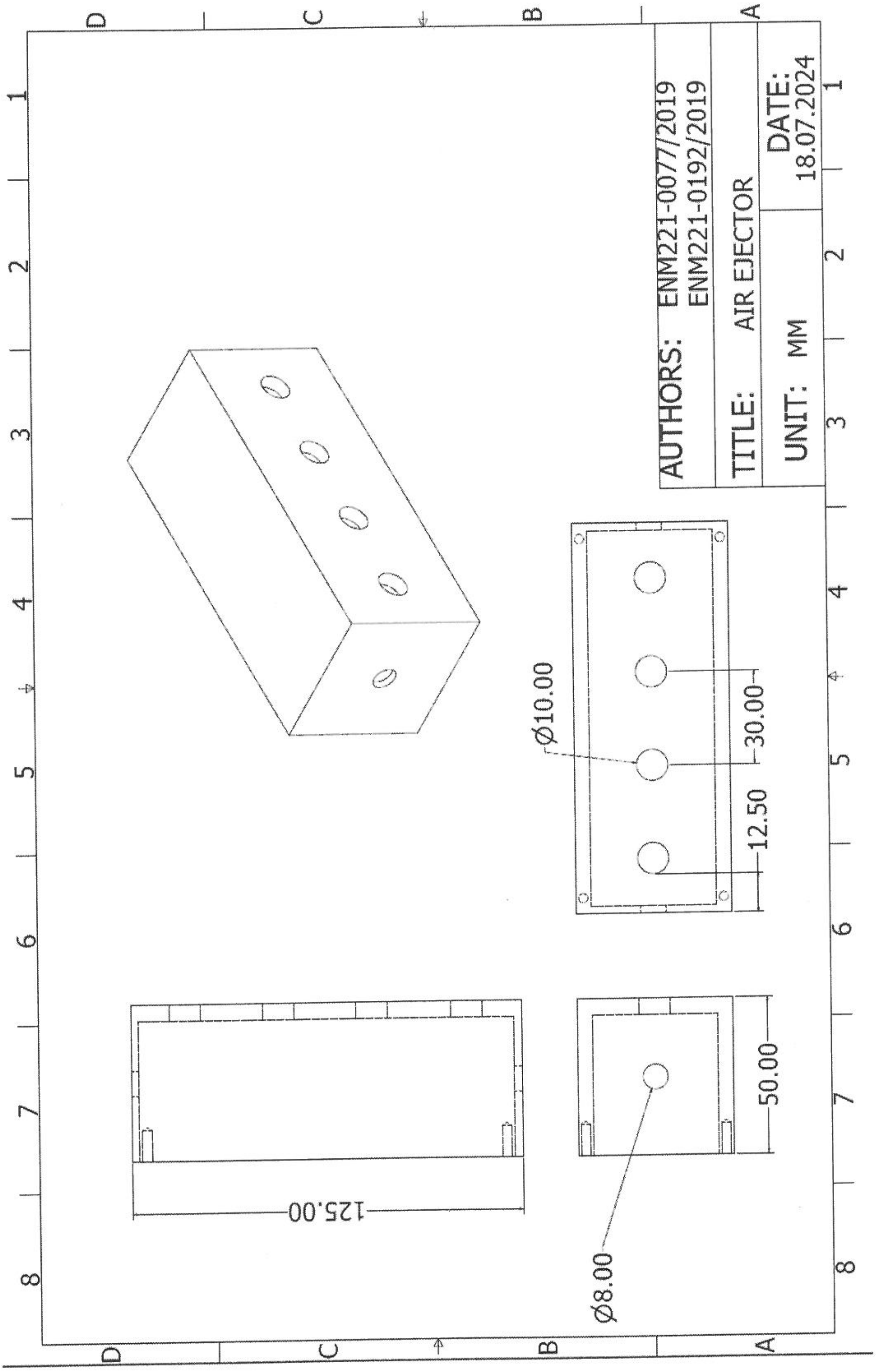

Figure 6.15: ejector holder