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College of Engineering and Technology

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Department of Mechatronic Engineering

Design and Fabrication of a Garbage Waste Separation and Sorting System

Final Year Project Report

FYP-14-18

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Declaration

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

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Abstract

Garbage has become a problem in the society and the ecosystem due to the improper disposal methods. Garbage disposed is either burnt or dumped, which leads to air, water, and soil pollution. Waste recycling is an effective way of reducing the amount of waste dumped into our landfills. In order to successfully recycle waste, the waste has to be separated and sorted. Currently, the traditional way of separating waste is by the use of different containers for each type of waste. There are several industrial processes being used to effectively sort the garbage collected but most of which depends on human labour. The aim of this project is to present a cost effective waste separation and sorting system which can replace the traditional way of waste management. The system designed and fabricated receives the incoming waste and takes it through a singularization process after which the garbage proceeds to the sorting system in the conveyor one item at a time. In the sorting system, sensors are used to categorize the garbage items depending on the type of material. Actuated blocking mechanisms are used to block and guide each garbage material to the allocated bin. From the survey conducted within the institution, three types of waste were considered namely metal, glass and plastic. The scope of waste being sorted is limited to cylindrically shaped bottles with the largest bottle size being a 0.5 litre and the smallest bottle size being a 250 millilitre bottle.

With the implementation of this project, recycling of the recovered material is possible. Test results from the prototype developed show that it is indeed possible to recover these items repeatedly, and this proves the concept that it is possible to implement a recycling system for a better environment.

Acknowledgment

We would like to acknowledge the following for their support and help regarding this project. To our ever-loving parents who are always there to give us courage to pursue our goals and provide financial and emotional support. To our lecturers and supervisors from who we learnt principles that helped us actualize this project. To our friends who are always capable of giving us the motivation and strength to keep on keeping on. And above all, to the One who created everything, the One who gives wisdom and strength.

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1 Introduction

1.1 Background

Waste, as defined by the United Nations Environment Programme (UNEP) [1], are objects or substances which the owner does not want, need, or use any longer and require treatment and/or disposal. Tons of garbage are produced each day ranging from food refuse, plastic waste, paper, glass among others. It is estimated that 2.6 trillion kilograms of waste are produced across the world yearly [2]. In JKUAT alone, tons of garbage are produced in the university ranging from kitchen waste, scrap metal, paper waste and food refuse. Waste sorting is defined as the process by which waste is separated into different elements to facilitate for its disposal or recycling. Waste sorting may be carried out manually either at the individual level or at a garbage collection facility by workers or through automatic separation in material recovery facilities. Waste sorting achieves sorting of waste into categories such as paper-based material, plastic-based material and organic matter.

In JKUAT, the garbage waste sorting process is conducted at the individual level whereby different bins for different waste have been provided for the end user to dispose of their waste in. This mechanism relies on the individual abiding by the unspoken rules of waste disposal to appropriately dispose of their waste in the correct bin. Despite the provision of these facilities, it is normal to find individuals disposing off garbage without considering appropriate placement. In scenarios where the garbage has been successfully sorted at the individual level, the garbage collectors normally mix the waste upon collection rendering the sorting efforts meaningless.

Waste sorting is an important process that precedes garbage recycling and disposal. In garbage recycling, recyclable waste is successfully separated and re-appropriated. With the tons of garbage produced within the institution on a daily-basis, recyclable waste collected can become a revenue stream for the school contingent on its successful separation and recycling. Since the existing mechanisms for sorting garbage are not effective in ensuring the successful categorization of waste, there is need to come up with an alternative mechanism in which garbage collected can be successfully sorted for purposes of recycling. According to research done across the world concerning the profitability of recyclable material [3], it was noted that the materials that are most profitable include; aluminium, polyethylene terephthalate (PET) plastic bottles e.g. the soda plastic bottles, newspapers, corrugated cardboard, steel products , high-density polyethylene (HDPE) plastics e.g. lotion, cooking oil and bleach packaging bottles, glass and e-waste.

1.2 Problem Statement

Tons of garbage are produced around the institution on a daily basis. The prevailing systems of garbage waste separation, which rely on an individual's initiative to correctly dispose off their waste, as well as the garbage collection culture of mixing up all waste, have failed to yield in sorted waste. The unsorted waste denies the institution of seizing opportunities of recycling of useful waste. There's need to develop a system that can automatically separate the waste and sort it accordingly to enable for the collection of recyclable waste. Figure 1.1 shows an image of the drainage system located at the JKUAT main gate filled with recyclable plastic bottles.

Figure 1.1: Drainage system filled with plastic bottles at the JKUAT Main Gate

A survey was conducted within the school to find out the percentage of different waste categories contained in the garbage collected. The locations where samples were taken from included the student center, tuck-shop and student's hall of residence, Hall 6. Figure 1.2 shows an image of a garbage bin located at the tuck-shop area. Three bins were sampled in each of those locations.

Figure 1.2: Garbage bin

This survey resulted in the statistics shown in the pie chart based on different samples of bins examined. The data collected showed that some of the most profitable materials for recycling, namely plastic bottles, glass and aluminium constituted a significant part of the garbage sampled. There is, therefore, a need to develop a sustainable solution for the garbage problem that is not only useful to the environment, but also profitable. Glass was selected as one of the materials to be sorted though it did not appear as part of the commonly disposed waste within the institution because it has some recyclability value [3].

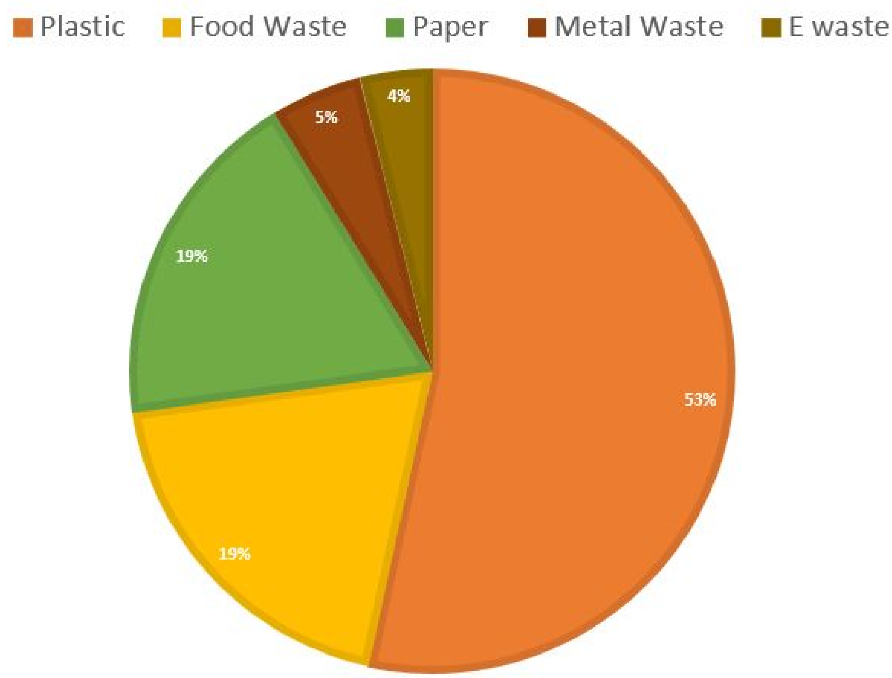

Figure 1.3: Survey Data

1.3 Objectives

The main objective of this project is to design and fabricate a garbage waste separation and sorting system. To achieve this objective, the following specific objectives were identified;

1. To design and fabricate a garbage separation mechanism that achieves singularization of the garbage.
2. To design and fabricate a garbage sorting mechanism to successfully identify and sort the waste as per the specified categories.
3. To test the integrated garbage separation and sorting system.

1.4 Expected Outcome

At the end of this project, the following outcomes are expected:

1. Garbage separation- The mechanism will work such that from a heap of garbage loaded into the machine, itemization/singularization of the garbage will be achieved.
2. Garbage sorting-The sorting system will identify and categorize each garbage item according to the type of material.
3. The integration of the garbage separation and sorting system should be effective in sorting garbage.

1.5 Scope

This project is aimed at the separation of unsorted garbage waste to aid in the sorting and successful aggregation of garbage. The sorted garbage should be within the following scope:

1. The types of garbage waste material considered are plastic, metal and glass because they are recyclable and they can be used to generate revenue.
2. The garbage sorted is mainly of circular cross-section such as bottles.
3. The range of bottle sizes to be sorted range from 350ml bottles and below.

2 Literature Review

Accumulated waste deposits are an indication of societal lifestyles, waste management practices and production technology. Some societies at the peak of their development have stagnated due to inadequate management of their waste leading to proliferation of disease; environmental degradation and ultimate impact on livelihoods [4]. Moreover, improper management of waste poses a threat to the health of the people living in areas near the landfills. Waste being one of the contributors of greenhouse gases, through burning of the waste in landfills, leads to climate change and it is for this reason that as a country, we should develop sustainable waste management technologies and initiatives to curb this growing global challenge.
Ever since the inception of the university, a garbage management system has been in place. As the university grew and demand for better garbage collection mechanisms were needed, the institution tackled this by either increasing the number of dustbins within the institution as well as increasing the frequency of garbage collection around the institution. The existing method of garbage separation and sorting utilized by the institution solely relies on the individual's initiative to place trash in the correct bin. However, due to the insufficient number of bins availed coupled up with poor trash disposal culture, this method has encountered challenges in its implementation. Furthermore, in the event that the sorting was successfully done by the individual, upon collection, the garbage collectors usually recombine the sorted trash rendering the sorting efforts meaningless.

In the recent past, there has been a surge in the usage of plastic bottles in the world. About a million plastic bottles are bought around the world every minute and the number is projected to increase by another 20% by 2021 [5]. Most of the bottles used for soft drinks and water are made from polyethylene terephthalate (PET), which is highly recyclable. However, efforts to collect and recycle the bottles to keep them from polluting the environment, are failing to keep up.

2.1 Garbage Waste Sorting

Waste sorting is the process by which waste is separated into different elements. Waste sorting can occur manually at the individual level and collected through garbage bins as shown in figure 2.1 , or automatically separated in materials recovery facilities.
At the individual/ household level, different cans are availed for the correct disposal of trash. Once this trash has accumulated to substantive amounts, it is deposited into garbage reservoirs awaiting collection.

Figure 2.1: Garbage bins for different items [6]

2.1.1 Material Recovery Facility (MRF)

A Material Recovery Facility (MRF) [7] as shown in figure 2.2 is a specialized plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. In material recovery facilities, hand sorting was the first method used in the history of waste sorting as shown in figure 2.3 .

Modern Material Recovery Facilities are categorized as either Clean MRF's or Dirty MRF's. Clean MRF's accept recyclable materials that have already been separated at the source from municipal solid waste generated by either residential or commercial sources

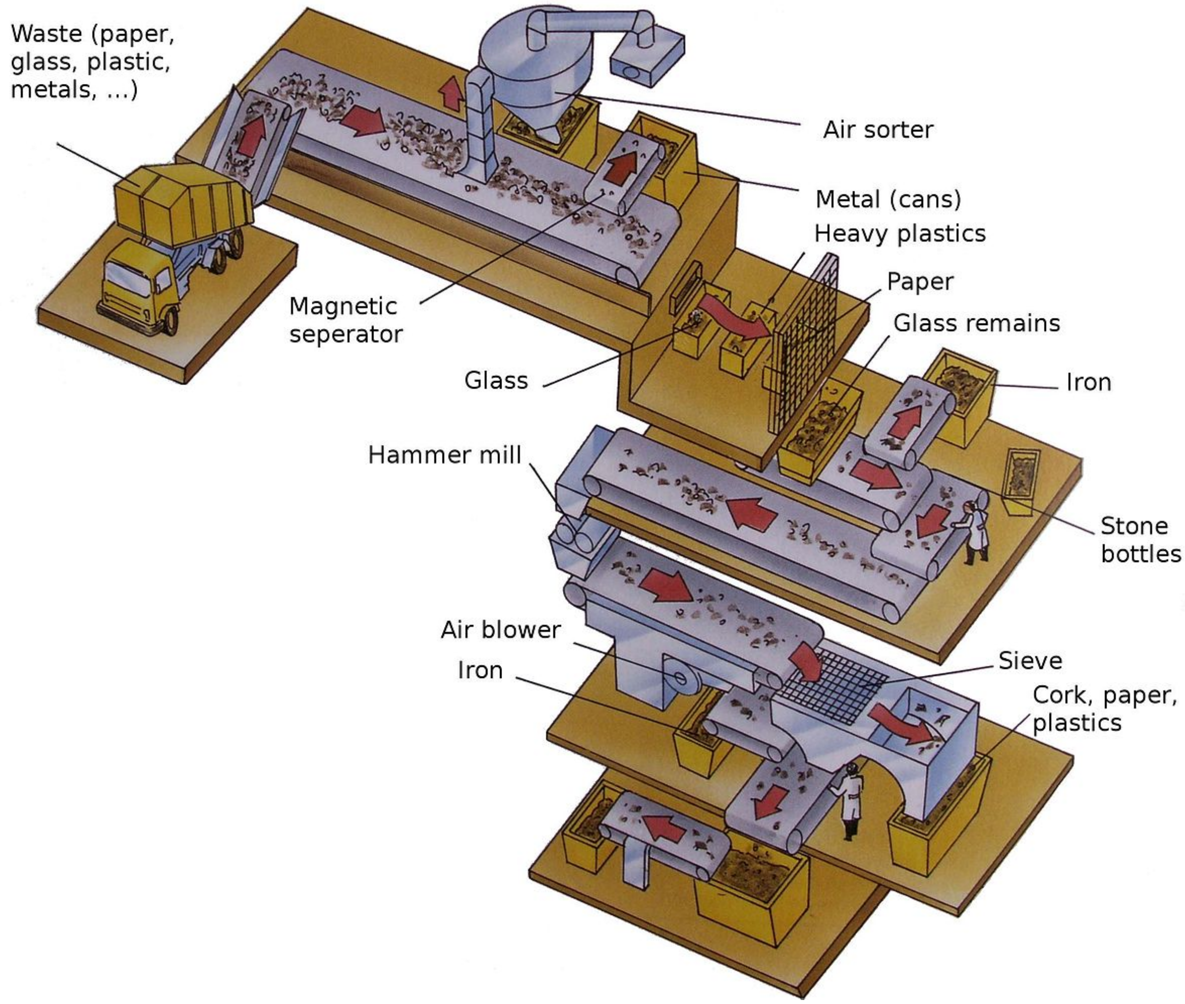

Figure 2.2: Material Recovery facility [7]

[8]. Dirty MRF's which are also called mixed waste MRF's accept a mixed solid waste stream and then proceeds to separate out designated recyclable materials through a combination of manual and mechanical sorting. The sorted recyclable materials may undergo further processing required to meet technical specifications established by end-markets while the balance of the mixed waste stream is sent to a disposal facility such as a landfill. The sorting process consists of the following basic steps [9]:

Step 1: Transportation of recyclable products

The co-mingled recyclable materials are transported to the MRF via recycling collection

Figure 2.3: Manual sorting of waste in a garbage sorting facility [7]

trucks. Upon arrival at the MRF, the recyclables are emptied into the receival bay. The recyclable materials then travel from the receival bay pit onto a conveyor and pass through a machine called the metering drum or paddle. The paddle turns and scrapes the top of the material pile as it moves up the conveyor belt. This helps to regulate the amount of material which is fed into the pre-sort stage.

Step 2: Pre-Sort

In the pre-sort stage cardboard and general waste items, plastic bags and other contamination, are manually removed. At this stage the MRF workers will also remove large plastic (drums, washing baskets, toys etc.) and steel items. The remaining materials continue on the conveyor.Whether by hand or machine, there are two basic sorting methods:
Positive sorting- the targeted material is pulled out of the material mix.

Negative sorting- foreign material and impurities are removed and the targeted material remains on the conveyor

Step 3: Star Screen Sorting

Star Screens are designed to further separate light materials from heavier material types.

A shaft fitted with a series of rotating star shaped discs works to propel the light materials (paper and cardboard) forward whilst the heavy materials (plastic, steel, glass and aluminium) travel backwards. The separated paper and cardboard products then undergo a final manual clean up, where any remaining contamination is removed. Once the majority of paper has been removed, a secondary set of star screens works to separate glass items from the remaining plastic, steel and aluminium products. Being heavier, the glass falls through the final set of star screens onto a glass conveyor belt and travels into a storage bunker. All glass is then transported to a beneficiation plant for further sorting.

Step 4: Removal of Steel

The remaining materials pass under a series of rotating overhead magnets that remove the ferrous metals (those that contain iron). The powerful rotating magnets lift the steel items from the conveyor belt and drops them into a storage cage below.

Step 5 - Removal of aluminium

Aluminium is separated using an electromagnetic fied known as an eddy current . The eddy current repels the aluminium and the cans fall into a storage cage below.

Step 6 - Optical Sorting

Optical sorting technologies are used to separate plastics types 1 and 2 (PET and HDPE respectively) from the remaining plastics categories. The process involves infrared sensors and air jets, which expel the plastics from the conveyor into storage bunkers below.

Step 7 - Manual Sorting

All remaining plastics (types 3-7) are manually separated from any remaining waste materials and sent down to storage bunkers below. Materials such as plastic, steel, aluminium and paper are compressed [10] into bales at the MRF. The bales make the product easy to transport and weigh, and thereby reduce transportation costs. All the products are transported to different reprocessing facilities for further sorting and screening. Each product then undergoes a different process to be turned back into products and packaging ready for us to purchase. Buying recycled products helps close the recycling loop.

In order to handle a higher number and diversity of recycled materials, as well as improve efficiency, MRFs' employ a range of specialized and automated technologies. Dirty MRFs' in particular utilize specialized equipment near the front end of the processing line to separate potentially recyclable materials from the remainder of the waste stream.

Material recovery facility employ the use of one or more of these methods:[11]

- **Trommel separators/drum screens**: Rotating trommels are used to separate materials by size as shown in figure 2.4 . A trommel screen is a perforated, rotating drum set at an angle to allow for gravity feed and discharge. The rotation creates a tumbling that separates out smaller-sized objects (e.g. dirt, grit, bottle caps and broken glass) that fall through the perforations. Larger objects work their way through the drum to exit at the downstream end. Trommels of different lengths and with varying perforation sizes can be set in a series for staged screening. Trommels typically range in length and diameter. Trommels are sometimes used in mixed waste MRFs after the presort area. In some mixed waste facilities, the trommel has small perforations to remove fines (dirt, grit, broken glass, etc.) that are sent for composting. In other mixed waste MRFs, the perforations may be large to make a first cut at sorting paper. Some trommels are equipped with knives to also function as bag breakers, or are enhanced with magnets to simultaneously remove ferrous metals. The rotation and tumbling of materials within the trommel can exacerbate glass breakage. This reduces the ability to recover glass, and also has the potential to contaminate fiber by becoming embedded in it.

- **Eddy current separator**: This method is specifically for the separation of metals. An eddy current occurs when a conductor is exposed to a changing magnetic field. Put simply, it is an electromagnetic way of dividing ferrous and non-ferrous metals.

- **Air Classifiers**: Air classifiers use blowing air to separate lighter weight materials from heavier materials. For example, the technology can be used to separate aluminum and plastic from glass. The technology can also suck lighter materials from the commingled material stream as it passes by on the conveyor, leaving the heavier

Figure 2.4: Trommel Separator [12]

material behind. An alternative application employs multiple layers of high velocity air blowing in parallel across the waste stream, taking the lighter materials to another conveyor and leaving heavier materials to drop off the end of the conveyor. The multiple layers of blowing air prevent swirling that would remix materials and is effective to separate materials that differ slightly in weight, such as different grades of paper.

- **Induction sorting**: Waste is sent along a conveyor belt with a series of sensors underneath. These sensors locate different types of metal which are then separated by a system of fast air jets which are linked to the sensors.

- **Capacitive sensing sorting**: Waste is sent along a conveyor belt with a series of sensors underneath. These sensors locate different types of material which are then separated by a system of fast air jets which are linked to the sensors.

- **Optical Sorters**: Optical sorting machines incorporate optical sensors with mechanical separators, most commonly small, powerful air jets that blow targeted materials off of a conveyor belt. Optical sorters are able to distinguish not only color differences based on visible light but also distinguish different materials, like plastic resins, based on other optical characteristics. Optical sorters are used by glass beneficiation plants to separate glass by color, but are more commonly used to sort plastics in MRFs. The higher market values for plastics, as compared to glass, make the acquisition of an optical sorter more economically viable. Over 70% of the MRFs with optical sorters have units to sort plastics, 17% have units that sort fiber, and 12% have units that sort glass. Two methods exist to feed material into the optical sensors. A singulated feed presents the objects one by one. This process is relatively slow and not well suited to a commingled recyclables stream. The more commonly used method is the mass feed, which presents a single layer of materials spread across the width of the conveyor belt to the optical sorter. Two sensors can be used in series to increase the sorting purity or to sort another stream. A common type of optical sorting equipment used in MRFs today employs Near Infrared (NIR) spectroscopy. In this method, the optical sorter exposes each piece of material to a light source such as a halogen lamp as the material moves past on the conveyor. A microprocessor within the optical sorter analyzes the quality of reflected light coming off of the material to determine its molecular composition. This unique molecular composition identifies the material for separation.

- **Near infrared sensors (NIR)**: When materials are illuminated they mostly reflect light in the near infrared wavelength spectrum. The NIR sensor can distinguish between different materials based on the way they reflect light.

- **X-ray technology** : X-rays can be used to distinguish between different types of waste based on their density.

- **Glass Cleanup Systems**: Single stream and especially mixed waste MRFs generally experience a higher degree of glass breakage than dual stream MRFs. As communities and processing facilities strive to maximize waste diversion, systems are being utilized to clean up or recover glass cullet from shredded fiber, dirt and

Figure 2.5: Unsorted Garbage being dumped [13]

other debris in the residue stream. Systems can have modular components, such as vibrating screens and air separation, to fit the specific needs of a facility. Unlike glass bottles, which can be used to manufacture new glass bottles, glass cullet is usually marketed for non-container uses, such as construction aggregates, insulation applications, and paving materials.

However, locally, due to the lack of resources to invest in the above technologies, sorting of garbage is either done manually or its ignored completely as shown in figure 2.5 .

Several universities globally have attempted to design and prototype waste separation machines namely the Automatic Waste Segregator(AWS) [14], Intelligent Waste Separator(IWS) [15], Automatic Smart Waste Sorter Machine [18], Automatic waste segregator [19], Autonomous Material Waste Sorter [20], Waste Segregation using Smart Dustbin [21].

2.1.2 Automatic Waste Separator(AWS)

The AWS [14] was designed to categorize the refuse into metallic waste, wet waste and dry waste. It employs parallel resonant impedance sensing mechanism to identify metallic items, and capacitive sensors to distinguish between wet and dry waste. Waste is pushed through the flap of the system. An IR proximity sensor detects this and starts the entire system. Waste then falls on the metal detection system. This system is used to detect metallic waste[14]. After this, the object falls into the capacitive sensing module. This module distinguishes between wet and dry waste. After the identification of waste, a circular base which holds containers for dry, wet and metallic waste is rotated. The collapsible flap is lowered once the container corresponding to the type of garbage is positioned under it. The waste falls into the container and the flap is raised. The waste in the containers now can be collected separately and sent for further processing.

- **Entry System and Initialization**: The waste is dumped manually into the waste incline by pushing it through the flap. It is important to note that this is done one by one, a single waste at a time as shown in figure 2.6 . The flap comes in the proximity of the IR which marks the entry of the waste, thus the system is initialized.
- **Metallic Detection System**: The object moves over the incline and falls on the inductive coil. If it is a metallic object, eddy currents are induced on its surface. This generates a magnetic field which opposes the original magnetic field which is generated by the coil. If the data obtained from the sensor exceeds a set threshold, the object is hence inferred as metallic. The waste continues down the second incline towards the apex. If the type of garbage is not metallic then the capacitive sensing module continues to sense the object, else the sensing module is stopped and the actuators are activated.
- **Capacitive Sensing module**: The property used for segregation of waste is the relative dielectric constant. Once a dielectric is introduced between the plates of

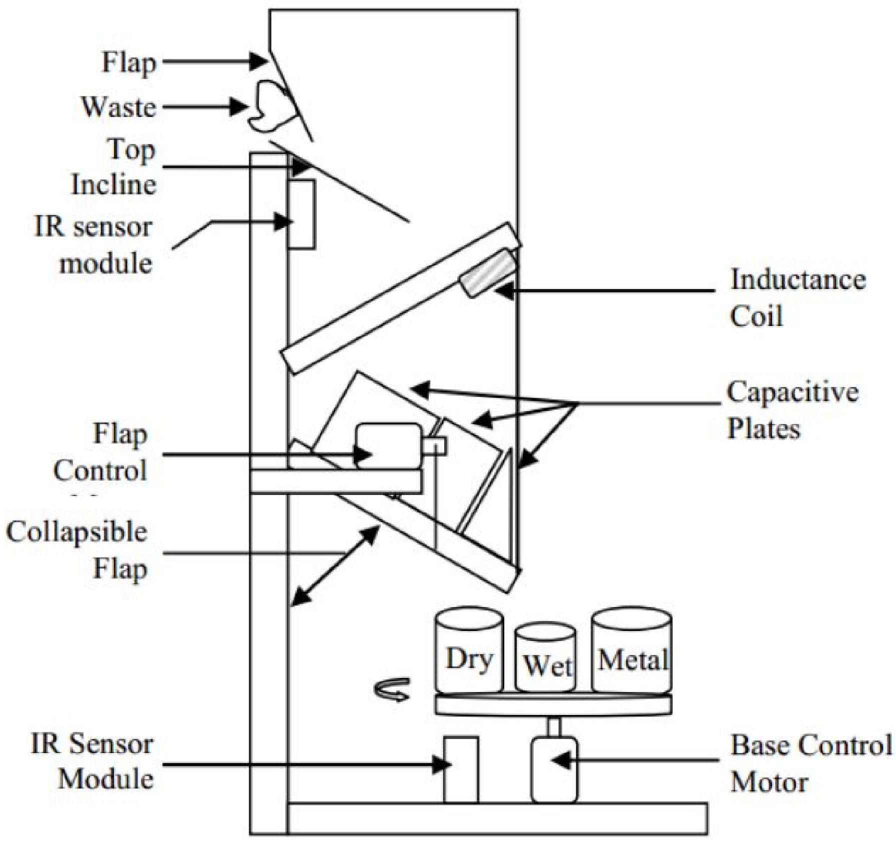

Figure 2.6: Automatic Waste Separator [14]

the capacitor the capacitance increases. Wet waste has a higher relative dielectric constant than that of dry waste because of the moisture, oil and fat, content present in kitchen waste. If the change in the capacitive count is greater than threshold then the type of garbage is inferred as wet waste else it is dry waste. Since the capacitance value of the plates is different, the change observed for the same object by the different plates is different. Hence different threshold levels are assigned for each pair of capacitors. Thus, the type of waste is identified as either wet or dry and the actuators are activated.

- **Segregation Module**: To achieve the segregation, two DC geared motors are used. They are cheaper as compared to the stepper motor and provide a solution suitable for this application. The containers are placed on a circular base which is mounted on the axle of a DC geared motor. The circular base rotates as the axle of the DC geared motor rotates. An IR sensor module is positioned under the circular base such that it generates an interrupt when the required container positions itself under the flap. This interrupt is used to stop the motor by the microcontroller. To avoid overshooting of the container due to the momentum of the base, the DC motor is rotated at lower speeds by using pulse width modulation (PWM) which is generated from the microcontrollers timer. Once the required container is positioned under the flap, a second DC geared motor lowers the collapsible flap by rotating the motor clockwise by 45 it then waits for 2 seconds to ensure that the waste falls down and finally raises the flap back to the initial position by rotating the motor anti clockwise by 45. PWM is used to rotate the motor. Thus the segregation is complete and the detected garbage type is stored to determine the direction of rotation for the next iteration. After this the microcontroller is put to low power mode until the entry of the next waste material into the system.

2.1.3 The Intelligent Waste Separator: Machine Learning

The Intelligent Waste Separator (IWS) [15] developed by students from Jesuit University of Guadalajara consists of a common trash can, with more containers inside it, using multimedia technology. Waste is thrown into the system one item at a time and the system determines which material it is made from. The prototype distinguishes between three different kinds of inorganic waste; aluminum cans, plastic bottles and plastic cutlery. The process to identify the waste is split into three categories; image processing, characteristic extraction and machine learning. The output of each step is the input to the next step.

Figure 2.7 shows the system diagram. It gives a general idea of how the IWS works and of the connections between the different blocks. First, the system starts when the button in the graphic user interface (GUI) represented by the touch screen is pressed. It triggers the system and the process in the multimedia processor (MMP) begins. Second, the webcam that is connected to the USB port takes an RGB image of the waste shape and sends

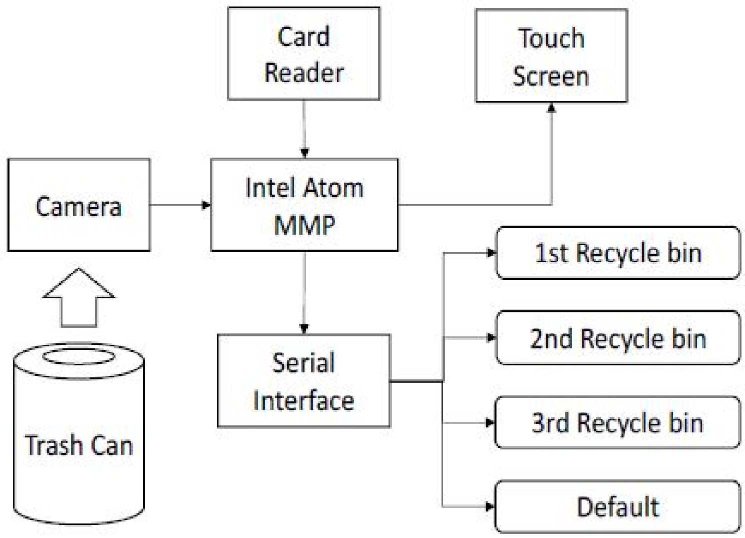

Figure 2.7: Intelligent Waste Separator[15]

it to the MMP. The latter processes the image in order to get the features of the waste. The system classifies the target based on the first two Hus Invariant Moments (HIM) in conjunction with the k-Nearest Neighbor (k-NN) [16] algorithm by using the Euclidean distance. Third, when the object is classified, the MMP sends a signal through the serial interface indicating which gate is to be opened. If the waste was not recognized, it is deposited in the default container. Figure 2.8 shows the system structure of the IWS system. In order to deposit waste in the corresponding container, the previous steps are needed.

Waste Identification

The IWS distinguishes between three different kinds of inorganic waste mainly aluminium cans, plastic bottles, and plastic cutlery. The model was first trained using the images of the three selected wastes to be sorted. The process to identify waste is split into three steps: image processing, characteristic extraction, and machine learning as shown in figure 2.9 The output of each step is the input to the next step.

Figure 2.8: Intelligent Waste Separator Model[15]

Image processing consists of converting an RGB image to grayscale and then binarizing it. This stage removes the unnecessary features from the image. The image is acquired by a Microsoft Webcam VX-6000 and converted to grayscale. The grayscale conversion consists of calculating the average value of the three components of the image: red, green, and blue. To accomplish that, a function from OpenCV library is used. After the grayscale image is obtained, it is binarized. To make the gray scale image with only two colors (0 and 255, respectively), the binarization process is applied. A fixed threshold, 127 in this case, is used to specify which intensity of color values are converted to 0 and which, to 255. Training is defined as guidance of a system to begin the classification stage. The k-NN classifier [16] is an effective classifier. It classifies a new item by searching for its k nearest training items (neighbors) according to a distance metric. In this case the Euclidean distance is used. Then, the new item is classified as belonging to the most common class defined by the majority vote of its k nearest neighbors; in this implementation $k = 3$. In

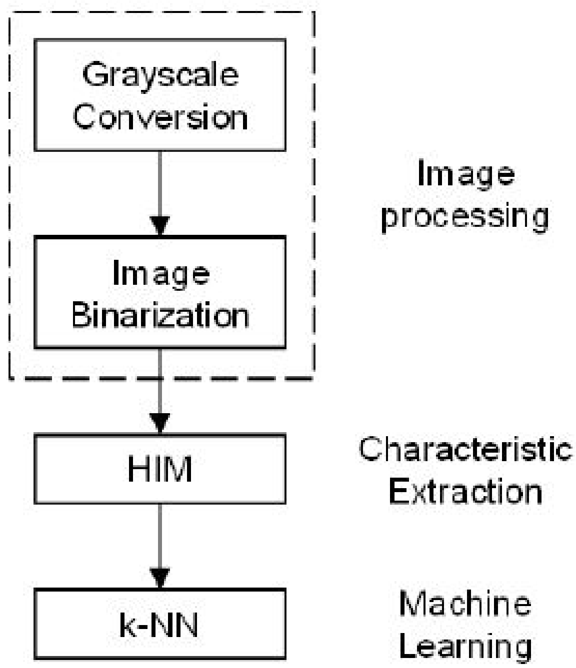

Figure 2.9: Waste identification process [15]

a case of ties, two or more classes collecting the same number of votes can be resolved by choosing one of the common classes randomly or the class of the nearest neighbor.

2.1.4 Automatic Smart Waste Sorter Machine

In the Automatic Smart Waste Sorter Machine [18] designed by students from Chittagong University of Engineering and Technology, the system activates when the IR detects a material is being put on the system tray. The weight sensor activates and finds out the weight of the trash. If the metal sensor detects the material as metal, then a servo actuated valve directs the trash in the allocated bin (which is dedicated for metals). If the glass sensor detects glass then it will perform the same action and put the trash in the allocated bin. If both sensors fail to detect the type of material, the LASER and Light dependent sensors are activated. The LASER is illuminated through the trash which determines the transparency of the material. If the LASER fails to pass then the material is decided as Paper and moves to allocated bin as shown in figure 2.10

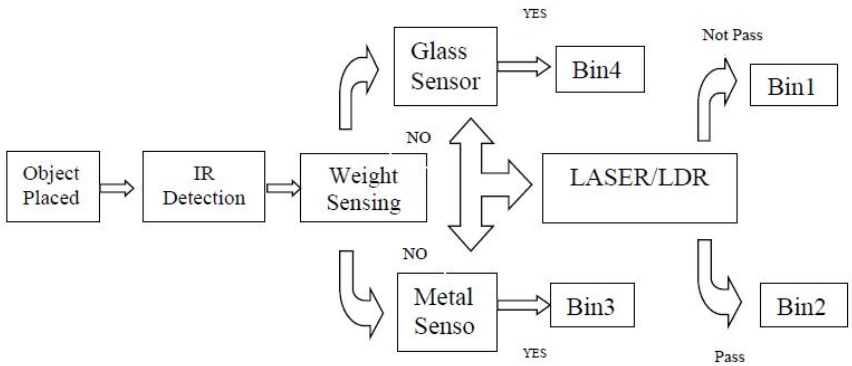

Figure 2.10: Sequential Flow [18]

The Automatic Sorter Machine setup consists of several bins as shown in figure 2.11 . Each bin is used to contain unlike materials. Bin 1 is for paper/glass, bin 2 is for metallic elements, Bin 3 is for plastic elements and bin 4 is for glass particles. At first, the object is placed at the detection zone. The sensor determines the type of material and the servo actuated valve directs the trash into the correct bin as shown in figure 2.12 . The trash has to be placed one item at a time onto the detection zone.

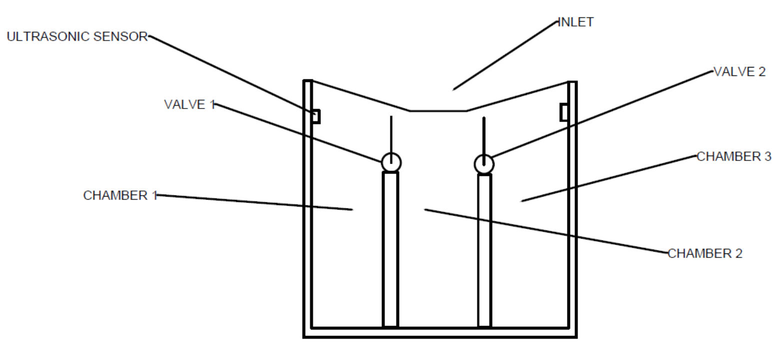

Figure 2.11: System Design [18]

The sorting system consists of Light Dependent Resister (LDR), LASER, Infrared (IR) transmitter and receiver, Metal Sensor (Capacitive proximity sensor E2K-C), glass sensor

(Omron E3SCR67C), Weight Sensor (MLC900 micro weight sensor) and a Liquid Crystal Display (Alpha-numeric 16*4 LCD). The whole program is run by a microcontroller (PIC 16f877A).

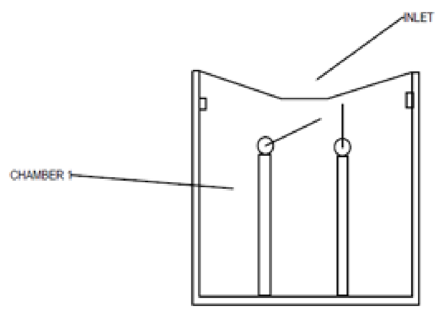

Figure 2.12: System Operation [18]

2.1.5 Automatic waste segregator

The Automatic waste segregator [19] indicated in figure 2.13 was developed by students from M S Ramaiah institute of Techmology.

Open Close Mechanism: The system has an open close mechanism that acts as a regulator to control the waste that falls on the belt. A 12V DC geared motor receives inputs from the microcontroller to monitor the clockwise and anticlockwise motion of the motor. This mechanism is initiated only if the IR sensor detects a waste in its vicinity as shown in figure 2.14 .

Inductive Proximity Sensor: An inductive proximity sensor based on the eddy current principle suitable for detecting conductive targets has been used. Three 12V inductive proximity sensors are used to detect if the incoming waste is metallic or not. This is fed as input to the microcontroller.

Slider section: When the inductive proximity sensors detect a metallic waste, a slider movement is initiated as shown in figure 2.15 which sweeps the waste away after it falls

Figure 2.13: Automatic waste segregator[19]

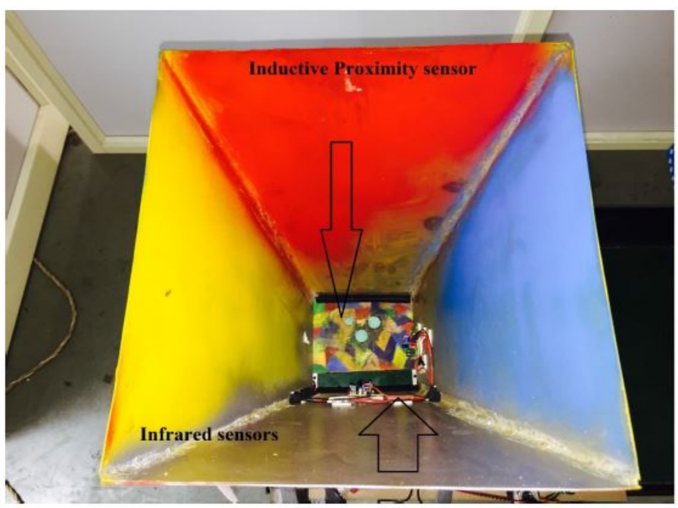

Figure 2.14: Intake System[19]

on the belt. Permanent magnets within the metallic bin aid in sorting magnetic metals from non-magnetic ones.

Blower Section: Dry and wet separation is based on their weight. Due to its high density and weight, wet waste refuses to be blown off even in the presence of a high speed blower.

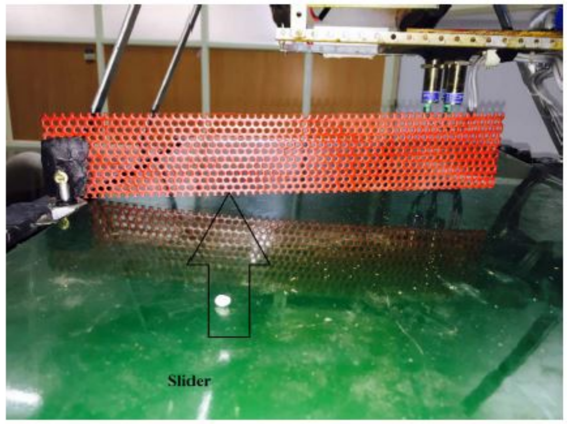

Figure 2.15: Slider Mechanism[19]

This technique is made use of to distinguish wet and dry waste. A relay will control the on and off of a high speed AC blower. As the blower is activated, the belt halts and dry waste is thrown out into the dry bin via a collecting chamber as shown in figure 2.16 . Wet waste stays on the belt and falls off due to gravity at the end of the belt as it rolls.

Figure 2.16: Blowing Mechanism[19]

2.1.6 Autonomous Material Waste Sorter

The Autonomous Material Waste Sorter [20] designed by students from Takoradi Polytechnic, Ghana is made from cardboard and expanded PVC for minimal weight. A 9400 rmp DC motor was gear boxed to spin the AWS at 900 rmp. A sensor detects magnets on each flap to determine loaded material to be sorted. A servo controlled by a micro-processor loads each material one by one from the fully loaded hopper as shown in figure 2.17.

Figure 2.17: Autonomous Material Waste Sorter [20]

Sorting Glass: A trap door was placed under the area where each material falls. The weight of the glass opens the trap door allowing the glass to fall into sorted-glass bin.
Sorting Plastic: The height of the AWS ceiling does not allow the plastic bottle to pass through. The force opens a magnetically closed door and allows the plastic to fall into the sorted-plastic bin.
Sorting Tin: A block fitted with magnets rotates continuously by a DC motor and pulls the magnetic tin container out. The material falls off into the sorted-tin bin.
Sorting Aluminium: Since aluminium is the last material to sort, it simply falls off the end into a sorted-aluminium bin.

2.2 Waste Segregation using Smart Dustbin

The Waste segregation using smart dustbin system [21] was designed by students from Acharya Institute of Technology, Bengaluru. When waste is dumped an IR sensor detects the entry of the waste. The transmitter continuously transmits the signal to detect the presence of an obstacle. When the waste is dumped into the bin, the receiver receives the reflected signal from the waste and starts the sorting process as shown in figure 2.18

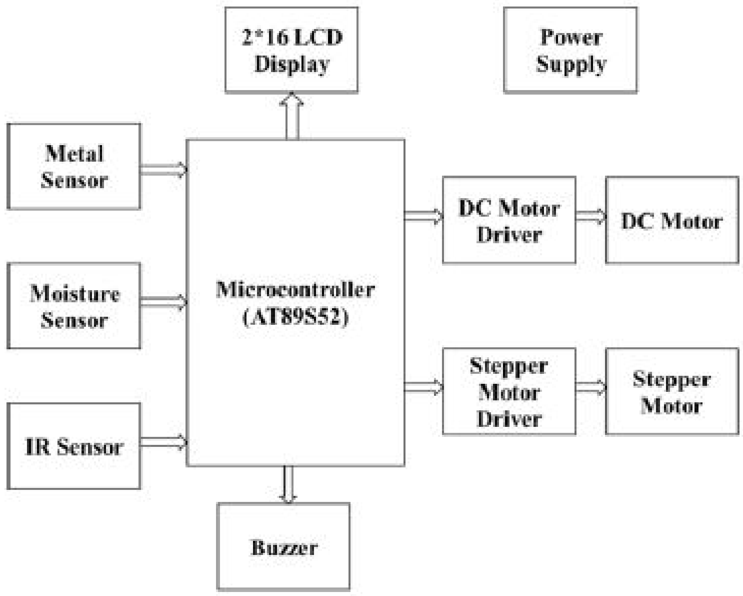

Figure 2.18: Process Flow [21]

Microcontroller AT89S52 is used which is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable Flash memory. The microcontroller in turn activates the dc motor by executing the program to rotate the motor in the forward direction. Two DC motors are used for the smooth rotation of the conveyor belt. Both DC motors rotate in forward direction allowing the waste to be detected by the sensors connected in series along the conveyor belt.

The first sensor connected is the proximity sensor to detect metal waste. This sensor gives accurate results even for smaller objects. The proximity sensor continuously emits electromagnetic waves and the microcontroller continuously checks the status of proximity sensor. If the sensor detects a metallic material, then a suitable bin is selected using a stepper motor. If the waste is not metallic then it passes through another sensor. Microcontroller continuously checks the status of moisture sensor selects the correct bin when a wet material is detected. Three bins are placed in circular manner with an angular separation of 120 degrees as shown in figure 2.19 . Based on the waste detected, the microcontroller activates the stepper motor which rotates the bins to select the appropriate one. A buzzer produces a beeping sound when any one of the wastes in sensed by any one of the sensors.

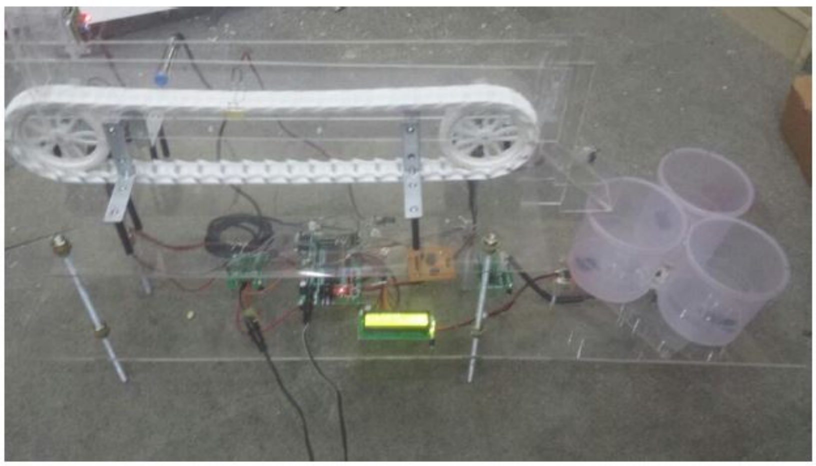

Figure 2.19: System Model [21]

2.3 Gap Analysis

In most of the student projects reviewed in the literature, sorting was only achieved when one item at a time was placed in the sorting chamber. This therefore means, that there is a need to develop a solution that integrates separating and sorting of garbage.

3 METHODOLOGY

Based on the literature review and research conducted, to achieve the effective sorting of the garbage according to the three types of material (glass, plastic and metal), it is necessary to factor in the following stages of operation :

1. **Garbage separation**

   This process entails the separation of accumulated trash into single entities to be fed into the next phase where sorting will take place as illustrated by figure 3.1.

2. **Garbage sorting**

   This process involves the categorization of the provided single entity of waste as illustrated by figure 3.1. The categories of waste in sorting include plastics, metal can, glass and other waste.

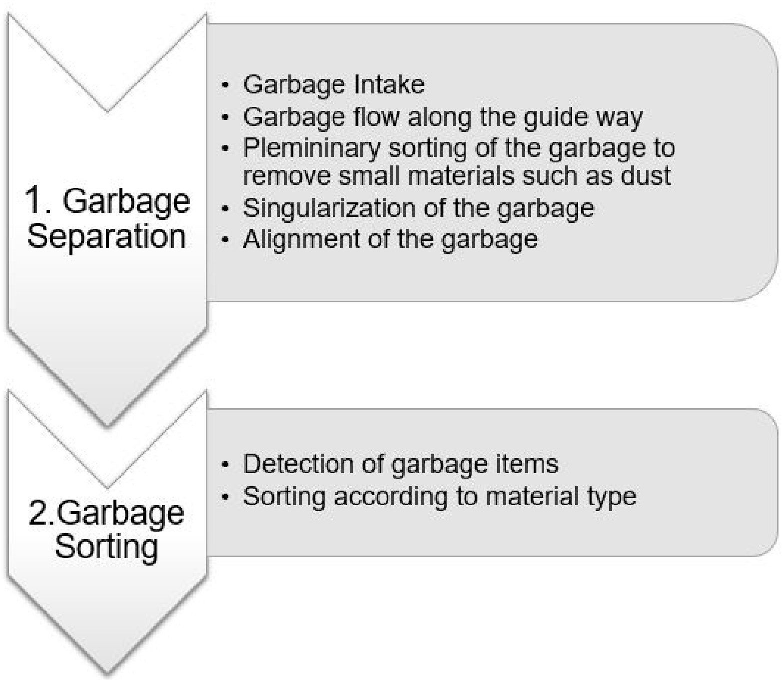

Figure 3.1: Process flow

To develop the system, three modules of a mechatronic system were considered as shown in Figure 3.2

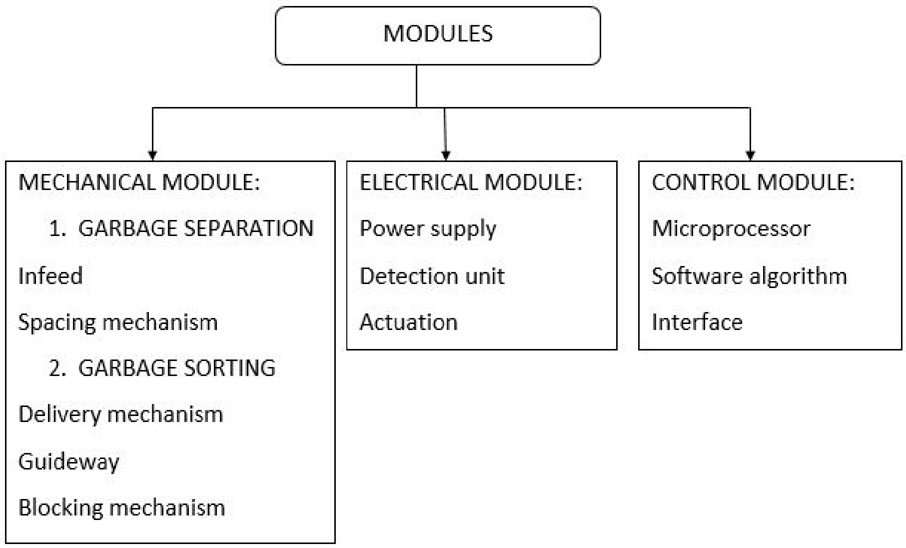

Figure 3.2: System Modules

In the mechanical module, the system structure discussed consists of the in-feed, guide-way, delivery mechanism, spacing mechanism and blocking mechanism. In the electrical module, the mode of power supply to be used is discussed together with the material detection unit and the actuation method. The control module involves the type of micro-controller to be used, software algorithm and the general user interface.

3.1 Mechanical Module: Garbage Separation

This is the first stage where garbage is fed to the system where the key objective is to achieve singularization. The separation system mainly consists of the following sub-systems; in-feed mechanism, guide-way and spacing mechanism.

3.1.1 In-feed Mechanism

This is the location where garbage is fed into the system. Its main function is to act as a reservoir for the garbage as it awaits sorting. In order to design an in-feed system, the following factors were considered:

- Size of the garbage

  The scope of garbage items to be sorted will mainly consist of plastic, glass and metal bottles with the maximum being a 2 litre bottle and the smallest being a 500-millilitre bottle having the dimensions shown in table 3.1 [22]. A 2-litre bottle has a mass of 2140 g when full and 53.61 g when empty with a height of 336 mm and diameter of 101.5 mm. The smallest bottle size to be sorted is a 500 millilitre bottle which has a mass of 532 g when full and 25 g when empty and a height of 223 mm and diameter of 65 mm.

Table 3.1: Bottle Sizes

Bottle size	**Details**
0.5L	Weight: 532 g Height: 223 mm Diameter: 65 mm
1L	Weight: 1073 g Height: 278 mm Diameter: 79 mm
1.5L	Weight: 1600 g Height: 320 mm Diameter:92 mm
2L	Weight: 2140 g Height: 336 mm Diameter: 101.5 mm

- Amount of garbage

  The in-feed system should be designed such that a sixth of the office-sized garbage bin can be emptied to the system. The capacity/volume is such that a standard office sized trash can [23] (with dimensions 235 mm by 180 mm by 265 mm and volume 0.36 cubic metres) can be emptied to the infeed.

- Exit of the In-feed

  The in-feed's exit should be such that it limits the amount of garbage exiting the system. The exit should allow the largest garbage to exit with ease .i.e. the largest bottle of diameter 101.5 mm. It should also be limiting in a way that two of the smallest garbage items of 65 mm diameter each (130 mm combined) cannot exit at the same time. Based on this, the hopper's exit measures 110 mm by 110 mm.

The integration of all the above factors resulted in the design shown in figure 3.3 and figure 3.4 .

The trough shaped hopper's exit was designed such that it can only allow a 2-litre bottle of diameter 101.5 mm to pass at a single instance with some allowance hence it has a dimension of 107 mm by 107 mm. It has a volume of 0.6 cubic metres (length of 390 mm, width of 515 mm, height of 179 mm) which can accommodate a sixth of the normal-sized office dustbin (volume 0.36 cubic metres).

Garbage flow at the In-feed: There is a need for continuous flow of garbage once it is poured into the in-feed system. This will ensure that there is no clogging of garbage in the in-feed system. The design considerations for selecting the method to be used to achieve this include:

- Efficiency-should facilitate free flow of garbage into the guide way mechanism.
- Integration with system -the method selected should be easily integrated within the system without affecting the overall garbage flow.

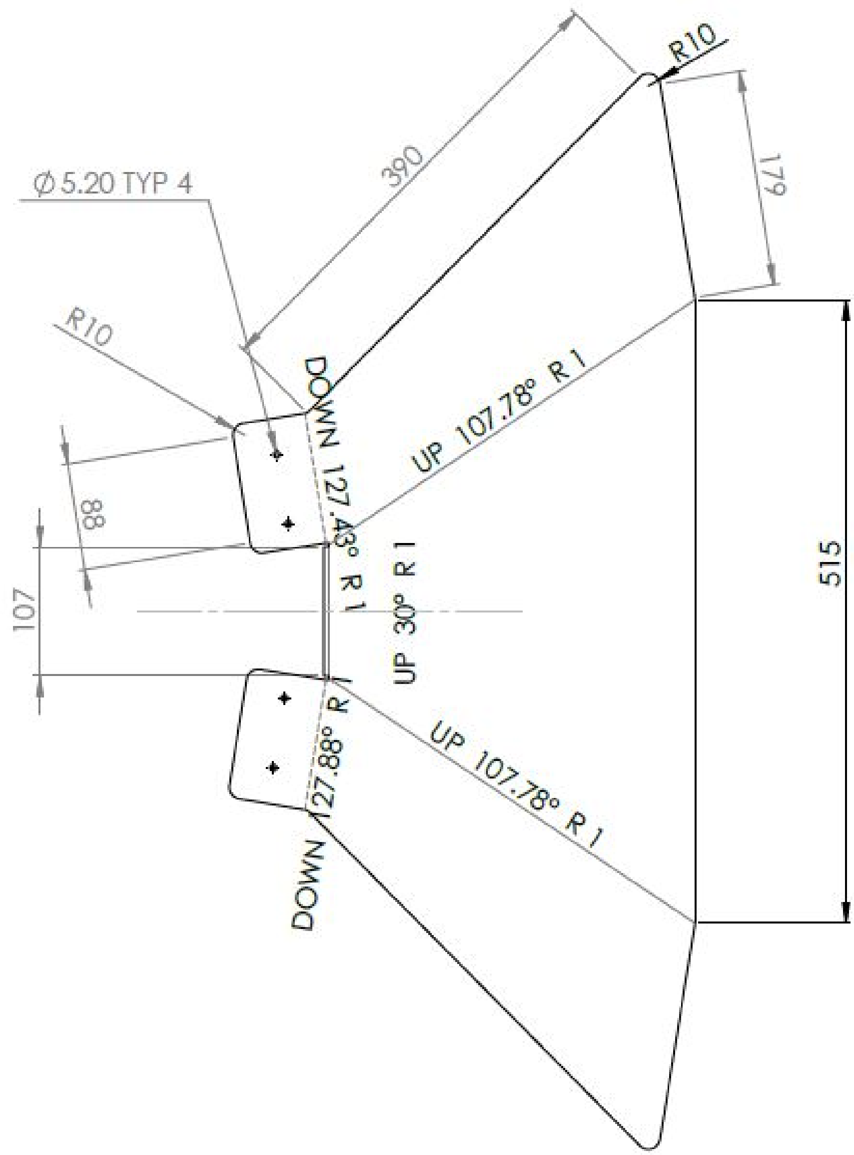

Figure 3.3: Hopper 2D View

To minimize the static friction of the garbage at the infeed and allow the garbage to flow with some acceleration, the infeed is inclined at an angle.

Material of the In-feed: Several materials were considered as shown in table 3.2. The suitable material suited for fabrication of the in-feed system should be corrosion resistant, have a high strength, durable and wldable. Based on these considerations, mild steel metal was selected. To prevent corrosion, the system will be painted upon completion.

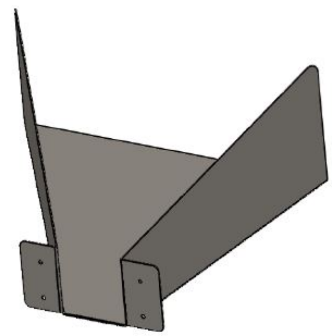

Figure 3.4: Hopper Isometric View

Table 3.2: Material Comparison

Possible solutions	**Availability of material**	**Ease of fabrication**	**Cost**	**Properties of the material**
Galvanised Steel	Readily available	Easy to bend and weld	Expensive	Ductile, corrosion resistant
Mild Steel	Readily available	Easy to bend and weld	Within budget	Ductile, corrosive
Aluminium	Not readily available	Relatively easy	Expensive	Soft, lightweight
Stainless Steel	Not readily available	Difficult	Expensive	corrosion resistance

Fabrication process of the In-feed system

To fabricate the In-feed system, the following processes were followed:

- The outline of the hopper 2D design shown in figure 3.3 was marked on a plain mild steel sheet metal using a scriber.
- The sheet metal was then cut according to the layout of the 2D design using a bench shear machine. A bench shear is usually used for cutting rough shapes out of medium-sized pieces of sheet metal. To cut the extremely delicate parts that could not fit into the bench shear, a hand held angle grinding machine was used. An angle

grinder is a hand-held power tool used for grinding, cutting and polishing using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel's surface cuts a small chip from the workpiece via shear deformation. Grinding is used to finish workpieces that must show high surface quality (e.g., low surface roughness) and high accuracy of shape and dimension. A smooth flat file was used to smoothen the edges and achieve near net shape.

- After the hopper 2D outline had been properly cut out, a bending machine was used to bend the metal to the desired 3D shape. A bending machine is a forming machine whose purpose is to create a bend on a workpiece. A bend is created by using a bending tool during a linear or rotating move. The bending machine was used to acquire only 90 degrees angles. To obtain other angles, a hammer was used to bend the metal to the desired angle while constantly measuring using a protractor.

- A hand drill was used to drill the holes that would be used to mount the hopper to the support structure using fasteners. A drill is a tool fitted with a cutting tool attachment or driving tool attachment, usually a drill bit or driver bit, used for boring holes in various materials or fastening various materials together. An M6 drill bit was used

The dimensions of the fabricated hopper were maintained as per its design with no changes to obtain the final product shown in figure 3.5

3.1.2 Guide-way Mechanism

The guide-way provides the path for the movement of garbage from the In-feed (hopper) towards the sorting mechanism. The main function of the guide-way is to guide the garbage to the sorting system while achieving singularization by feeding a single garbage unit at a time to the sorting mechanism and avoid clogging.

The design considerations for the guide-way mechanism include:

Figure 3.5: Fabricated Hopper

- Geometry

  The geometry should be able to allow the flow of garbage with ease considering the shape of the bottles. It should also assist in aligning the garbage in a vertical manner as it flows towards the sorting mechanism.

- Size of the guide way

  This includes the length and width of the guide way. The length of the guide-way should be able to hold a maximum of two 2l bottles. The width of the guide-way should hold the garbage without falling off taking into account the diameter of the largest bottle being sorted is 101mm and and smallest 65mm .

  The guide way should also facilitate preliminary sorting by allowing smaller sized materials that are not within our scope (i.e less than 65mm diameter) to fall off before being sorted .

- Ease of garbage flow

  The design should allow the garbage items to flow with ease and minimize delay.

Taking into account the above considerations resulted in the design shown in figure 3.6 and figure 3.7

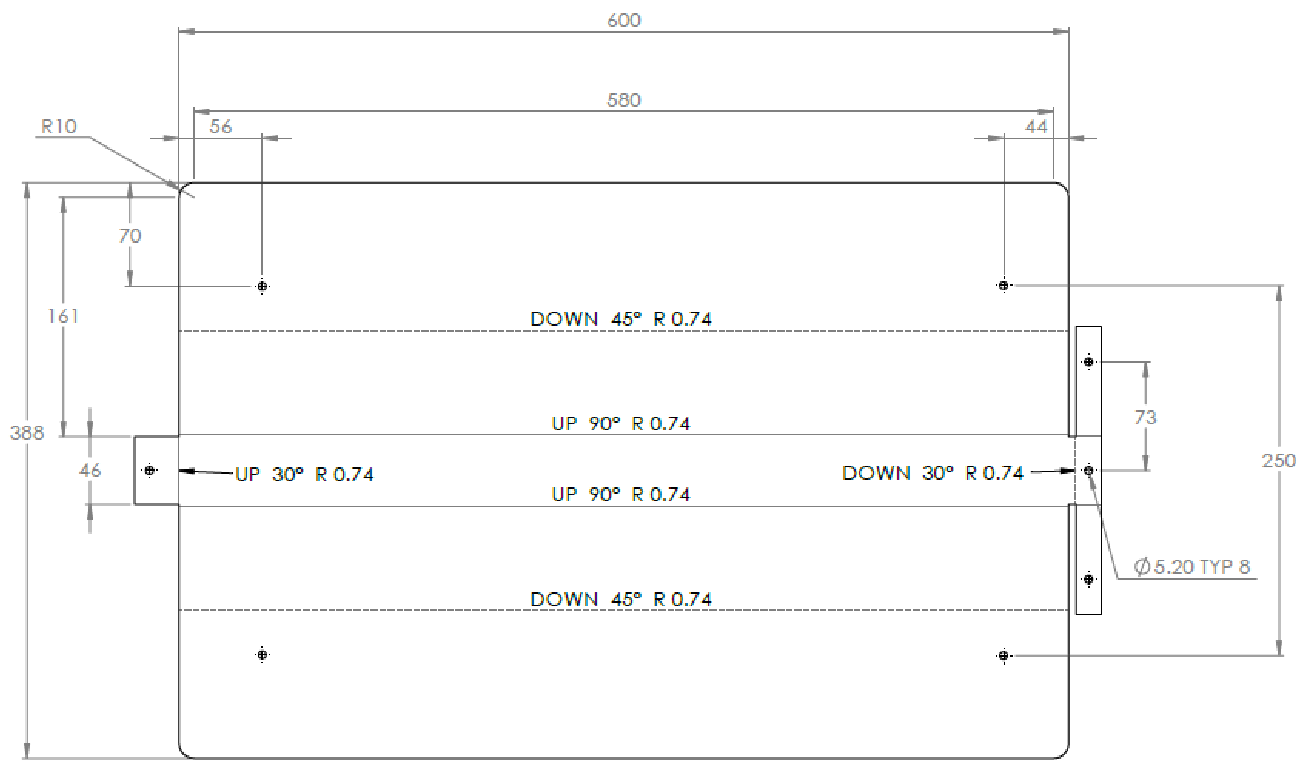

Figure 3.6: Guide-way

The guide-way has a length of 600 mm to accommodate at maximum, two 2-L bottles (600 mm in length) with ease. It has a width of 110 mm to accommodate the largest garbage item of diameter 101 mm being sorted. A slot has been provided at the base to allow preliminary sorting of smaller garbage items. The slot has a width of 46 mm ,thus the smallest garbage item of diameter 65 mm cannot fall into the slot.

Material for the guide way: The same factors analyzed in selecting the type of material to be used in making the in-feed system are also applicable to the guide-way system, hence the use of mild steel in making the guide-way.

Garbage flow in the guide way system: There's need for a continuous flow of garbage once

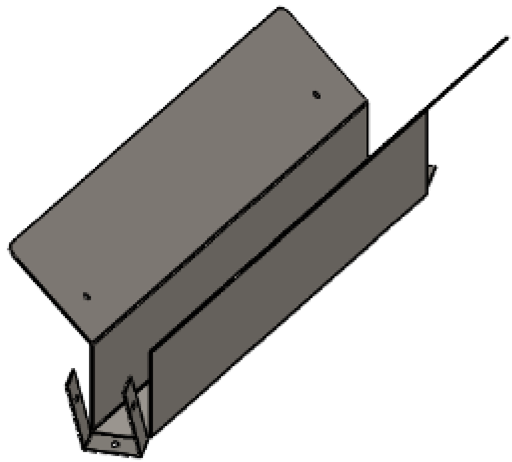

Figure 3.7: Guide-way Isometric View

it enters into the guide way from the in-feed system. The design considerations used for selecting the method to enable garbage flow in the in-feed system are also applied here.

To determine the optimum angle of inclination required for the system, the following considerations were taken into account:

1. Maximum possible mass of the garbage item on the guide-way at a single instance : 2140 grams -This is the mass of the largest bottle that will be sorted.

2. Desired maximum speed

   To determine the speed of flow,the following equation was used

   $$v = \frac{d}{t} \tag{3.1}$$

   where d- distance and t- time.

   Length of the quide-way = 0.6m

   Minimum time required for one garbage item to move across = 2s

   $$\frac{0.6}{2} = 0.3\ m/s$$

3. Desired acceleration of the conveyor

To determine the acceleration required,the following equation was used

$$v = u + at \tag{3.2}$$

where

v= $0.3m/s$ (final velocity)

u= $0m/s$ (initial velocity)

a=acceleration required

t= 1s (acceleration time)

$$a = \frac{v}{t}$$
$$a = \frac{0.3}{1}\ m/s^2$$
$$a = 0.3\ m/s^2$$

4. Coefficient of friction (between steel and aluminium) : 0.47

   With reference to figure 3.8

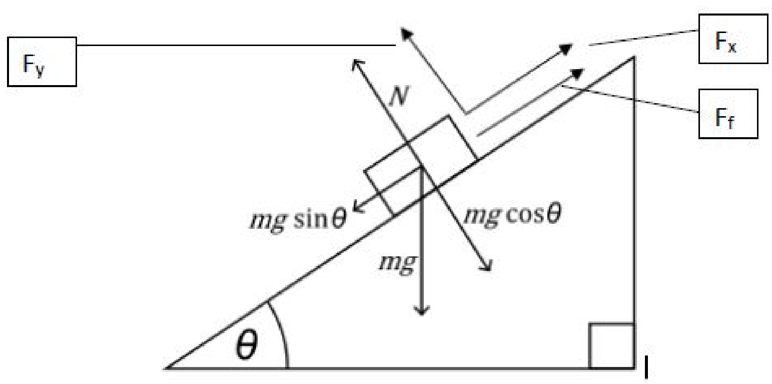

Figure 3.8: Inclination Angle [21]

$$\sum F_x = ma$$

$$ma = F_{gx} - F_f$$

where F_{gx} - force along the x-axis and F_f - frictional force

$$ma = 2.14 \times 0.3 = 0.642\ N$$

$$F_{gx} = F_g \sin\theta$$

$$F_g = 2.14 \times 0.98\ m/s^s = 2.0972N$$

$$F_{gx} = 2.0972 \sin\theta$$

$$F_f = uN$$

$$F_{gy} = 2.0972 \cos\theta$$

$$F_N = F_{gy} = 2.0972 \cos\theta$$

where F_N - Normal force and F_{gy} - force along the y-axis

$$F_f = 0.47 \times 2.0972 \cos\theta$$

$$F_f = 0.9857 \cos\theta$$

Thus;

$$2.0972 \sin\theta - 0.9857 \cos\theta = 0.642 \tag{3.3}$$

From trigonometric identities,

$$\sin\theta = \sqrt{1 - \cos^2(\theta)} \tag{3.4}$$

Replacing $\sin\theta$ in equation 3.3 gives:

$$\theta = 30.51^\circ$$

The desired angle of inclination chosen is therefore 30.51°. However, for ease of fabrication, the angle was rounded down to 30°.

Fabrication process of the Guide-way

To fabricate the guide-way system, the following processes were followed to obtain the final product as shown in figure 3.9.

- The outline of the guide-way 2D design shown in figure 3.6 was marked on a plain mild steel sheet metal using a scriber.
- The sheet metal was then cut according to the layout of the 2D design using a bench shear machine.
- After the guide-way 2D outline had been properly cut out, a bending machine was used to bend the metal to the desired 3D shape. To obtain other angles, a hammer was used to bend the metal to the desired angle while constantly measuring using a protractor.
- A hand drill was used to drill the holes that would be used to mount the guide-way to the support structure using fasteners. An M6 drill bit was used

Figure 3.9: Fabricated Guide-way

3.2 Mechanical Module: Garbage sorting

Garbage sorting is responsible for classifying and segregating the garbage from the separation system. It consists of the delivery mechanism, the detection unit and the blocking mechanism. Once the type of garbage material is identified correctly, it is then directed to the appropriate collecting bin.

The detection unit is meant for identification of the type of garbage, after which the information is relayed to the blockade mechanism to divert the garbage to the collecting bins.

3.2.1 Delivery Mechanism

The delivery mechanism is responsible for transporting the garbage from the guide-way to the collecting bins. The design considerations for the delivery mechanism include:

- Type of motion- The garbage needs to be continuously moving on the sorting system to ensure efficiency of the sorting system.
- The dimensions/size of the garbage- The maximum sized garbage within our scope, the 2- litre bottle should fit in the delivery system.
- The weight of the garbage- The delivery system should be able to handle the total weight of the garbage from the separation system.
- Speed control- There is a need to control the speed of the delivery mechanism such that it will be synchronized with the response of the detection unit.

Taking into account the above considerations, several possible solutions can be used for this purpose. These include the use of a trommel, a chute or a conveyor. The conveyor system was selected for the delivery mechanism since it can allow for speed control, can provide continuous motion, and can handle different garbage sizes and weight without clogging. For the sorting mechanism, the scope is narrowed to sorting a maximum size of 500ml bottles since to sort larger bottles would require a longer conveyor system. The length of the conveyor system is 1560 mm . This takes into consideration the positioning of the detection unit, the size of the mechanical blockades, the positioning of the spacing flap and sufficient space to accommodate two 500 ml bottles on the conveyor at an instance. The conveyor width is limited to only 120mm such that two 500 ml bottles cannot pass through side by side and one 500 ml bottle can be successfully ejected from the conveyor without being stuck.

The dimensions for the selected conveyor housing are shown in figure 3.10 and figure 3.11.

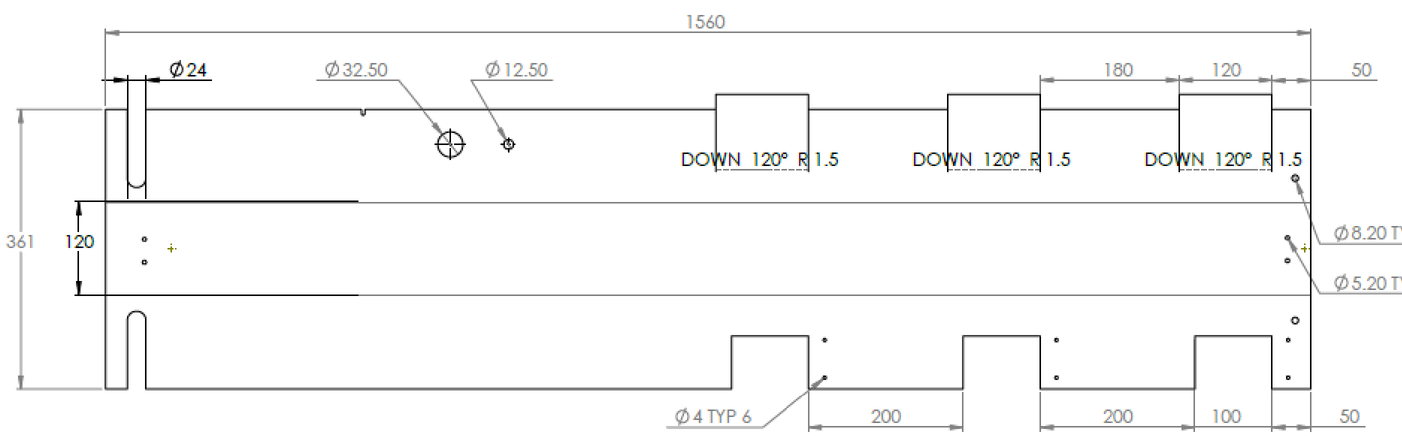

Figure 3.10: Conveyor Housing

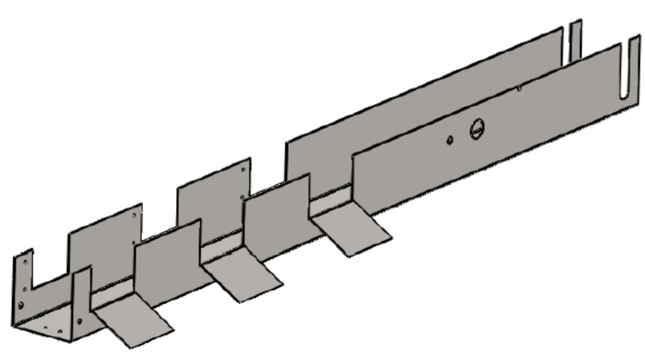

Figure 3.11: Conveyor Housing Isometric View

Fabrication process of the Conveyor

To fabricate the conveyor system, the following processes were followed to obtain the final product as shown in figure 3.12.

- The outline of the conveyor 2D design shown in figure 3.10 was marked on a plain mild steel sheet metal using a scriber.
- The sheet metal was then cut according to the layout of the 2D design using a bench shear machine.
- After the conveyor 2D outline had been properly cut out, a bending machine was used to bend the metal to the desired 3D shape. To obtain other angles, a hammer was used to bend the metal to the desired angle while constantly measuring using a protractor. A hand-held grinder was used to cut the slots to be used to eject the garbage into the respective bins.
- A hand drill was used to drill the holes that would be used to mount the conveyor to the support structure using fasteners. An M6 drill bit was used

Figure 3.12: Fabricated Conveyor

The parts of the conveyor selected include:

1. *Two rollers (Driver and driven)*: The rollers are made of nylon plastic which is easy to machine and provides friction necessary to move the conveyor belt. The rollers to be used should have a length equal to the width of the conveyor to fit within the system space. Based on this, a length of 155 mm was selected for the driver roller. The length accommodates the width of the conveyor which is 120mm and provides an extension for motor coupling. The driven roller has a length of 120 mm which is enough to fit within the conveyor. Their diameter should be smaller than the height of the conveyor. Based on this, the diameter should be between 20 mm to 30 mm. The selected rollers will be 30 mm in diameter which is sufficient enough to hold the weight of the bottles on the conveyor as shown in figure 3.13 and 3.14. The rollers will be enclosed in bearings to facilitate efficiency while rotating with minimum friction. The shielded with retaining ring bearing was selected for this purpose.

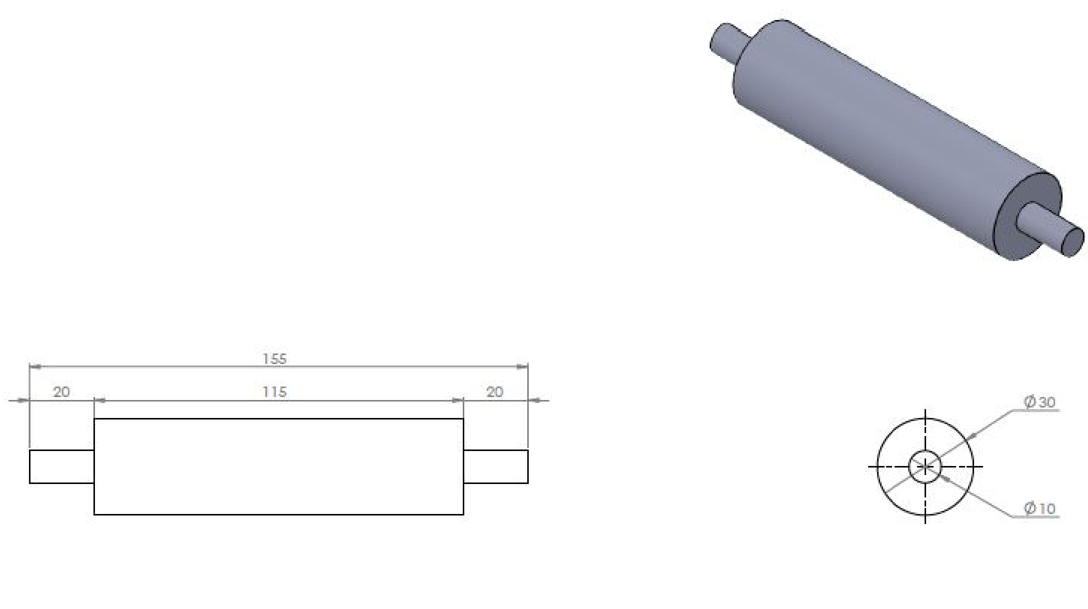

Figure 3.13: Driver roller design

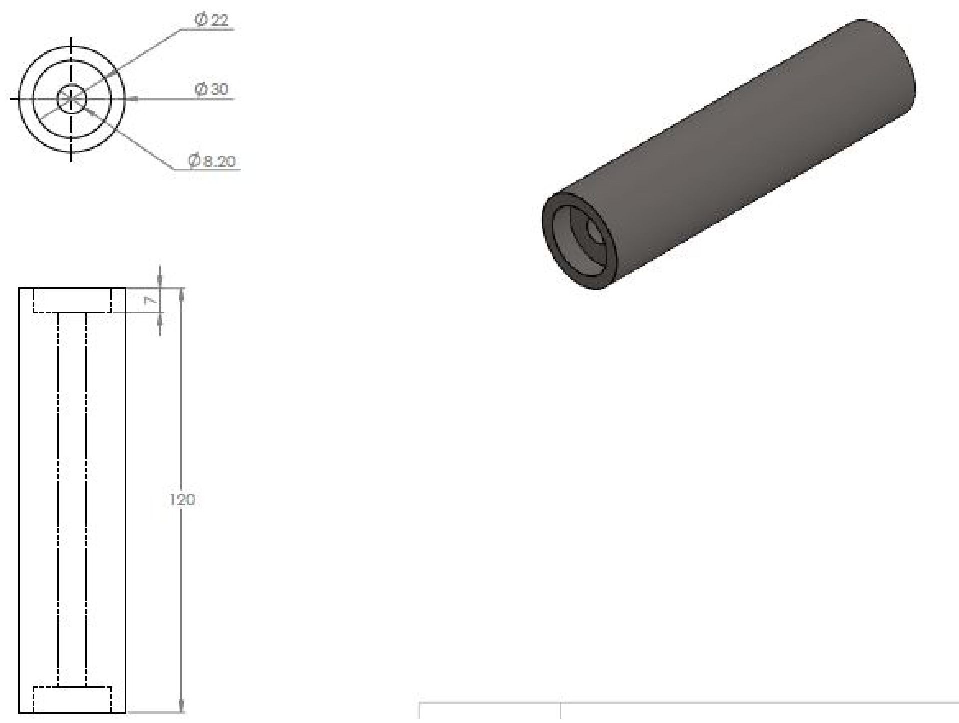

Figure 3.14: Driven roller design

2. *Conveyor belt*: The conveyor belt is made of canvas material which can sufficiently handle the weight of the garbage. The canvas material is suitable for this purpose since it can provide the necessary friction to carry the bottles without slip.

Fabrication process of the rollers: To fabricate the rollers shown in figure 3.15 and 3.16 , the nylon plastic was first faced using a lathe machine to achieve the desired length. It was then step- turned to achieve the desired diameter. A 26 mm drill bit was used to drill the slot where the bearing for the driven roller would be placed. A 12 mm drill bit was used to drill the through hole where a bolt would be placed to allow the roller to rotate freely. The rollers were knurled to obtain the roughness required to grip the conveyor belt. The lathe machine was also used to machine the bearing housing for the driver roller as shown in figure 3.17.

Figure 3.15: Fabricated driver roller

Figure 3.16: Fabricated driven roller

Figure 3.17: Bearing housing

Conveyor System Actuation

The following are the design considerations for selecting the mode of actuation for the conveyor system:

- Type of motion- The actuation method needs to allow for continuous motion of the garbage.
- Weight of the garbage- The torque of the motor should handle the weight of the garbage in the delivery system.
- Speed control- The mode of actuation should be able to control the speed of the conveyor system to enable the synchronization with the detection unit in the sorting system.

Several actuation mechanisms can be used for this purpose as shown in table 3.3 . These include dc geared motor, servo motor, stepper motor and linear pneumatic actuators. However, the dc geared motor was selected since it can provide a wide range of torque requirements, ease of speed control and is relatively cheap compared to linear or stepper motors. It is also suitable for use in conveyor systems.

Motor Sizing

In order to achieve motion of the conveyor, a motor will be coupled to a roller to provide the torque and speed needed to move the garbage unit to the sorting unit. The motor motion required should be unidirectional since the garbage materials will be moving in one forward motion without reverse.

DC motors were considered since speed variation can be achieved by varying the voltage supplied to the motors. This will ensure that the garbage units at the conveyor can move at a speed sufficient enough to allow a faster sorting operation. In order to determine the motor ratings, the following parameters were used:

Table 3.3: Drive mechanism

Drive Mechanism	**Common Use case**	**Angular motion**	**Continuous motion**	**Torque Capability**	Cost
DC-geared	Mobile robot, pulley, conveyor belt, lifting system.	No	Yes	High Torque High Speed	Relatively cheap
Servo	Control position	Yes (0-180 degrees)	No	Low Torque Low Speed	Cheap
Stepper	Rotation stage	Yes (0-360 degrees)	No	High Torque Low Speed	Relatively cheap
Linear	Sliding door	No	Yes	High Torque Low Speed	Expensive

1. Total Mass

   - Maximum possible mass of garbage on the conveyor at single instance

     3 2-litre bottles (2140 $g \times 3$)= 6420 g : The 2140 g for full bottles was used as a safety factor.

   - 2 Nylon rollers (53.25 $g \times 2$) = 106.5 g

   - Conveyor belt = 200 g

     Total Mass : 6.727 kg

2. Desired maximum speed of the conveyor

   To determine the speed required for the conveyor,the following equation was used

$$v = \frac{d}{t} \tag{3.5}$$

   where v-speed, d-distance and t-time.

   Length of the conveyor = 1.45 m

   Time required for one garbage item to move across = 5 s

$$\frac{1.45}{5} = 0.29\ m/s$$

3. Desired acceleration of the conveyor :

   To determine the acceleration required for the conveyor,the following equation was used

   $$v = u + at \tag{3.6}$$

   where
   v= $0.29m/s$ (final velocity)
   u= $0m/s$ (initial velocity)
   a=$0.29m/s^2$ (acceleration)
   t= 1s (acceleration time)

   $$a = \frac{v}{t}$$

   $$a = \frac{0.29}{1}\ m/s^2 = 0.29\ m/s^2$$

4. Roller diameter : 0.02 m (radius - 0.01 m)

5. Angle of Inclination of the conveyor : 0 degrees

6. The rolling friction and air drag are negligible

The motor speed ratings can be determined by the following :

$$n_w = \frac{v}{w_c} \tag{3.7}$$

$$n_w = \frac{v_{max}}{2\Pi\,(R_w)} \tag{3.8}$$

$$n_w(RPM) = \frac{0.29\,m/s}{2\Pi\,(0.01\,m)} \times \frac{60\ sec}{1} = 276.93\,rpm \tag{3.9}$$

where n_w- revolution of the wheel, v- velocity, w_c- wheel circumference, R_w- wheel radius.

The no-load speed rating of the motor should therefore be greater than 276.93 rpm in order to compensate for loss of speed due to the weight of the conveyor and any friction incurred.

Torque ratings for the conveyor motor

With reference to figure 3.18 and 3.19

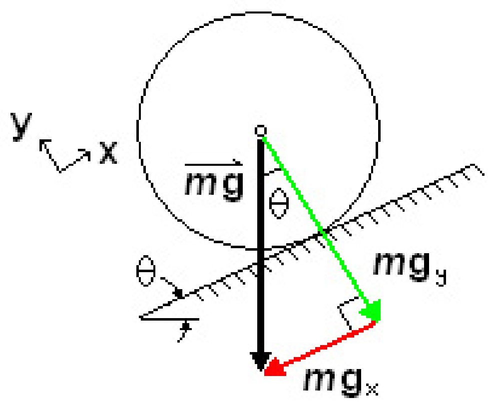

Figure 3.18: Motion of a wheel [26]

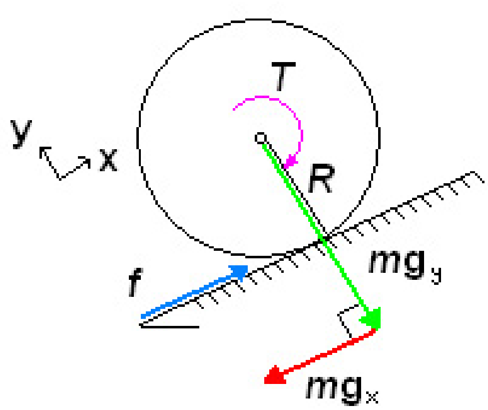

Figure 3.19: Motion of a wheel [26]

where M- total mass of the conveyor contents, a- acceleration of the conveyor, N- number of motors to be used on the conveyor, Mg_y is balanced by the normal force the surface exerts on the wheel.

$$mg_x = M \times g \times sin\theta \quad (3.10)$$

$$\Sigma F(x) = 0 \quad (3.11)$$

$$Therefore \quad Ma = f - (M \times g \times sin\theta) \quad (3.12)$$

$$f = M(a + g \times sin\theta) \quad (3.13)$$

$$T = f \times R \quad (3.14)$$

$$T = MR\,(a + g \times sin\theta) \quad (3.15)$$

$$T = \frac{MR\,(a + g \times sin\theta)}{N} \quad (3.16)$$

$$T = \frac{6.727 \,\text{x}\, 0.01\,(0.29 + (9.81 \times sin0))}{1} \quad (3.17)$$

$$= 0.0195083\,Nm$$

Taking the required efficiency of the motor used to be 80 percent due to losses that may occur as a result of power losses in the motor due to friction or gearing system (if a geared motor is used), the total power required to be supplied to each motor is calculated as follows;

$$T = 0.0195083\,(Nm)\,\text{x}\,\frac{100}{80} = 0.025\,(Nm)$$

From the above analysis ,a geared motor with the following minimum specifications will be used :

Torque - 0.025 Nm

Speed - 276.93 rpm

The ZGB37RG (eccentric shaft output) geared motor was selected as shown in figure 3.20 and has a speed of 300 rpm which is higher than the required speed of 276.93 rpm and

Figure 3.20: Geared motor [27]

a torque of 8.8 Nm which is higher than the torque requirement. It is suitable for speed control and provides the necessary torque required. It has the following specifications: voltage 12 V DC, rpm; 300, overall length; approximately 7.6 cm, diameter; approximately 4 mm, shaft length: approximately 2 cm, shaft diameter; approximately 0.6 cm. A flexible coupler was used to connect the driver roller to the geared motor as shown in figure 3.21 . The coupler is made of machined aluminium and has a spiral cut that makes it slightly flexible so it can be fit to two shafts even if it is not perfectly co-linear and will help reduce binding effects.

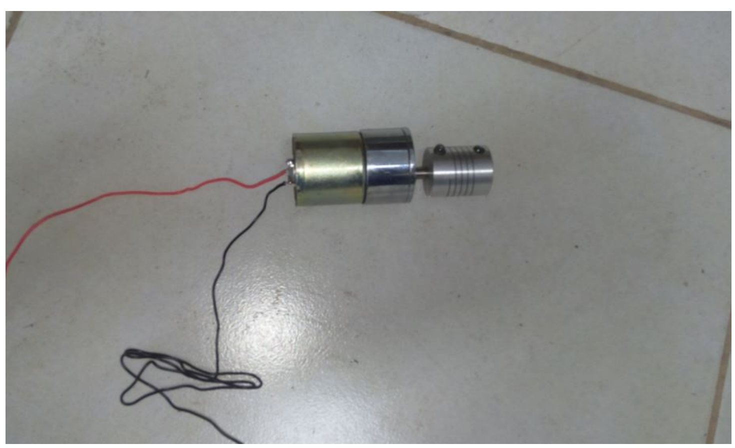

Figure 3.21: Motor connected to the coupler

3.2.2 Geared motor driver selection

To optimally drive the geared motor and facilitate ease of speed change, a motor drive is required. The design considerations for selecting the motor driver for the geared motor include:

1. Speed control- the controller should be able to effectively control the speed of the geared motor of the conveyor by varying the analog signal supplied to it by the microcontroller. This needs to be adjusted depending on the response of the sensors in the detection unit.
2. Power requirements- The controller should be able to withstand the power drawn by the motor during its operation. The voltage of the motor selected is 12V.
3. Cost- The cost of the controller should be within the budget

The above factors were considered and the L298N driver was selected as shown in figure 3.22. The following are the specifications for the L298N motor driver: the power supply range, Vs, of 7-35 V is within the working limits of the motor, logic part of the terminal, Vss has a range of 5-7 V and a maximum power consumption of 20 W

3.2.3 Spacing Mechanism

The spacing mechanism is meant for slowing down the garbage units to create adequate space in between them. This is done to give each material enough time to be detected and sorted. The design considerations for the spacing mechanism include:

- Efficiency -It can be able to provide sufficient spacing in between the garbage items.
- Positioning of the sub-system .i.e. the best position to place the spacer.
- Whether the weight of the garbage is sufficient enough to go through the spacer.

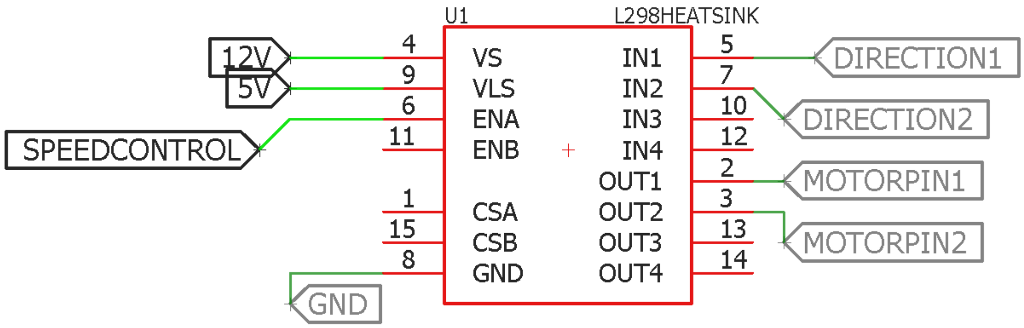

Figure 3.22: Geared Motor Driver Configuration

Taking into account the above considerations resulted in the design of a hinged flap. Factoring the positioning of the spacing mechanism, the hinged flap with a width of 110 mm will be positioned at the entrance of the sorting system in order to provide the space required for adequate sorting. This width is similar to the width of the conveyor.

3.2.4 Blocking Mechanism

The blocking mechanism is used to divert the garbage from the conveyor system to the collecting bin once it has been identified by the detection unit. To design a blocking mechanism used to guide the garbage items to the required bins, the following considerations were taken into account:

- The Material- the availability, ease of fabrication, cost and weight of the material.
- Method of actuation.
- Type of motion- angular motion is required for diverting the garbage from the conveyor system.

From these considerations, several possible solutions were considered as shown in the previous table 3.3. A servo-actuated blocking mechanism was selected as the most feasible system to use because of the angular motion, ease of actuation and cost. The material of the blockade will be aluminium since it is aesthetically pleasing,can handle the weight of the bottles and is within the scope of the budget.

Figure 3.23: Servo Motor MG996 [27]

The geared servo motor- MG996 selected shown in figure 3.23 has the following specifications: operating speed ; 0.17 sec / 60 degrees (4.8V no load) , tall torque ; 9.4kg/cm (4.8 v), 11 kg/cm (6v) ,operation voltage; 4.8 - 7.2 volts.

The size of the blocking mechanism which the servo will be attached to should be greater than $\frac{3}{4}$ the width of the conveyor as shown in the figure 3.24 and figure 3.25. This will ensure that the smallest garbage item is diverted to the collecting bin efficiently.

The servo motor has to be mounted properly to provide the motion required to block the garbage items and guide them to the required bin. The servo motors will be held to the casing of the conveyor using fasteners. To fabricate the blocking mechanism and servo holding brackets, aluminium plates were cut into the required size and bent to the required angle that would deflect the garbage into the correct bin as shown in figure 3.26. The servo motors will be positioned opposite to the exits of the garbage as shown in figure 3.27.

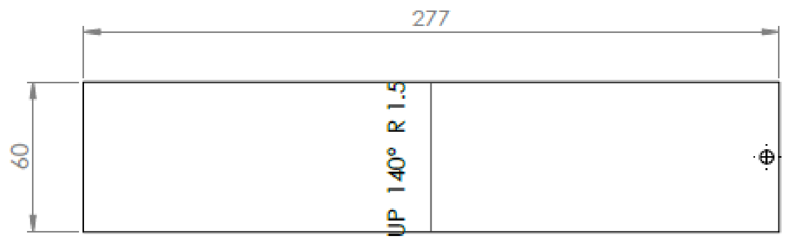

Figure 3.24: Blocking Mechanism-2d

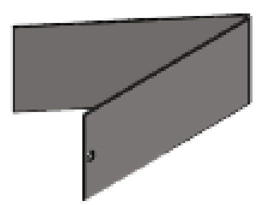

Figure 3.25: Blocking Mechanism-3d

3.2.5 System Support Structure

The following factors were considered while designing the support structure for the system:

1. Geometry of the subsystems.

   The geometries of the subsystems in the garbage separation section and the garbage sorting section have to be considered. In garbage separation, the hopper and in-feed are inclined at an angle of 30° as determined earlier while in garbage sorting the conveyor is not inclined. Therefore, the support structure for the garbage separation has to be higher than that of the conveyor to provide the inclination required. The

Figure 3.26: Deflection plates mounted on the servo

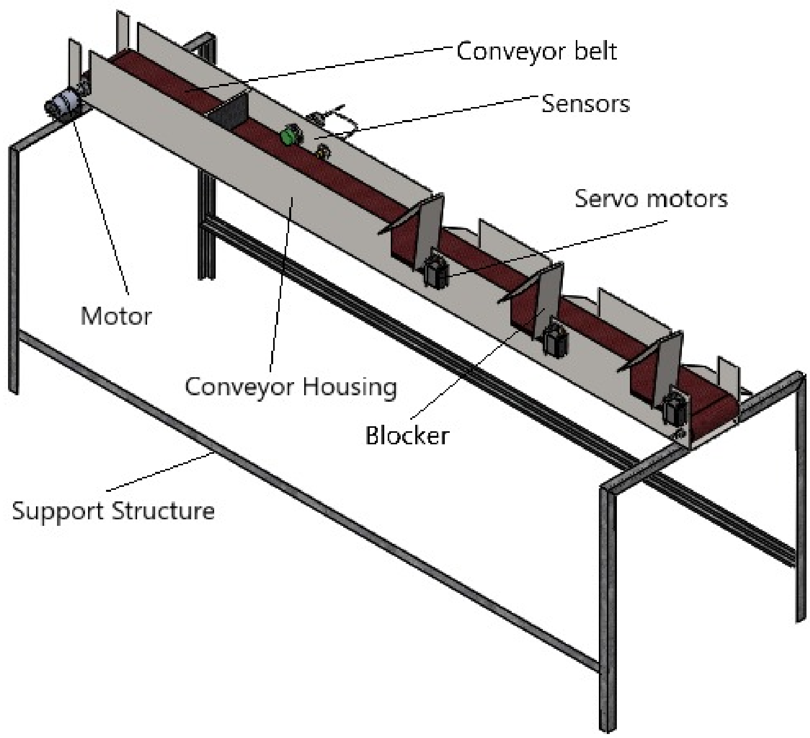

Figure 3.27: Mounting of the servo

size of the individual subsystems was considered while determining the width of the support structure.

2. Ergonomic factors

   Based on the research conducted [24], wherever the tasks at the conveyor require wide-ranging bodily motion and/or physical exertion, then the work should be done from a standing position. The design height should be determined by the degree of exertion required and the dimensions of the objects being worked upon. A range of 65 to 120 cm can accommodate the majority of the workforce and a variety of tasks. As most conveyors have a fixed height surface, it is recommended to fix the belt to a height suitable for the tallest operator.

3. Weight

   To determine the type of material to be used for the support structure, the weight of the system was considered. This is because the weight to be handled will determine how strong and firm the system's support structure needs to be. Most of the subsystems are made of galvanised sheet metal.

Based on the above considerations, the designed structure has the following features:

Garbage Separation: At the infeed, the height of the structure is 1000 mm which is ergonomically fit for operation. The height of the stucture at the guide-way is 670mm which is ergonomically fit. The height difference from 980mm to 670 mm provides the required angular inline of 30° .The complete design is attached under the parts drawing section in the appendix.The structure is 500 mm wide which accommodates all the sizes of the in-feed and the guide-way. The complete design is attached under the parts drawing section in the appendix.

Garbage Sorting: The height of the support structure of the conveyor is 670 mm which is ergonomically fit. It also provides a continuous alignment from the guide-way to the conveyor. The complete design is attached under the parts drawing section in the appendix. The structure is 500 mm wide which accommodates the size of the conveyor. The complete design is attached under the parts drawing section in the appendix.

The material used to fabricate the system support structure is mild steel. This is because it has the structural integrity required to support the weight of the system. Welding is the method of choice used during the fabrication process of the support structure.

Design Changes

3.2.6 System Height

Based on the original design, the system support structure was supposed to be 1000 mm in height at the hopper and 670 mm at the conveyor. However, to reduce material wastage and cut costs on the budget, the height was trimmed from 1000 mm to 600 mm at the hopper and 670 mm to 270 mm at the conveyor. This height changes still maintained the desired angle of inclination and were suitable for purposes of demonstration.

3.2.7 Metal Crushing Unit

Empty metal cans collected at a Materials Recovery Facility (MRF) [7] are usually first separated into steel and aluminium. They are then crushed, baled and sent to re-processors [10]. At the recycling plant, the cans are melted down and poured into large blocks, cooled and then rolled into large coils of thin metal. These coils are then used by manufacturers to make new products, including new tins and cans. Based on this, an additional crushing unit to crush the metal cans after they have been sorted was added to the original design.

Design Considerations of the Metal Crushing Unit

1. Method of actuation- The actuation method needs to provide the necessary torque required to crush the metal cans. An actual testing of a beverage can crusher [30] determined that 220 Newtons was the maximum force input required to fully crush a seamed steel beverage can whereas the force required to crush all aluminum beverage

cans ranged from 22.2411 N to 88 N. The actuator should also have a stroke length that is more than 170 mm and 115 mm which are the lengths of the largest and smallest metal cans that will be sorted.

2. Mounting- The direction in which the actuator is mounted will dictate which drive mechanism is the best. The selected actuator needs to fit within the existing structure without making major changes.

Based on these considerations, several actuators were considered; pneumatic, electrical, hydraulic and mechanical actuators. However due to the ease of actuation and proper mounting, a linear electric actuator was selected. A linear actuator is an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor. An electric actuators best feature in comparison to other actuators is the flexibility of its motion control capabilities. Electric linear control systems allow for user-friendly program control for all motion profile variables. These can also be easily altered in the programs software after the actuator has been placed in its given application. These actuators can also achieve the high forces that hydraulics produce, and are adaptable to rugged environments.

A 12V DC linear actuator shown in figure 3.28 was selected for this purpose. It has the following features; Operating voltage- 12V DC, stroke length- 200 mm, static load- 300N which is sufficient to crush the metal cans being sorted, speed- 30mm/s.

To effectively crush the metal cans after they have been sorted, it was determined that positioning the linear actuator adjacent to the metal bin was the best position as it did not require many design changes to the existing structure as shown in figure. The metal bin has to be made of a material that can withstand the force of the linear actuator. Mild steel was selected for this purpose but an additional angle line would be used to reinforce the bin to avoid collapse during the crushing process. The garbage bins have a overall dimension of 800 mm by 200 mm that are compartmentalized into 3 bins for metal, glass and plastic as shown in figure 3.29. These dimensions were selected as they

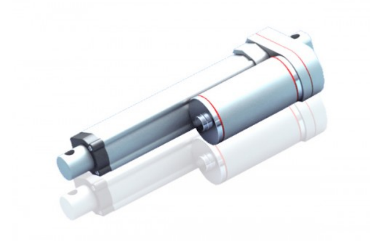

Figure 3.28: Linear Actuator [27]

would accommodate the sorted garbage with ease and they provided the positioning of the bins at the exits along the conveyor as shown in figure 3.30 and figure 3.31 . The linear actuator would transverse along the metal garbage bin whenever any metal has been sorted through a slot that is located on the side-wall. A 20 mm by 20 mm crushing plate is attached to the linear actuator using a holder that would facilitate the crushing process as the actuator is activated. To increase the strength of the bin and the crusher, extra metal bars were added as reinforcement in order to ensure effective crushing of the bins without collapse.

Fabrication process of the crushing unit

The bins were fabricated by marking the 2D outline of the garbage bin as shown in figure 3.29 on a sheet metal. The outline was then cut by a shear machine and bent into the correct angles using a bending machine to obtain the final product shown in figure 3.32.

3.2.8 Spacing Mechanism

The spacing mechanism was tasked with ensuring adequate spacing between two consecutive items as they travel through the conveyor. However, it was eliminated having seen that the prevailing vibration mechanism effected in the separation system provided enough spacing with human intervention when necessary as well as due to budgetary constraints.

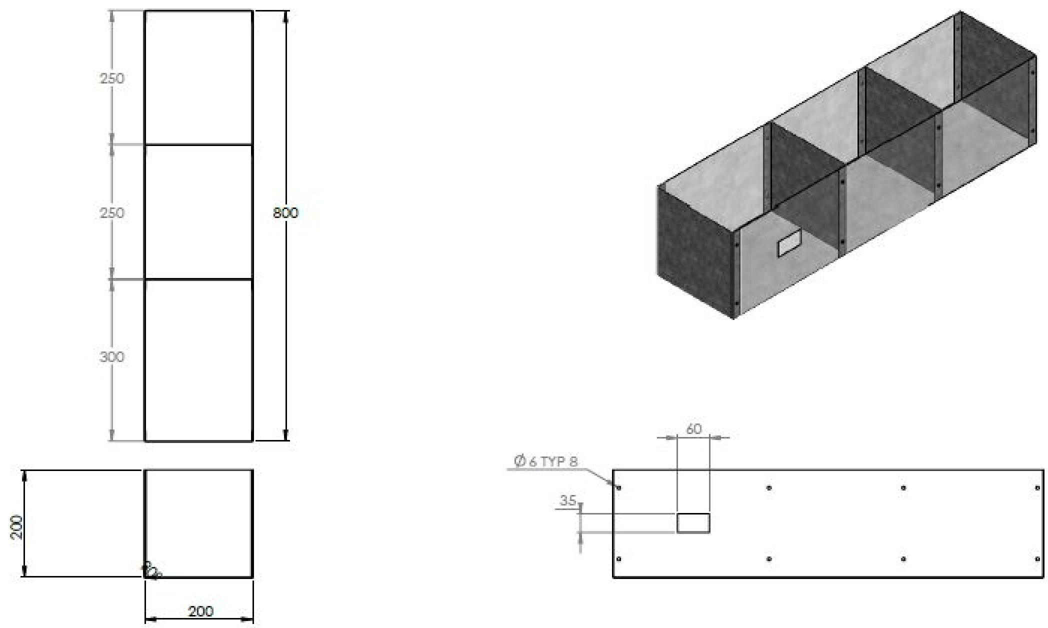

Figure 3.29: Garbage bin design

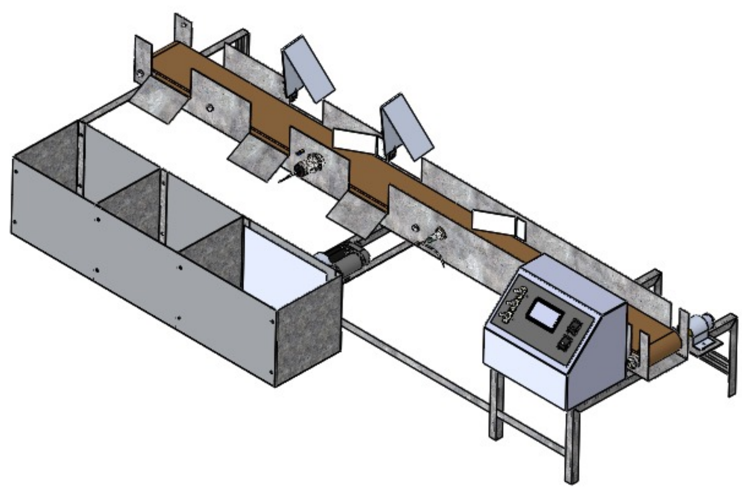

Figure 3.30: Crushing Unit

3.3 Electrical Module

3.3.1 Detection Unit

The detection unit is responsible for the determining of the type of material that each garbage item moving along the conveyor is made of. It is located along the conveyor

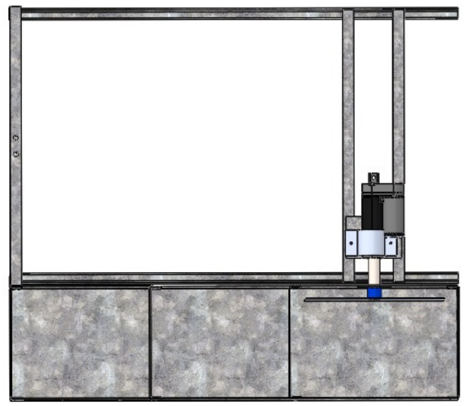

Figure 3.31: Crushing Unit - Top View

Figure 3.32: Fabricated Garbage Bin

just before the blocking mechanism. To determine the type of sensors required for the detection, the following design considerations were considered:

- Sensing Range (3 mm -35 mm)
- Working principle-target material
- Efficiency and Quick response

Taking into account the above considerations, the following sensors were selected and used for the detection process:

1. Inductive sensors

   These non-contact proximity sensors detect ferrous targets, ideally mild steel thicker than one millimeter. When a ferrous target enters the magnetic field produced by an inductive sensor, small independent electrical currents called eddy currents are induced on the metals surface. This changes the reluctance (natural frequency) of the magnetic circuit, which in turn reduces the oscillation amplitude. The change in reluctance is used to determine the presence of a ferrous material as shown in figure 3.33 .

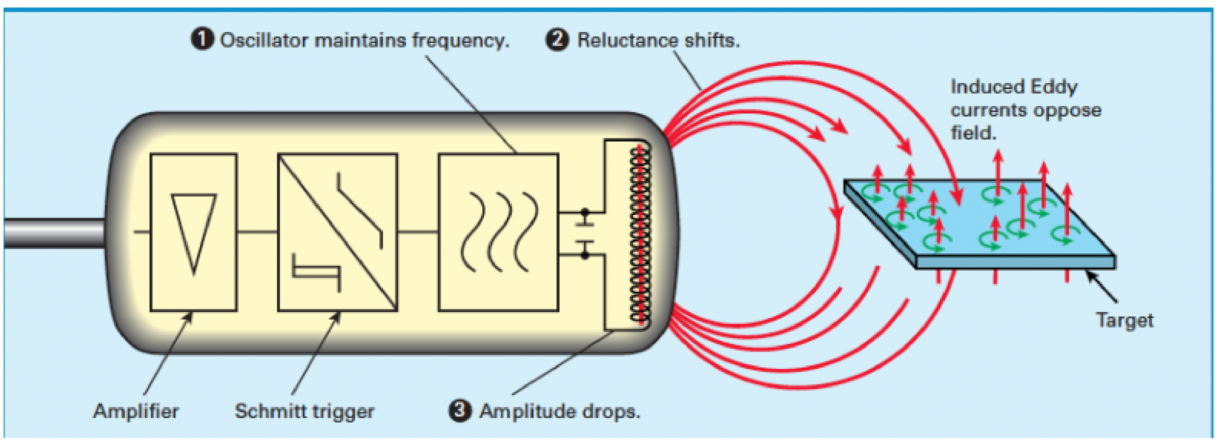

Figure 3.33: Operation of induction sensors [28]

   The selected inductive sensor shown in figure 3.34 has the following specifications: Model LJ12A3-4-Z/BY: output type PNP NO (Normal Open), detecting distance 4mm, supply voltage DC 6-36V, current output 300mA

2. Capacitive sensors

   Capacitive proximity sensors can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form. This, along with their ability to sense through nonferrous materials, makes them ideal. As a target enters the sensing zone the capacitance of the two plates increases, causing oscillator amplitude change, in turn changing the Schmitt trigger state, and creating an output signal.

Figure 3.34: LJ12A3-4-Z/BY Inductive Proximity Sensor Detection [27]

The selected capacitive sensor has the following features :

Model LJC18A3-H-Z/BY: output type ; PNP NO (Normal Open), detecting dis-

Figure 3.35: Capacitive sensor [27]

tance; 1-10mm, detecting object; metal or non-metal material, supply voltage; DC 6-36V; current output; 300mA.

3. Phototransistor or Light dependent resistor plus Laser pointer

   Photo sensors are used in determining varying light intensities. Light Dependent Resistor (LDR), Photo Diode, Photo Transistor and Photo Darlington Pair are some of the commonly used photo sensors. A Phototransistor is an electronic switching and current amplification component which relies on exposure to light to operate. When light falls on the junction, reverse current flows which is proportional to the luminance. Photo-transistors are used extensively to detect light pulses and convert them into digital electrical signals. These are operated by light rather than electric current. The photo-transistor shown in figure 3.36 was used to differentiate between clear glass and plastic based on the light intensity that passes through. To concentrate light towards the photo-transistor, a laser pointer shown in figure 3.37 was used.

Figure 3.36: Phototransistor [27]

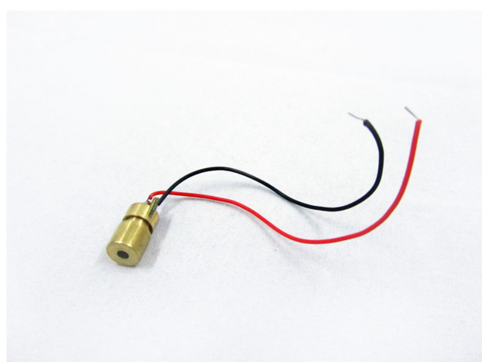

Figure 3.37: Laser Pointer [27]

Sensor Location

The sensors have to be positioned just before the exits along the conveyor to ensure that there is no delay between sensing and actuation of the servo blockades. The inductive sensor is positioned just before the first exit to ensure that once a metallic material has been detected, the servo actuated blockade is activated. The capacitive sensor and the phototransistor are located just before the second exit. They work in collaboration to differentiate between glass and plastic. The sensor range is limited to only 4 mm. To ensure that the garbage material is close enough to the sensors, deflection plates have been positioned along the conveyor to guide the garbage materials towards the sensors as shown in figure 3.38.

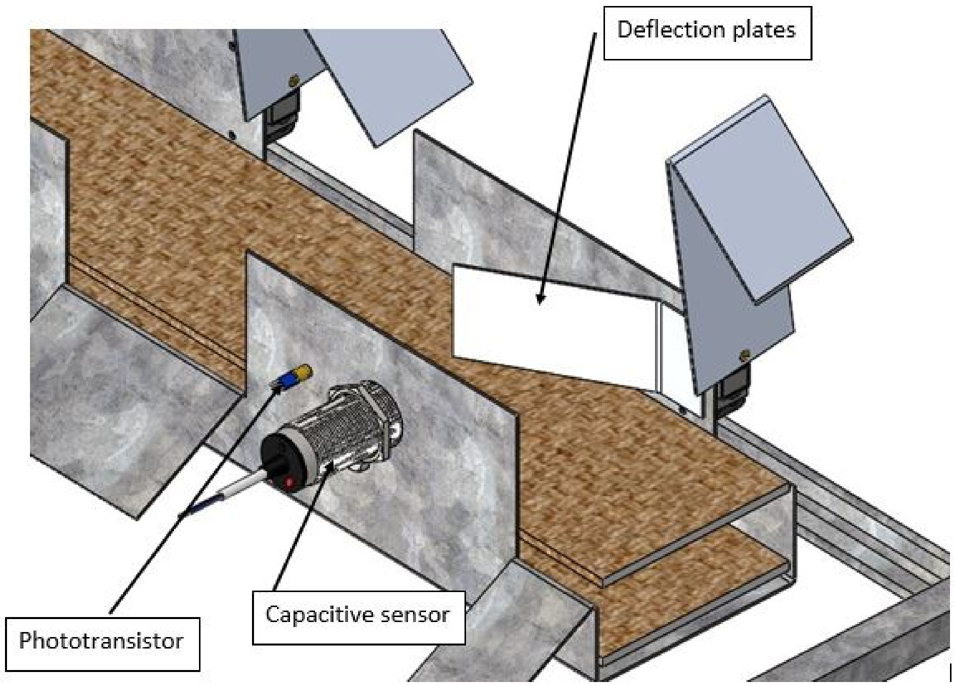

Figure 3.38: Sensor position

3.3.2 Electrical Circuit

The circuit has two main parts namelythe power conversion and the printed circuit board (PCB).

1. **Power conversion**

   Power from the mains line is used to provide power to the system. Several components within the system were considered while designing the power circuit as shown in table 3.4. From table 3.4 , it is clear that the system requires three sets of volt-

Table 3.4: Power ratings

COMPONENT	CURRENT RATING	VOLTAGE RATING
Geared Motor	300mA	12V
Vibration Motor	300mA	8V
Servo Motor	220mA	4.8V - 7.2V
Linear Actuator	300mA	12V
Microprocessor	500mA	5V-9V
Capacitive Sensor	300mA	6-36V
Inductive Sensor	300mA	6-36V
Phototransistor and Laser Pointer	220mA	5V
User Interface	500mA	5V

age levels; 12V, 9V and 5V. To provide power from the mains, the output voltage required is 12v from a 240 V input. Thus, there is need to regulate the voltage. To step down power from the 240 V mains supply, an adapter will be used as shown in figure 3.39

Figure 3.39: Power Adapter [29]

The adapter chosen for use in this case has the following specifications :
Model: PLIU-1077, input; 100-240 VAC , 50/60Hz, output; 12 VDC , 2000mA, adapter size; (approximately) 7 cm x 3.5 cm x 2.7 cm, the cable length: 76.3cm.

Voltage Regulation

Once the power has been stepped down to 12v using the adapter, there is need to further step-down the voltage input to 5V and 9V for use by the other sub-systems as shown in figure 3.40.

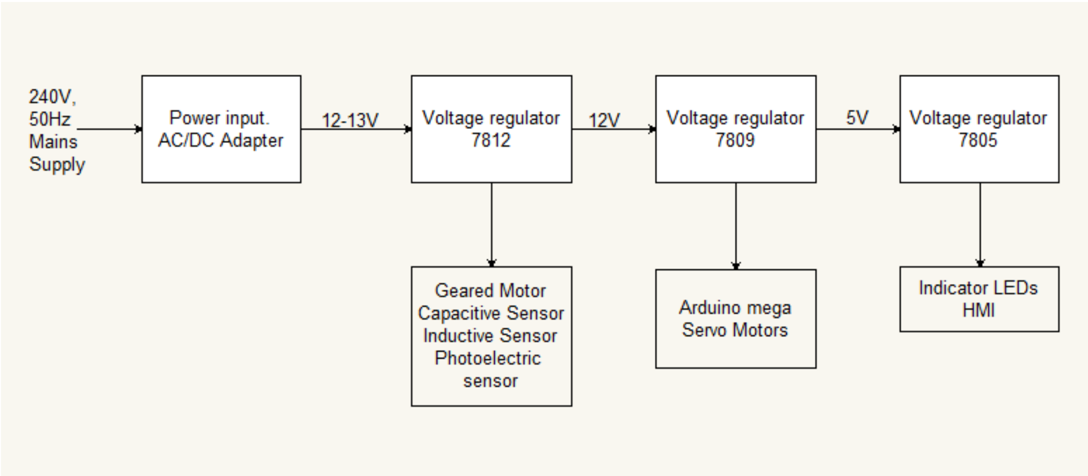

Figure 3.40: Power supply flow

To perform this function, a voltage regulation circuit was used. Some of the components within the voltage regulation circuit are : Voltage regulators,Capacitors and Indicator Light Emitting Diodes.

Selection of Voltage regulators

The TO-220:L78 series voltage regulators were selected because of the following reasons.

- The regulators are affordable.
- They provide several fixed output voltages making it useful in a wide range of applications.
- Each type embeds internal current limiting, thermal shutdown and safe area protection, making it essential indestructible.
- The TO-220 has a provision for the mounting of a heat sink to reduce the heat dissipated in the circuit.

Selection of Capacitors

The selection criteria for the capacitor are :

- The capacitor should provide high frequency characteristics to ensure stable conditions under all load conditions.
- The bypass capacitor should be mounted with shortest possible leads across the regulator input terminals.

Based on these considerations, the 0.22uF was selected.

Selection of Power indicator LEDs

The indicator LEDs show the status of the power supply. This is an important tool to aid in trouble shooting of the circuit in case of power failure. The LEDs require current limiting resistors to prevent damage to the LEDs. To determine the resistor capacity, the following considerations were taken:
Forward voltage= 2.2 V
The maximum current = 20 mA

$$V = I \times R \tag{3.18}$$

$$R = \frac{V}{I} \tag{3.19}$$

$$R = \frac{(12 - 2.2)\ V}{20\ mA}$$

$$R = 490\ \Omega$$

Therefore, the minimum resistor that can be used is a $R = 490\ \Omega$

Factoring in the above power calculations, the power supply circuit is shown in figure 3.41.

The input power from the power adapter enters the power conversion unit through a DC female jack. The output power from the adapter is 12V, 3A. Voltage regulators were used to regulate the voltage to 12V, 9V and 5V. The 12V line is used to power the capacitive sensor, inductive sensor, geared motor and the linear actuator. Due

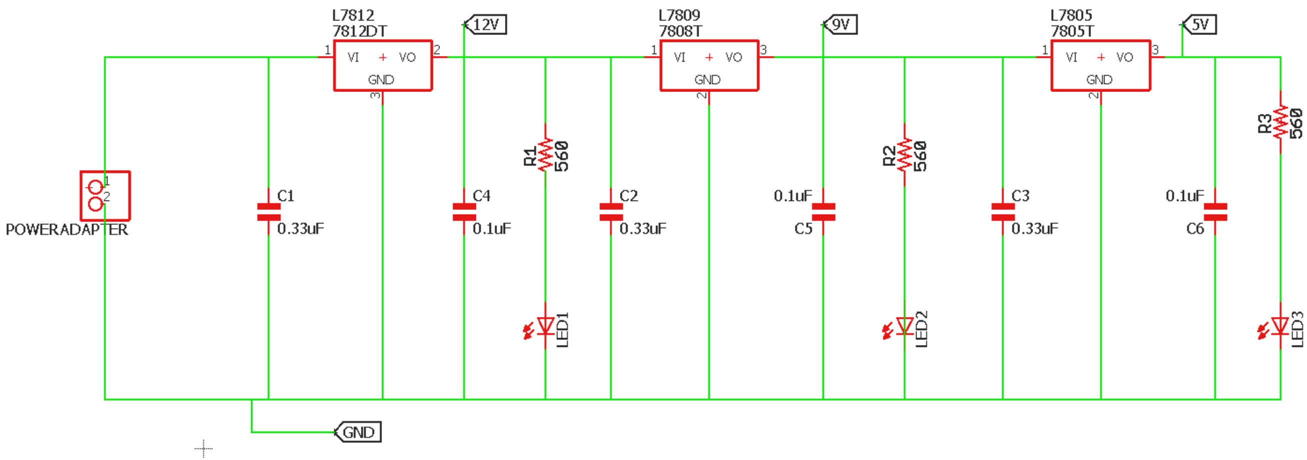

Figure 3.41: Power Supply Circuit

to the current requirement of these components, the power conversion unit was designed in such a way that the LM7812 voltage regulators are connected in parallel with additional circuitry. Therefore, with this connection the current output on the 12V line is 2A in contrast to a single regulator that provides 1A. To protect the circuit from reverse voltage, diodes were connected between the 12V regulators. The 9V line is used to power the microcontroller. The 5V line is used to power the other devices such as the LCDs, servo motors, photo-transistor and the laser pointer. Three LEDs are used to show the status of the various power lines. The voltage to the LEDs is regulated using resistors.

2. **Printed Circuit Board (PCB)**

   A printed circuit board (PCB) mechanically supports and electrically connects electronic components or electrical components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it.

   Controller Mounting: In order to minimize the space on the PCB and reduce the number of wires looped, the controller was mounted on the lower side of the PCB using header pins. This intricate design also ensured the ground of the PCB board and the microcontroller were linked. The controller is powered from the 9V terminal on the board via a DC power jack.

Input/output terminals: Input/output devices are connected to the PCB board via terminal blocks. This ensures that the wires are secured safely on the board to avoid any loose connections. The terminal blocks for the servo motors are located on the upper side of the board, just above the controller. The other terminal blocks are for connecting the L298N motor driver, capacitive sensor, inductive sensor, phototransistor, laser pointer and limit switch. Extra terminal blocks were also added on the PCB for extra analog and digital pins connected to the controller. To aid in controlling the actuators, toggle switches and rocker buttons were added which are positioned on the user interface. The toggle switches are used to turn on the servo motors individually while the rocker buttons are used to turn on the geared motor, linear actuator and the vibration motors. The rocker buttons and the toggle switches are connected to the PCB board via terminal blocks. Factoring all the components in the circuit and the various power lines from the power conversion circuit resulted in the design shown in figure 3.42

Fabrication of the PCB board

To fabricate the PCB, manual etching process was used. Etching is traditionally the process of using strong acid or mordant to cut into the unprotected parts of a metal surface to create a design. Etching is a ”subtractive” method used for the production of printed circuit boards: acid is used to remove unwanted copper from a prefabricated laminate. This is done by applying a temporary mask that protects parts of the laminate from the acid and leaves the desired copper layer untouched. The following steps were followed in the fabrication of the PCB board:

(a) A double-sided copper board was cut to fit the dimensions of the design.

(b) The mirror for the top side and the normal side of the bottom side were printed

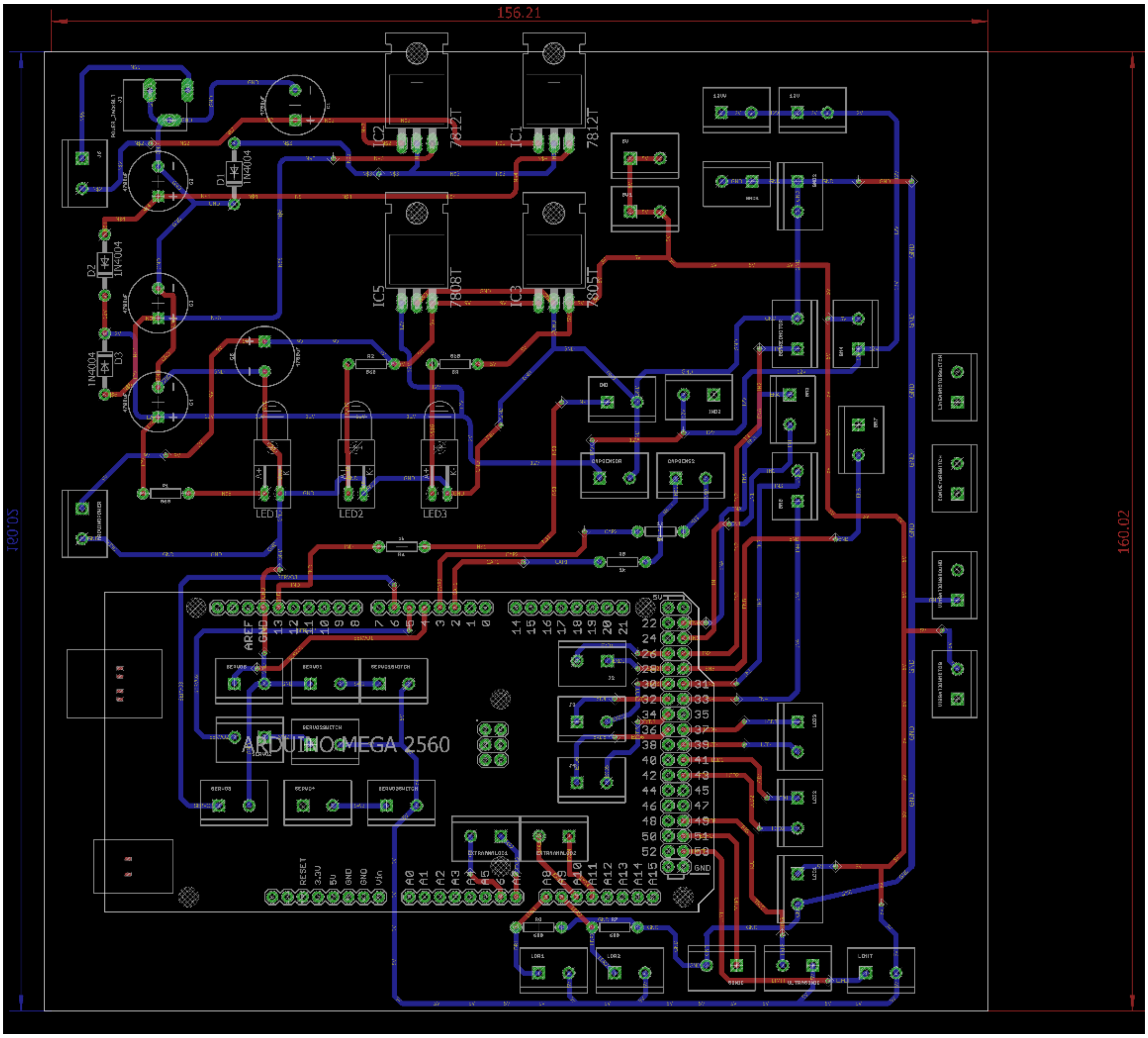

Figure 3.42: PCB Design

on a shiny/glossy paper.

(c) The copper board was then cleaned using sandpaper to ensure the design sticks when it is transferred.

(d) The top and bottom side designs were cut and placed faced down on the copper board while ensuring both designs were aligned.

(e) The copper board was then ironed to transfer the printing onto the copper board, and the glossy paper removed.

(f) The board was then checked to ensure that all the tracks were transferred to the copper board

(g) The board was immersed into an etching solution (Hydrochloric acid and hydrogen peroxide) and agitated for about 20 minutes until all the copper had dissolved.

(h) After all the copper had been removed, the board was cleaned using a water bath and the ink removed from the board by rubbing the tracks with alcohol. This resulted in the pcb shown in figure 3.43

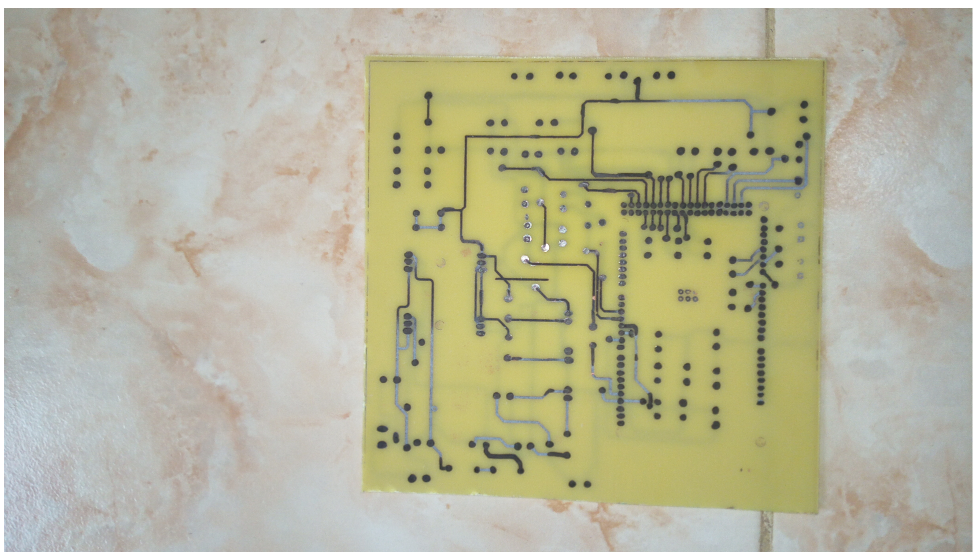

Figure 3.43: Etched PCB

(i) The holes were then drilled on the board. These included the holes for mounting the components and also via holes.

(j) The next step was to ensure all the vias were connected by soldering a piece of wire in the via hole. The other components were then soldered onto the board as shown in figure 4.8.

(k) The board was then tested for continuity to ensure all the components on the board were connected appropriately. Figure 3.45 shows the fabricated PCB with the microcontroller mounted from the bottom.

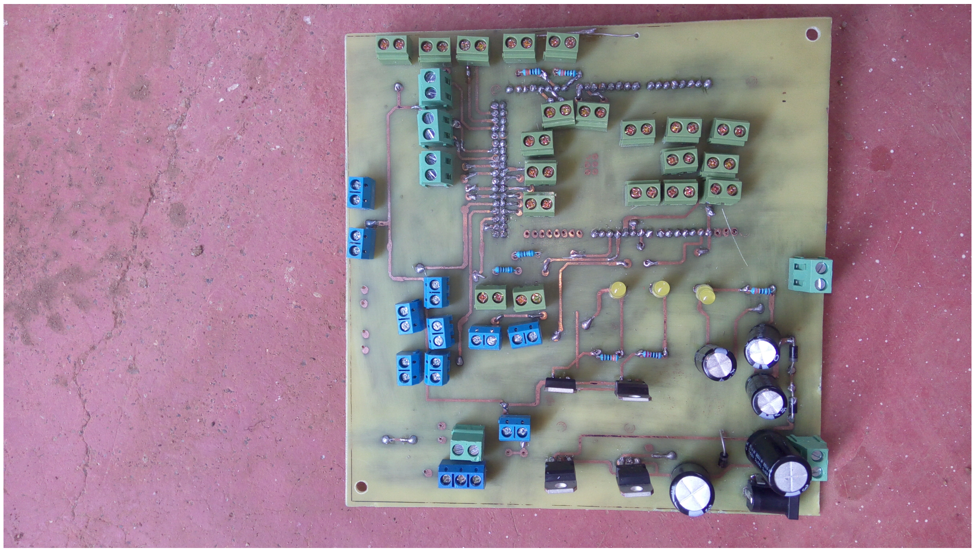

Figure 3.44: PCB with soldered components

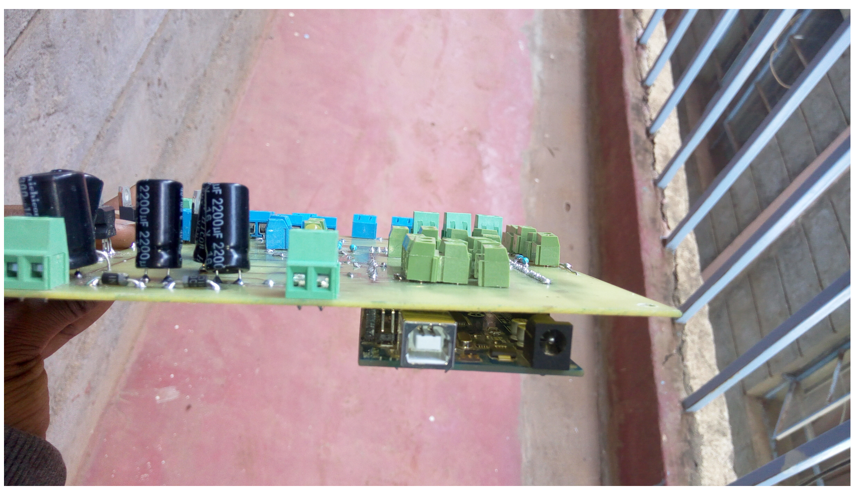

Figure 3.45: Microcontroller mounting on the PCB

3.4 Control Module

A control unit is necessary to integrate all the different modules within the system. The control system includes the interface module, micro-controller, and software.

3.4.1 Interface Module

The interface module plays an important role in controlling the operation of the system. The fuctions of the user interface include :

- Provides the user with option of selecting the type of garbage to sort.
- Indicates the amount of garbage sorted in each category.
- System control for turning the system on and off.

To perform these functions,the 12864B Graphic LCD was selected for this purpose. The 12864B Graphic LCD module shown in figure 3.46 is a 128 x 64 pixel LCD display with a blue backlight and white foreground. The display is fully programmable and can display a combination of both graphics and text. It can operate in both parallel and serial (SPI) modes which can be configured by the external pin PSB. In SPI mode only 3 data pins are required to drive this display. No potentiometer is required to set the contrast as this is pre set by the factory to optimum level.

Figure 3.46: Graphical LCD [27]

3.4.2 Microcontroller

The microcontroller will be receiving input signlas from the sensors and provide the necessary action to be taken based on the material that has been detected. The following are the design considerations that were factored in selecting the microcontroller to use for the system.

- Number of I/O ports- The system has three servo motors, one geared motor, a vibration motor , three sensors and HMI interface. Therefore, the microcontroller has to have multiple I/O ports.
- Efficient storage space for the program
- Computing speed to avoid excessive loading of the commands

Taking into account the above considerations, the Arduino Mega microcontroller shown in figure 3.47 was selected. It has the following characteristics: operating voltage; 5V, input voltage (recommended); 7-12V, digital I/O pins; 54 (of which 15 provide PWM output), analog input pins; 16, DC current per I/O Pin; 20 mA.

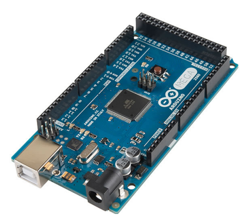

Figure 3.47: ATmega 2560 [27]

3.4.3 Software

The microcontroller will be receiving inputs from the measurement systems and provide the necessary output required based on the logic used. The micro-controller will receive inputs from the capacitive sensor, inductive sensor and phototransistor and the output signal will be sent to the geared motor, servo motor and the vibration motor. The logic used in material detection is shown in figure 3.48

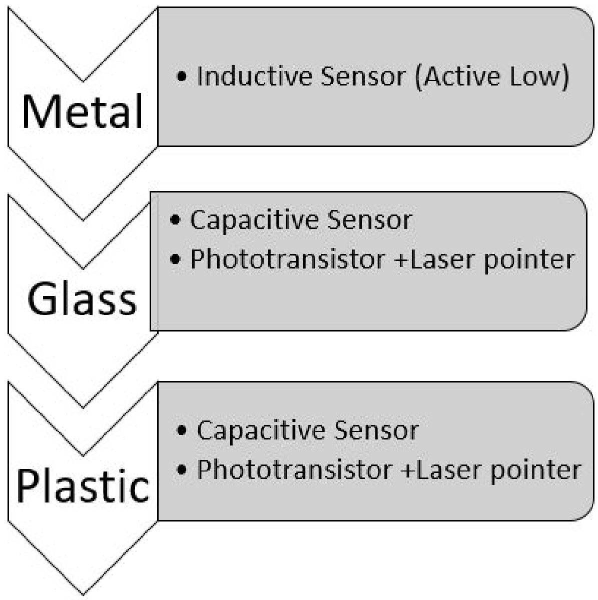

Figure 3.48: Detection Logic

The inductive sensor is used to detect metallic materials. The capacitive sensor in collaboration with the photo-transistor is used to differentiate between clear plastic and glass. Figure 3.49 shows the control algorithm flow chart.

Design of the control box

To design the control box shown in figure 3.50, the positioning and the size of the fabricated circuit unit (pcb) were considered. The pcb designed has a dimension of 150 mm by 150 mm and has the arduino mega mounted on the lower part and soldered devices on the top. To fabricate the control box, galvanised aluminium was used as it was readily available and it was easy to bend relative to mild steel. The pcb would be suspended in the control box to avoid contact with the surface of the control box that would lead to a short circuit. It will also be insulated to prevent the same. The user interface of the control box shown in figure 3.50 will be made of perspex that would be aesthetically pleasing and is within the allocated budget. It contains slot allocations for the LCD used , various switches and status indicator buttons and toggle switches.

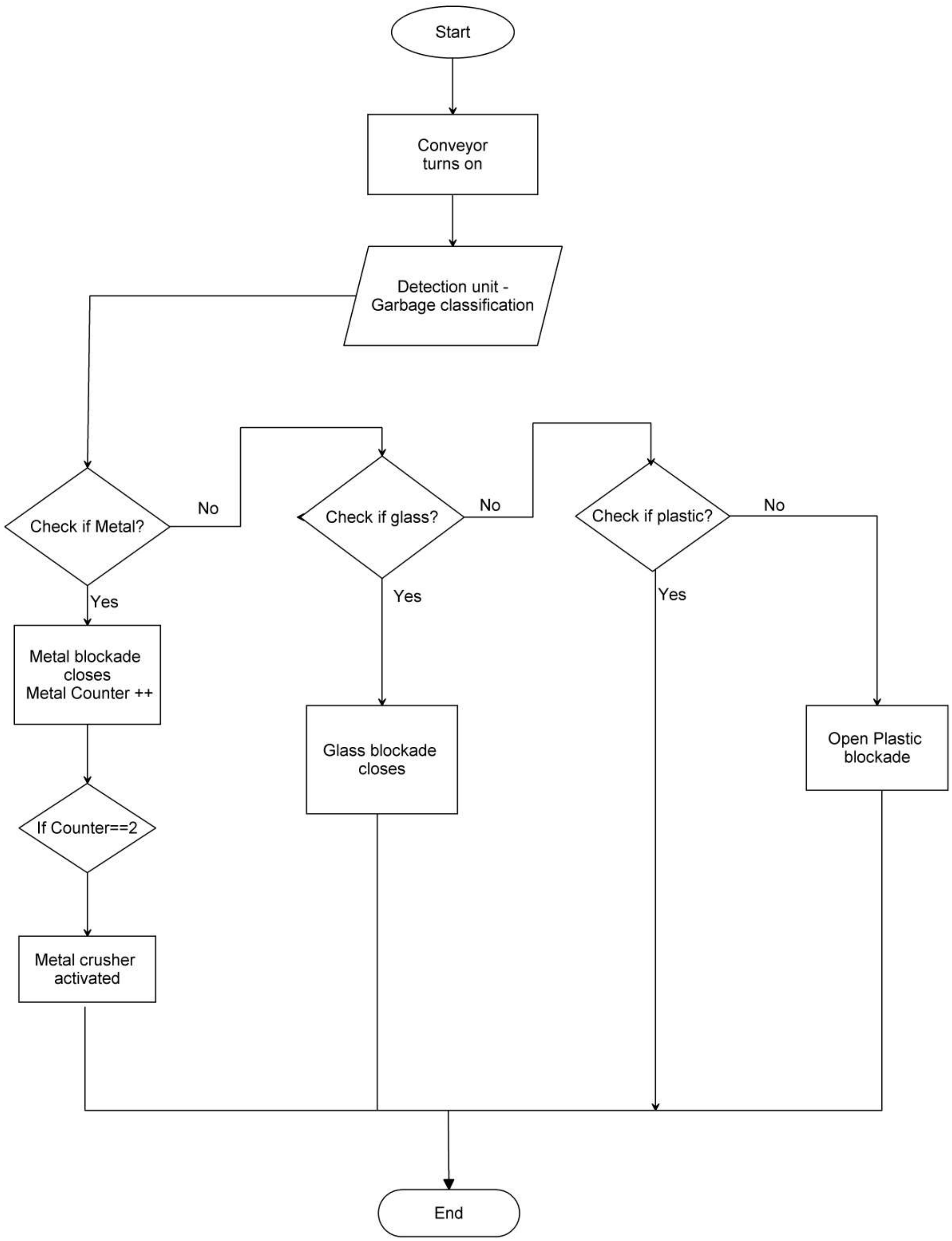

Figure 3.49: Control Flow Chart

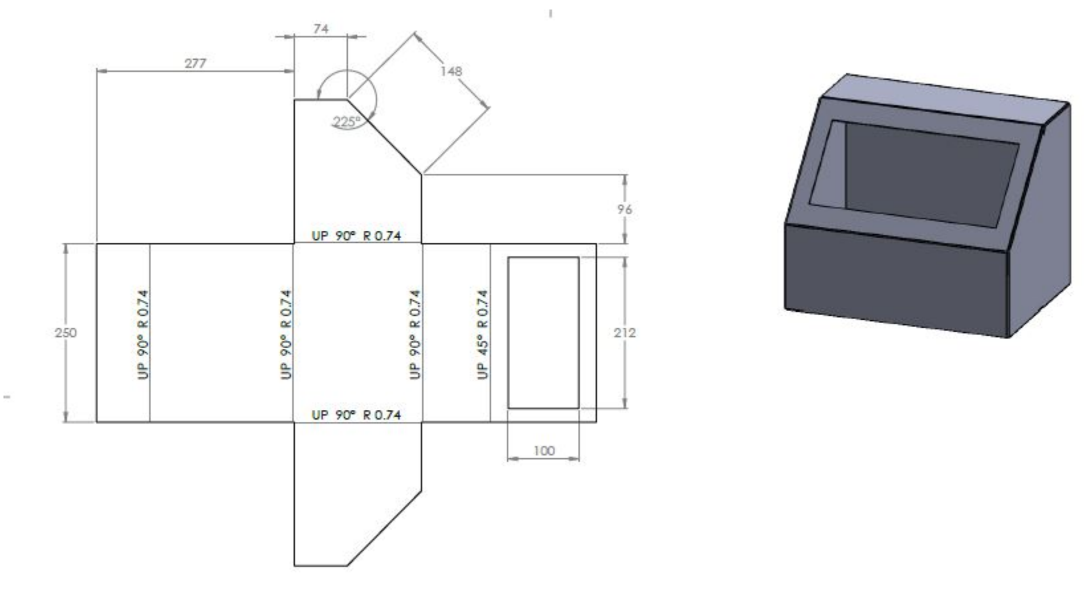

Figure 3.50: Control Box Design

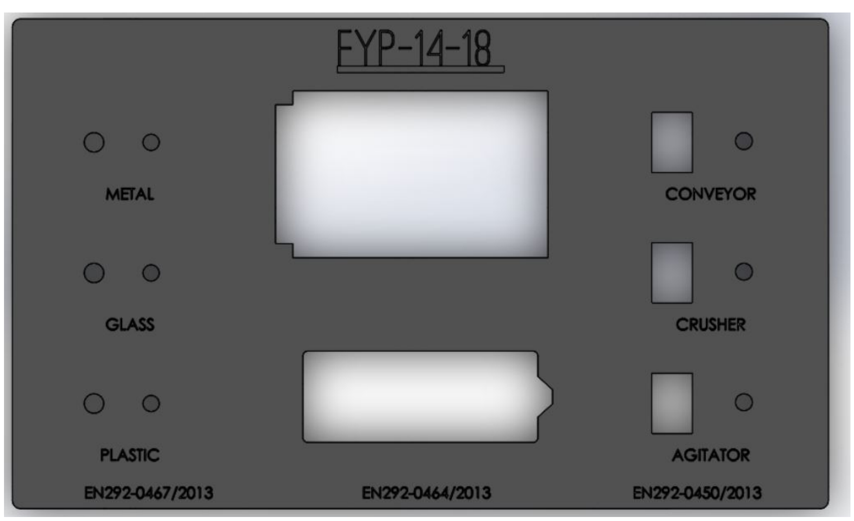

Figure 3.51: User Interface on the control box

4 RESULTS AND DISCUSSIONS

This chapter presents the results of a design and fabrication process for a garbage waste separation and sorting system. The output of this project consists of:

1. Mechanical Module
2. Electrical Module
3. Control Module
4. System Integration

4.1 Mechanical Module

4.1.1 Garbage Separation

The garbage separation mechanism consists of: the hopper, slider, v-shaped guide way and the support structure for both the guide way and the hopper. A heap of garbage is loaded onto the hopper after which through the angular inclination provided in the hopper, the garbage flows to the guide way. The assembled design for the separation system is shown in figure 4.1 and 4.2.

A detailed parts list and individual part dimensions of the garbage separation system are included in the parts list under section B in the appendices.

The garbage separation system was fabricated based on the designs and dimensions provided in figure 4.1 and figure 4.2. The overall assembly of the fabricated garbage separation system is shown in figure 4.3.

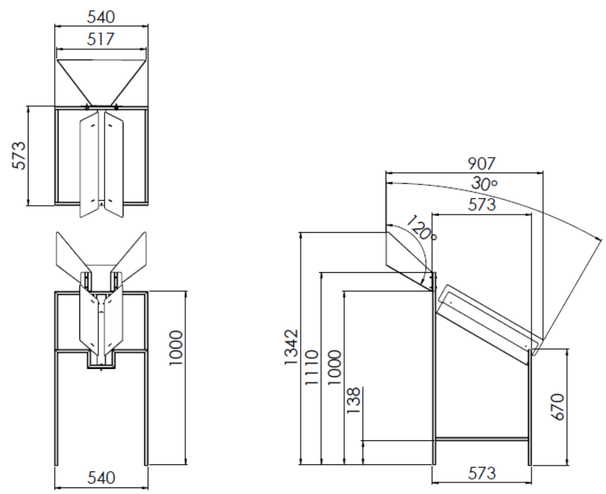

Figure 4.1: Garbage Separation Orthogonal View

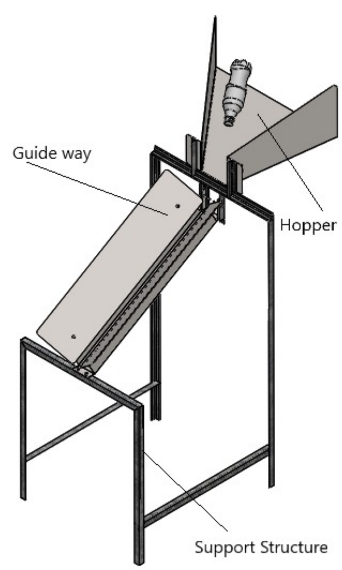

Figure 4.2: Garbage Separation Isometric View

Figure 4.3: Fabricated Garbage Separation System

4.1.2 Garbage Sorting

Garbage sorting mechanism consists of the: conveyor belt, sensors, blocking mechanism and the actuators for both the conveyor and the blocking mechanism. The conveyor system is used to deliver the garbage items to their appropriate collecting bins after identification by the sensors. The assembled design for the system is shown in figure 4.4 and 4.5

A detailed parts list and individual part dimensions of the garbage sorting system are included in the parts list under section B in the appendices.

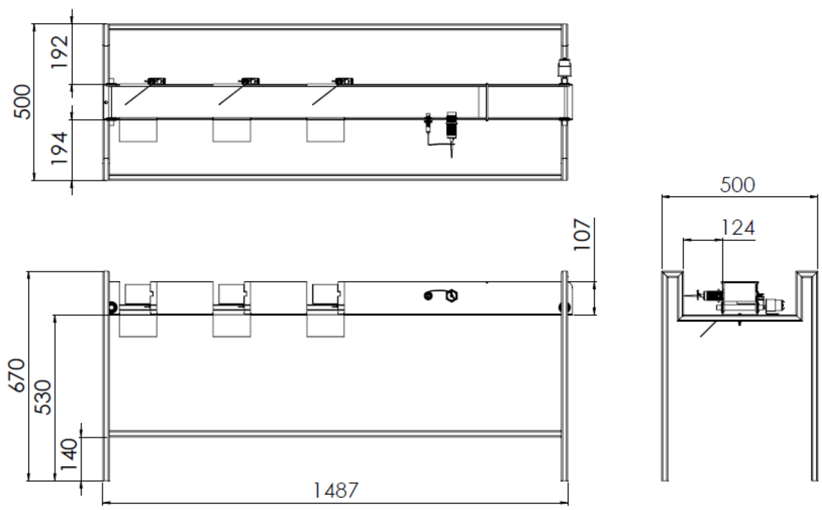

Figure 4.4: Garbage Sorting Orthogonal View

The garbage sorting system was fabricated based on the designs and dimensions provided in figure 4.4 and figure 4.5. The overall assembly of the fabricated garbage separation system is shown in figure 4.6

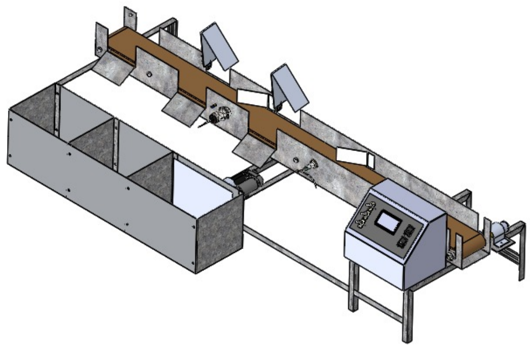

Figure 4.5: Garbage Sorting System Design

Figure 4.6: Fabricated Garbage Sorting System

4.1.3 Garbage Separation and Sorting

Integrating the two modules to perform the separation and sorting operation, the final fabricated system achieved is shown in figure 4.7.

Figure 4.7: Complete System Integration

4.2 Electrical Module

The elecrical circuit of the system mainly comprised of the fabricated printed circuit board and the signal and power lines from the individual components to the control box. The pcb was carefully fitted into the control box as shown in figure **??** and the inner wall of the control box was insulated using cardboard to prevent any residual current from flowing through the structure as it is made of metal. The metal casing was also earthed by providing a common ground between the system structure and the pcb. The user interface consists of a graphical lcd to show the system operation, a grove lcd to show the amount of garbage collected and several switches to control the various components in the system as shown in figure 4.9.

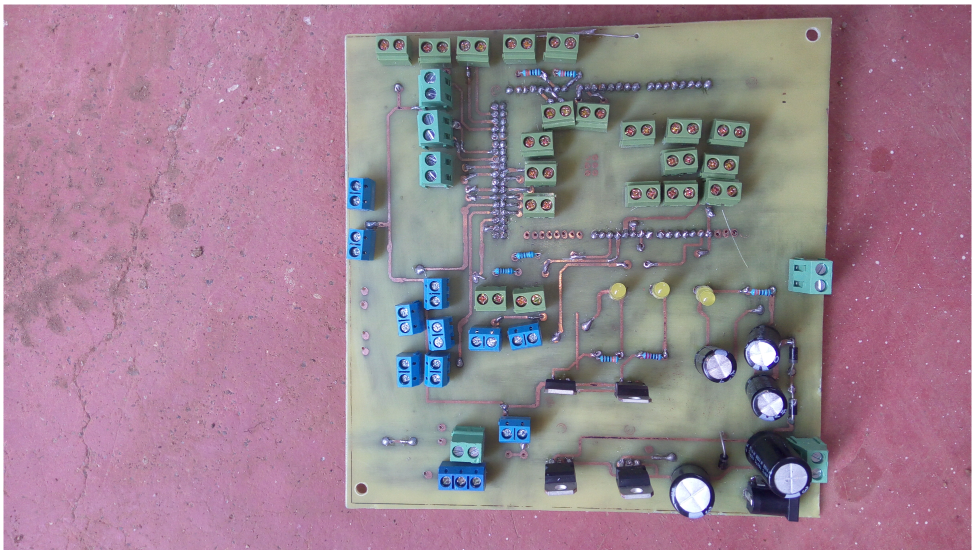

Figure 4.8: PCB with soldered components

Figure 4.9: Control Panel

Four core wire cables were used to connect the various components within the system. This provided easy access to the wires while eliminating the overlapping of many wires within the system. The wires were housed under the conveyor housing using square PVC trunking lines as shown in figure 4.10.

Figure 4.10: Cable Trunking

4.3 Control Module

Different sequences of logic were used to be able to differentiate the three types of material within the specified scope (metal, glass, plastic).

Metal Detection

To detect metallic materials, the inductive sensor was used. This sensor is active low and is activated when the metallic material is within the 4 mm range of the sensor. To conduct the tests to determine the accuracy of the sensor, the coca-cola can shown in figure 4.11 was used as it was within the specified dimensions of the sizes of cans being sorted. The inductive sensor worked efficiently as it was able to detect metallic materials as shown in figure 4.12 from the serial monitor of the microcontroller.

Plastic and Glass Detection

To differentiate between transparent plastic and glass, a capacitive sensor and a photo-

Figure 4.11: Metal Can

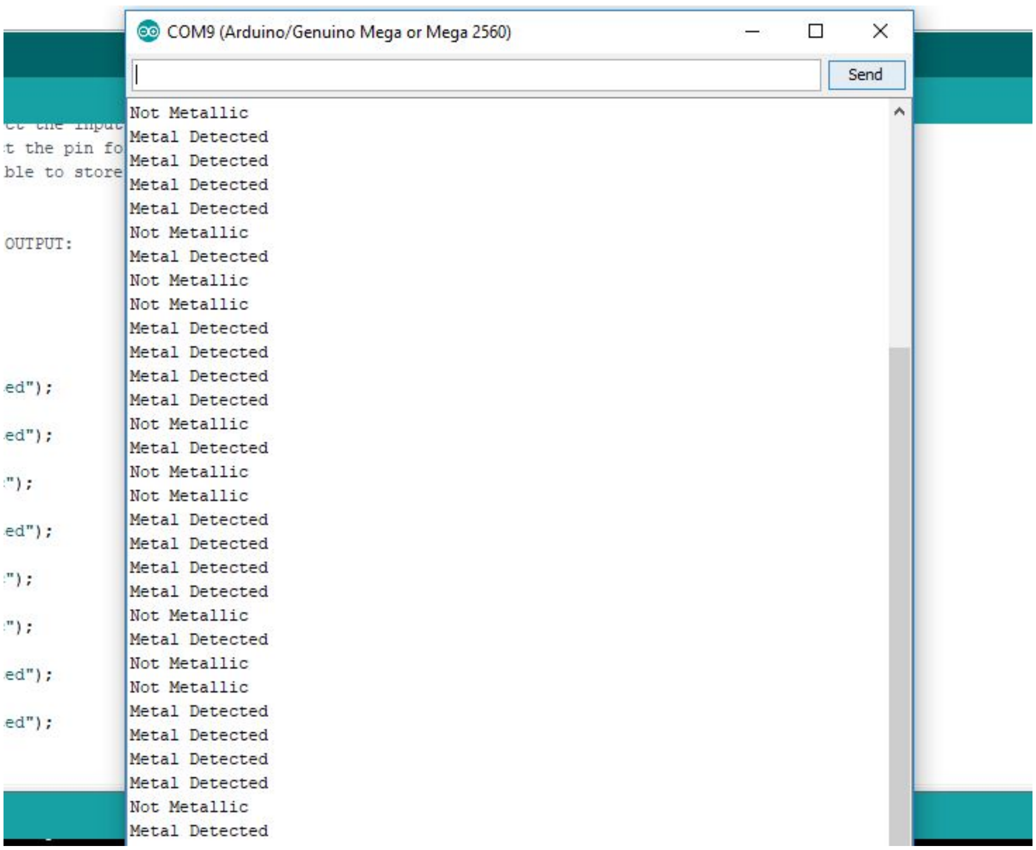

Figure 4.12: Serial Monitor- Metal Inductive Sensor Data

transistor were used. The capacitive sensor was able to detect glass due to the material density but could not detect transparent plastic due to its small material density. However, to differentiate plastic and glass from other materials such as wood, paper, food stuffs etc. that may be part of the garbage, a phototransistor was used as it could measure the varying light intensities that was transimitted by the laser pointer. To test the functionality of this logic, the plastic and glass bottles shown in figure 4.13 were used. The integration of the capacitive sensor and the phototransistor was able to effectively detect and differentiate between transparent plastic and glass materials as shown in figure 4.12 from the serial monitor of the microcontroller.

Figure 4.13: Plastic and Glass Bottles

4.4 System Integration

While integrating the garbage sorting and separation system, the following results were obtained:

1. *Garbage Separation*: Once the heap of garbage was poured into the hopper, the garbage items were able to move from the intake to the conveyor in a single line. However, clogging at the intake was the main problem. This was offset by attaching several vibration motors on the hopper as shown in figure 4.15. that could agitate the garbage and hence prevent clogging. It was also noticed that the garbage was flowing at a higher speed than anticipated due to the angle of incline along the

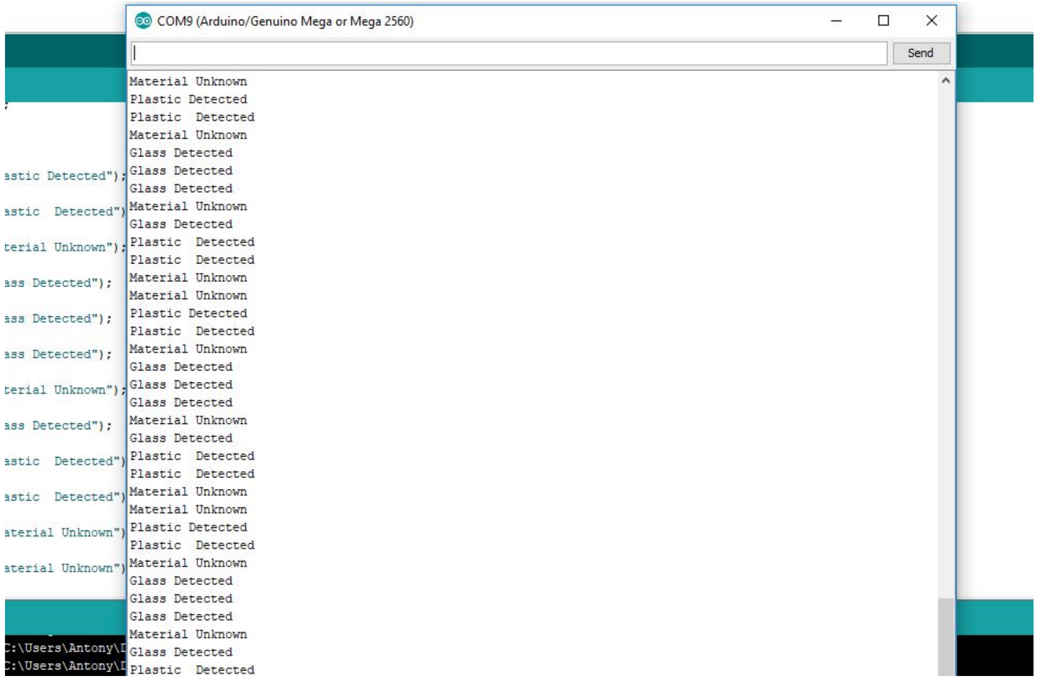

Figure 4.14: Serial Monitor- Glass and Plastic Sensor Data

guide-way. This was remedied by adding mechanical blockades that slowed down the garbage items as they got onto the conveyor.

2. *Garbage Sorting*: Once the garbage items got onto the conveyor, they were detected and guided to the respective bins. A recurring challenge we faced was spacing based on different item sequences e.g. metal-glass-plastic, glass-metal-plastic,plastic-glass-metal sequences. We tackled this by varying the speed of the conveyor and employing human intervention at the release stage to ensure adequate time is provided for the items to be sorted. The average spacing time from testing was concluded to be 3 seconds coupled with 92 percent of the rated speed(300 rpm) using the pulse width modulation feature in the micro-controller to supply the optimal value to enable the geared-motor controller.From testing, we found out that it would take 6 assorted bottles 35-40 seconds to be successfully sorted. Hence, the system could achieve to sort 10-12 bottles per minute(excluding the crushing functionality)

3. *Metal Crushing*: After the metallic materials have been sorted, the metal crushing

Figure 4.15: Vibration motor mounted on the hopper

unit is actuated. This involves the linear actuator traversing forward and crushing the metal cans. This process operation occurred as expected. The main problem encountered was the sequence of operation that was used in the program. Since the micro-controller used works on a sequential flow logic, the use of interrupt functions had to be used to interrupt the normal flow of the program to actuate the linear actuator and return to the main program after the crushing was complete.

Following the integration of the above modules, the garbage materials were able to be sorted according to their material structure and the metal cans were crushed after they had been sorted.

5 CONCLUSION

As outlined in chapter one, the objectives of this project was to:

1. To design and fabricate a garbage separation mechanism that achieves singularization of the garbage.
2. To design and fabricate a garbage sorting mechanism to successfully identify and sort the waste as per the specified categories.
3. To test the integrated garbage separation and sorting system.

To this effect,the design and fabrication of a garbage waste separation mechanism was successfully achieved. The design and fabrication of the garbage sorting mechanism was also achieved. The integration of the two systems was achieved to some degree with the main challenges being:

1. Sensor range- The sensors acquired to perform the sorting operation had a limited range of between 2 mm- 5 mm. This posed a challenge in the detection process as the garbage items had to be very close to the sensors.
2. Material separation and spacing- Due to the difference in size of the garbage items being sorted, it was difficult to properly singularize and space the garbage items as they got onto the conveyor.
3. Motor Torque and Conveyor Material- The motor acquired for the conveyor had the required torque to carry plastic and metallic materials. However, it lagged when a glass bottle was placed on the conveyor. This is because the material used as the conveyor belt sagged hence stalling the motor.

Factoring the challenges faced during the actualization of this project, the following recommendations were made:

1. The acquisition of sensors with the required range should be done earlier. However, these long range industrial grade sensors are quite expensive than what the budget can accommodate.

2. To effectively separate and space the garbage materials, there's need to add an extra mechanism that will facilitate the entry of materials in the conveyor one at a time. The added mechanism needs to factor in the difference in size of the garbage materials.

3. The proper industrial grade conveyor belt should be used for the conveyor belt to avoid slip and sagging when in operation.

Regarding comparison of the system against some products in the market discussed in the literature review, it was found that the latter sort similar kinds of waste on a larger scale but also incorporate human labour to perform the separation. The system designed has several advantages over the traditional way to separate waste such as:

1. The separation and sorting of waste has introduced some autonomy hence reduced human effort.

2. The system can be modified to separate other kinds of waste which are not necessarily aluminum cans, plastic bottles, or glass.

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Appendices

A Time Plan

The time plan used in design and fabrication process is shown in figure A.1

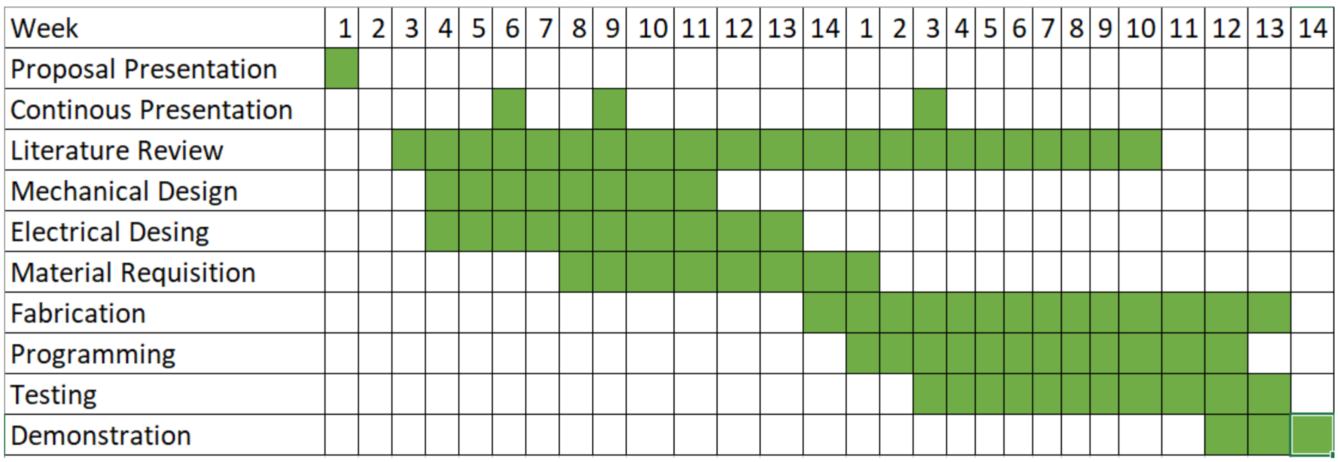


Figure A.1: Time Plan

B Production Plan

The production plan used in the fabrication process is shown in figure B.1.

C Budget

Following the cost incurred during the fabrication process, the system was within the scope of the allocated budget as shown in figure C.1

TIME	SYSTEM	SUB-SYSTEM	ACTIVITY	FACILITIES	MATERIALS REQUIRED	SEQ/CONC	PROGRESS
February			Updating the design of the sytem		Design softwares	sequential	Completed
Mar & April			Material Acquisition				Completed
May- Week 2	Separation	Hopper	Marking out the size of the hopper on the sheet metal. Cutting out the sheet metal and carrying out bending operation on the sheet metal.	Fitting Workshop	Mild Steel Sheet metal	sequential	Completed
		Guide-Way	Cutting and bending of sheet metal to create the V-shape	Fitting workshop	Mild steel sheet	Sequential	Completed
May-Week 3	Sorting	Conveyor casing	Cutting and bending of sheet metal	Fitting workshop	Mild Steel	Sequential	Completed
		Detection Unit	Testing and optimization of the sensors. This is to ensure that the sensors identify the different tupes of material.		Sensors‖ Inductive , Optical and capacitivre sensors	Concurent	Completed
May- Week 4	Separation and	Support structure	Cutting angle line(bars) to the right dimensioin followed	Welding workshop	Angle Line(12ft)	Sequential	Completed
June- Week 5 & Week 6	Sorting	Conveyor	1) Maching the nylon plastic to make rollers for the conveyor 2) Making the bearing housing(for holding the bearings on the conveyor casing 3) Mounting of the geared motor and coupling to the rollers 4) Testing and optimization of the conveyor‖ Getting the right speed	Machine workshop	Mild steel rod ‖ nylon plastic ‖ coupling	Sequential	Completed
		Detection Unit	Mounting of sensors on the conveyor casing and testing and optimization of the sensors response.		Sensors	Sequential	Completed
		Blocking Mechanism	Mounting of servo motors on the conveyor casing and		Servo Motor	Sequential	Completed
June- Week 7	Electrical	Control board	PCB milling the circuit board 2) Fabricating the casing for the control box and mounting of the control panel.	IPIC workshop		Sequential	Completed
June - Week 8	Separation & Sorting		Optimizing the singularization system to ensure there is no clogging of bottles			Sequential	Completed
July- Week 9			Testing and optimization of system				Completed
July- Week 10	System		Completion of report for the FYP-18 and PPT			Concurrent	Completed
July Week 11	System		Demonstration/ Presentation	ELB 114	PPT and the system	Sequential	Pending

Figure B.1: Production Plan

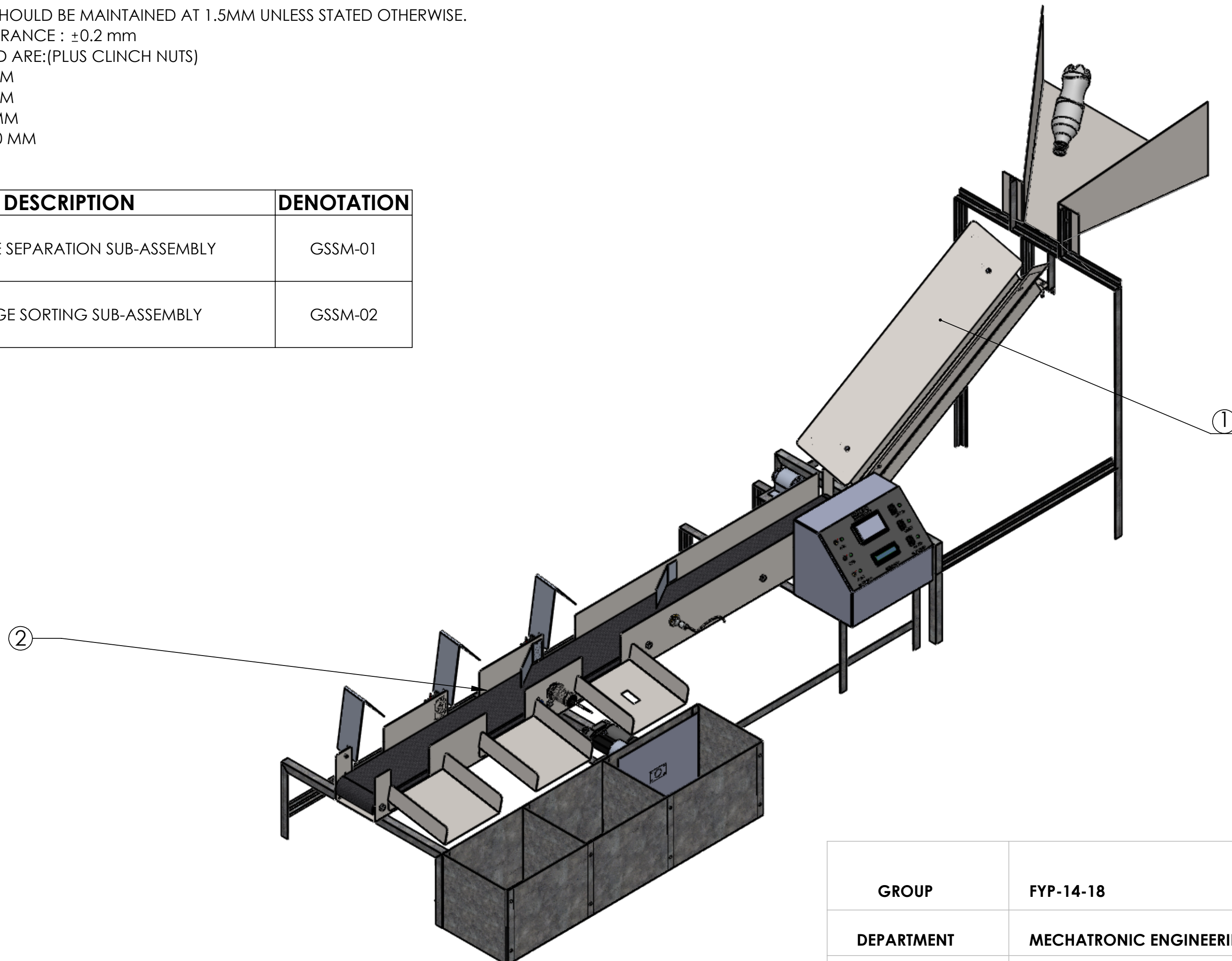
D Code

The code is hosted on GitHub. It can be found at `https://github.com/EmmanuelKinyanjui/FYP-14-18`

E Part Drawings

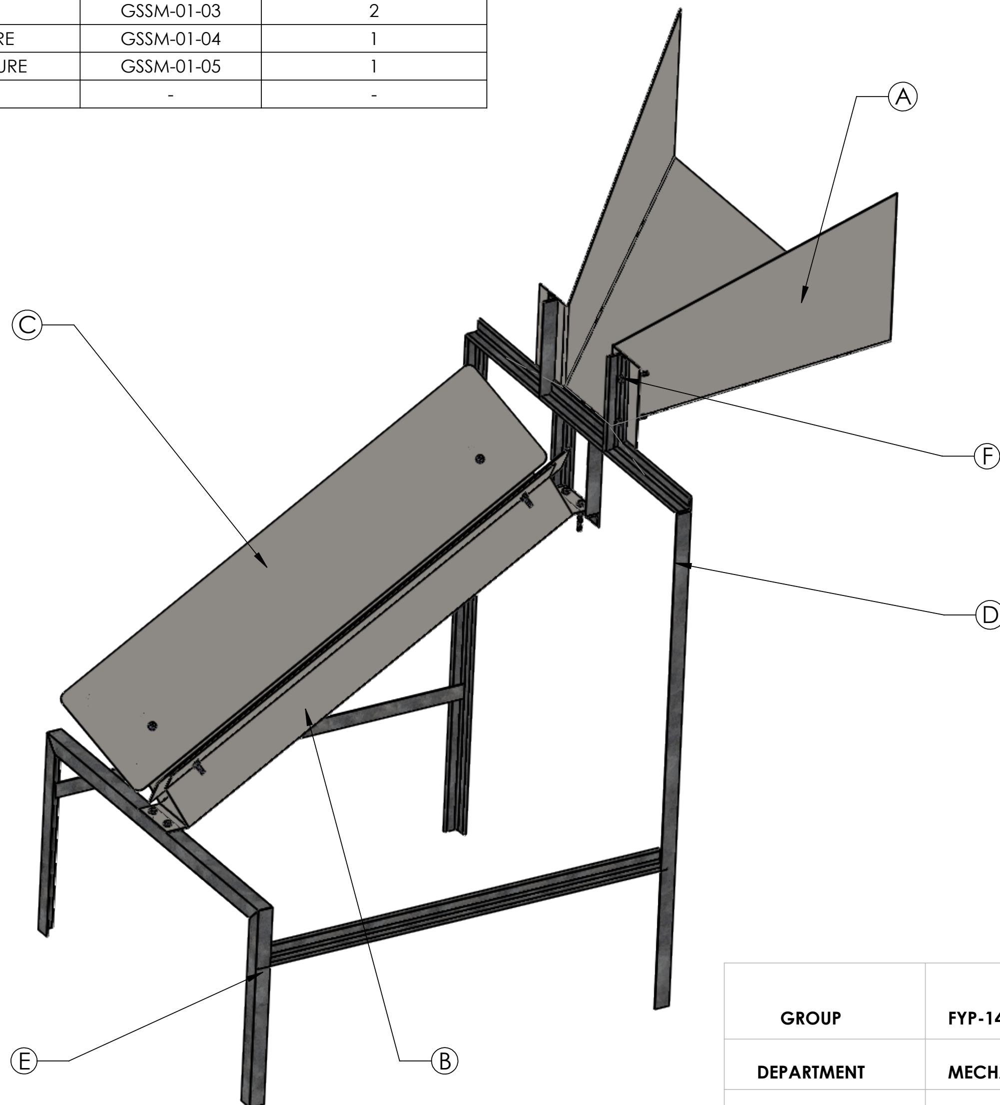
NOTES (UNLESS SPECIFIED OTHERWISE):
1. THE 3-D CAD AND DXF FILE IS THE MASTER. DRAWING FOR REFERENCE ONLY.
2. ALL BENDS TO BE 90 UNLESS OTHERWISE STATED.
3. INTERNAL BEND RADII TO BE EQUAL TO OR LESS THAN MATERIAL THICKNESS.
4. METAL THICKNESS SHOULD BE MAINTAINED AT 1.5MM UNLESS STATED OTHERWISE.
5. DIMENSIONAL TOLERANCE : ±0.2 mm
6. THE FASTENERS USED ARE:(PLUS CLINCH NUTS)
   - M3 X 20MM
   - M4 X 20MM
   - M6 X 20 MM
   - M10 X 150 MM

PART	DESCRIPTION	DENOTATION
1	GARBAGE SEPARATION SUB-ASSEMBLY	GSSM-01
2	GARBAGE SORTING SUB-ASSEMBLY	GSSM-02

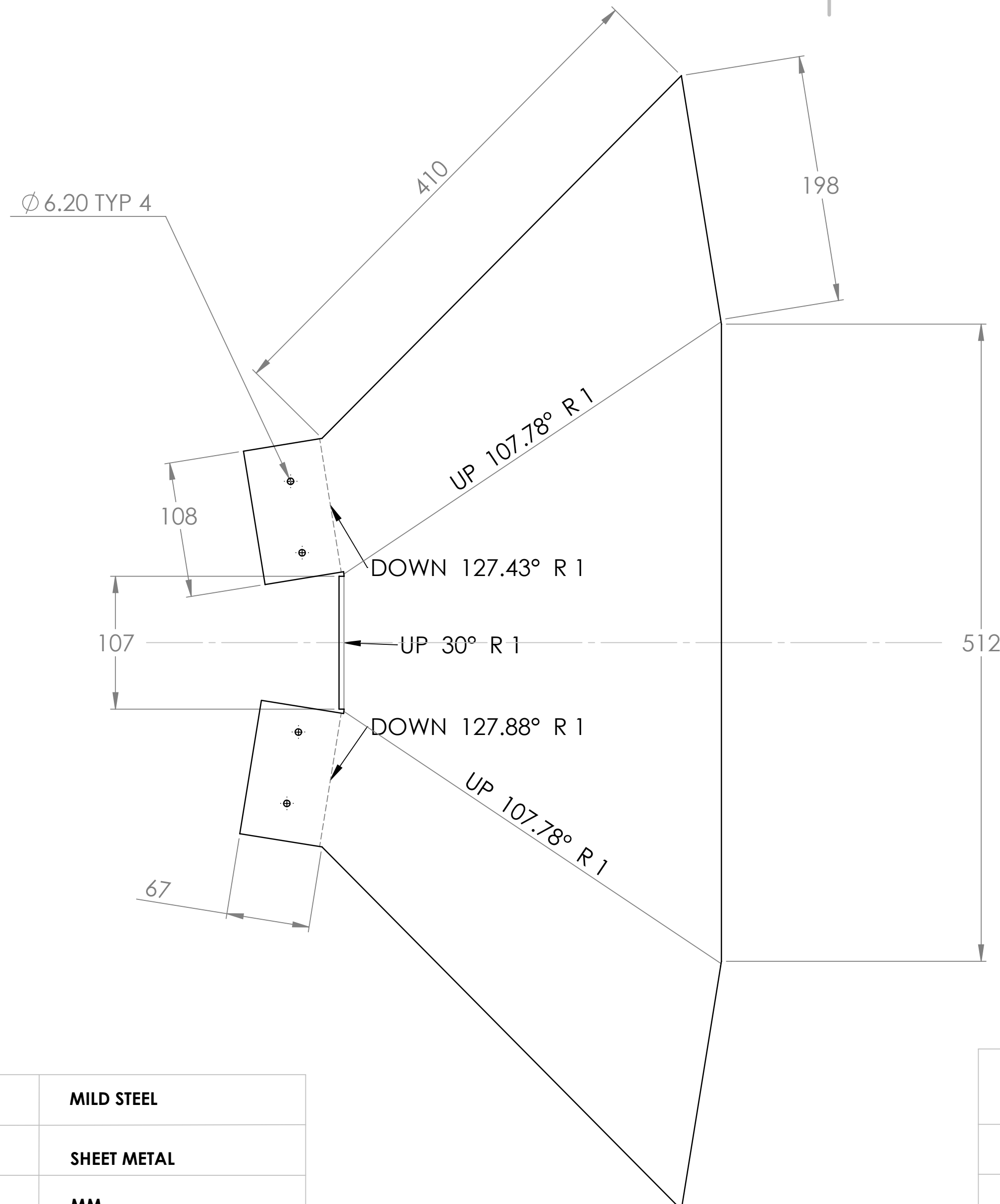


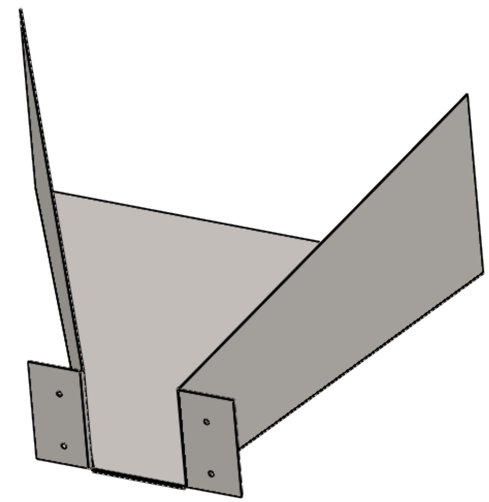
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GARBAGE WASTE SEPARATION AND SORTING MACHINE ASSEMBLY
AUTHOR	EN292
UNIT	MM
SCALE	1:10

PART	NAME	CODE	QUANTITY
A	HOPPER	GSSM-01-01	1
B	GUIDEWAY	GSSM-01-02	1
C	SLIDER	GSSM-01-03	2
D	HOPPER SUPPORT STRUCTURE	GSSM-01-04	1
E	GUIDEWAY SUPPORT STRUCTURE	GSSM-01-05	1
F	M6 BOLT + NUT	-	-



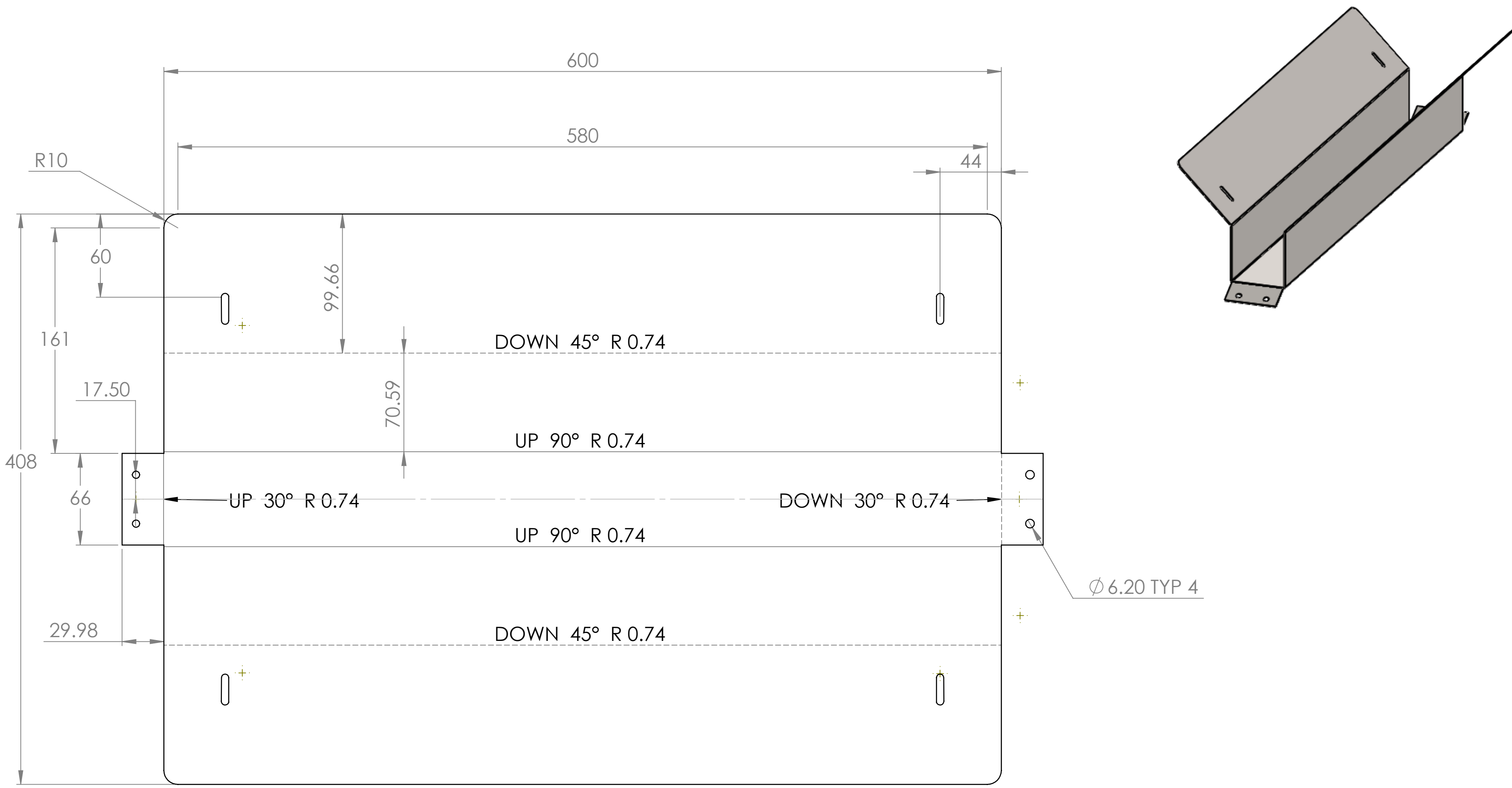
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01 (WASTE SINGULARIZATION ASSEMBLY)
AUTHOR	EN292
UNIT	MM
SCALE	1:6





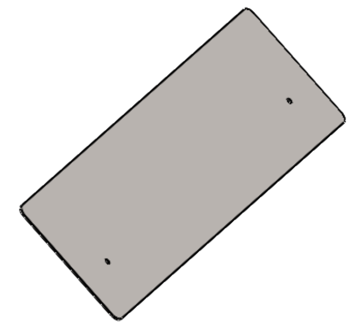
MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

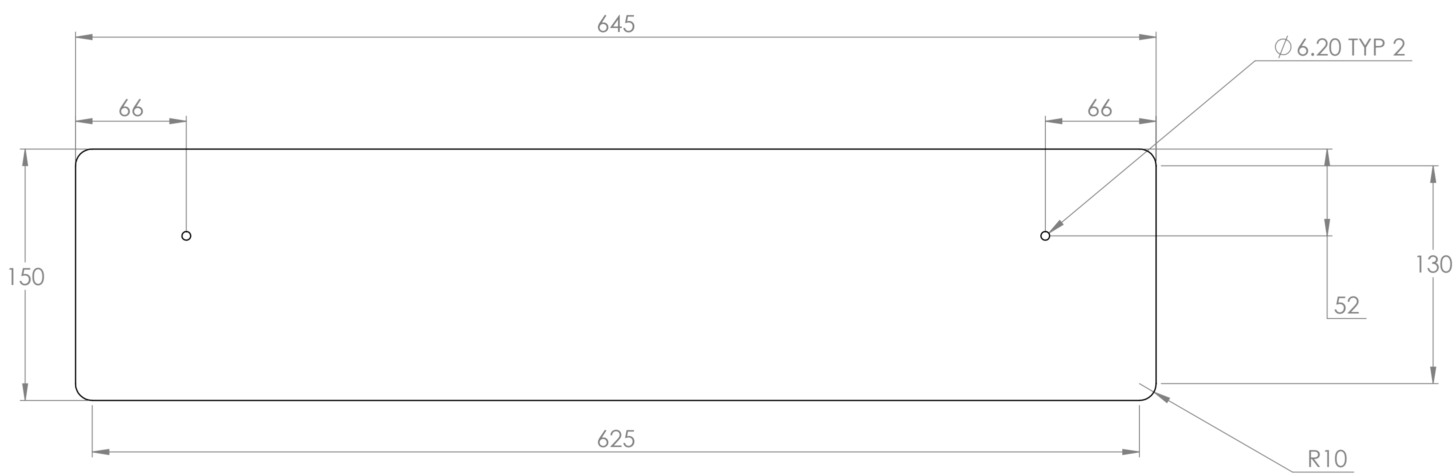
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01-01 (HOPPER)
AUTHOR	EN292
UNIT	MM
SCALE	1:4



MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

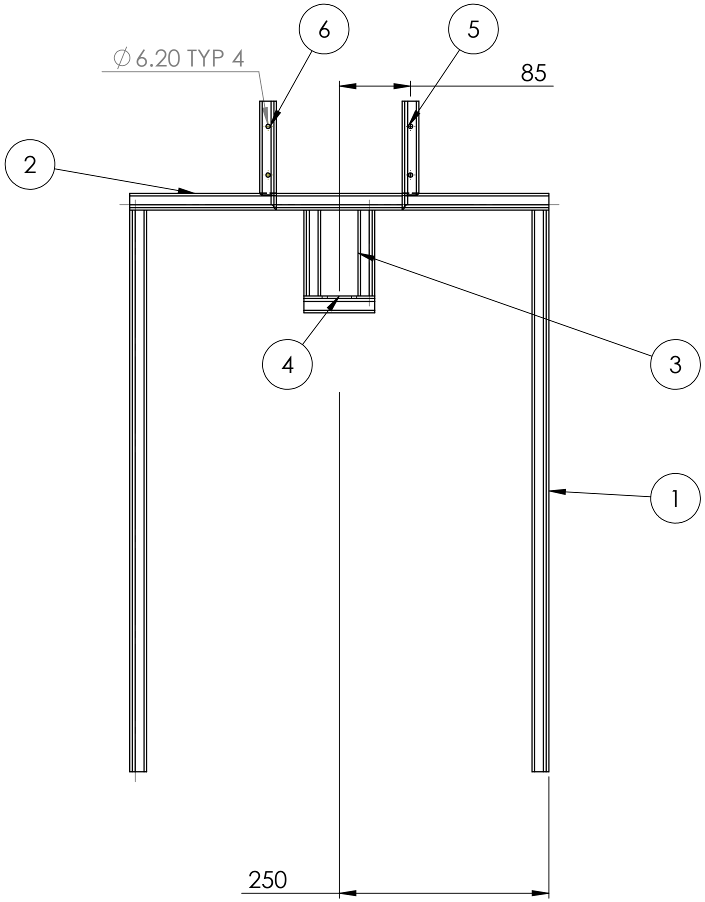
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01-02 (GUIDE WAY)
AUTHOR	EN292
UNIT	MM
SCALE	1:3

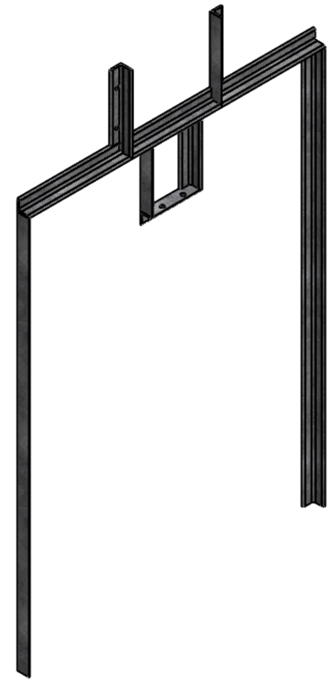




MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	2

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01-03 (SLIDER PLATE)
AUTHOR	EN292
UNIT	MM
SCALE	1:3

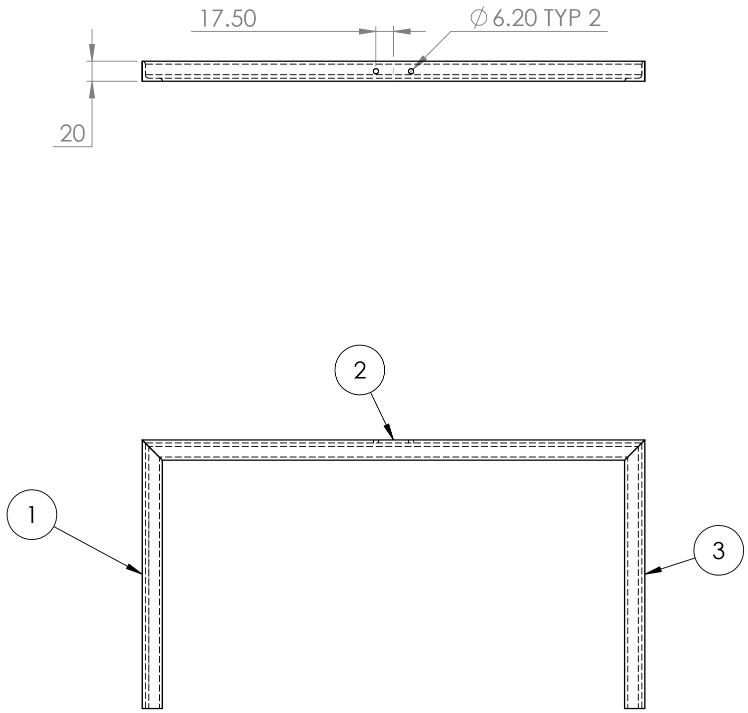




ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	L 20 X 20 X 3	670
2	1	L 20 X 20 X 3	500
3	2	L 20 X 20 X 3	102.41
4	1	L 20 X 20 X 3	84.48
5	1	L 20 X 20 X 3	128.76
6	1	L 20 X 20 X 3	128.76

MATERIAL	ANGLE BAR - L
PROCESS	WELDING
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01-04 (HOPPER SUPPORT FRAME)
AUTHOR	EN292
UNIT	MM
SCALE	1:6

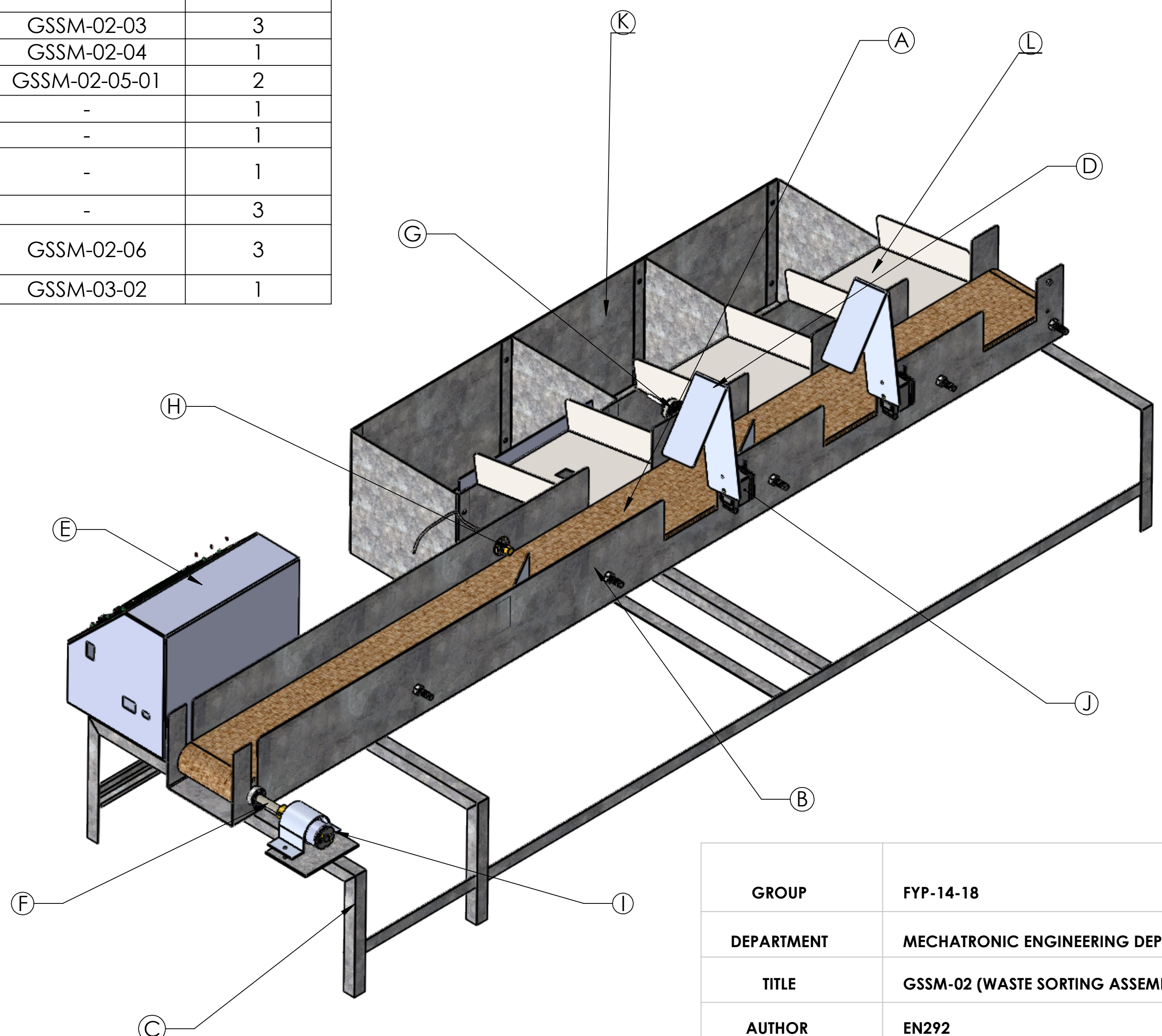


ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	L 20 X 20 X 3	267
2	1	L 20 X 20 X 3	500
3	1	L 20 X 20 X 3	267

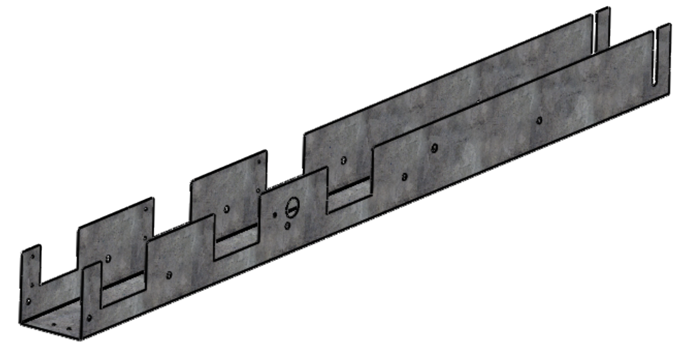
MATERIAL	ANGLE BAR - L
PROCESS	WELDING
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

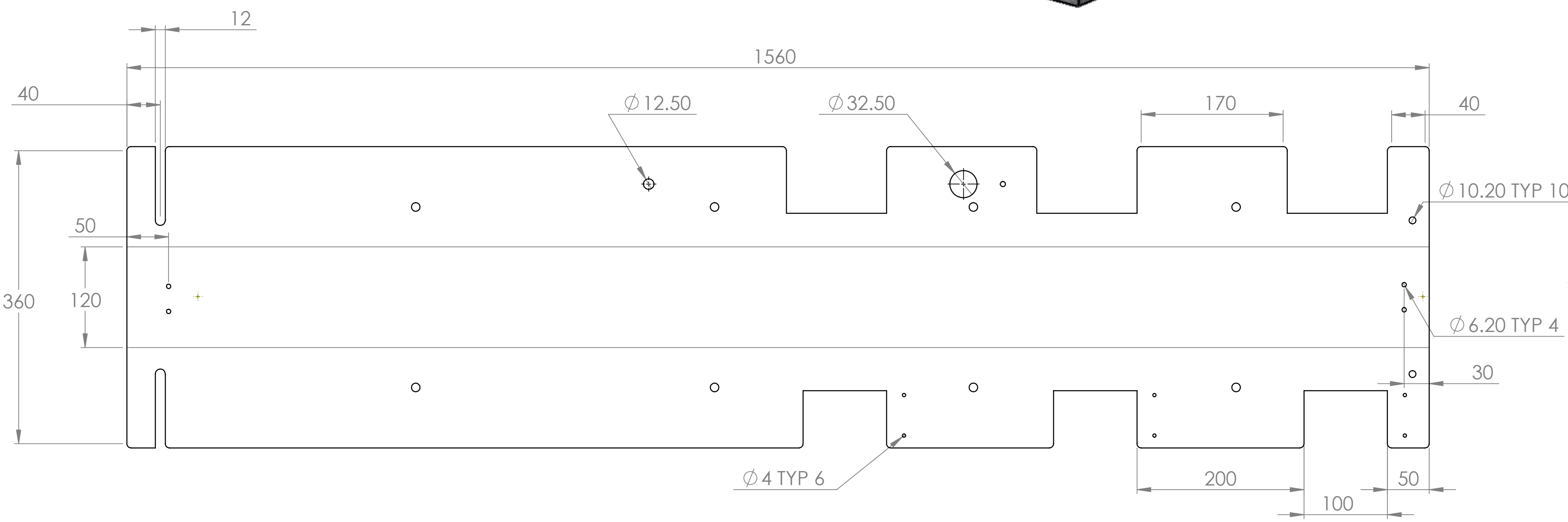
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-01-05 (GUIDEWAY SUPPORT FRAMEWORK)
AUTHOR	EN292
UNIT	MM
SCALE	1:5

PART	NAME	CODE	QUANTITY
A	CONVEYOR BELT	-	1
B	CONVEYOR HOUSING	GSSM-02-01	1
C	CONVEYOR SUPPORT STRUCTURE	GSSM-02-02	2
D	BLOCKER	GSSM-02-03	3
E	CONTROL BOX	GSSM-02-04	1
F	DRIVING ROLLER	GSSM-02-05-01	2
G	CAPACITIVE SENSOR	-	1
H	INDUCTIVE SENSOR	-	1
I	DC GEARED MOTOR + BRACKET	-	1
J	SERVO MOTOR	-	3
K	MATERIAL EXIT GUIDEWAYS	GSSM-02-06	3
L	BINS	GSSM-03-02	1



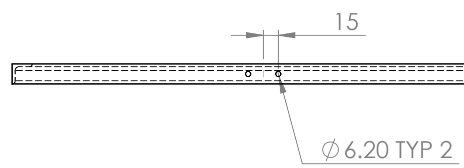
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02 (WASTE SORTING ASSEMBLY)
AUTHOR	EN292
UNIT	MM
SCALE	1:6

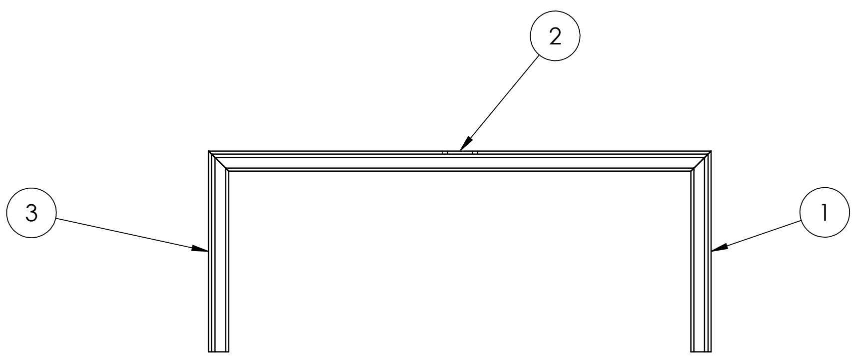




MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-01 (CONVEYOR HOUSING)
AUTHOR	EN292
UNIT	MM
SCALE	1:5

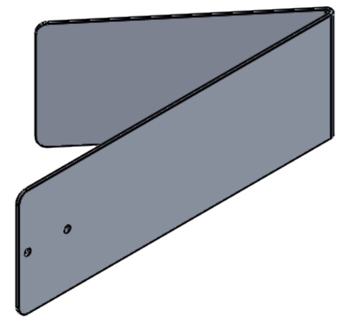




ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	L 20 X 20 X 3	200
2	1	L 20 X 20 X 3	500
3	1	L 20 X 20 X 3	200

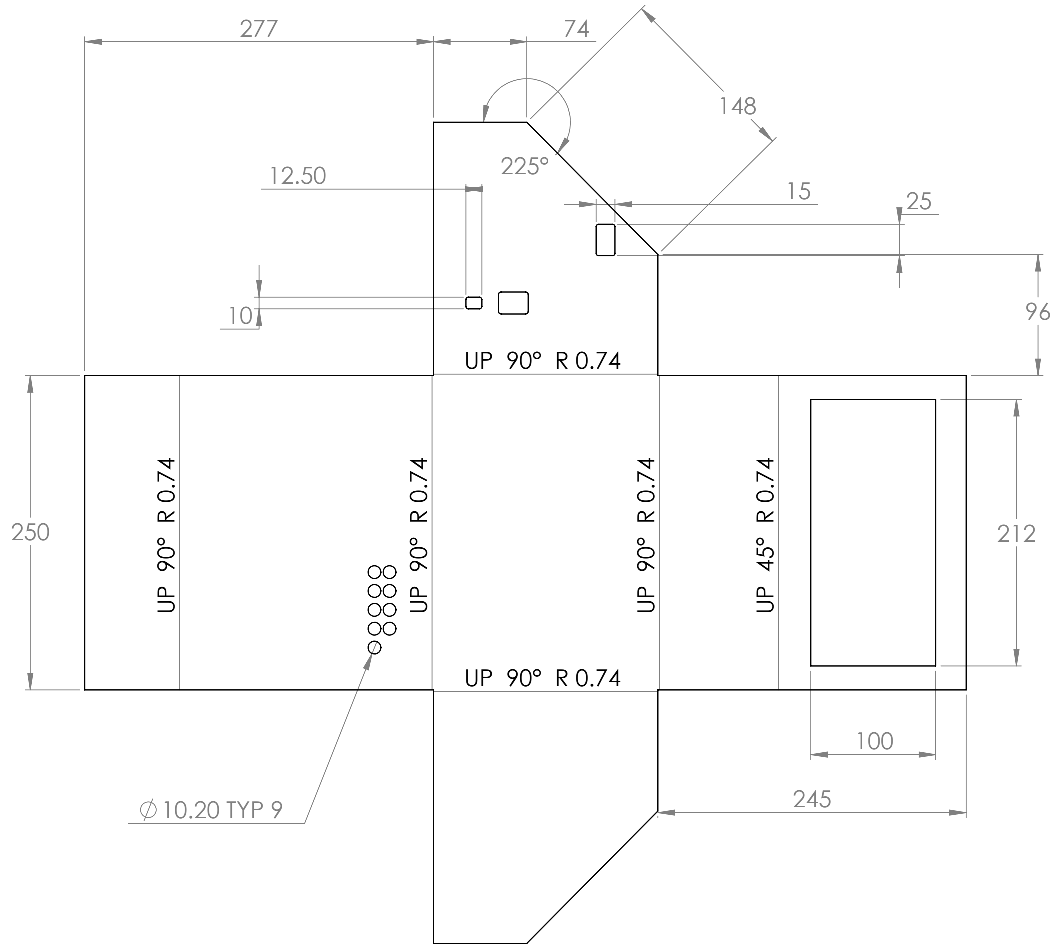
MATERIAL	ANGLE BAR - L
PROCESS	WELDING
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	2

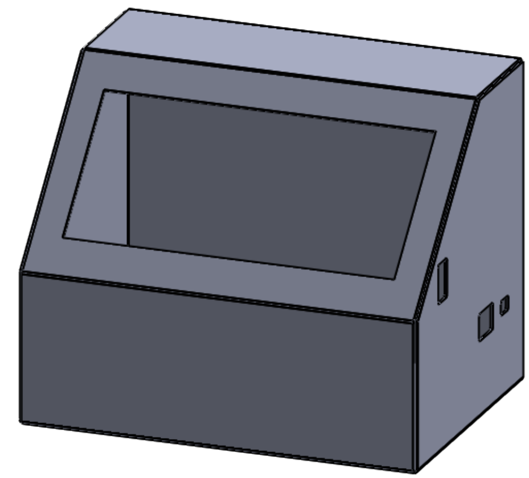
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-02 (CONVEYOR FRAME)
AUTHOR	EN292
UNIT	MM
SCALE	1:5



MATERIAL	MILD STEEL
PROCESS	SHEETING
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	3

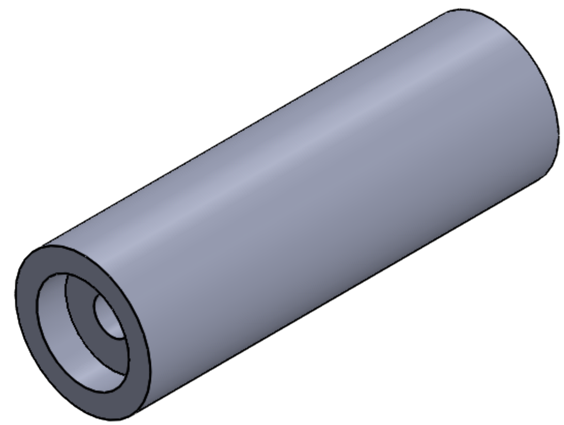
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-03 (DEFLECTION PLATE)
AUTHOR	EN292
UNIT	MM
SCALE	1:1

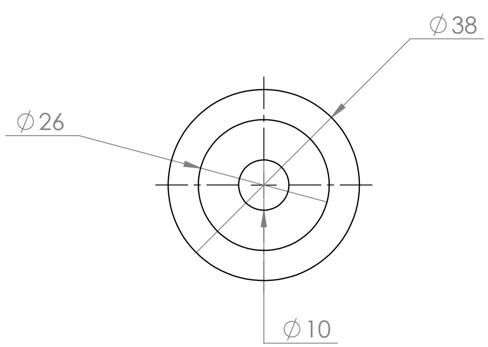


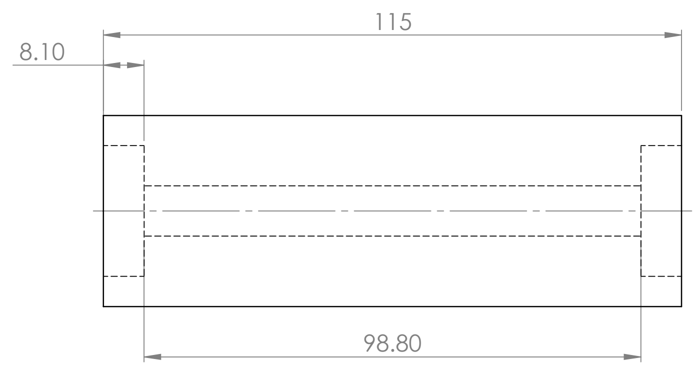


MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	REFER TO NOTES
FINISH	REFER TO NOTES
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM 02-04 (CONTROL BOX)
AUTHOR	EN292
UNIT	MM
SCALE	1:3

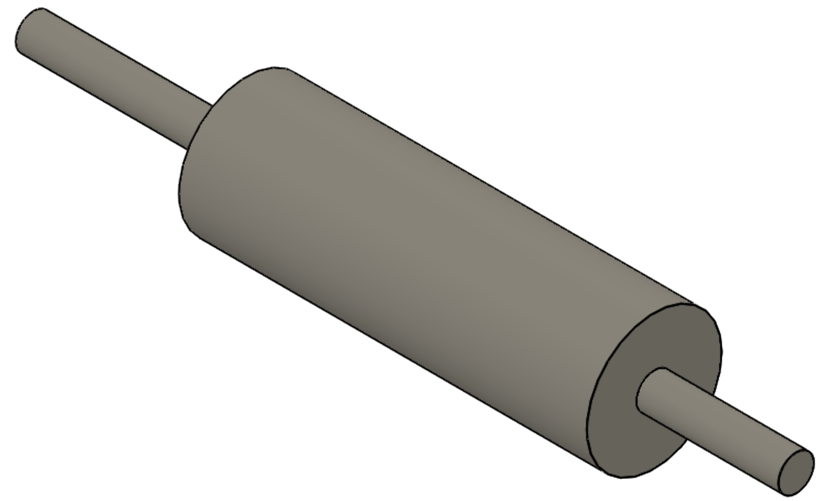


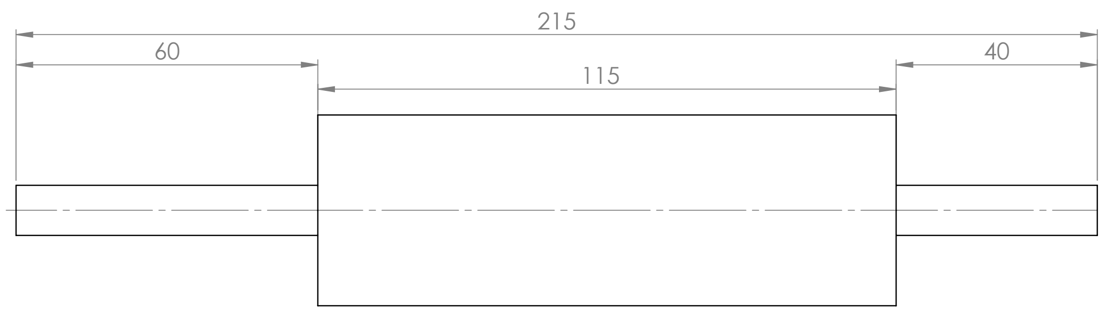


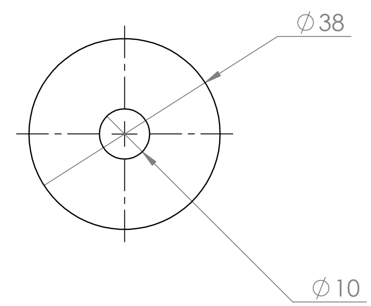


MATERIAL	NYLON PLASTIC
PROCESS	LATHING
DIMENSIONS	MM
COLOR	NA
FINISH	NA
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-05-02 (DRIVEN ROLLER)
AUTHOR	EN292
UNIT	MM
SCALE	1:1

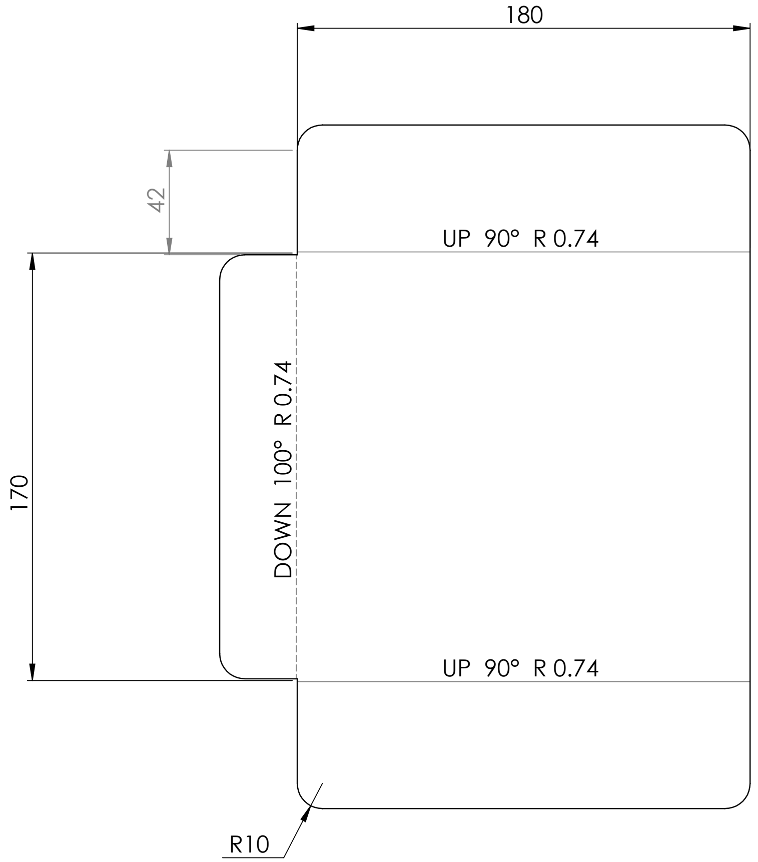


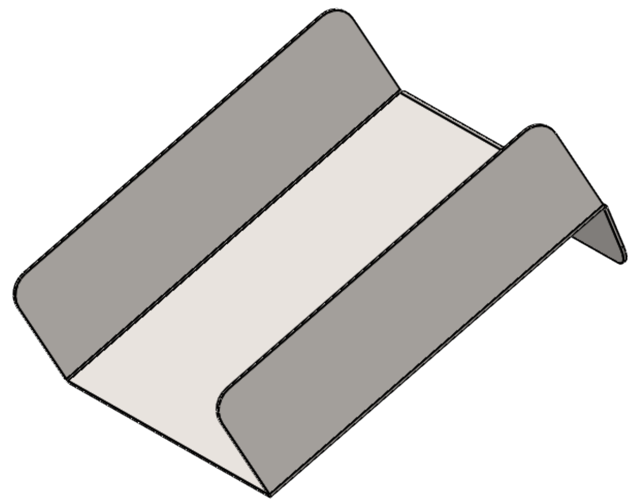




MATERIAL	NYLON PLASTIC
PROCESS	LATHING
DIMENSIONS	MM
COLOR	REFER TO NOTES
FINISH	REFER TO NOTES
QUANTITY	1

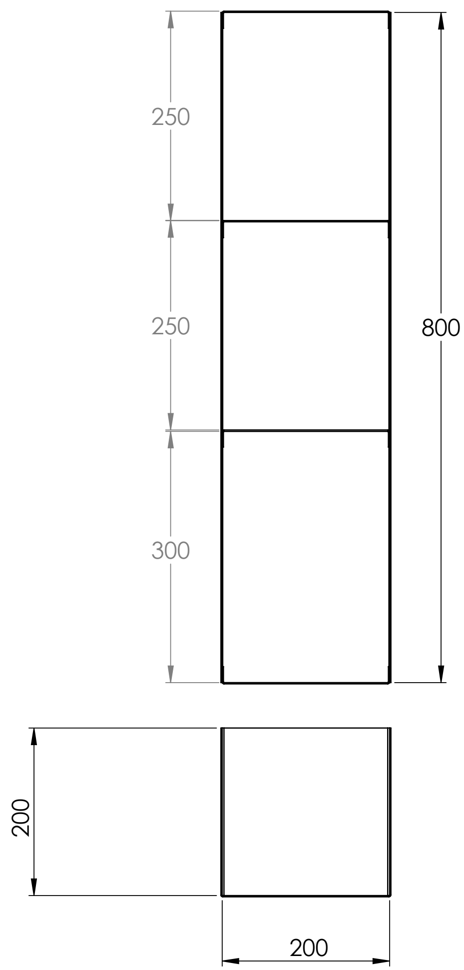
GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-05-01 (DRIVING ROLLER)
AUTHOR	EN292
UNIT	MM
SCALE	1:1

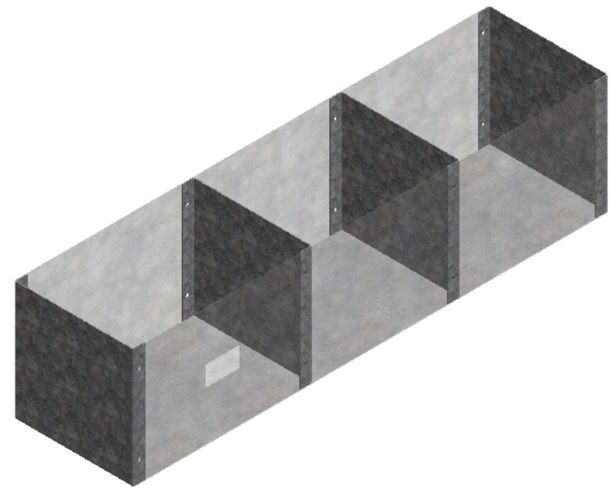


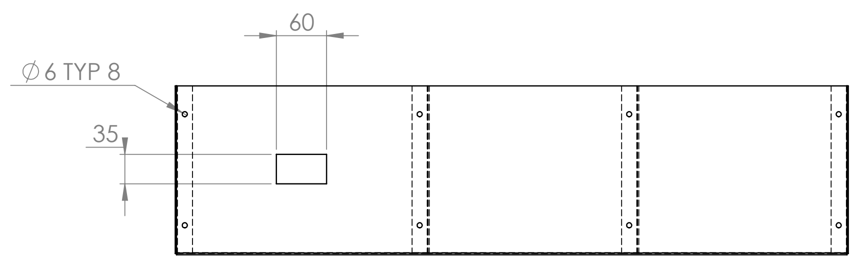


MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	REFER TO NOTES
FINISH	REFER TO NOTES
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-02-06 (MATERIAL EXIT GUIDEWAY)
AUTHOR	EN292
UNIT	MM
SCALE	1:2







MATERIAL	MILD STEEL
PROCESS	SHEET METAL
DIMENSIONS	MM
COLOR	REFER TO NOTES
FINISH	REFER TO NOTES
QUANTITY	1

GROUP	FYP-14-18
DEPARTMENT	MECHATRONIC ENGINEERING DEPARTMENT
TITLE	GSSM-03-02 (WASTE BINS)
AUTHOR	EN292
UNIT	MM
SCALE	1:6

FYP-14-18: Budget

Project Title: Design and Fabrication of a Garbage Separation and Sorting System

Students` Names	**Cell Phone Number**
1. KINYANJUI Emmanuel	0726 212150
2. KARIUKI Antony	0720 966960
3. CHANG'ACH Dennis	0728 480518

S/NO	ITEM	SPECIFICATIONS (Minimum)	UNIT	QTY	UNIT PRICE	TOTAL AMOUNT	SUGGESTED SUPPLIER	COMMENTS
1	Arduino Mega	Arduino Mega 2560 R3	Pcs	1	1,500.00	1,500.00	Ktechnics	Similar one Available in the lab
2	Servo Motor	Continuous Servo Motor	Pcs	3	1,200.00	3,600.00	Ktechnics	
3	Geared Motor	ZHENGKE ZGA37RG Eccentric	Pcs	1	1,300.00	1,300.00	Ktechnics	
4	Motor Driver-L298N	Dual H Bridge Control Board for Arduino	Pcs	1	500.00	500.00	Ktechnics	With fitted Heat sink
5	Vibration motor		Pcs	2	1,000.00	2,000.00	Ktechnics	
6	Capacity Proximity Sensor	Part Number: LJC18A3-H-Z/BY	Pcs	2	1,200.00	2,400.00	Amazon	
7	Inductive Proximity Sensor	Part Number:LJ12A3-4-Z/BY	Pcs	1	1,100.00	1,100.00	Amazon	
	Shipping cost	Amazon				1,500.00	Amazon	
8	Power Adapter	Product code:KL-SDK-0403	Pcs	1	500.00	500.00	Nerokas	
	On/off buttons		Pcs	2	50.00	100.00	Nerokas	
9	Push Buttons	Tactile Push Button	Pcs	5	10.00	50.00	Nerokas	
10	Capacitors	Electrolytic Capacitors	Pcs	5	10.00	50.00	Nerokas	
11	Resisitors Pack		pack	1	150.00	150.00	Nerokas	
12	Voltage Regulators	7805 ‖ 7809 ‖ 7812	Pcs	3	50.00	150.00	Nerokas	
13	Connecting wires	Male-Male ‖ Female‖ Male	Pack	4	100.00	400.00	Nerokas	
14	Copper Wire	Single Strand Wire	Metres	10	30.00	300.00	Ktechnics	
15	Connectors	Male-Male ‖ Female‖ Male	Pcs	4	20.00	80.00	Nerokas	
16	Screwed Connectors	with screw fasteners	Pcs	2	50.00	100.00	Thika Electrical	For connecting components
17	Power jack	Female power jack	Pcs	1	50.00	50.00	Nerokas	
18	Sheet Metal	1.5mm ‖ Mild Steel	Sheet	1	3,200.00	3,200.00	Wanjon Dealers	
19	Angle bar	20 feet ‖ 20 * 20 * 2.5		1	700.00	750.00	Wanjon Dealers	
21	Bolts & Nuts	M6 *25 - Hex	Pcs	25	30.00	750.00	City General	
22	Bolts & Nuts	M6 *25 - Flat Head	Pcs	10	20.00	200.00	City General	
23	Roller Bolts	M10* 150	Pcs	4	100.00	400.00	City General	
24	Bearing	M10 * 26	Pcs	4	570.00	2,280.00	City General	
25	Roller	Nylon Plastic ‖ 1.5"	Metres	1	1,815.00	1,815.00	City General	
26	Coupling	Jaw Coupling		1	800.00	800.00	City General	
26	Conveyor belt	Canvas	m2	1	N/A	-	Available	
27	LCD	Graphic LCd 128*64	Pcs	1	1,200.00	1,200.00	Nerokas	
28	Toggle switch		Pcs	4	50.00	200.00	Nerokas	
29	Keypad		Pcs	1	150.00	150.00	Nerokas	
			Pcs	1	50.00	50.00		
	TOTAL AMOUNT					**27,625.00**		

1.Signed by Supervisor--- DATE--

2.Signed by Supervisor--- DATE---

3.Signed by Project Coordinator------------------------------------- DATE---