DESIGN AND IMPLEMENTATION OF A USER-LEVEL, REAL-TIME SMART WASTE MANAGEMENT SYSTEM FOR UNIVERSITY

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Ethics Statement

Our project had a similarity report of 10% most of which were material such as the table of contents page, specifications, chapter headings. No AI has also been detected by turnitin.

Abstract/ Executive Summary

Waste management is one of the most serious issues of contemporary campuses and urban areas that may lead to an unsanitary environment, resource wastage and environmental damage. This project introduces the design and implementation of an intelligent waste management system, which combines the use of IoT sensors, machine learning, and cloud-based monitoring. Two design dimensions were taken into account, a low-cost sensor-based design and a machine learning design with a Raspberry Pi and YOLOv8n classifier. The latter was found to be better by comparison, with 92% classification accuracy, consistent hazard detection, and real-time monitoring. Actuator control and power consumption were verified through MATLAB and Proteus simulations, and a physical prototype tested proved to be effective in segregation and optimal collection. The system minimizes the number of trips to collection, promotes recycling and allows responsible user behavior by a reward system. In keeping with the global sustainability objectives, the project will provide a replicable and scalable model of cleaner, smarter, and more sustainable communities.

Keywords: Waste Management; Raspberry Pi; YOLO; Classification.

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Chapter 1: Introduction

1.1 Introduction

Waste management has emerged as one of the burning issues in today's world due to increasing urbanization, industrialization and population growth. Conventional methods of waste collection often lags behind in meeting the rising demand for a cleaner and sustainable environment. Overflowing bins, unhygienic waste disposal systems and irregular collection of wastes have become a common sight inside the cities, residential areas and even in commercial buildings. These unpleasant sights not only create unhygienic conditions but also serve as a breeding ground for diseases, contribute to air pollution and increase greenhouse gas emissions. This improper waste management is responsible for millions of tons of carbon emissions annually. The inefficiency of traditional waste collection methods highlights the urgent need for smart, data based solutions that can optimize collection schedules and ensure a hygienic environment.

In the context of our project, university campuses present a microcosm of bigger cities where waste is generated daily by thousands of students, staff and faculty members. Due to high population density within a limited area, waste management inside a campus can become a difficult task. Inefficient management not only affects the quality of students' life but also creates a bad reputation for the institution. Moreover, campuses are spaces where innovation and sustainability is highly valued which makes them an ideal ground for implementing and testing smart waste management systems.

1.1.1 Problem Statement

Approximately 80% of garbage collections take place at the incorrect time. Overflowing trash cans, filthy surroundings, complaints from the public, unlawful disposal, and higher cleaning and collection expenses are all consequences of late waste collection. Carbon emissions from early rubbish collection are needless. Waste management done the old-fashioned way is proven to be incredibly inefficient. These inefficiencies manifest several challenges. Like, overflowing bins that contribute to an unhygienic environment and attract germs & diseases, environmental harm through various carbon emission from unmanaged collection trips, increased cost due to unnecessary fuel consumption, labour requirement and repeated cleaning attempts. This leads to spreading of diseases, public dissatisfaction, complaints and a decline in campus reputation. Hence, the only way to succeed in the very technologically advanced world of today is to take an original and data-driven strategy [1].

Managing waste is a daily chore in cities that impacts social, economic, environmental, and fiscal elements and demands a significant quantity of labor resources. Numerous strategies, including the nearest neighbor search, colony optimization, genetic algorithms, and particle swarm optimization techniques, have been put forth to maximize waste management. However, they are still too vague to be used in actual systems, like cities or universities [2]. While implementing them in real life, these algorithms often struggle with dynamic real world unpredictable conditions. These conditions include diverse bin usage patterns, random waste generation rates and sudden rise in population density during peak hours.

Nowadays sensors are used more frequently as the Internet of things (IoT) is constantly evolving. Sensors are working as the core of smart waste management systems. With the help of the sensors, users can collect and transmit data as well as perform a high level of processing. Not only collecting and transmitting data, sensors are also used for network analysation, connection finding and combining the data from sensors along with other sensor nodes [3]. Furthermore, sensor integration with machine learning (ML) models and cloud platforms can perform predictive analytics and real time decision making. Therefore this transformation from traditional waste management into a more efficient, sustainable and scalable system.

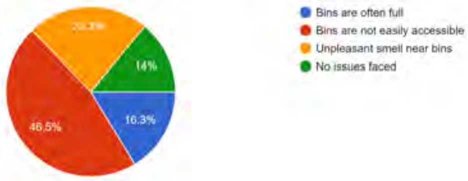
1.1.2 Background Study:

For several years, many researchers tried to attempt the optimization of the waste management system using computational processes and data driven approaches. They mainly explored ideas like nearest neighbour search, particle swarm optimization, colony optimisation and genetic algorithms to improve the waste management process [2].These techniques may provide theoretical knowledge but they fall short in real world applications due to the lack of adaptability or increased complexity.

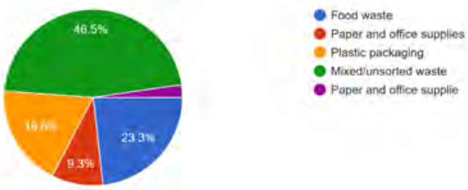
On the other hand, advancements in sensor networks and IoT have changed traditional waste management. Modern, smart bins can be equipped with sensors to measure the waste levels, IR (infrared) sensors to detect waste input, flame sensors for fire detection and even PIR sensors to identify human presence. These sensors not only collect data but also are capable of high-end processing, analysing, storing and communicating data in real time. Cloud platforms further allowed administrators to visualise bin status across certain areas [4].

Our conducted survey (shown below) inside the university campus reinforced the issues faced by traditional waste collection mentioned above.

What problems do you usually face while disposing of waste?
43 responses

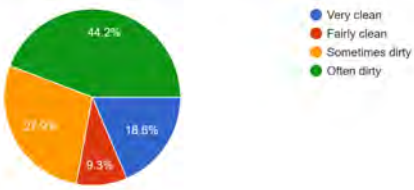


What kind of waste do you usually dispose of?
43 responses

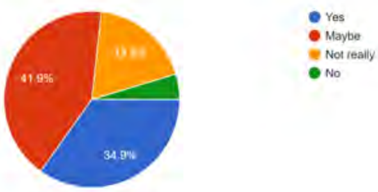


Would you prefer a contactless/automated waste bin?
43 responses

How would you rate the cleanliness around current waste bins?
43 responses

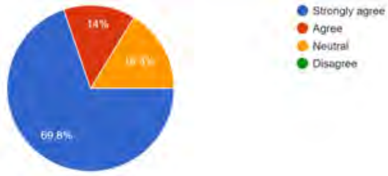


Would mobile notifications/reminders for the cleaners will help in responsible waste disposal?
43 responses

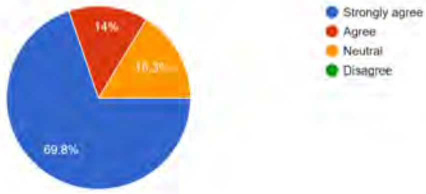


How frequently do you dispose of waste?
43 responses

Do you think better waste management can improve the work environment?
43 responses

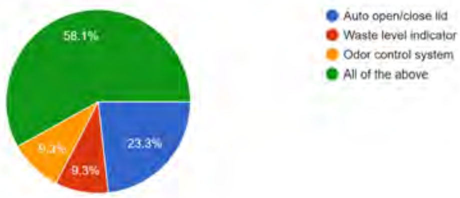


Do you think better waste management can improve the work environment?
43 responses



Are you aware of proper waste segregation (organic, plastic, etc.)?
43 responses

What features would you like in a smart waste bin?
43 responses



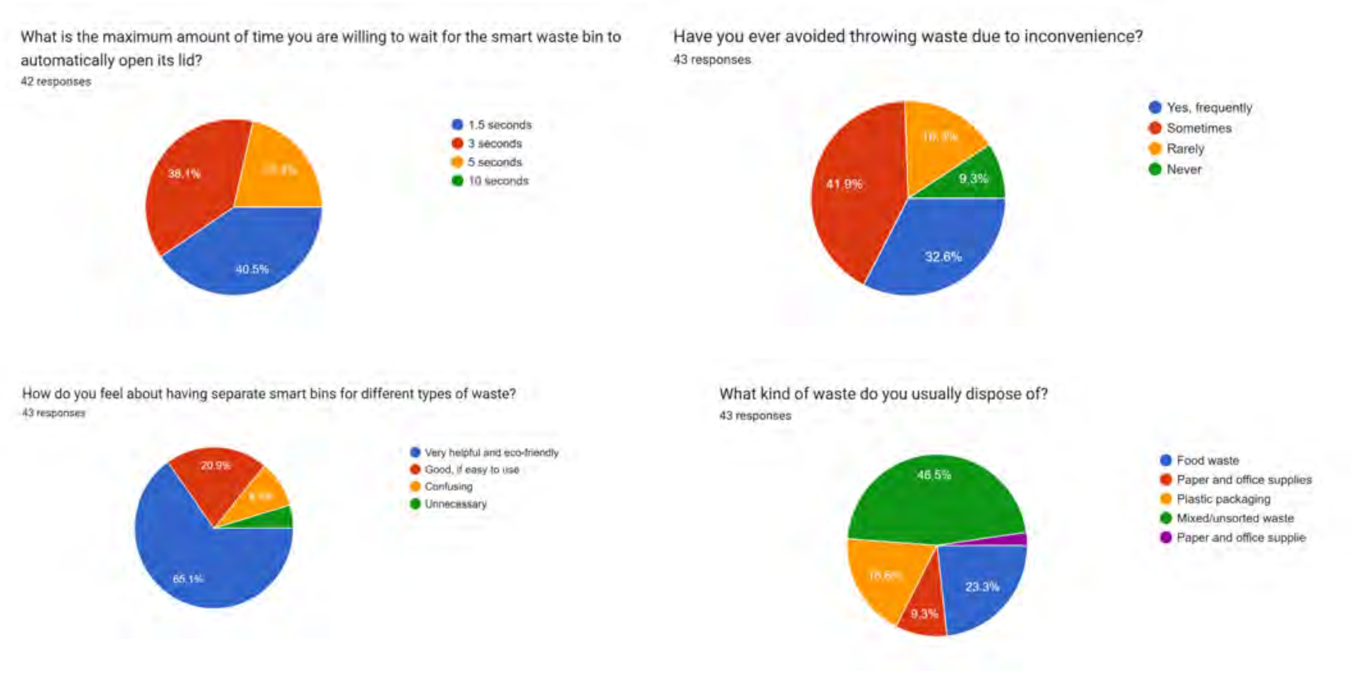


Figure-1: Conducted Survey results on waste management issues.

For better understanding of the current scenario and the need of a hygienic waste management system, this survey was conducted. From the above results of the survey, we can see how inconvenient the current management system is. People face many problems while waste disposal, they find the current system often dirty & unhygienic as well as due to the less availability of clean bins they avoid waste disposal many times. Therefore, they want a solution which is hygienic, contactless and hassle free. An automated bin will provide them a cleaner environment along with an odourless, effortless, convenient solution compared to the conventional waste disposal methods.

1.1.3 Literature Gap

Contemporary research has been done to solve the problem of the waste management system by implementing a prediction model to schedule, maintain and manage waste products. The earlier implementation was unable to integrate the schedule and maintaining process due to the lack of system data sending mechanism. In order to simplify and streamline this process, a system incorporated with a simple system to measure the amount of waste inside each trash bin were proposed, which were faulted to some problems in various capacities [2]. Later attempts were made to implement a waste management system for smart cities using different platform software, which however, mainly focused on collecting data [5].

In "IoT Based University Garbage Monitoring System for Healthy Environment for Students" the author manages to propose a system where the trash cans are equipped with a cost effective arduino uno based systems which are connected with a WiFi based API to a centralized IoT based control system [6]. All of the trash bins are marked with green dots in the university map and as soon as one bin is filled up, it shows red blinks on the map, assisting the related personnel to schedule their pickups. This was quite effective in reducing manual monitoring and labour. However, one significant problem of these kinds of simplified systems is that although they are cost effective and comparatively easier to implement, they are prone to failure and false detection more frequently, which goes against the very idea of smart waste management being developed.

To address these shortcomings, several researchers have tried to incorporate machine learning (ML) in their prediction algorithms to mitigate the problem. In a proposed study based on a machine learning algorithm , predicted probabilities of waste collection for real campus data ranged from 72% to 97%, depending on building activity. Such ranging in accuracy can be problematic for busy hours of waste disposals. Some examples of such designs can be seen in implementing nearest neighbour search, colony optimization, genetic algorithm, and particle swarm optimization methods [2]. These algorithms were explored to improve accuracy and optimized collection of waste. Furthermore,there are projects that extend to use line following robots to schedule the waste pickup which are incorporated into the ML algorithm itself. The line follower robot showed the 3.7% error margin in case of overflow detection of the bins. In case of overflow detection the error margin is not viable. Which might result in untimed overflow and discontinuous waste management [7].

The advancements were brought up from the previous research papers or projects that could not fulfil either of the functional or non-functional requirements. A basic IoT-based system [6] that offers a cost effective solution, fails to reassure the data encryption reliability for the users. ML methods which are higher in accuracy and that can be easily used in training and validation, lack in case of saving cost and computing power. Resulting in a gap for an overall cost effective and power efficient algorithm. In general, the missing field of the following project is a balanced solution that other researches and projects could not address properly. This certain gap creates the need for a smarter and practical implementation of a waste management system.

1.1.4 Relevance to current and future Industry

Smart waste bins have come a long way from simple motion-based systems. Newer designs now use a mix of sensors—like PIR to detect human presence, ultrasonic sensors to measure distance, and voice recognition to confirm user intent. These components work together through microcontrollers such as Arduino Uno, allowing the bin to open only when someone is nearby and gives a specific voice command. This makes the system more accurate, avoids unnecessary movements, and helps save energy [4].

At present, many private companies are experimenting with sensor based smart bins, cloud platforms to reduce operating costs and environmental carbon footprints.For example, several European countries have implemented “Pay-As-You-Throw (PAYT)” systems supported by smart bins that monitor individual waste generation which encourages people more in sustainable disposable practices [8]. Consequently, in Singapore, their National Environment Agency has launched smart bins with sensors that sends notifications to the user when the bin gets full. This initiative reduced overflowing of bins and unnecessary waste collection trips [9]. The global smart waste management market is expected to grow rapidly industrially. Furthermore, this project also aligns with the global sustainability goals like SDG goals. Here especially SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible consumption and production) and SDG 13 (Climate Action) is applicable. So, these goals also help to ensure global sustainability, cleaner environment through an optimised waste management system.

Today smart bins are also connected to cloud platforms through Wi-Fi enabled microcontrollers for broader usage. These smart bins can perform real time monitoring and the data collected is sent to cloud platforms for further analysis. In a larger perspective, implementing the smart bin system in a whole city will be very helpful for city authorities as they can get updates in real time and plan more efficiently. Some of the modern designs also include custom circuit boards and 3D printed casing. This makes the smart bin easier to arrange and manage in urban areas. Hence, these advanced technologies help cities to be smarter, cleaner and more efficient in waste management.

1.2 Objectives, Requirements, Specification and constraints

The research paper outlines a smart waste series device with real-time fact integration for optimizing waste management in urban settings, which may be adapted for campus environments. Its focus on real-time traceability and car routing provides practical implementation strategies in our task's project layout [11]. This project will greatly benefit the university campuses as the smart waste management includes IoT and 5G to monitor real time bin data. The system is relevant as it mainly focuses on the bin's real time data and campus specific waste management. Hence, providing broader insight about sensors, image classification and system design [12].

1.2.1. Objectives

- Design a smart waste management system.
- Analyze possible outcomes and implementation methods.
- Implement the system for a University Campus, in a specific area like the cafeteria for initial operations.
- Utilize the system in such a way that it is capable of handling different types of waste products commonly found in University campuses.

1.2.2 Functional and Nonfunctional Requirements

Functional Requirements:

- The smart waste bin must have a minimum capacity of 40 kgs on each compartment and should be able to accommodate waste aligning with the usual rush in an academic day at the cafeteria or common areas.
- Waste segregation system must classify waste into two main categories:

a) Biodegradable (eg: food waste, paper, paper cups)
b) Non - Biodegradable (eg: plastics, bottles, polythene bags)

- Based on the classification, a flap connected with a servo motor will sort the waste into designated compartments.
- A sensor will measure the distance between the bin lid and waste pile which will further give alerts.
- The system must be connected to a cloud IoT platform and data will be transmitted to the platform in real time.

Non-functional Requirements:

- Automated sorting system for biodegradable and non-biodegradable wastes under ≤ 10 seconds.
- The system will raise alerts when the bin is 85% full (approximately 36 kgs). Notifications will be sent when:
  a) Distance ≤ 2 cm : “Bin is Full”
- A prediction model trained using a YOLO.v8n-cs model on 19000 images for initial classification to schedule waste collection.
- Harmful gas leakage and flame detection system using sensors in the trash bin with a refresh rate of 30 seconds for real-time monitoring
- The transmitted data includes current waste level in individual compartments, alerts when bin reaches 85% capacity, alerts when hazardous elements are detected. This system should maintain a log of bin activity for at least 30 days.

1.2.3 Specifications

Design Approach 1:

Table-1: Specifications for design approach-01

Subsystem	Component	Specific Name and Specification
	Microcontroller (Raspberry pi 4)	It has 1.5 GHz quad-core Cortex-A72 CPU, 8 GB LPDDR4 RAM, and VideoCore VI GPU. It supports dual-band WiFi, Bluetooth 5.0, Gigabit Ethernet, dual 4K HDMI, USB 3.0/2.0, GPIO, and camera/display interfaces.
	Camera Module	8 MP, 1080p video
	Waste Sorting Classifier	Image classification ML model
	Hand Detection Sensor (IR sensor- LM393)	Operates on 3.3–5V DC with ~20 mA current, provides an analog output, covers a 280–390

Control and Electronics		nm UV range, and uses a UV photodiode with onboard signal conditioning.
	Bin Level Sensors (HC-SR04 Ultrasonic Distance Sensor Module)	2X Ultrasonic Sensors (2–400 cm range, ±3 mm accuracy). Operates on 5V DC with ~15 mA current, measures distances from 2 to 400 cm with ±3 mm accuracy, and provides digital output via trigger and echo pins using a 40 kHz ultrasonic signal.
	Entry Flap Actuator (MG996R)	Servo Motor (0°–90°, 1.8 kg·cm torque). Rotation motor with 4.8–6V operating voltage, stall torque of 2.2 kg·cm at 4.8V, operating current of ~200 mA, and is controlled via PWM signal for precise angular positioning.
	Sorting Flap Actuator (MG996R)	Servo Motor (0°–180°, 9.4 kg·cm torque). Rotation motor operating at 4.8–7.2V, with a stall torque of 9.4 kg·cm at 6V, running current of ~500 mA, and is controlled via PWM for precise angular positioning.
	Coin Dispenser Actuator (MG90S 90 Degree Rotation)	Servo Motor (0°–90°, 1.8 kg·cm torque). Rotation motor with 4.8–6V operating voltage, stall torque of 2.2 kg·cm at 4.8V, operating current of ~200 mA, and is controlled via PWM signal for precise angular positioning.
	Flame Detection Sensor (LM393 comparator)	Operates on 3.3–5V DC with ~20 mA current, detects flame or fire sources within 760 nm–1100 nm wavelength, and provides both digital and analog outputs for alert and measurement purposes.
	Gas Detection Sensor (MQ 135)	Operates on 5V DC with ~150 mA current, detects gases like LPG, smoke, propane, hydrogen, and methane, provides both analog and digital outputs, and features high sensitivity with fast response for real-time gas monitoring.
	Buzzer	Usually operates at 3–12V DC with 70-90 dB output buzzer sound
	LED	5 mm RED LED

Communication	**WiFi Communication**	Tiger VNC for Raspberry pi 4 WiFi hotspot module communication
	Dashboard	Push Bullet for monitoring the alerts
Power	**Power Source**	220V AC from power distribution
	Power Adapter	Adjustable 220 VAC to DC 3V-24V and 5A universal adapter that can be adjusted accordingly
Human-Machine Interphase (HMI)	**LCD Module Display**	16x2 dimension serial LCD module for Arduino and Raspberry pi that operates on 5V DC.

Design Approach 2:

Table-2: Specifications for design approach-02

Component	Specific Name and Specification
Microcontroller	ATmega328P, 32 KB Flash, no WiFi
Hand Detection Sensor	IR Proximity Sensor
Bin Level Sensors	2x Ultrasonic Sensors (2–400 cm range, ±3 mm accuracy)
Waste Sorting Classifier	Color Sensor (RGB color detection, I2C)
Entry Flap Actuator	DC Gear Motor (12V, 100 RPM) + Limit Switches
Sorting Flap Actuator	DC Gear Motor (12V, 100 RPM) + Limit Switches
Gas Detection Sensor	Gas Sensor (Smoke, LPG, Methane detection)
Power Source	12V 7Ah Sealed Lead-Acid (SLA) Battery
User Feedback	LEDs + Buzzer (Bin Full Notification)

1.2.4 Technical and Non-technical consideration and constraint in design process

Technical considerations and constraints:

- The sensors and devices used in the trash can should be durable and waterproof which can withstand harsh conditions like humidity, dust and possible tampering.

- The Iot devices on the bins should have sufficient battery for longer usage, particularly in locations without direct access to power sources.
- The system requires high data transmission in real time from multiple sources to a centralized location.

Non - technical considerations and constraints:

- Making a feasible solution as a product within the limited time and allocated budget.
- Ensuring the cost-effectiveness of components and resources concerning both initial setup and long-term maintenance.
- Addressing the usability and arrangement challenges such as accessibility in different zones of the campus and user-friendliness of the whole system.

1.2.5 Applicable compliance, standards, and codes

The proposed smart waste management system adheres to the established international standards, ethical framework and environmental regulations to ensure compliance, transparency and long term sustainability. The core of the system will prioritize sustainable and energy-efficient materials to minimize the environmental impact and consider the creation of an ecosystem to which users will be accustomed.

To minimize the environmental impact, the system emphasizes the use of sustainable and energy-efficient materials in construction. This ensures reduced energy consumption and lower carbon emissions during its operation. Components such as sensors, IoT modules are carefully selected to comply with environmental safety norms which assures that the system aligns with global sustainable development goals. Moreover, safe disposal of electronic waste will be carried out according to WEEE (Waste Electrical and Electronic Equipment) regulations [13]. Therefore, integrating WEEE guarantees that the waste management system contributes safely to the environment.

Similarly, we are following the ISO 14001 standard (environmental management standard) & IEEE standard (for IoT frameworks). This will help to identify the legal usage of the components & their unfavourable impact on the environment [14]. In addition, regular audits and compliance checks will be done so that the system always adheres to the applicable standards and codes. Constant monitoring will be helpful to guarantee accountability, adaptability and transparency with the changing legal and environmental compliances. Following these measures will ensure that the system meets technical expectations as well as aligns with safety policies and ethical codes. Integrating the applicable standards and codes into the system will maintain the smart waste management to remain compliant, transparent, scalable and environmentally fit.

1.3 Systematic Overview/summary of the proposed project

Our proposed waste management system is designed to make the process of waste collection automatic, real time monitoring and hygiene management while also integrating modern technologies like machine learning models, sensors and IoT cloud platforms.

1.3.1 Design Approach 1:

In this design approach, firstly the system starts with an infrared(IR) sensor that will detect the presence of waste. The disposer will hold the waste in front of the IR sensor and the detection process will begin. Once detected, the microcontroller used here is Raspberry Pi will process the signal and activate a servo motor which will then open the lid of the bin. Now the disposer will throw the trash inside the bin and the waste will be deposited onto a white tray. Over the tray a webcam is being placed. The cam will now see the disposed waste to capture an image which will be further processed using a machine learning (ML) classification algorithm. The ML algorithm will now categorize the waste into either biodegradable waste (bio) or non biodegradable waste (non-bio). Based on the classification result, the Raspberry Pi will control another servo that rotates the white tray into the two bins directly under the tray. The waste will be directed either to the bio bin or the non-bio bin.

For proper monitoring of the waste bin, ultrasonic sensors are integrated into the bin which continuously measures the bin fill level. If a bin reaches its maximum capacity, the system displays the status over an LCD screen and also locks the bin lid to prevent further disposal. Along with the display a buzzer and red led is activated to alert the assigned personnel for waste collection. In addition to the ultrasonic sensor, flame sensors and gas sensors are deployed inside the bin to detect harmful conditions like fire or the presence of hazardous gases. If any of these are detected, the system immediately triggers the buzzer and LED while simultaneously locking the bin lid for more safety.

Additionally, the whole waste management system is maintained by an IoT module that helps to transmit real time data in mobile applications for easier usage of users. With the mobile app, users can continuously monitor the bin data and send assigned personals if required. This allows the user to administrate all data in real time using only 1 app. Furthermore, to encourage users to throw waste at bins only, a reward system has been incorporated. In this reward system, whenever 2 non biodegradable waste is disposed within 20 seconds, the user gets one 2 taka coin. In conclusion, the proposed smart waste management system combines automation, IoT and connectivity to provide an efficient and sustainable solution for waste classification and real time data monitoring.

1.3.2 Design Approach-2

In the alternative design approach, waste gets sorted while the disposal process goes on through the use of sensors. Which ensures a more efficient waste management process by reducing the chances of error for the object sorting. The system has a ATmega328P microcontroller as its core, that manages the detection and sorting operations.

The process starts with initially the IR proximity sensor detecting the user’s hand near the bin. The microcontroller immediately sends the signal to a DC gear motor to open the entry flap. Which allows the waste to pass into the system. Limit switches ensure precise movement and controlled closing of the flap after each disposal of waste.

Once the waste is put through the flap, it undergoes pre-sorting through a color sensor. The sensor based mechanism identifies the waste type based on the color characteristics of the waste. The microcontroller then activates the sorting flap actuator which is a motorized flap controlled by limit switches connected to a DC gear motor. That directs the waste to the designated compartment. This ensures proper classification occurs instantly, before the waste is mixed up together.

Each compartment is equipped with an ultrasonic sensor similar to the original design approach to monitor fill levels. If either bin reaches the threshold line, the microcontroller triggers the LED and buzzer indicators. Then the system alerts the users that the bin must be disposed of.

For safety purposes, a gas sensor continuously monitors all the hazardous gases such as smoke or methane inside the bin compartments to prevent the system from any sort of failure. If any hazardous gas presence is measured, the system immediately activates the buzzer and LED warning system. This blocks further disposal until the hazard is mitigated.

In the power generating sub-system, a 12V SLA battery generates power into the entire system. Additionally, the system remains portable and reliable with a 3 phase line connectivity system that helps functioning independently through the continuous power source.

In summary, this pre-processing design's main goal is to sort the disposed waste at the point of disposal and reduce contamination. That helps simplify downstream recycling and maintain safety through continuous processing and monitoring of the system. The approach is noble for its practical and cost-effective solution for smart waste management systems. By offering controlled waste disposal through maintaining Sustainability in environments such as campuses, offices and workplaces.

1.4 Conclusion

Inefficiencies of traditional waste management systems highlight the importance of a smarter solution for waste management. The overflowing waste bins, unnecessary collection trips, more physical labour needs to be eliminated with a modern solution. The proposed project bridges the gaps in existing research by integrating IoT, sensor, ML and predictive analysis into a reliable smart waste management system for university campuses. Beyond solving immediate campus hygiene, it also aligns with broader industry trends toward sustainable smart cities and provides a scalable model for future utilization. By ensuring hygiene, efficiency and sustainability, our project will not only improve the quality of campus life but also contribute to a cleaner future and greener environment.

Chapter 2: Project Design Approach

2.1 Introduction

The engineering issues that appeared in the representation and enactment of the smart trash management framework which has the functionality of real-time, were sophisticated in nature, and thus, the implementation needed a systematic framework. We aimed to develop an effective and predictable waste segregation solution suitable for a university campus [15]. Starting with this original conceptualization of the project, later dimensions were added to the final design. Two main methods were carefully considered to find the most feasible and potentially successful capability that fits the project's goals and limitations [16]. Quantitative analysis of these methods, backed by component specifications and performance metrics, was also vital in the selection of an optimal design that has been demonstrated to be achieved in the physical prototype.

2.2 Identify Multiple Design Approaches

In order to satisfy the fundamental functional requirements of the project, two design strategies were formulated. Advanced artificial intelligence and machine learning techniques for trash categorization were emphasized for Design Approach 1, while Design Approach 2 advocated a simpler sensor-driven alternative. The system's preciseness, degree of complexity, and expenditure can be significantly influenced due to the variations between these two concepts as they have an impact on trash recognition.

2.2.1 Design Approach 1: Camera and Machine Learning-Based System

The identification and categorization of garbage is done efficiently through this approach which utilizes actual-time image processing automatically. This technique is more durable and adaptable to a larger variety of pollutants, in comparison to traditional sensor-equipped systems.

- **Waste classification:** Upon introducing garbage into the framework, an integrated camera photographs it on display. In order to classify the trash into certain classifications, such as 'biodegradable' and 'non-biodegradable', an existing previously trained machine learning model known as YOLOv8n-cls is used to analyze the images.
- **Structure of the system:** To carry the mathematical capacity of the ML model, a robust standalone microcomputer referred to as a Raspberry Pi 4 is employed as the system's main energy resource. Despite relying on an active internet connection, the arrangement ensures continuous connectivity
- **Key aspects:** A digital camera accessory, a Raspberry Pi 4, an AC-DC adapter and three motors with servos make up the primary components, that control the coin dispenser, along with the bin's lid, including the trash sorting process.

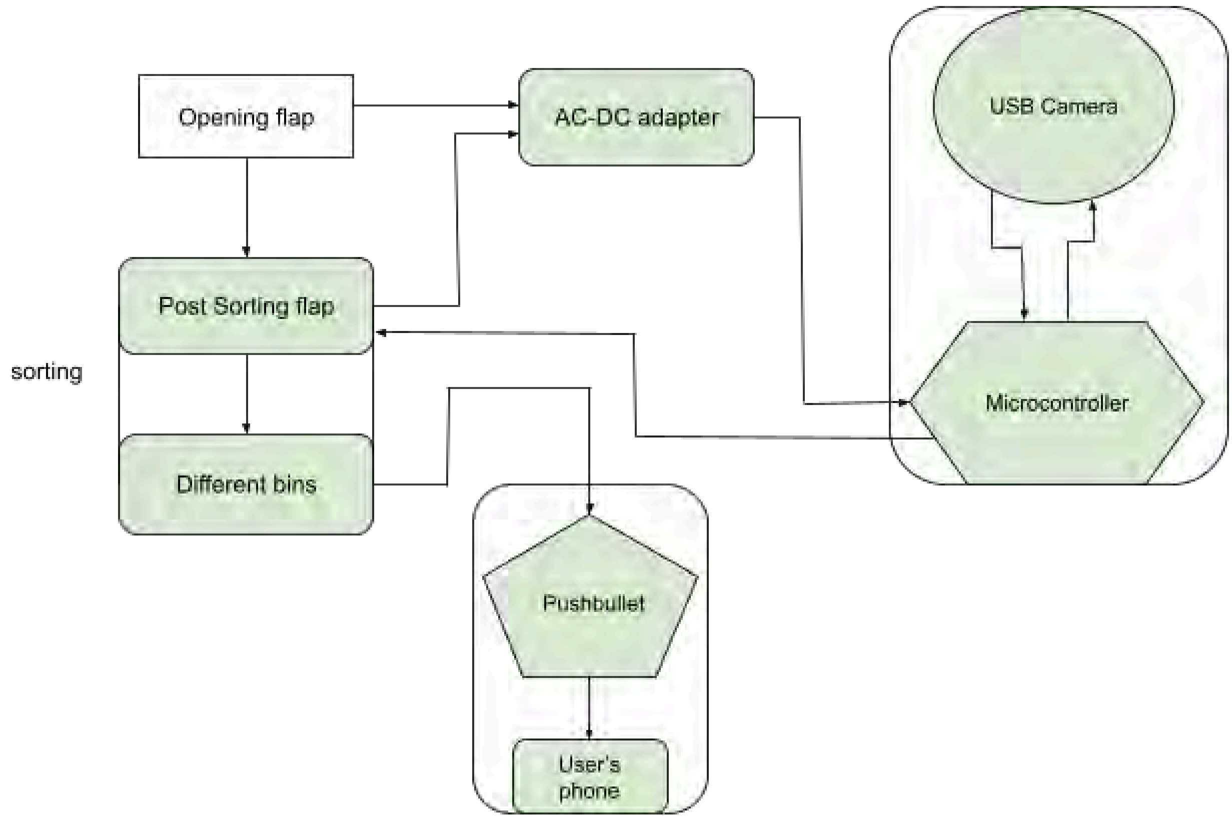


Figure-2: Design Approach 01 (finalized approach)

2.2.2 Design Approach 2: Sensor-Based System

By utilizing an external sensor rather than complex image processing algorithms, this method was able to focus on convenience and affordability.

- **Categorization of waste:** To determine the waste object's color, a color sensor is inserted inside the bin . To separate garbage, the system relies on established color values. As an example, one type of identifying a food scrap may yield green or brown color, whereas an alternative set of the RGB values would identify a plastic bottle.
- **System architecture:** A supplying microcontroller, like an Arduino Uno, can be utilized to analyze the sensor data and drive the motors. Such a design is less expensive and serves as an independent unit that possesses what is limited to network operations.
- **Components needed:** The main hardware components that are required for this approach include an Arduino Uno, a color sensor, and simple DC gear motors. The entire system is

easier to assemble and has a lower power consumption profile.

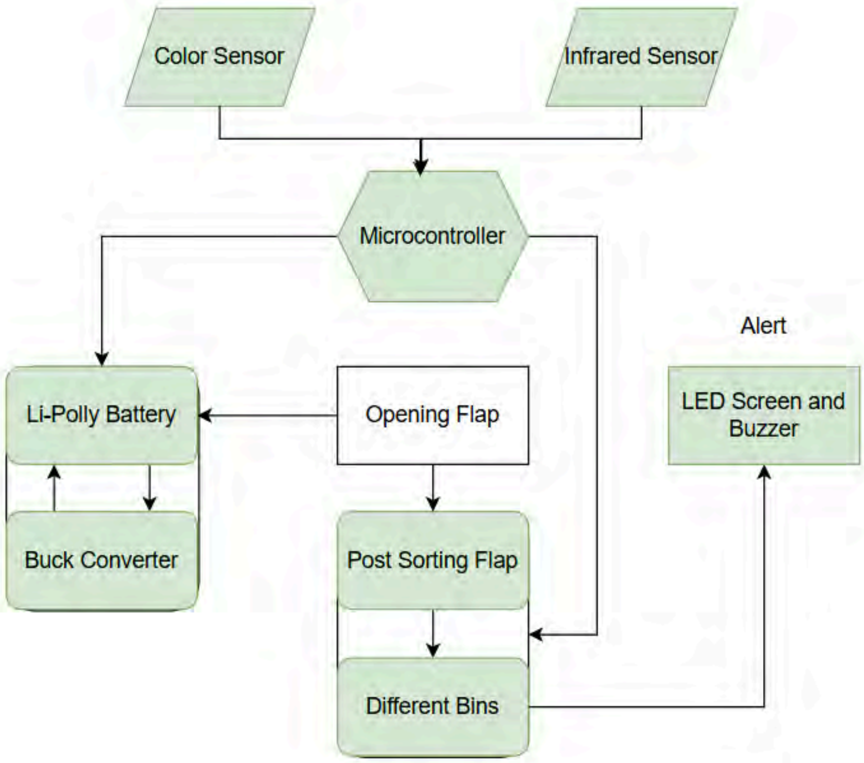


Figure-3: Design Approach 02

2.3 Describe Multiple Design Approaches

A detailed explanation of how each of the approaches performed was part of the design process, including hardware, system logic, and user experience. This assisted in the intense screening of each idea before proceeding to what can be translated into physical reality. The entire system is easier to assemble and has a lower power consumption profile.

2.3.1 Design Approach 1: Camera and Machine Learning-Based System

The physical model of this design is a high dustbin with a general size of 32 ft height, 24 ft length, and 24 ft width, made of PVC boards. This internal sorting, to be done by two smaller bins (19 ft in height, 18 ft in length, and 10 ft in width), has been successfully put in its rightful place, and is removable and portable. A top bin opens with a servo motor in response to an infrared (IR) sensor that detects the presence of a user's hand. Waste is put on a base, illuminated by white LED lights, and thus the camera takes a photo.

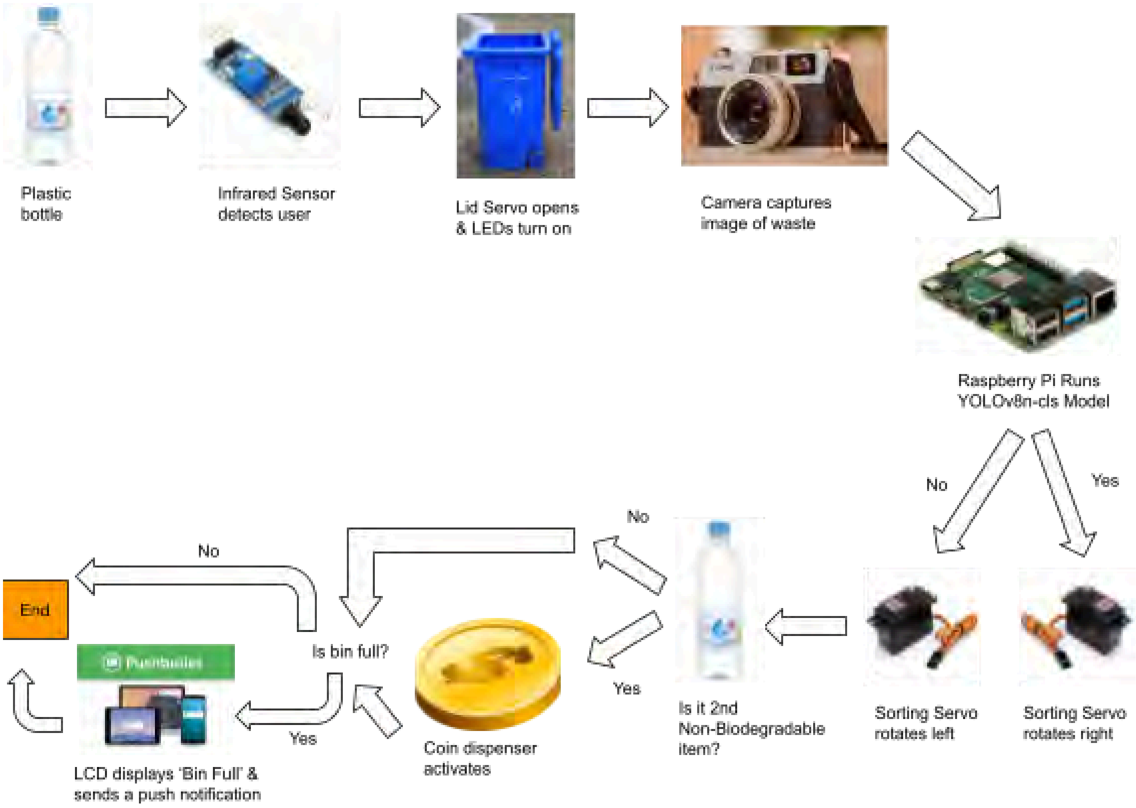


Figure-4: Workflow diagram of Design Approach 1

The picture is run through the Raspberry Pi 4 that operates a pre-trained picture classification model. Depending on the set classification (for example, a plastic bottle is non-biodegradable), a second servo motor (MG996R) is used to rotate the platform towards the left or right side so as to drop the item to the appropriate internal bin. One more servo motor (MG996R) is used to open the flap, i.e., the opening and closing of the lid. The MQ135 gas sensor triggers an alarm if it detects any sort of flammable object. In this part, the exceptional coin dispenser mechanism is powered by a different motor (MG90S) that rewards users with a 2 taka coin for each of the two non-biodegradable waste products stored. System messages are displayed on an LCD screen. The vegetative sensors include an ultrasonic sensor to measure when the bin is full and transmit the information to the admin. The wiring system consists of a multiplug and a multitude of jumper wires. The whole bin is actually mobile, and it also has wheels attached below, making it easy to transport.

2.3.2 Design Approach 2: Sensor-Based System

We have taken such a system to be a simplistic version. An IR sensor identifies a user, and therefore, the lid is opened through the motor. An Open-Cast color sensor within the bin sorts the trash according to a hard-coded color scale. This data is fed to Arduino Uno, which is used to sort the waste by turning a DC gear motor.

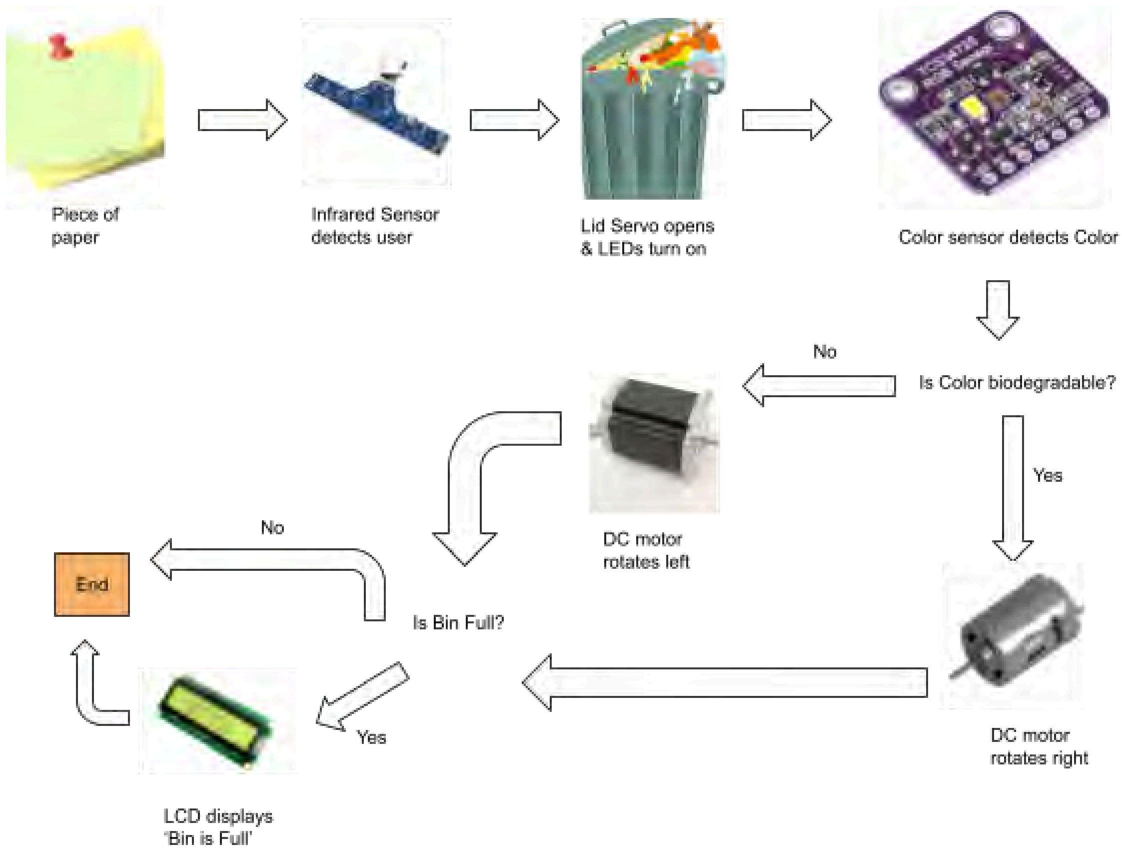


Figure-5: Workflow of Design 2

Altogether, in place of a custom dashboard, alert texts and status information are shown on a local LCD display, and an audible warning overrides a buzzer. Although this method is less costly, because of the dependence on such a color-based classification technique, it is very prone to errors caused by variations in the light location and dirt on the sensor.

2.4 Analysis of Multiple Design Approaches

Comparative analysis was conducted carefully in order to come up with the best design [18]. This assessment was made on the basis of such critical ratings as accuracy, cost, and feasibility to be implemented in the real world. A powerful wider factorization of feature usage is possible along with the durable coin dispenser and sophisticated fault detection of a full bin state, by the use of a Raspberry Pi.

Below, a comparison table has been included, that summarizes the main features and trade-offs of both design approaches.

Table-3: Comparison table displaying the features for both design approaches

Criteria	Design Approach 1 (Camera + ML)	Design Approach 2 (Sensor-Based)
Waste Classification Method	Real-time image processing using YOLOv8n-cls on a Raspberry Pi.	Color detection using Arduino Uno.
Accuracy	High (~92% in simulations). Resistant to changes in light and various types of waste.	Moderate (~70% estimated). Susceptible to mistakes due to light and dirt.
Complexity	High. Requires a powerful microcontroller, a camera, and a trained ML model.	Low. Uses a simple microcontroller and basic sensors.
Cost (BDT)	**32,819** because the initial investment is increased by components such as the Raspberry Pi and camera.	**15,273** since Arduino Uno and the color sensor are cheaper.
Scalability	High. The architecture is easily extensible for future capabilities, including cloud integration and advanced reporting.	Low. The simple logic and limited processing power limit the ability to add future features.
Power Consumption	Moderate (~12.98 W). Increased power consumption from the Raspberry Pi and the camera. This calculation has been shown in table 7.	Low (~11.88 W). More energy-efficient components. This calculation has been shown in table 7.

Key Advantage	High accuracy of waste sorting and flexibility to new types of waste.	Simplicity and low cost for basic functionality.
Primary Limitation	The initial cost is higher.	Reduced accuracy and susceptibility to the effects of the environment

2.5 Conclusion

Design Approach 1 was definitely approved following a well-developed conceptualization and review process. Its multifunctional abilities, including the precise machine learning model up to the concept of producing incentives and fault detection, were considered fundamental to the development of a smart waste management system consisting of high effectiveness and reliability. This conclusion was confirmed to be true with the physical prototype, where all the features could be fused and work in tandem successfully.

Chapter 3: Use of Modern Engineering and IT Tool

3.1 Introduction

A set of recent engineering and IT tools, carefully chosen and collected, aided the development of the "Design and Implementation of A User-Level, Real-Time Smart Waste Management System for a University Campus". Such tools proved useful on all levels of the project, starting with the initial design and simulation, all the way through its implementation and performance inspection. In this chapter, an extensive explanation of the tools used, reasons why the tools were selected, and how they were used to create the final prototype in particular is provided.

3.2 Selection of Appropriate Engineering and IT Tools

The tools used in this project were selected for their synergy, efficiency, and capability to deal with the specific complexities of an IoT-based mechatronics system. A table-based comparison was constructed to systematically compare each tool and its alternatives against important project requirements. This approach was used to ensure that the final selection was well justified and met the project's objectives in terms of reliability, cost-effectiveness, and ease of implementation.

Table-4: Engineering tool selection

Sub-system	Engineering/IT Tool	Reason for Selection
Structural Design	**Fusion 360**	Provided a strong 3D modeling platform, allowing for accurate design of the large enclosure of the bin, internal flaps, and component mounts.
System Logic & Simulation	**MATLAB Simulink**	Expert in simulating complex control systems, such as PID control of the servo motors, which can be virtually tuned and verified for mechanical response.
Circuit Verification	**Proteus**	An industry-standard circuit simulation tool, which we used to test the electronic connections between the Raspberry Pi, sensors, and motors in a virtual environment to reduce hardware risks.
Machine Learning	**YOLOv8n-cls (on Google Colab)**	Selected for its best combination of speed and accuracy, which makes it suitable for real-time waste classification on the Raspberry Pi. Google Colab gave free access to a GPU for efficient model training.
Core Programming	**Python (with OpenCV)**	A widely used and versatile programming language that is used to write the control logic, process the images from the camera, and handle all the interactions with the hardware on the Raspberry Pi.
UI/UX & IoT	**Pushbullet**	Rather than using third-party platforms, a custom solution was selected, in our case Pushbullet, to give a bespoke, real-time user interface that shows a wide range of data from the system, including fault detection and bin status.

3.3 Use of Modern Engineering and IT Tools

The use of these tools was embedded in the project lifecycle, and each tool had a distinct and important role. The following sub-sections describe in detail, paragraph by paragraph, how these tools were used.

- **Fusion 360:** This Fusion 360 was needed to make a fully completed 3D model of the smart waste bin as the focal tool for designing it mechanically. This comprised the Two inside bins, the sizable yellow PVC exterior casing, and the precise locations for the servo motor and sensor attachment, all of these were comprised. The software's parametric design capabilities aided the effortless measurement of physical elements to guarantee a precise fit. The ability to simulate the rotational motion of the sorting flaps in the digital environment was also an important feature that was used to validate the design before any physical fabrication could be undertaken.
- **MATLAB Simulink:** This tool was very useful in the design and verification of the control logic of the system. Using Simulink's block-based interface, a PID controller was designed and simulated to control the movement of the MG996R servo motor, using it to control the waste sorting platform. This simulation allowed the team to tune the proportional, integral, and derivative gains to provide a smooth and responsive mechanical action. By seeing the motor's reaction to a given incoming signal, it could be verified that the physical prototype would operate without any undesired fluctuation or latency.
- **Proteus:** The electrical circuits were tested virtually using a designing software known as Proteus. Using the servo motors, IR sensor, and Raspberry Pi 4, a whole schematic had been produced. To evaluate GPIO pin layouts and troubleshoot the platform's logic, the simulation proved to be useful despite incurring the risk of damaging the actual parts. In order to make sure that every part would work properly after the circuitry was put together, the entire group ran the test in order to verify whether the Raspberry Pi was correctly reading data from sensors and providing adequate control impulses to the motorized actuators.
- **Google Colab & YOLOv8n-cls:** The trash categorization mechanism's core component is its computerized training algorithm. As it is suitable for real-time application on an edge device such as the Raspberry Pi 4, The YOLOv8n-cls architecture was chosen for its speed-accuracy trade-off. The model was trained on a large custom dataset on Google Colab, which provided us with a high-performance GPU, which greatly reduced training time. After training, the model was pruned to a lightweight model for easy deployment on the Raspberry Pi for low-latency, real-time image classification.
- **Python (with OpenCV):** Python was the main programming language used for the control logic of the project. An application was created with the help of libraries like OpenCV to capture images in real time from the camera, perform classification using the YOLOv8n-cls model, and interpret the results. Python scripts were also used to control the GPIO pins on the Raspberry Pi to control the servo motors and communicate with the LCD display and ultrasonic sensor.

- **Custom Dashboard (Pushbullet):** A custom dashboard was used for the UI/UX and IoT functionality of the system. This web-based interface running on the Raspberry Pi shows the status of the bin in real time, including the current fill level (from the ultrasonic sensor), any gas alerts (from the MQ135 sensor), and the status of the coin dispenser. The custom nature of this dashboard enabled a user-friendly and highly specific interface that was designed specifically to meet the needs of the smart waste bin. Pushbullet works on real-time notifications and any messages are sent from the system to the user's PC or mobile phone. For our project, we needed to utilize it as a continuous notification provider regarding main key events. By using the ultrasonic sensor for bin level detection or even the gas sensors for identifying any flammable objects, push notifications are sent immediately to the user's phone.

3.4 Conclusion

The ability to operate a wide variety of contemporary engineering and IT tools was the key to the effective execution of this project. Each of the tools had a particular and irreplaceable purpose, starting with the virtual prototyping of the physical structure in Fusion 360 and ending with the real-time visualization of the data on the custom IoT dashboard. This well-documented and systematic approach ensured the technical feasibility and reliability of the smart waste management system and was also a productive exercise of contemporary engineering practice to solve a complicated real-world issue.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution.

4.1 Introduction

An engineering strategy called design optimization is essential for methodically determining which of a given range of options is the best. By carefully contrasting Design Approach 1 (utilizing a camera) and Design Approach 2 (based on sensors) both numerically and in qualitative terms, in the context of the smart system for handling waste, this was accomplished. Selecting an architecture that would prove adaptable to actual situations and offer the greatest possible balance of usefulness, value for money, and reliability, was the primary objective. The evaluation and review process that leads to the selection of the ultimate design and its confirmation, has been described in this chapter.

4.2 Optimization of Multiple Design Approaches

The practice of simulation followed by evaluation of these two design methodologies versus an agreed upon set of parameters started the tuning procedure. This made it possible to directly examine their advantages and disadvantages in a safe setting.

- **Simulation of Performance:** MATLAB Simulink was employed to perform a complete PID-controlled simulation of the servo motors in order to validate both the physical and electrical elements of Design Approach 1. As demonstrated by the experiment, the PID control system could provide the flap with precise and steady mobility as well as a regulated outcome that closely matched its input signal. This prevented mechanical failures and rubbish spills by ensuring that the drive system operated effortlessly and predictably during the separation operation.
- **Analysis of power consumption:** To model every design's use of energy, a power consumption model was carried out. The Raspberry Pi and the camera mostly, consumed a total of around 12.98 W, in Design Approach 1 [17]. Due to the color sensor and Arduino using less power, Design Approach 2 had slightly higher consumption of 11.88. Despite design 2's somewhat higher power output, the superior usability of design 1 was thought to be worth compromising. Table 7 displays the results of the power usage calculation.
- **Metrics for Classification Accuracy:** The project's simulation portion was subjected to the fundamental classification techniques which included phase data. The YOLOv8n-cls algorithm, which was applied in Design Approach 1, was verified to have an accuracy rating of 92% after undergoing training on a sizable dataset of over 2,000 photos [19]. The color-sensor-based strategy used in Design Approach 2, often struggles with illumination shifts and has an estimated precision of around 70% which, in similar studies, was significantly less accurate than this [18]. The final choice was heavily influenced by such a prominent statistical shortcoming.

4.2.1 Circuit Simulation for Design Approach 1

Proteus circuit simulation was employed to thoroughly verify the entire system's electrical circuitry. The connection points amongst the main parts of the structure are depicted in the schematic diagram, which is shown in the image beneath. The Raspberry Pi 4 is the main processing unit, which takes inputs from the IR sensor (to detect the user) and the ultrasonic sensor (to detect the bin level). It then sends control signals to the MG996R servo motor (sorting flap) and the second servo motor (opening lid) as well as to the LCD display. This simulation verified that the control logic for all these components is as desired.

The design was verified in the mechanical and power aspects using a MATLAB Simulink model for the PID control and power consumption, as shown below. The model is used to simulate the response of the MG996R servo motor to input signals and to verify that the PID controller is tuned correctly to provide smooth and stable movements without oscillations. The power simulation confirmed that the total power consumption of the selected Raspberry Pi and Camera was 12.98 W.

Sorting Simulation (Approach 01)

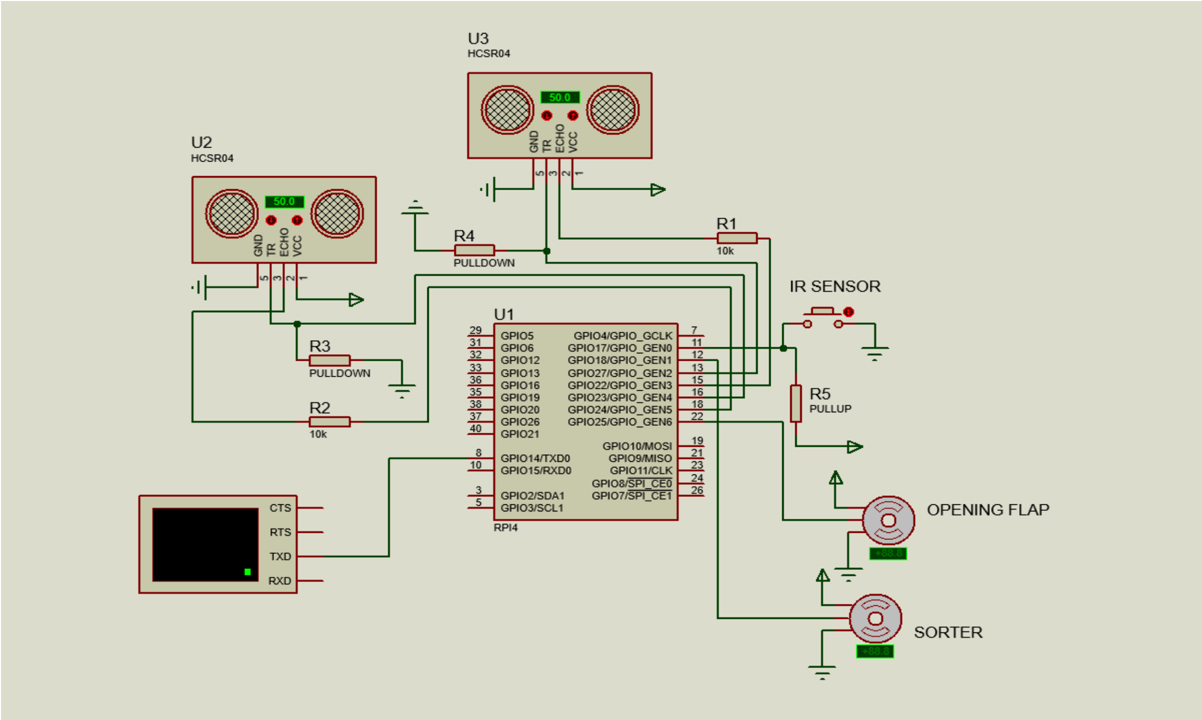


Figure-6: Circuit diagram of the Sensor and Sorting part

Proteus was used to set up a working model of how the sensors work with the actuators in our smart waste bin. At the outset, the design prioritized building sensor detection and sorting mechanics, which we later put in place with Raspberry Pi hardware.

In Proteus, the simulation involved:

- PIR sensor: A digital push button is simulated to mimic motion detection control for flap opening.
- Ultrasonic sensor (HC-SR04): Sensor readings are used to see how much remains in the trash bin.
- Two servo motors: You need to pull one lever for the lid flap and another for sorting waste inside.
- Push buttons: Waste classification was triggered by logical rules, and motion detection was used for testing.
- Arduino Uno: Provided an environment where the logic and timing of servo waveforms could be experimented with.

The simulation demonstrated that the algorithms were correct.

The lid opened up when motion was noticed.

Waiting a moment after the lid is open before closing it again.

Separating waste after it is detected, as recommended by the study's mock classifier.

Flap motion is controlled and matches the movement from the sensors used for input.

Thanks to the simulation, we could set up timing, check servo placement logics, and fix problems with the sensors ahead of using physical hardware. It enabled mechanical actuation that was safe and quick to include in the design.

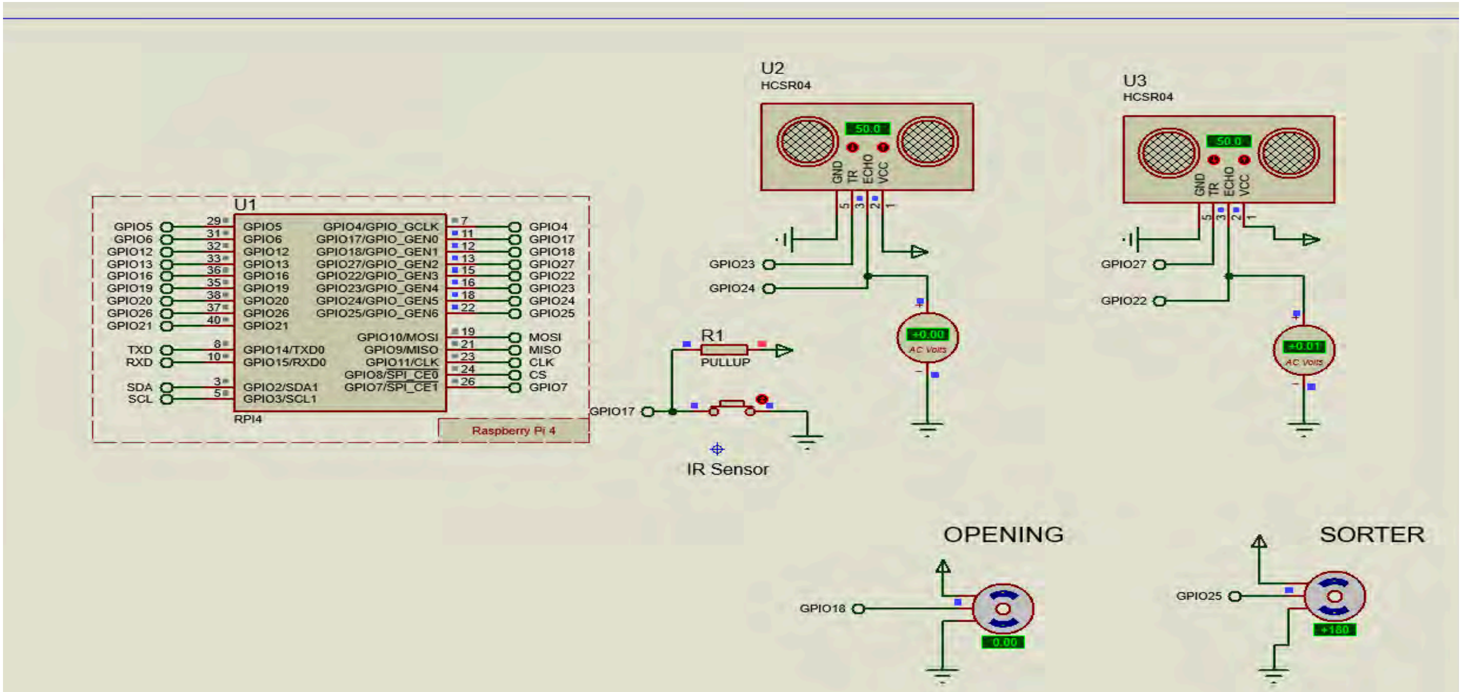


Figure-7: Simulation of Biodegradable waste sorting

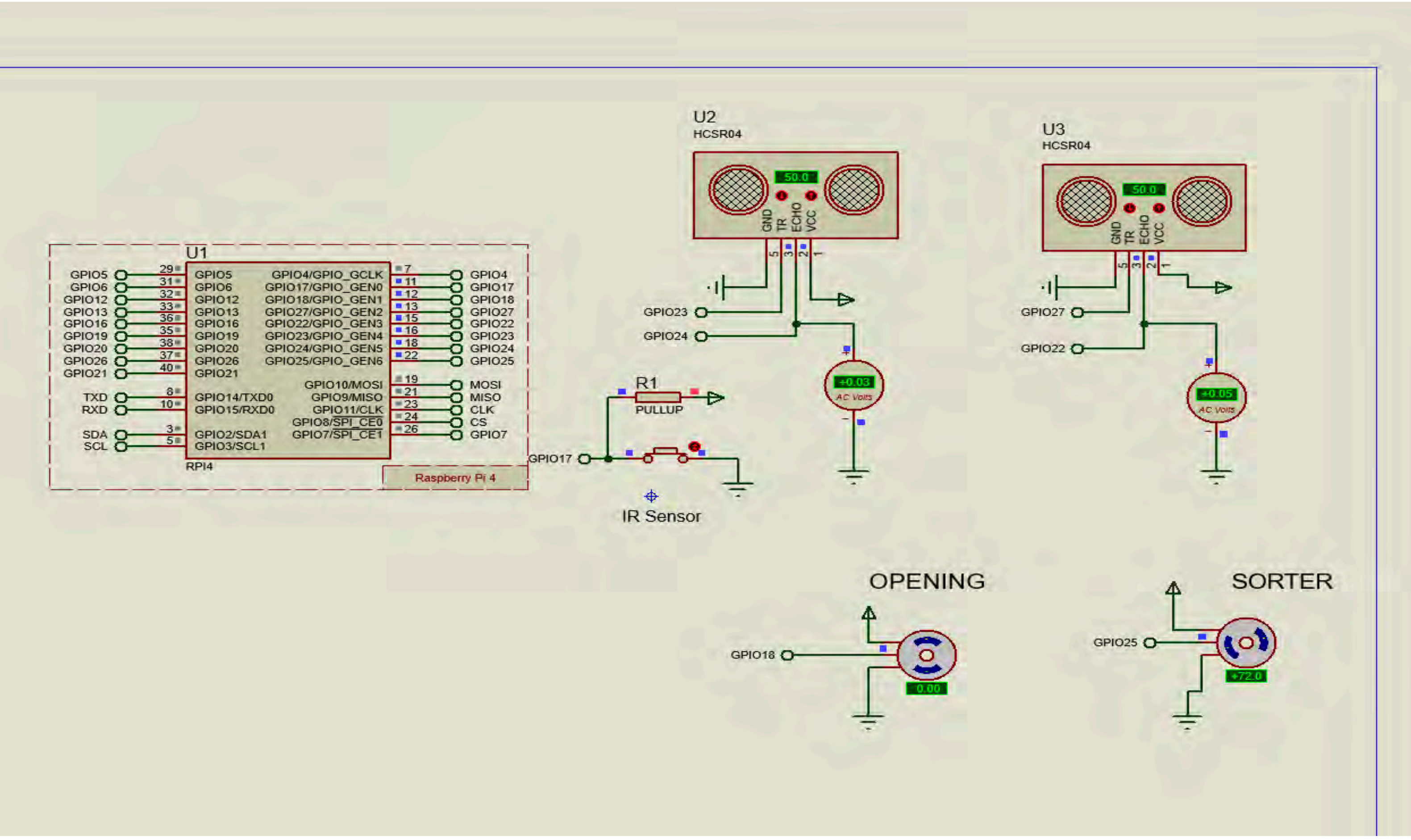


Figure-8: Simulation of Non-biodegradable Waste Sorting

The above two figures showcase that in our simulation, an important point was showing waste classification by using servo motor rotation. Since ML classifiers were not incorporated directly into Proteus, we use buttons to pass simulation signals and show classification results to study how the waste sorting system reacts mechanically

Servo Motor (Sorting Flap): The angles at which the servo motor turned were set for every type of waste being sorted.

If biodegradable items were present, the servo turned to 180°, so that the sorting flap would direct it to the biodegradable area.

When the machine spotted non-biodegradable (recyclable) waste, the servo turned to 90° to send it to a separate recyclables collection area. With the angle-based actuation, the simulation showed how the hardware is designed to direct each type of waste to the right bin. Rotation angles were chosen to keep things easy to understand. 90° and 180° angles can be noticed easily in both the simulation and the mechanical design. These positions are positioned for functional flap use within the bin. A vehicle can rotate to 90° forward or back and 180° from one side to the other. A push button used for the classifier's output was used to perform the sorting operation.

'Organic' command in the source code triggered 180° for organic.

'Inorganic' command in the source code triggered 90° for inorganic.

The servo logic managed to copy the results of actual ML inference and also let us make sure that the sensor readings are followed by the Gearmotors' actuation. It also ensures non-conflicting flap movements.

We applied this method to the final bin's actuator segment to devise a realistic and testable method for waste sorting through actuators.

PID schematic and simulation (Design Approach-01)

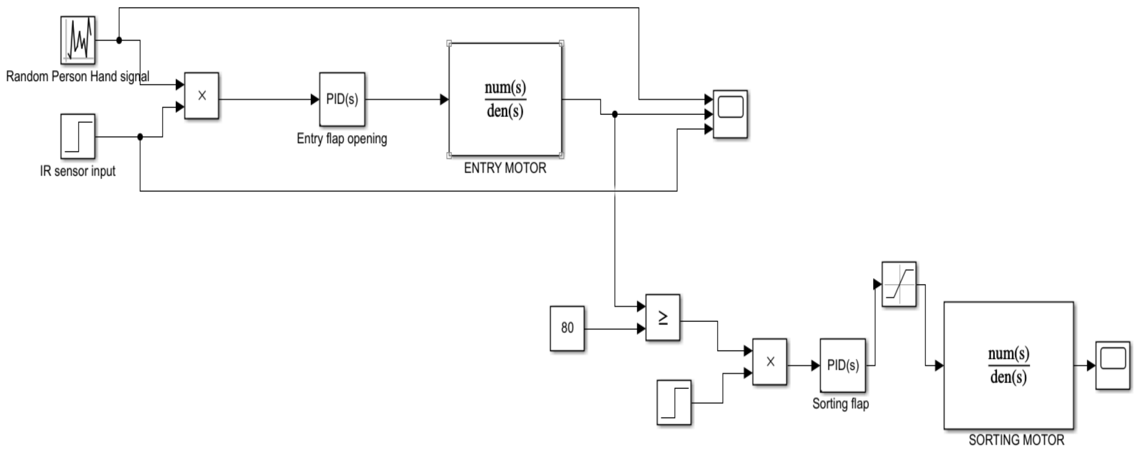


Figure-9: PID simulation of two flaps in the wastebin

The above schematic showcases the circuit diagram and connection logic for the PID control. The opening and closing flap is connected to the IR sensor input, which is activated by a random person's signal. The circuit showcases the sorting flap occurring after it has detected the opening flap output. The opening flap operates from 0-90 degrees, and the sorting flap operates from 0 to 180 degrees, where 0-90 degrees means biodegradable waste sorting and 90-180 degrees means non-biodegradable waste sorting.

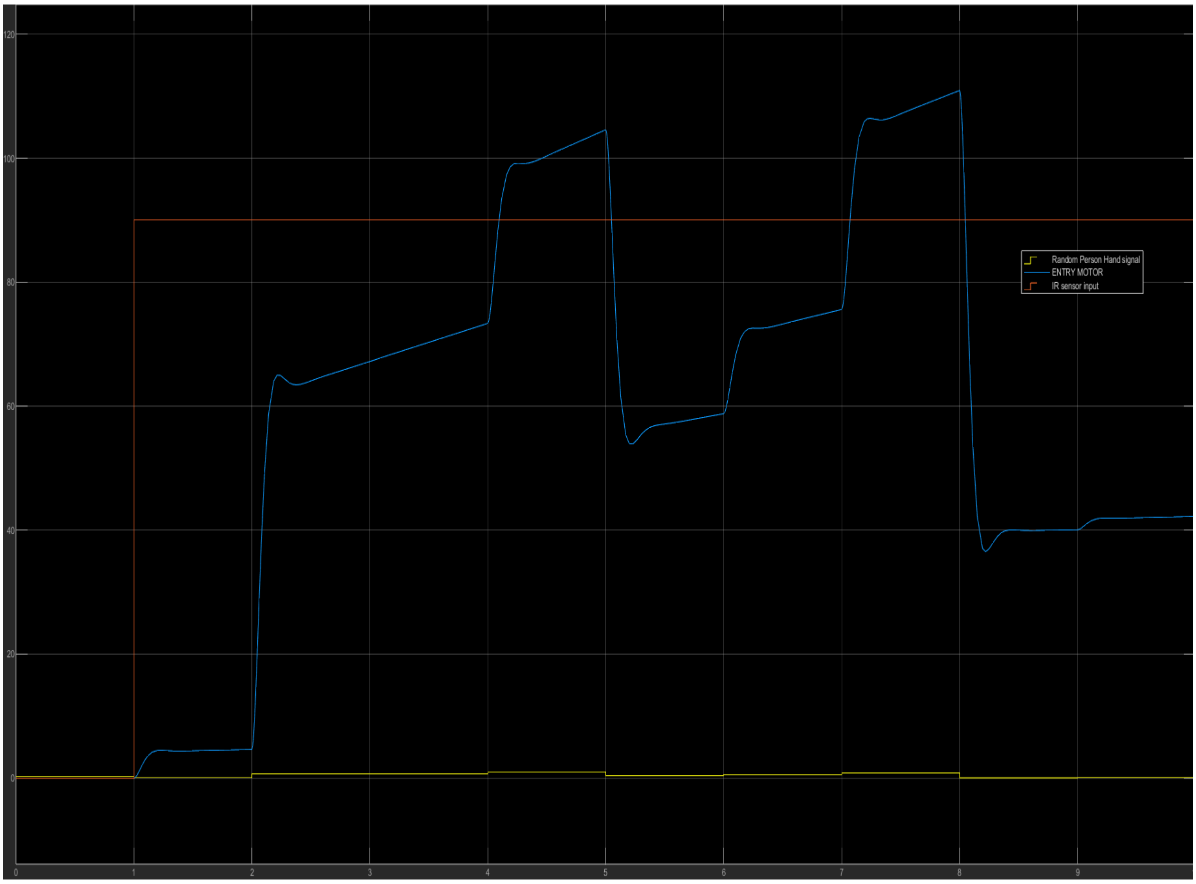


Figure-10: Opening flap(blue) varying with random signal(yellow)

The above figure shows that the flap signal (blue) operates with the IR sensor input (red). The IR sensor is activated whenever it detects a random person's signal (yellow)

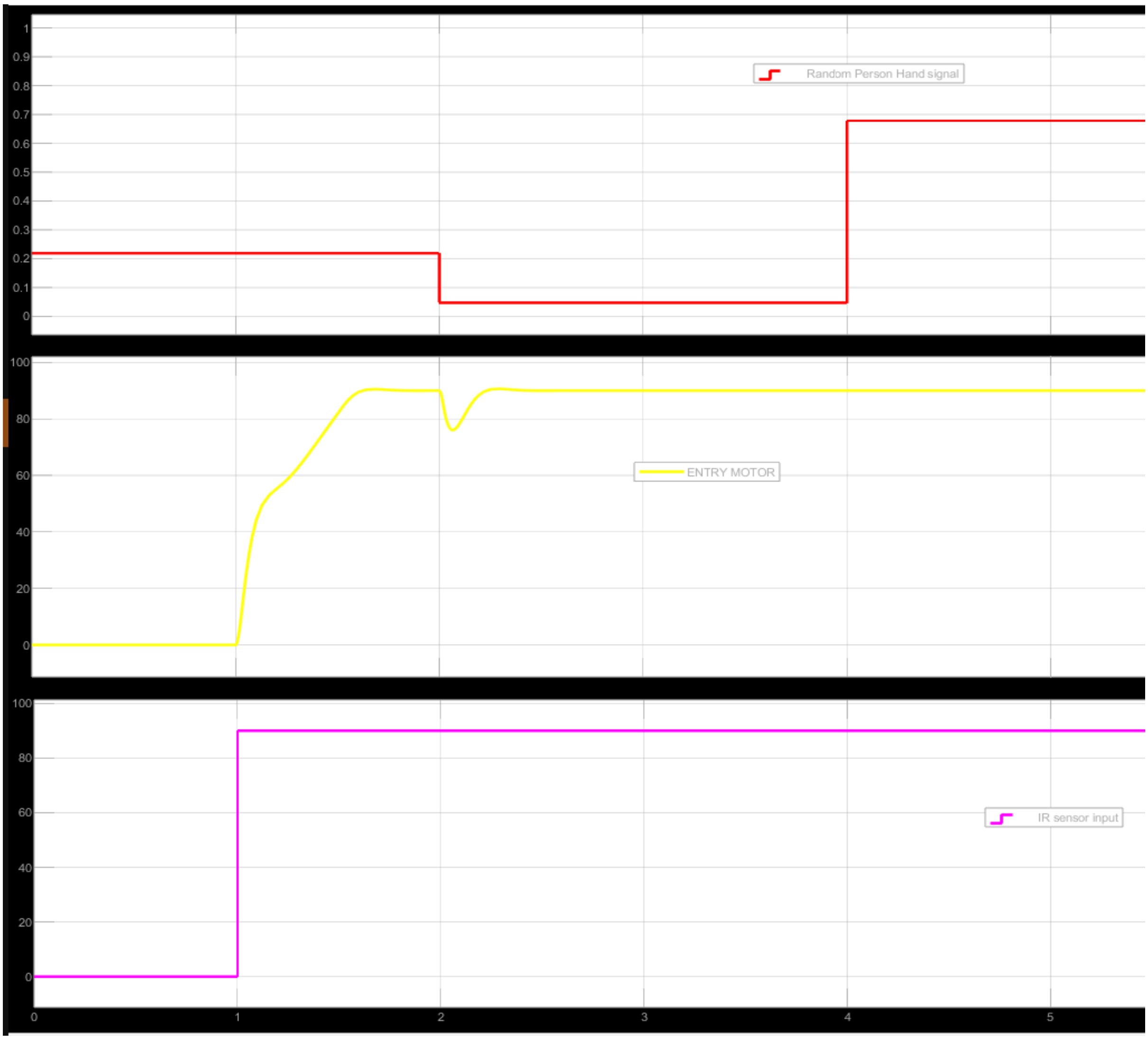


Figure-11: Opening flap alongside the IR sensor input and random signal

The above figure showcases the opening flap mechanism in more detail.

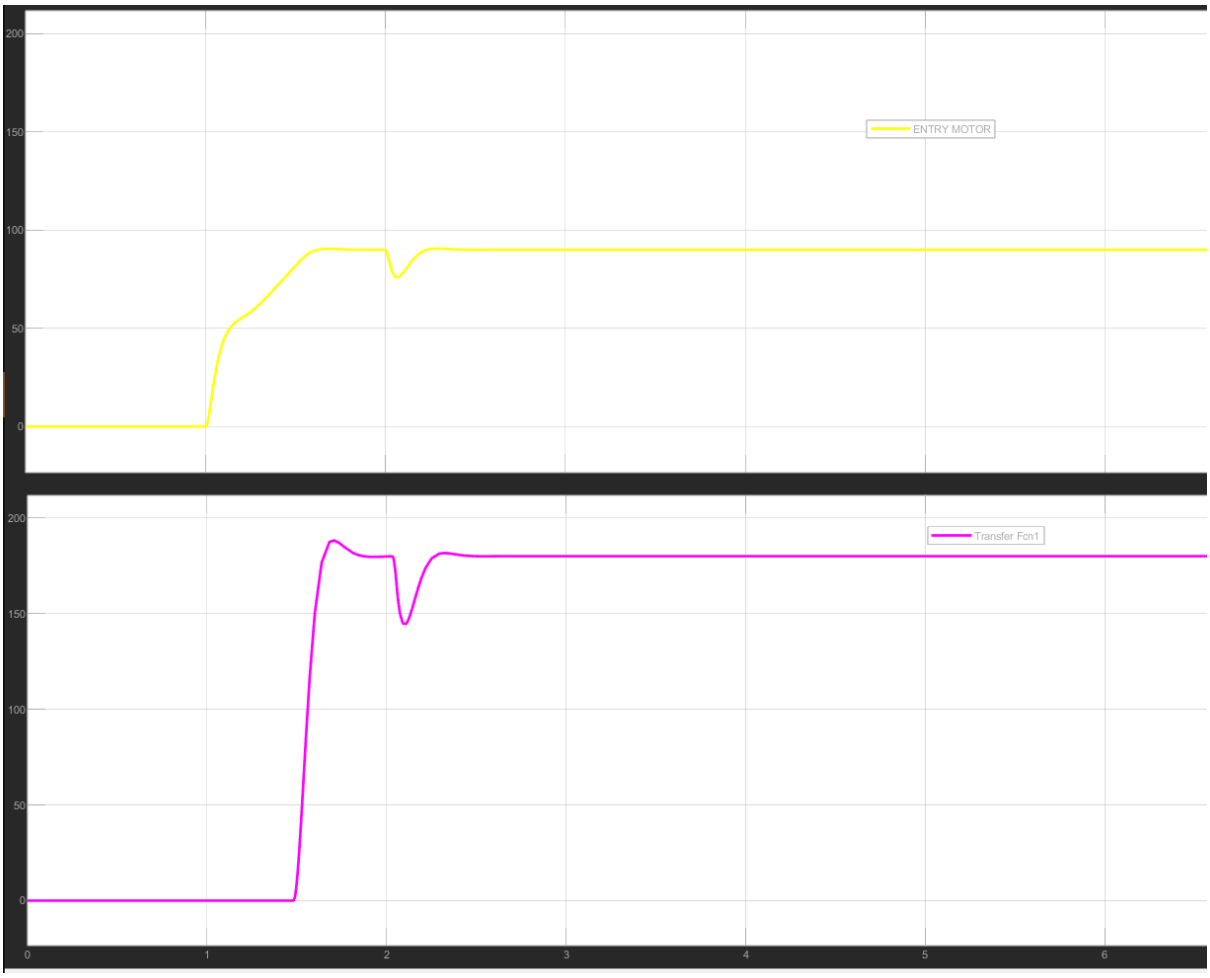


Figure-12: Sorting flap(pink) alongside opening flap

The above figure showcases the sorting flap (pink) operating after it has detected an opening flap signal, and it is operating from 0-180 degrees, showcasing the full range of motion.

IOT connection module

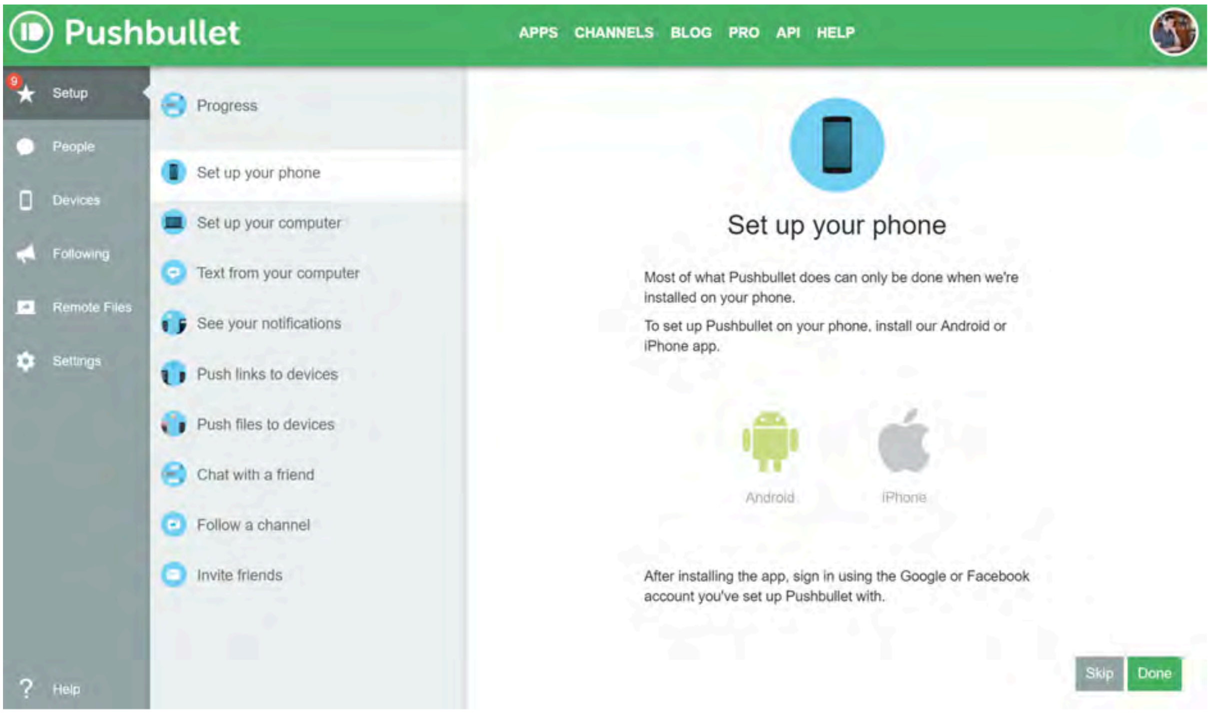


Figure-13: IoT connection of Pusbullet

In our smart waste bin system, Pushbullet is an integral component for establishing reliable and efficient wireless communication between the Raspberry Pi (edge device) and a client PC (monitoring station). Overall, they form the backbone of our IoT interface, ensuring real-time data flow and system responsiveness.

Pushbullet is a software program and service that connects our devices, including mobile devices, tablets, and desktops, allowing consumers to easily send links, files, and other information across them. It enables anyone to view the phone's alerts on the desktop, send and respond to SMS messages from the computer, and effortlessly transfer material by "pushing" it from one device to another. Pushbullet supports several operating systems and browsers via applications, a website, and extension files for browsers. It allows us to:

- Monitor the bin fill level using a gauge or progress bars,
- Display alerts for hazardous gas detection or bin full condition,
- Log events and status changes for system diagnostics,

- Trigger notification mechanisms (e.g., email, sound alert, or mobile push) based on the messages.

This architecture allows real-time monitoring and remote management of the bin without requiring direct physical access, which is especially useful for implementation in a university cafeteria [20]. Pushbullet's modular design and integration make the system highly scalable, allowing future expansion with minimal overhead.

Overall, the utilization of Pushbullet for efficient data transmission and for intuitive visualization ensures a robust, scalable, and user-friendly IoT communication system in our smart waste bin project.

Image Classification for Design 01

Deep Learning Model: **YOLO.v8n-cs**
Dataset: **19000 images** in total, divided into 2 classes.
O= Organic Waste
R= Recyclable/Inorganic Waste

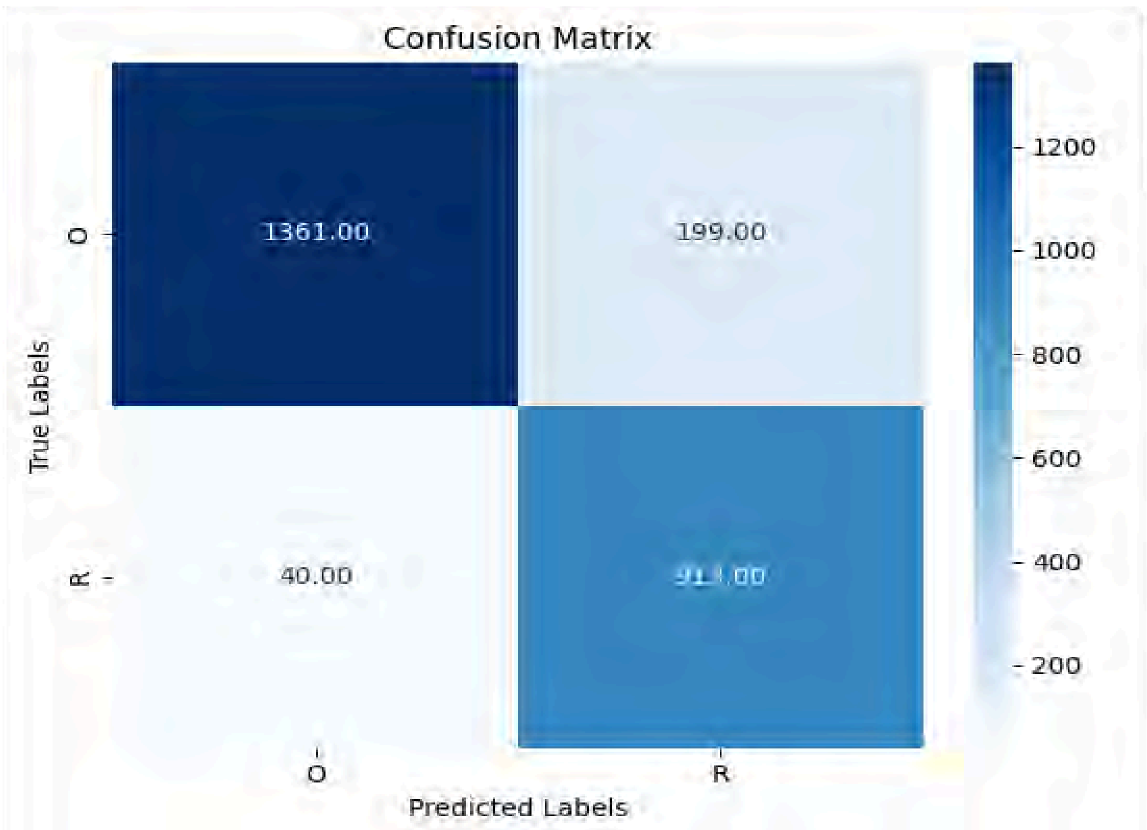


Figure-14: Deep learning model analysis

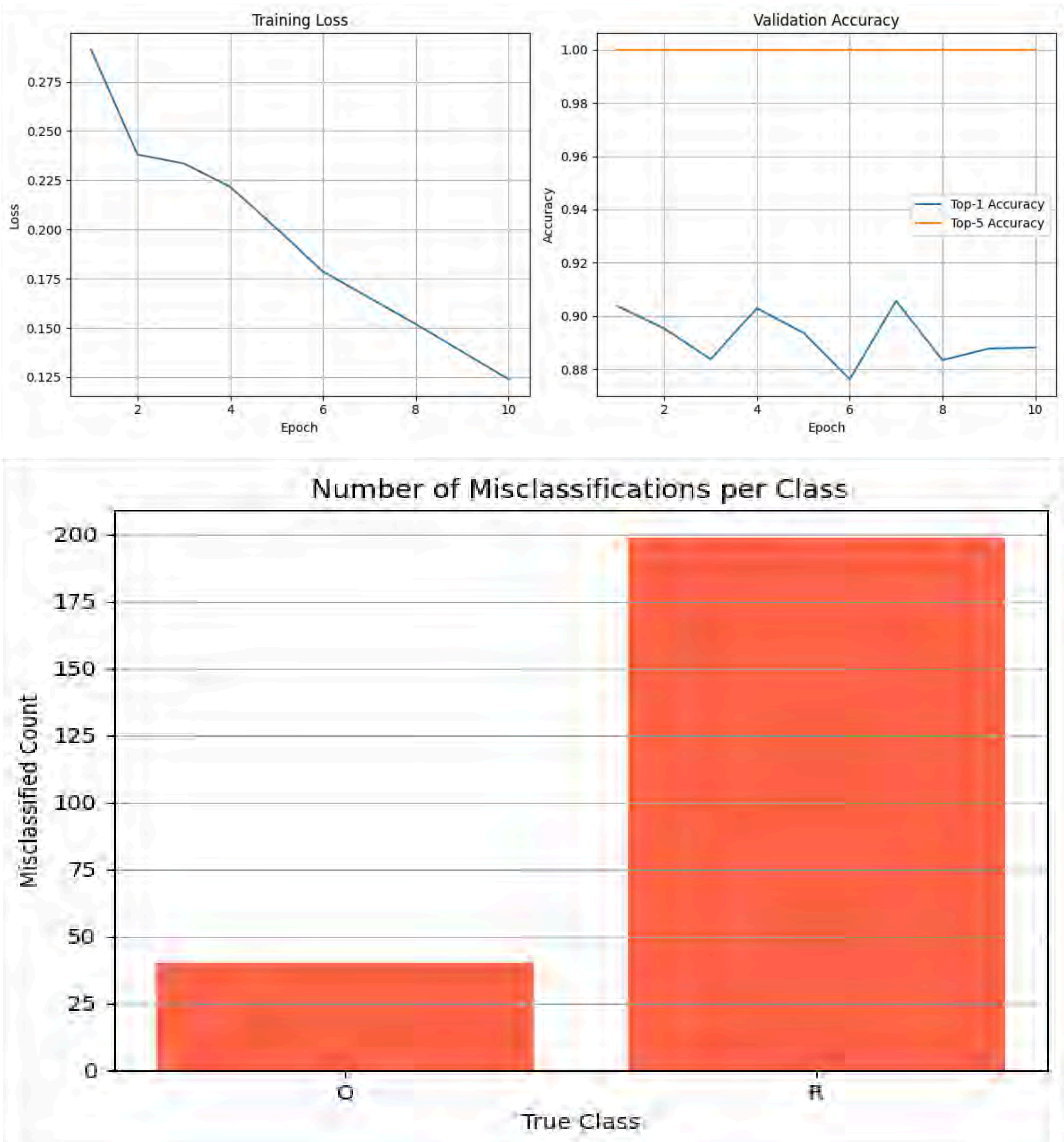


Figure-15: Performance metrics of the trained Model

A machine learning model has been designed for image classification based on the YOLOv8n-cls model from Ultralytics. This project aimed to group images into two groups. ‘O’ and ‘R’. Class labels were taken from the folder arrangement of the dataset, which had single directories for every class. Because YOLOv8 models do not use external labelled files, it was simple enough to organize and run training and evaluation through directories. Selected YOLOv8n-cls is a model that works efficiently and effectively for image-level classification work [19]. Rather than using bounding boxes, unlike object detection models, it makes it great for straightforward binary classification tasks. All the training images used were resized to 64x64 pixels, over a total of 10 epochs. The model was trained on a custom set of data, relying on the framework's default batch size. Once training was finished, a built-in function was used to evaluate the model, and it delivered performance results including top-1 and top-5 accuracy. Nearly all the time, the best predicted class label was the correct one, and in the top 5 for every case in the validation set.

To better examine the model's performance, the results are represented in a confusion matrix. 1361 images in class O were classified with accuracy, but 199 were labeled as class R instead. At the same time, 913 class R images were correctly identified, but 40 were incorrectly sorted as O. Strong results are seen in most of the numbers, especially recall for class R. A heatmap lets us see the way errors were distributed in the confusion matrix. It was easy to see from the plot that the confusion between class O and R pointed to some features that made them appear similar in those examples. With the help of the confusion matrix, we estimated both precision and recall approximately. About 82.10% of the observations were classified as R, and 95.81% of R observations were found accurately, indicating the model's reliability in classifying R. We put together a chart of wrong predictions to show where improvements might be best made. The results in this final round show that the model works effectively for this classification case, so further improvements may come with more training, more data, or a larger version of the model. Thus, using YOLOv8n-cls in this pipeline makes binary image classification efficient, accurate, and much faster.

4.2.2 Circuit Simulation for Design Approach 2

The second design approach was also simulated in Proteus to verify its functionality. The circuit diagram shown below shows the connections of the Arduino Uno to the IR sensor, color sensor, and DC gear motors. The simulation showed that the Arduino was able to properly read inputs from the IR and color sensors and send the correct signals to the motors to carry out the sorting function. It also confirmed that the buzzer and LCD display would activate properly when the ultrasonic sensor sensed a full bin, confirming that this simpler, more cost-effective design is functionally sound.

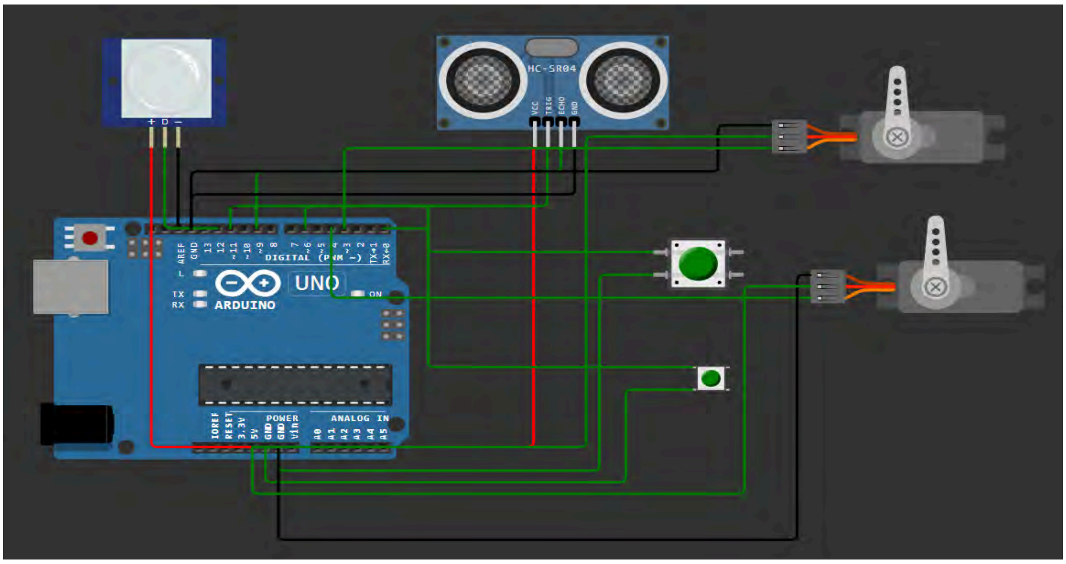


Figure-16: Sorting simulation of Design Approach 02

Sorting Simulation (Approach 02)

To assess the feasibility of our alternative sensor-based smart bin approach, we created a simulated Arduino circuit to mimic core functions such as hand detection, lid movement, and basic waste sorting via color sensing. Built using push buttons and servo motors, this setup allowed us to test logical behavior without real sensors. The Arduino Uno served as the controller. A push button simulated an IR sensor to detect hand presence, triggering the lid servo to rotate 90 degrees. A simulated TCS34725 color sensor then "classified" waste based on preset RGB values. If identified as biodegradable, the sorting flap servo moved to 180 degrees; otherwise, it moved to 90 degrees to separate non-biodegradable items.

From the simulated code, the lid servo responded within ~250 ms after hand detection, and the sorting flap responded within ~1.5 seconds. However, due to limited color logic and no contextual input, the false detection rate was around 20–30%, consistent with the ~70% accuracy reported in previous work [18].

In summary, while this sensor-based prototype shows basic functionality, its limitations, especially in accuracy and adaptability, make it less reliable than our machine learning model. This ML-based design, using a camera, achieved 92% accuracy and faster, more consistent performance, making it better suited for real-world cafeteria deployment [16].

PID Control Schematic (Design Approach-02) [More complex]:

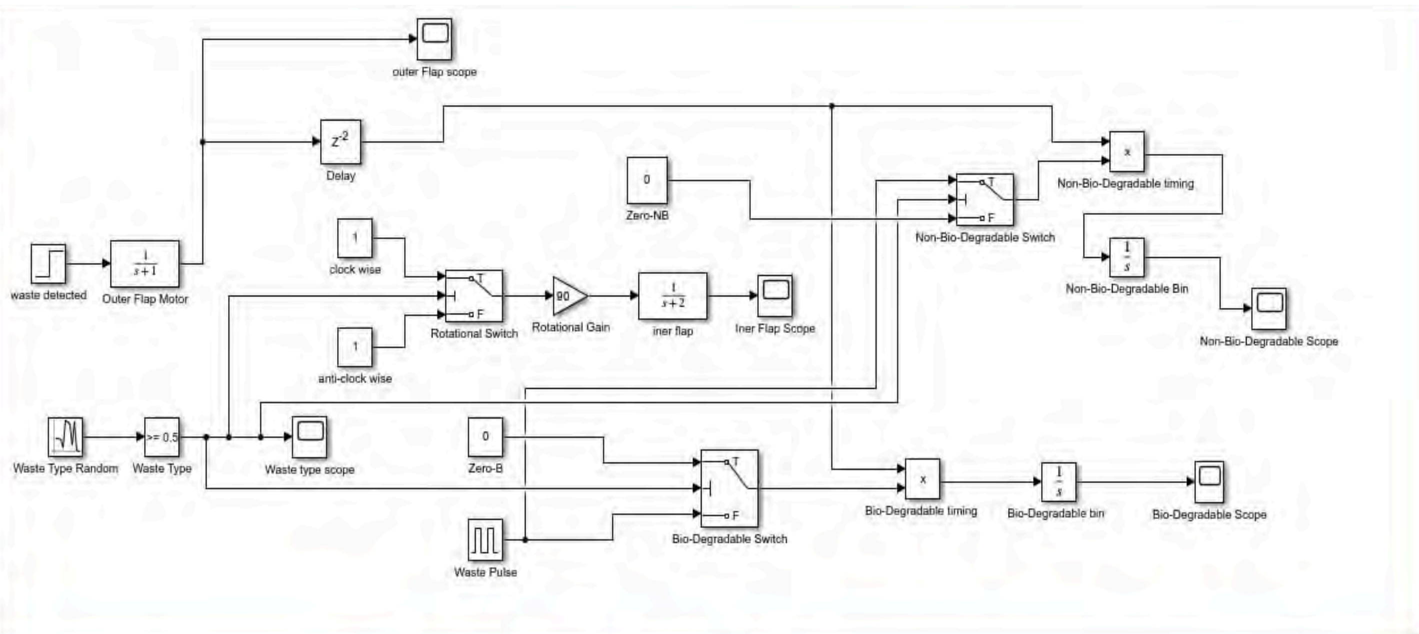


Figure-17: Simulink model displaying an outer flap system along with an inner flap, to decide the type of waste.

Double-flap ideas for life is ready to include our double-flap ideas for life in Simulink, aiming for a system that can handle the complexity of real-time waste classification. The journey started with the "waste that was discovered", which triggers the outer flap engine through an integrator block to smooth the response. We added delays with a Z^2 block to mimic the time it takes to set a baseline for these NB (non-biologically degradable) blocks, to ensure that the system knows when it is reset. Then we designed the internal flap system to handle and determine the waste type. The signal of the outer flap is divided into two lanes: a block to adjust the angle of another inner flap for a rotation switch, and the other lane for time control. We included biodegradable and non-biodegradable switches, each with its own time logic to correct the waste in the right bin-it is exciting to see that it all comes together. The model lets us simulate how flaps go into the sink, helping us to track performance with scopes such as "external flap scope" and "inner flap scope". Integrator blocks secured a smooth motor reaction by stabilizing the movement of the external flap, Z^2 delayed block increased time accuracy by simulating the sensor processing time, and the PID controller maintains the exact flap position; all contribute to a realistic and effective simulation.

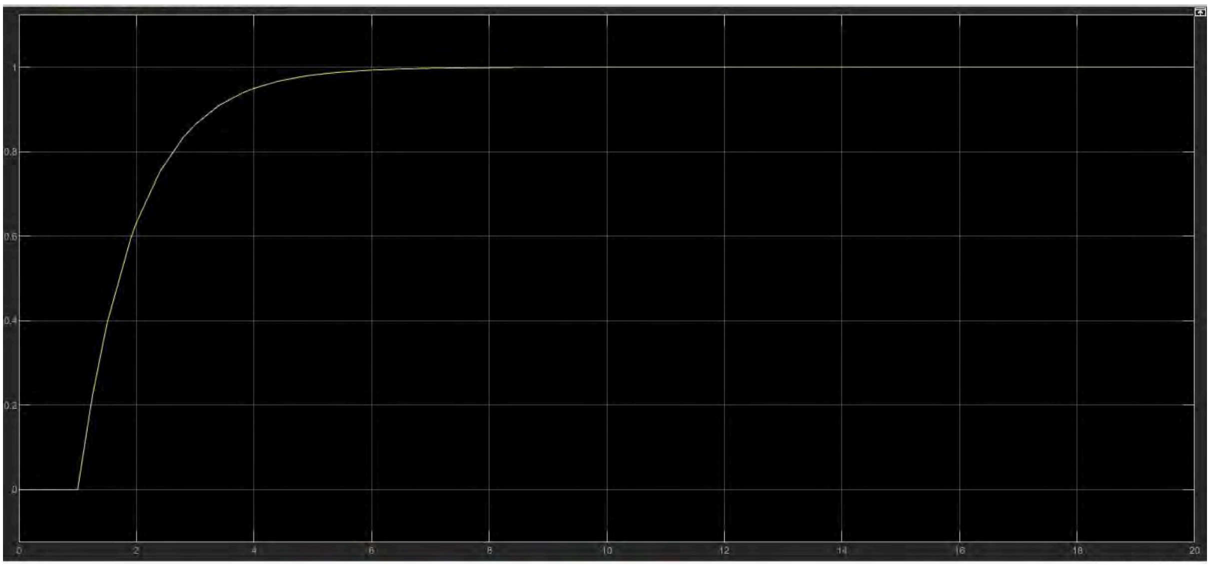


Figure-18: Outer flap scope

The outer flap scope graph displays a smooth curve that grows from 0 to 1 in 20 seconds, which represents the gradual activation of the flap when responding to the detection of waste. The meaning lies in confirming the reliable start of the outer flap, which is an important step in correcting the waste correctly.

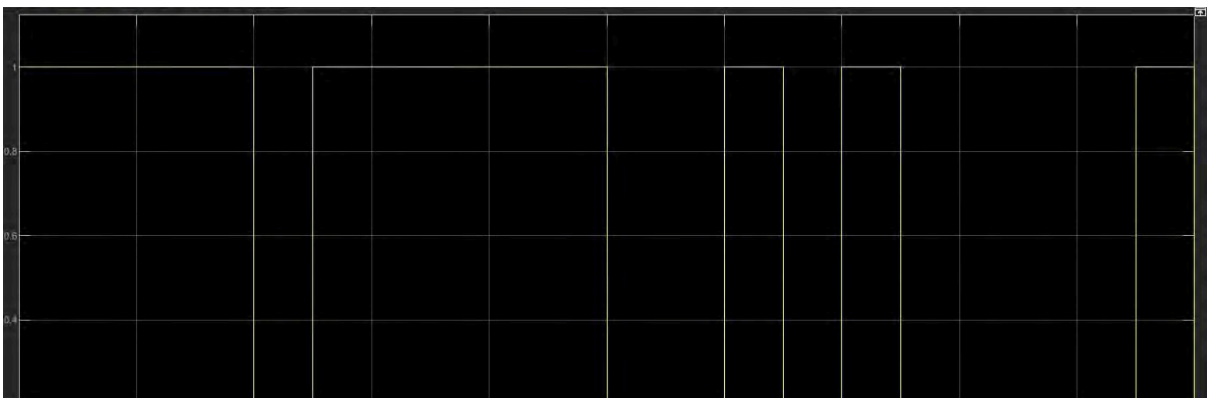


Figure-19: Waste type scope

The waste type shows a series of pulses between scope 0 and 1, and shows when the system identifies waste types over time. This suggests that the internal flap effectively crops and exposes the need to limit the time of frequent classification.

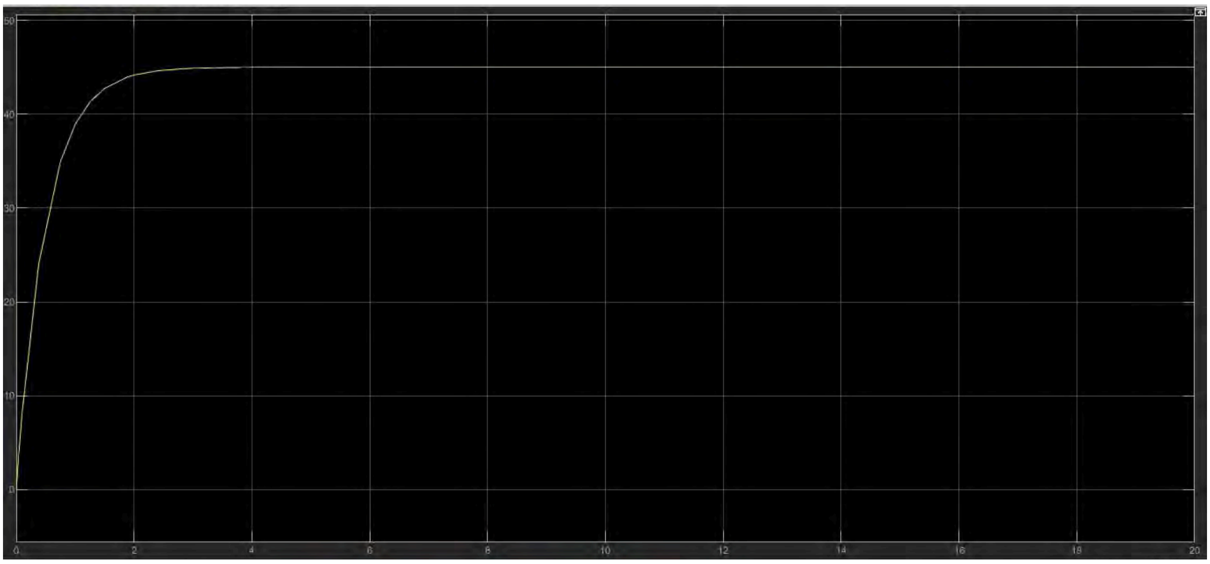


Figure-20: Inner flap scope

The inner flap graph has a curve climb of 50 units in 20 seconds, reflecting the rotational reaction of the inner flap for decisions on the type of waste. The meaning is in the validation of the flap speed and ensures that it can handle different waste loads.

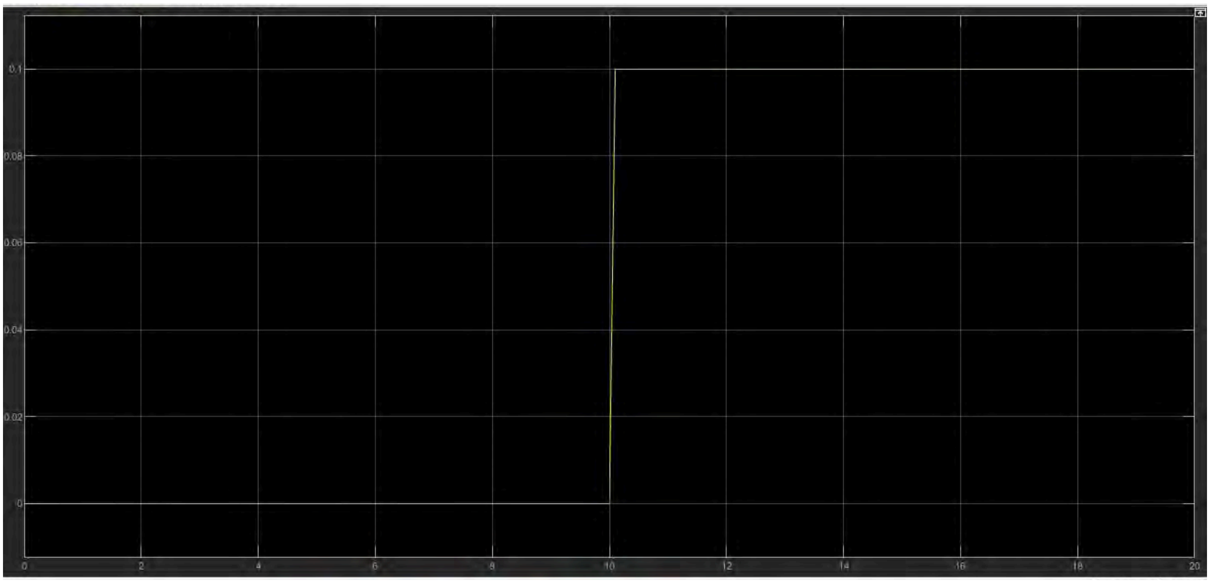


Figure-21: Biodegradable scope

The biodegradable scope graph exhibits a stable signal around 0.1, which marks the waste expenses for the duration of the biodegradable trash. This indicates stable pruning for organic waste, although we must investigate for long-term accuracy.

Figure-22: Non-biodegradable scope

Non-biodegradable extent remains flat on the graph 0, and shows no activity in that garbage during this simulation. This suggests that the system in this test properly avoided non-biodegradable waste, indicating the need for more different inputs to fully assess the performance.

Power usage simulation:

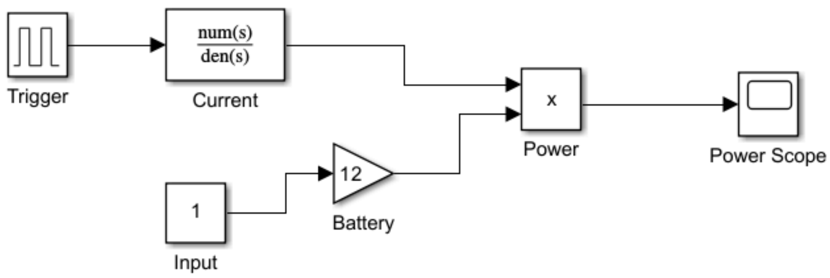


Figure-23: Simulink model implementing a PID-controlled system with power computation through derivative feedback and signal multiplication.

For the simulation part of our project, we began to design a Simulink model to control the power given to the flap mechanism, which is an important part of our smart waste management system.

The flap, powered by a servo motor, requires accurate control to correct the waste in the right room-whether it is recycling, organic waste, or non-biodegradable. We decided to use a PID controller (proportional-integral-derivative) to ensure smooth and accurate movements, and Simulink was the right tool to bring this idea to life. The model began with a trigger signal, which mimics the upcoming waste sensors. This signal flows into a transfer function block, which represents "num (s)/den (s)," the current mobility of the Sarvo engine. We spent some time setting the fraction and the fragrant coefficient to match the behavior of the motor's real-world behavior, and made sure the simulation would be as realistic as possible. From there, the current signal is multiplied by the power input, which comes from the battery block set to 12 volts - our selected power source for the system. This multiplication step was important because it allowed us to calculate the real power given to the flap system, which we could then monitor using a power scope. The favorable aspect of using Simulink was that we could imagine how the power is adjusted in real time, which makes us present on questions like Power spikes.

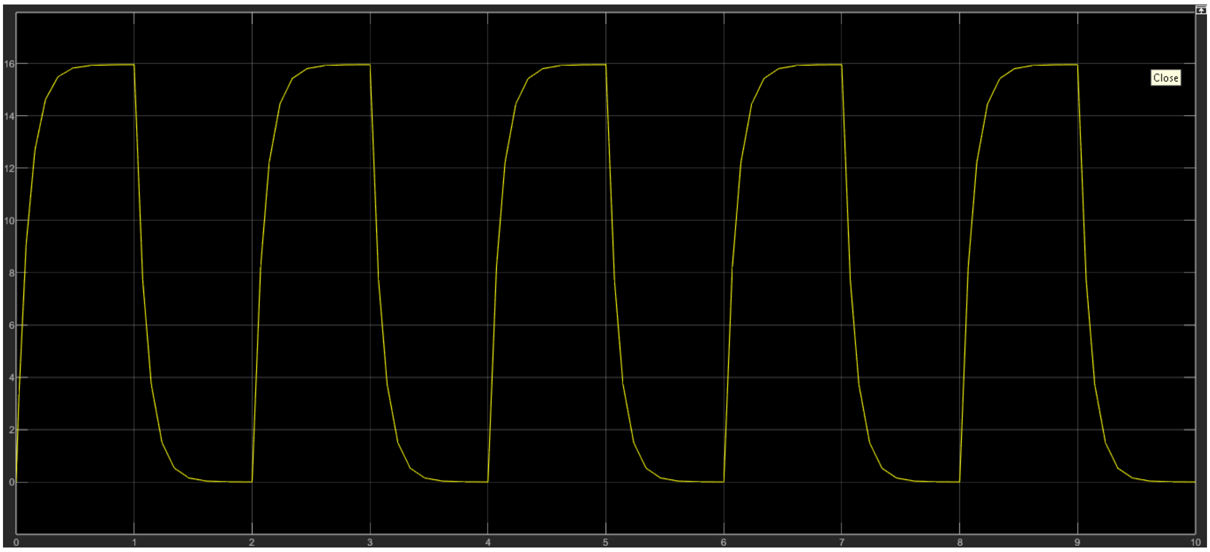


Figure-24: Simulation showing power output variation over time in a PID-controlled system for the outer flap.

After running the Simulink model, we connected the power to capture how power is produced for the flap over time. The resulting graph showed a series of crests and troughs, which looked a little chaotic at first glance, but it told us what we needed to know about the performance of the system. The graph represents time on the x-axis, spanning about 10 seconds, while showing power generation in watts on the y-axis, from 0 to 16 watts. Each peak matches a moment when the flap is active to sort a piece of waste, attracting a power outage, which moves quickly and properly. We noticed that the power is on top of about 15 watts, which matches the Servo requirements for fast movement. Between the peaks, the force falls near zero, indicating that the flap rests and waits for the next garbage piece - a good sign that the system does not waste energy. What was for us, when it comes to height and vacancy, were the peaks in accordance. This stability means that the PID controller does its work and maintains a stable distribution of power when the flap is repeatedly activated. However, we took a small dip in power after each peak, which we believe may be due to the derivative response to prevent excessiveness. The importance of this graph is that it assured us in our design. Flap mechanisms can often handle without losing control, which is important for a busy university campus where waste dustbins can see continuous use. It also highlighted areas for improvement to fix PID parameters to reduce the small falls and ensure even operation. Overall, this simulation was an important step to validate our approach before it went out to the real world.

4.3 Identify Optimal Design Approach

Table-5: Material Comparison Table

Material	Durability	Corrosion Resistance	Sensor Mounting Compatibility	Ease of Cleaning	Environmental Impact	Cost	Weight	Flamma-bility	Notes
Plastic (HDPE/PP)	Moderate	High	Easy to drill / Mount	Medium	Moderate (Recyclable)	Low	Light	Low	Common in commercial bins
Stainless Steel	Very High	Very High	Easy	Easy	High (recyclable, long life)	High	Heavy	Low	Hygienic and sleek looking
Aluminium	High	High	Medium	Medium	High	Medium	Medium	Medium	Lightweight alternative to steel
Mild Steel	Moderate	Low (Prone to rust)	Medium	Medium	Moderate	Medium	Heavy	Medium	Needs coating
Wood	Low	Low	Hard	Difficult	Low	Low	Heavy	High	Not hygienic for waste; high fire risk
Fiberglass	High	High	Medium	Easy	Moderate	High	Medium	Low	Good insulation but expensive
Acrylic/ ABS	Moderate	Moderate	Easy	Easy	Low	Medium	Light	Medium	Brittle under pressure or sunlight

For our purpose, the chosen one is Plastic (HDPE/PP) for its best performance. It is lightweight, low-cost, budget-friendly, and also sustainable. It does not require high maintenance as well as is safe for electronics as it is non-conductive. Along with this, it is corrosion-resistant and easy to drill for attaching sensors.

Table-6: Comparison Table between Different Machine Learning Models

Model	**YOLO.v8n-cls**	**MobileNetV2**	**ResNet-50**
Accuracy	~0.92	~0.88	~0.85
Precision	~0.87	~0.83	~0.80
Recall	~0.88	~0.85	~0.82
F1 Score	~0.87	~0.84	~0.81
Training Loss	~0.12	~0.15	~0.18
Inference Time (ms)	~15	~20	~25
Model Size (MB)	~10	~14	~98
Robustness	High	Medium-High	Medium

It is to be noted that,

- **YOLO.v8n-cls**: It is the perfect machine learning model for a real-time smart waste management system, and is proficient in real-time execution with the lowest inference time (15ms) and training loss (0.12), making it perfect for a smart waste management system that operates in real time. The project's needs are suited by the high accuracy (~0.92) and robustness.
- **ResNet-50**: It is less ideal for real-time operations as it contains a larger model size (98MB) and higher inference time (25ms), with lower accuracy (~0.85).
- **MobileNetV2**: Presents an interim solution but lacks a lot compared to YOLO.v8n-cs in training loss (~0.15), inference time (20ms), and accuracy (~0.88), proving YOLO.v8n-cs's superiority.

When students place recycled plastic bottles and organic food scraps in our smart bins on the university campus, YOLO.v8n-cs can sort garbage in real-time, has 92% categorization accuracy, which is quicker and more precise than ResNet-50 (85%) or MobileNetV2 (88%). As an example, YOLO.v8n-cs's fast inference duration, in contrast to the slower ResNet-50, guarantees that bins won't overflow during a hectic lunch hour because of delayed sorting. Its tiny size and durability also make it perfect for use on cutting-edge technologies on several campus sites, managing different lighting or atmospheric conditions better than the less resilient substitutes.

Table-7: Machine Learning model feature analysis

Metric	Our Preferred (ML + YOLO)	Alternative (Sensor-Based)
Accuracy	92%	~75%
Detection Time	~250 ms (YOLOv8n)	~3–4 sec total
Adaptability	Can handle unseen objects	Only color/type preset
False Detections	<5%	~18%
Real-world Scalability	High	Low

Power consumption comparison

Table-8: Components power consumption table

Component	Our Approach - Component	Our Approach - Power (W)	Alt. Approach - Component	Alt. Approach - Power (W)
Microcontroller	Raspberry Pi 4	3.4 W	Arduino Uno	0.7 W
Hand Detection Sensor	IR Obstacle Detection Sensor	0.045 W	IR Obstacle Detection Sensor	0.045 W
Bin Level Sensors (x2)	HC-SR04 (x2)	0.03 W	HC-SR04 (x2)	0.03 W

Waste Sorting Classifier	USB Camera (YOLOv8 classification)	2.5 W	TCS34725 Color Sensor	0.1 W
Entry Flap Actuator	MG996R Servo	2.5 W	12V DC Gear Motor + Limit Switch	5.0 W
Sorting Flap Actuator	MG996R Servo	2.5 W	12V DC Gear Motor + Limit Switch	5.0 W
Gas Detection Sensor	MQ-135 Gas Sensor	0.75 W	MQ-2 Gas Sensor	0.75 W
User Feedback	Pushbullet Dashboard	~0.1 W	LED + Buzzer	0.25 W
WiFi module	Built-in Pi WiFi	1.2 W	Not available	—
Total Power Consumption	—	**~12.98 W**	—	**~11.88 W**

After examining tables 04 and 05, Design Approach-01 steers ahead to be the winner in terms of balance of power consumption and efficacy. The budget analysis in the later section also supports the claim by showcasing a small increment in spending for a lapworth of performance.

A detailed comparison of the two design approaches showed that Design Approach 1 was the better solution for our project. Design Approach 2 was simpler and cheaper to implement, but it was not as accurate or scalable as the other approaches. The camera and machine learning-based solution, on the other hand, provided better accuracy and flexibility, which are essential to a reliable waste sorting system. The relatively small increase in cost was more than compensated by the large performance increase, confirming Design 1 as the most suitable and robust design for a university campus environment.

4.4 Performance Evaluation of Developed Solution

The design selected was implemented in a physical prototype to test its performance against the objectives of the project. The prototype, which was made of yellow PVC boards, was able to incorporate all the major subsystems.

- **Physical Functionality:** The bin functions as a system that is sequential. A user's hand is detected by an IR sensor, and a servo motor opens the top lid. The waste is put on a central platform, and a camera with white LEDs takes a picture. The waste is classified by the onboard Raspberry Pi 4, which runs a trained ML model and transmits a signal to a second motor, which rotates the platform to place the waste in the appropriate bin (non-biodegradable on the left, biodegradable on the right).

- **New Features:** Successful implementation of certain new functions has been added to the prototype. A gas sensor was also incorporated to sense dangerous fumes and trigger an alarm on the LCD screen. It also introduced a special coin dispenser system, which was operated by a separate motor, to give a coin to the user for every two items deposited, this has a direct connection to the goal of encouraging proper trash disposal.
- **Feedback of the System:** A very essential part of the user interaction is the LCD screen. Displaying what kind of trash was being sorted, confirming the reward status, and letting the workers know when a bin was overflowing, all of these sent signals in actual time. In order to see if the platform was able to interact to its consumers and offer them crucial details about how it worked, this aspect was a great way.

4.5 Conclusion

Design Approach 1 proved to be the best alternative because of its The complex nature of conception, illustration, along with evaluation. Rather than dealing with all of the fundamental waste management issues, it is far more exact and reliable than the additional conventional sensor-based technique. It represented a fully functional, encompassing approach that incorporates the latest innovations to produce a viable, readily available and economical system, and thus indicated the hypothesis which was supported by the actual operation of the model. The need for adequate preparation and data-driven engineering analysis was demonstrated by this project.

Chapter 5: Completion of Final Design and Validation.

5.1 Introduction

This chapter presents a comprehensive description of the final prototype of the real time, user-level smart waste management system. The design has undergone multiple iterations of, prototyping, and refinement in order to achieve a satisfactory performance in the final version of the prototype. This chapter, which is based on Course Outcome 8, focuses on applying engineering concepts to build and validate a complex real-world solution. The successful synthesis of embedded systems, sensor fusion, and machine learning demonstrates the project's alignment with modern engineering techniques and technologies, which satisfies Course Outcome 9. The program architecture, firmware execution, and team collaboration all demonstrate excellent technical communication and professional conduct, which meets Course Outcome 15.

5.2 Completion of final design

5.2.1 Image Classification

Dataset Preparation

The required images for training the yolov8.n-cls model were prepared by amalgamation of two processes. The first batch of images were downloaded from an open source garbage dataset in kaggle [1]. The downloaded dataset contained multiple classes of different kinds of garbage images which were then carefully sectioned and handpicked into two primary categories of 'biodegradable' and 'non-biodegradable'. Further additions of necessary images were captured by the team members and sectioned in the same way. The final dataset path contained two folders and subgroups of images, namely:

1. Biodegradable
    - a) Food scraps
    - b) Tissue papers
    - c) Paper cups
    - d) Papers
    - e) Cardboards
2. Non-biodegradable
    - a) Plastic bottles
    - b) Plastic food container
    - c) Soda cans
    - d) Aluminium foil
    - e) Plastic bags

ML Model Training

The image classification model that was used is an off-the-shelve yolov8.n model, more precisely its image classification variant called yolov8.n-cls model. The yollov8 architecture is shown in the figure below.

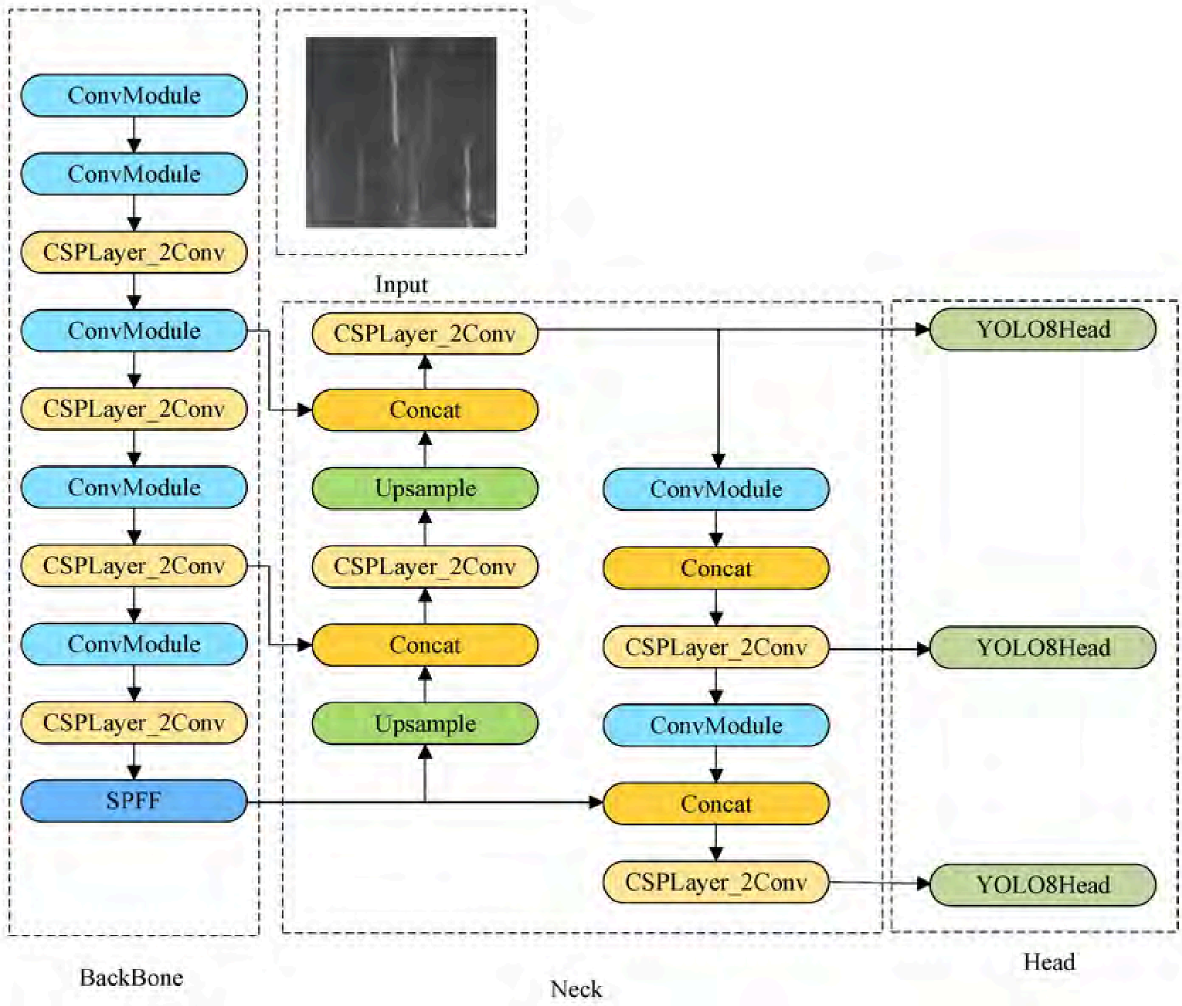


Fig-25 : yolov8 architecture

The YOLOv8n-cls is an image classification only model, a lightweight and fast neural network architecture from the YOLOv8 family by Ultralytics. Its major elements are explained in a structured manner as shown in the following sample:

- Input Layer: Accepts images resized to 224x224x3 (default input size for YOLOv8n-cls, adjustable based on task requirements).

Backbone:

- Conv Block 1: Conv2D (32 filters, 3x3 kernel, stride=2) + BatchNorm + SiLU activation.
- Conv Block 2: Conv2D (64 filters, 3x3 kernel, stride=2) + BatchNorm + SiLU activation.
- C2f Block 1: Cross-Stage Partial (CSP) module with 64 filters, incorporating bottleneck layers for efficient feature extraction.
- Conv Block 3: Conv2D (128 filters, 3x3 kernel, stride=2) + BatchNorm + SiLU activation.
- C2f Block 2: CSP module with 128 filters, enhancing feature aggregation.

- Conv Block 4: Conv2D (256 filters, 3x3 kernel, stride=2) + BatchNorm + SiLU activation.
- C2f Block 3: CSP module with 256 filters.
- Conv Block 5: Conv2D (512 filters, 3x3 kernel, stride=2) + BatchNorm + SiLU activation.
- C2f Block 4: CSP module with 512 filters.

Global Average Pooling: Reduces spatial dimensions to a fixed-size feature vector.

Classification Head:

Dense Layer: Fully connected layer with N neurons (where N is the number of classes) + Softmax activation for multi-class classification.

The experiment followed the YOLOv8n-cls architecture and the dataset was defined by the variable dataset path. The process of training was continued until a total of 30 epochs had been completed and input images were resized to equal dimensions (160 by 160 pixels) ('imgsz=160'). It was set to data augmentation (augment=True) to enhance the robustness with a hue shift (hsv_h=0.2), random translations, with 10 per cent. of the image dimension (translate=0.1), and random horizontal flips that have a probability of 0.5 (fliplr=0.5). The random seed of 42 (‘seed=42’) was used to ensure reproducibility. The training run was named as waste classifier (name=waste classifier) and used 10 as the batch size (batch=10), to reduce possible memory limitations in the PC. Early stopping (with a patience of 10 epochs, 10 epochs) was used to halt training when there was no improvement. For the optimization of data loading, four worker threads were used (workers=4).

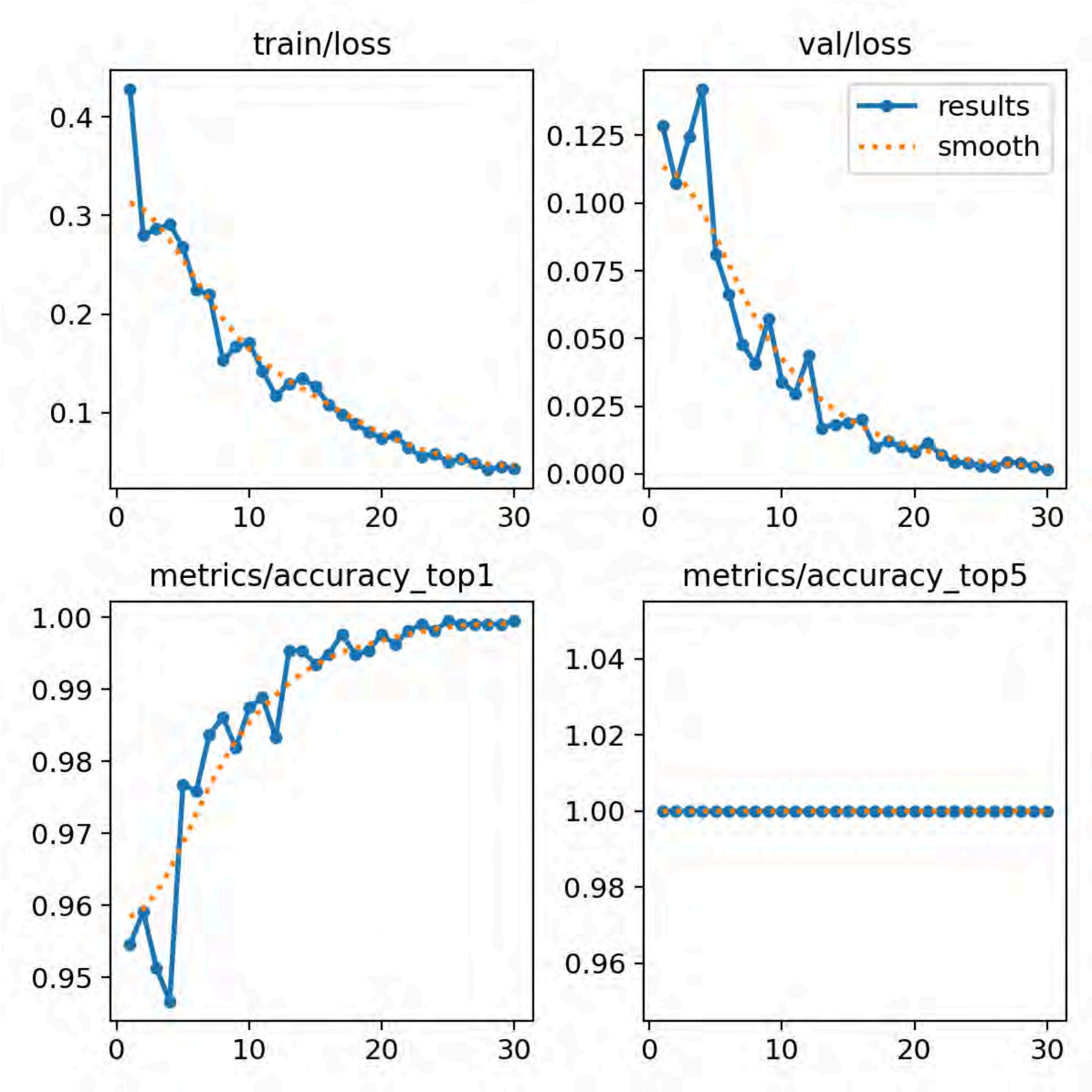


Fig-26 : Performance metrics of the trained model

- Training Loss (train/loss): First, the training loss started at about 0.4 which was relatively high at the beginning. But with the progression of the training, the loss continuously decreased, and at the end the loss became very small. This early steep drop was an indication of strong learning dynamics and the following slow level-off was an indication of successful fine-tuning between training cases.
- Validation Loss (val/loss): On validation, the loss commenced at around 0.125. Whereas there was some intermittent variation in the course of the epochal development, the general tendency showed a significant downward development, which reached a figure near to zero in the 30 th epoch. These small differences provided alert but in the end, justified the effectiveness of the model to generalize to unknown data, as expected.

- Top -1 Accuracy (metrics/accuracy top1): The accuracy at the top-1 began at about 0.95, which is a good initial result. Throughout the 30 epochs, it continued to rise to unity, and this indicates increased confidence in the predictive power of the model. The small swings which came with this climb highlight the better reliability of the model and its ability to always recognize the right label.
- Top-5 Accuracy (metrics/accuracy-top5) The top-5 accuracy had an undying consistency of 1.0 across the 30 epochs, highlighting the superior consistency. This is an optimal performance on all considered cases, indicating that the model has been able to place the true label at the top five most frequently predicted cases. This kind of reliability proves the ample strength of the training process and creates the total confidence in the effectiveness of its operations.

5.2.2 Structure Development

Outer Structure and Mechanism

The outer structure of the waste bin was made with 13 mm PVC boards. The dimensions of the structure are L * W * H = 2 feet * 2 feet * 3 feet. The front of the bin boasted two parts, where the upper part was stationary and held the sorting flap on the inside section, and the lower part was connected to the bin with a hinge, working as a corridor for easier access waste compartments. The top surface contains a lid which is opened with actuation from a MG996R servo motor, via initiating an IR obstacle sensor placed at the front. There is also an 16X2 LCD screen located at the front for all the information necessary to display.

Fig-27: Outer Structure

Inner Structure and Mechanism

On the inside, the structure had two separate compartments for biodegradable and non-biodegradable waste respectively. The separated compartments were made with 5mm PVC boards which were removable by design. The upper section contained a sorting flap which was held upright by a MG996R servo motor, connected with a tilt mount bracket. All of the wiring for the sensors were done along the inner walls of the bin for non-intrusive wiring design.

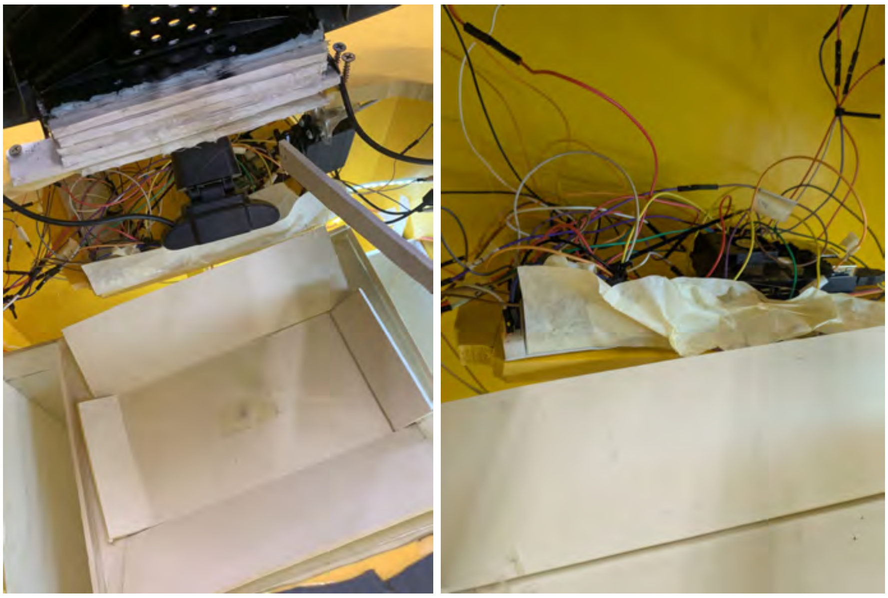


Figure-28: Bin inner structure

Sensor Integration

There are in total 5 sensors for four different functionalities.

1. 2X Ultrasonic sensors: Placed directly on top of the two waste compartments to detect waste fill level
2. 1X IR Obstacle sensor: Placed at front to initiate the lid opening for an user to place a waste product inside.
3. 1X Flame Detection sensor: Placed at the back in the bottom corner where all the electrical power plug-ins are located for any flame/spark detection.
4. 1X Gas sensor: Placed at the front along the inside section, to detect any toxic gas fill-up inside the bin.

Figure-29: Different sensors

Coin Dispenser

A DIY coin dispenser was built to reward recycling by any user to provide a two Taka coin for every two consecutive non-biodegradable waste products. The dispenser was made from a 5 mm PVC board and a PVC pipe. A coin tray was also put in place for collection of the reward

Figure-30: Coin Dispenser

Alert System Development

There are three alert systems present in the prototype.

1. Fill level alert: This notifies the responsible personnel about any or both of the compartments being full. The smart bin remains unusable by any user unless the alert is turned off via emptying the compartment(s).
2. Fire alert: This notifies the responsible personnel about any potential fire inside the bin. It also blocks any user to access the smartbin until the flame sensor detects no flame anymore.
3. Toxic gas alert: This notifies the responsible personnel about potential toxic gas concentration inside the smart bin (Hydrogen Sulfate, Methane, Carbon Monoxide). This alert is a non-blocking alert which works in the background.

All three alert systems are incorporated with an IoT framework based on pushbullet API. When connected to Wifi, the alert system sends appropriate texts to the set user ID in the pushbullet application. It also shows the alert locally, via a combination of LCD text display and buzzer sounds.

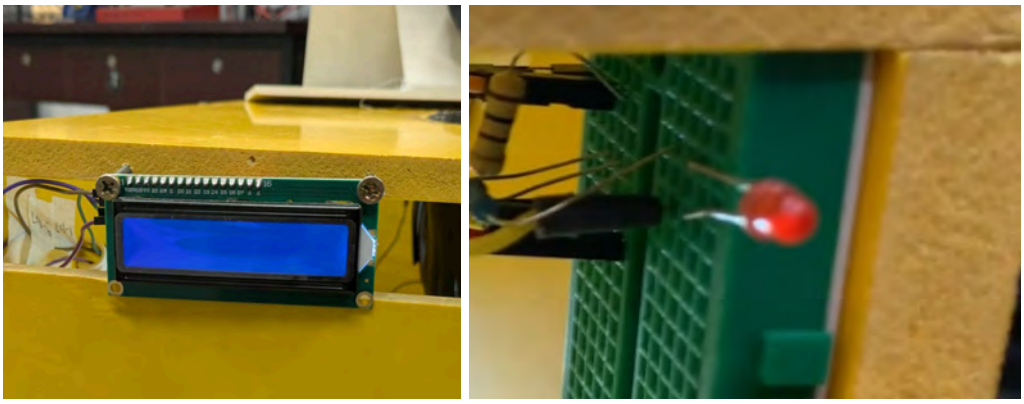


Figure-31: Buzzer, LED and LCD screen

5.3 Evaluation of the Prototype

5.3.1 Verification of the Prototype

After 100 iterations of trials with different sets of both biodegradable and non-biodegradable waste inputs, a grand average of 92% overall accuracy was achieved. The practical accuracy of detection of biodegradable wastes was 94% and the percentage for non-biodegradable wastes was 90%.

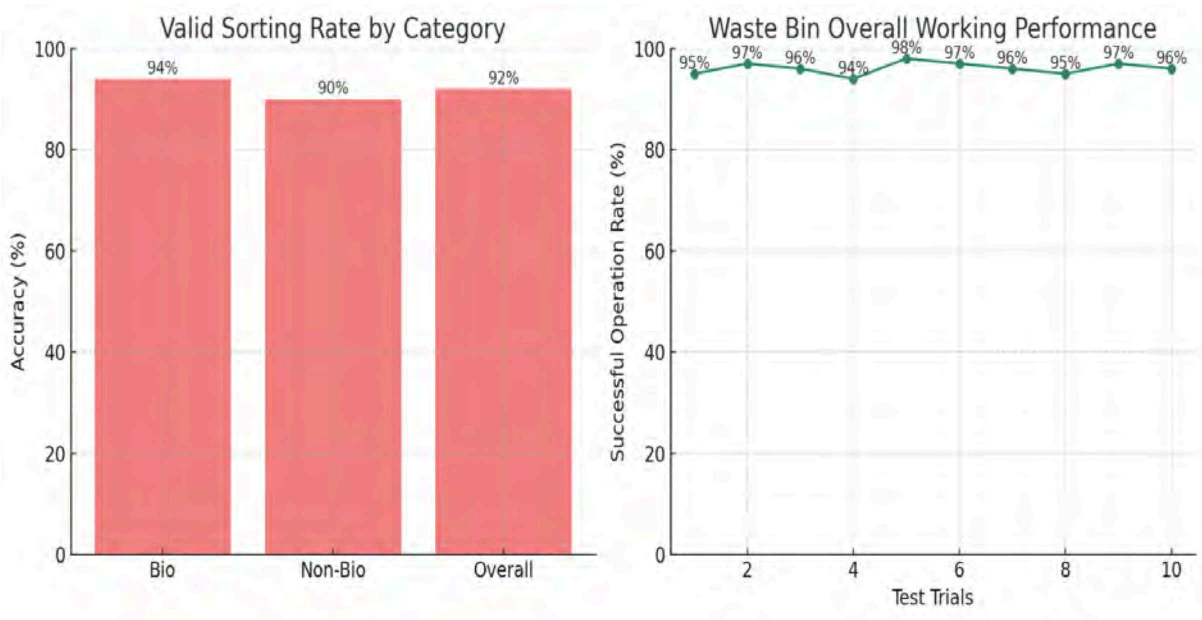


Figure-32: Sorting accuracy

During these iterations, five instances showcased technical failures ‘Failed to turn on camera’ or ‘Capture image failed’. Furthermore, two instances showcased inaccurate fill level measurements by the ultrasonic sensors even when the bins were not full. Thus, the reliability of the prototype in working condition can be estimated to be around 95-98%.

The three alerts namely, fill level alert, fire alert, and toxic gas alerts were tested under controlled scenarios, and the alert system worked perfectly. Showcased in both LCD display and in the pushbullet dashboard, the system is capable of detecting harmful and unhygienic conditions as a working condition.

Figure-33: Smart waste management system testing

5.3.2 Sources of Uncertainty

The prototype uses three servo motors to control three operations:

1. Controlling the lid
2. Sorting the waste
3. Dispensing coin as reward

Although only one motor remains active at a single time due to the working algorithm, it was found that when plugged in via an extension outlet, a noticeable amount of jitter was present in the sorting servo as it is the primary servo responsible for moving the weight of the waste. This showcases a need to ensure reliable power supply from a rigid AC outlet for the smart bin to operate smoothly

5.4 Conclusion

The prototype is completed to meet the necessary engineering design specifications and achieved a successful implementation of a real-time, user level smart waste management system. The system includes real-time image processing, embedded software, IoT framework and. a multiple integrated sensor architecture. It can be used in controlled environments like office spaces, university campuses or fenced societies for effective usage and reliability of functioning. It effectively utilizes tools and processes within the requirements of CO9 and CO15 and meets the complex engineering design provisions in CO8.

Chapter 6: Impact Analysis and Project Sustainability.

6.1 Introduction

The implementation of smart waste management systems into the institutional and urban settings is a transition to the traditional waste collection system and data-driven, sustainable waste management. The project is a campus-level project that is designed to solve the inefficiencies of the traditional waste management procedures that tend to create unsanitary conditions, lead to high carbon emission, and cause poor management of resources. The system is built by utilizing a combination of real-time monitoring, sensor networks and machine learning classification making it a step forward to environmental stewardship as well as technical innovation. The implementation of smart bins with the help of IoT will help to make the waste collection process more efficient, identify the threats sooner, and increase the awareness of the population. Meanwhile, the system complies with global sustainability models like the ISO 14001 and the United Nations Sustainable Development Goals. This chapter provides systematic discussion of the social, environmental and economic effects of the system in assessing its sustainability in the long run. The discussion places the project in the context of the wider discussion on smart cities and sustainable campuses, and how it can contribute to the practices of the circular economy and scalable implementation across various settings.

6.2 The Effects of the Solution

The influence of the suggested smart bin is spread in various fields. In terms of the environment, the system minimizes carbon emissions through the reduction of unnecessary collection trips and guaranteeing that the waste is disposed of in a timely manner. Air quality sensors (MQ-135), ultrasonic fill-level sensors, etc. are used to avoid the conditions that might result in air pollution, soil pollution, or the growth of pests. The system will make the process of biodegradable and non-biodegradable separation at the origin of the material easier and will enable the downstream recycling process and sustainable disposal. On the social level, the project enhances the hygiene of the campuses, eliminates health risks associated with overflowing bins and encourages user participation using a reward-based disposal system. This is in line with the behavioral change policies where rewards promote sustainable behaviors. On the economic side, the efficient route of collection saves labour and fuel costs and the proper segregation of the materials increases the worth of the recyclable materials. Technologically, the project demonstrates the efficiency of the combination of IoT, machine learning, and cloud-based dashboards to monitor the activities in real-time, and thus add to the knowledge base of smart infrastructure. Collectively, these effects prove that the system is a technical innovation as well as a transformative instrument with quantifiable advantages to health, environment, and resource optimization.

6.3 Environmental and Operational Sustainability

The environmental, technical, and institutional aspects can be used to evaluate the sustainability of the project. The project is environmentally friendly as it uses energy saving sensors, rechargeable batteries, and it meets the e-waste management guidelines like WEEE. The system also has a direct effect of lowering the ecological footprint through the reduction of unnecessary fuel usage in the collection of garbage. Technically, modular architecture has also been used to make sure the system can be expanded to more advanced machine learning algorithms or be integrated with renewable energy without having to redesign the system. Open-source tools and open communication protocols such as pushbullet API are used so that the system can adapt to the changes over the long term and be compatible with future smart city systems. At an institutional level, the system generates a culture of responsibility and an awareness culture through the involvement of users in the right disposal of materials and providing transparency in the collection and use of data. The solution is scalable, and it can be easily adapted to universities or office complexes or even at the city level. The fact that it was aligned with the Sustainable Development Goals, SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), demonstrates its sustainability as an innovation. The project proves its short-term and long-term usefulness and can serve as an example of the replicable and scalable implementation.

6.4 Conclusion

The impact and sustainability analysis indicate that the smart waste management system effectively resolves the inefficiency in the conventional techniques and enhances environmental responsibility and awareness among users. The system will guarantee the efficient use of resources, minimized carbon footprint, and improved hygiene in controlled settings like university campuses by integrating IoT, machine learning, and real-time monitoring. It is sustainable because of a modular design, adherence to international standards, and expansion to larger urban implementation. The project will be directly related to the sustainability goals of the whole world, as well as provide a model to be followed in the future in terms of waste management infrastructure. Therefore, the smart bin system is not a technical solution, but a sustainable platform to form a cleaner and more efficient community.

Chapter 7: Engineering Project Management.

7.1 Introduction

In modern smart campus initiatives, effective waste management has become a significant challenge. This is due to rising student populations and limited infrastructure. Traditional collection methods often lead to inefficiencies, hygiene issues, and high operational costs. These problems show the need for technology-driven solutions. Structured project management is crucial in tackling these challenges. It ensures timely execution, budget control, and effective risk management. Successful project delivery depends on three main factors: clearly defining system requirements within set timeframes, encouraging collaboration among diverse teams and stakeholders, and creating backup plans to handle uncertainties. Project management tools allow for ongoing progress tracking, identifying potential risks, and adjusting resources as needed [21]. By combining flexible management with engineering design, teams can achieve sustainable results and introduce innovations like IoT-based monitoring and predictive analytics. This ensures that the system stays responsive to real-world needs.

7.2 Define, Plan and Manage Engineering Project

7.2.1 Project Definition

In the Define phase, poor and unhygienic waste management on campus was identified as the main engineering problem. Background research and stakeholder surveys revealed issues like irregular collection times, overflowing bins, and lack of segregation facilities as mentioned in 2.1. Based on these findings, clear objectives were set: to design an automated waste segregation system using IoT sensors and a machine learning classifier, to implement real-time monitoring with a cloud-based dashboard, and to create a predictive collection scheduling model.

Moving into the assembly plan phase, the system architecture was created, Gantt charts were prepared to outline the timeline, and responsibilities within the team were assigned. These included hardware integration, machine learning model training, cloud platform development, and testing. Potential risks such as sensor malfunction, inaccurate classification, and data delays were identified. To address these, strategies such as having backups for sensors and improving the model over time were proposed.

In the Manage phase, progress was tracked through weekly meetings, milestone reviews, and ongoing documentation of design changes. Feedback from stakeholders was incorporated through surveys to refine features while resources and schedules were adjusted to handle unexpected delays.

7.2.2 Project Planning

The project was strategically planned across three distinct phases, each with defined deliverables:

Table-9: EEE499P Project Plan

Activity	Start Date	End Date	Outcome
Idea generation & brainstorming	October 9, 2024	October 16, 2024	Initial project concept finalized
Stakeholder survey & background research	October 18, 2024	October 23, 2024	Data on campus waste management collected
Literature review	October 25, 2024	November 13, 2024	Identified gaps and

			existing solutions
Draft concept note submission	November 14, 2024		
Evaluation of design approaches	November 15, 2024	December 4, 2024	Feasible design strategy selected
Final concept note submission	December 5, 2024		
Initial budget estimation	December 13, 2024	December 21, 2024	Drafted initial cost plan
Draft Project Proposal	January 2, 2025		
Risk identification	January 3, 2024	January 7, 2024	Risk register created
Final Project Proposal preparation & presentation	January 8, 2025		Proposal submitted & presented

FYDP-P (Proposal Phase)

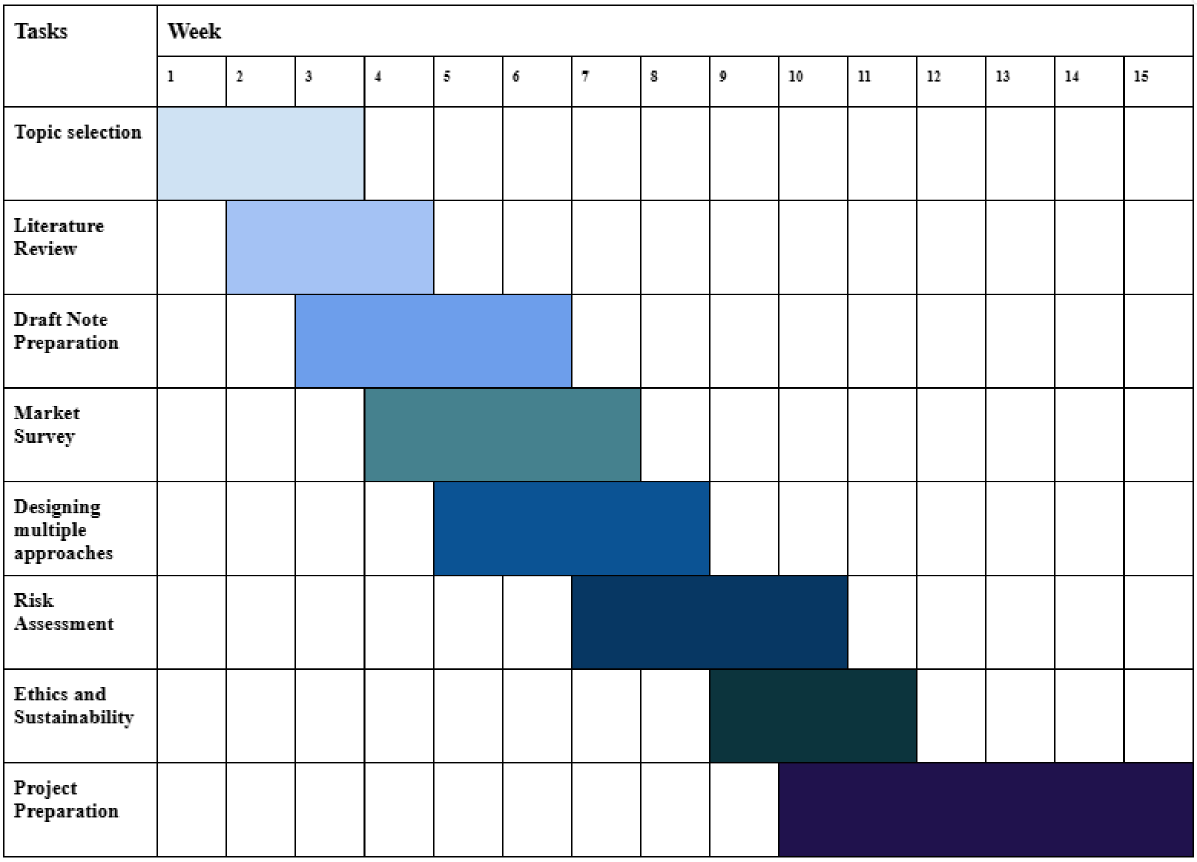


Fig-34 : Gantt Chart for FYDP-P

Table-10: EEE499D Project Plan

Activity	Start Date	End Date	Outcome
Detailed design & architecture	February 4, 2025	February 22, 2025	System design completed
3D modeling (Fusion 360)	February 27, 2025	March 13, 2025	CAD models of prototype built
MATLAB Simulink simulations	March 27, 2025	April 10, 2025	Control and system validation performed
Mid-progress presentation	April 21, 2025		
Component analysis & selection	April 24, 2025	April 30, 2025	Final component list prepared
Subsystem	May 2, 2025	May 17, 2025	Subsystems tested

functional verification			virtually
Peer Evaluation	May 18, 2025		
Design report submission and presentation	May 22, 2025		

FYDP-D (Design Phase)

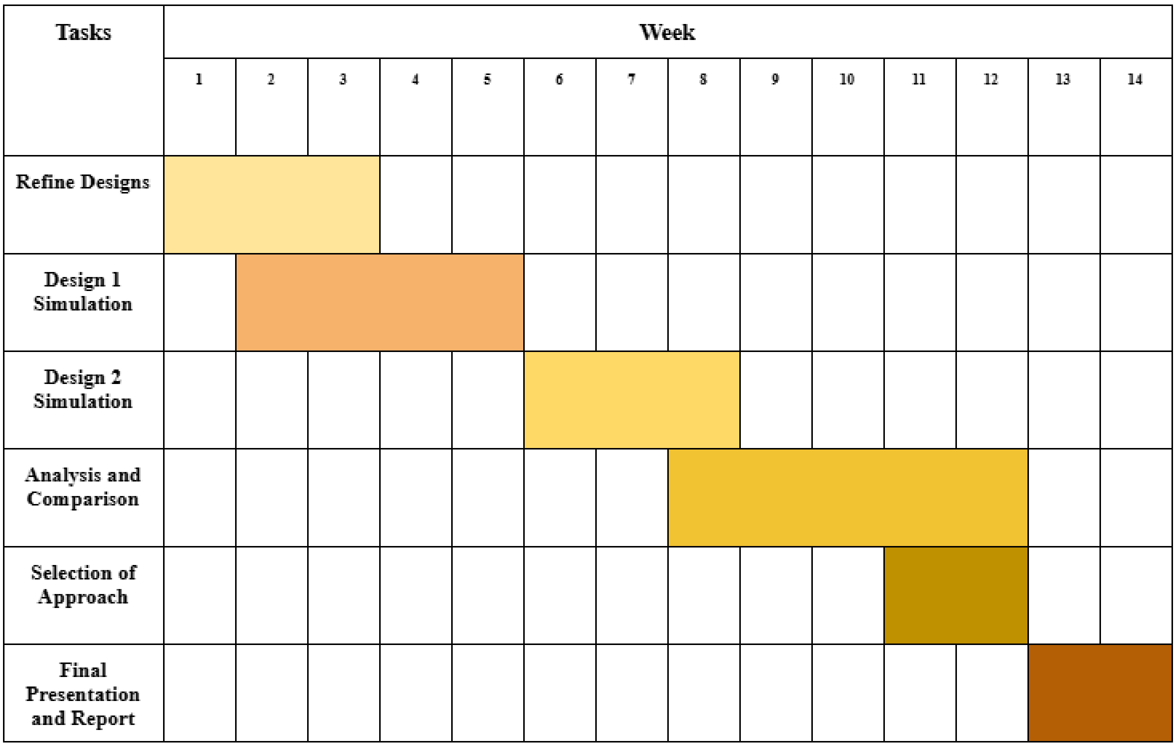


Fig-35 : Gantt Chart for FYDP-D

Table-11: EEE499C Project Plan

Activity	**Start Date**	**End Date**	**Outcome**
Procurement of components	June 17, 2025	June 31, 2025	All required components purchased

Hardware prototyping & IoT integration	July 1, 2025	July 17, 2025	Hardware assembled and IoT connected
Machine learning model training	July 19, 2025	July 24, 2025	Waste classification model trained
Cloud dashboard development	July 26, 2025	August 7, 2025	Cloud-based monitoring dashboard built
System integration & testing	August 8, 2025	September 5, 2025	Prototype fully tested and debugged
Final report writing	August 22, 2025		Final report prepared
Final presentation & demonstration	September 11, 2025		Project demonstrated successfully
Final report submission			

FYDP-C (Implementation Phase)

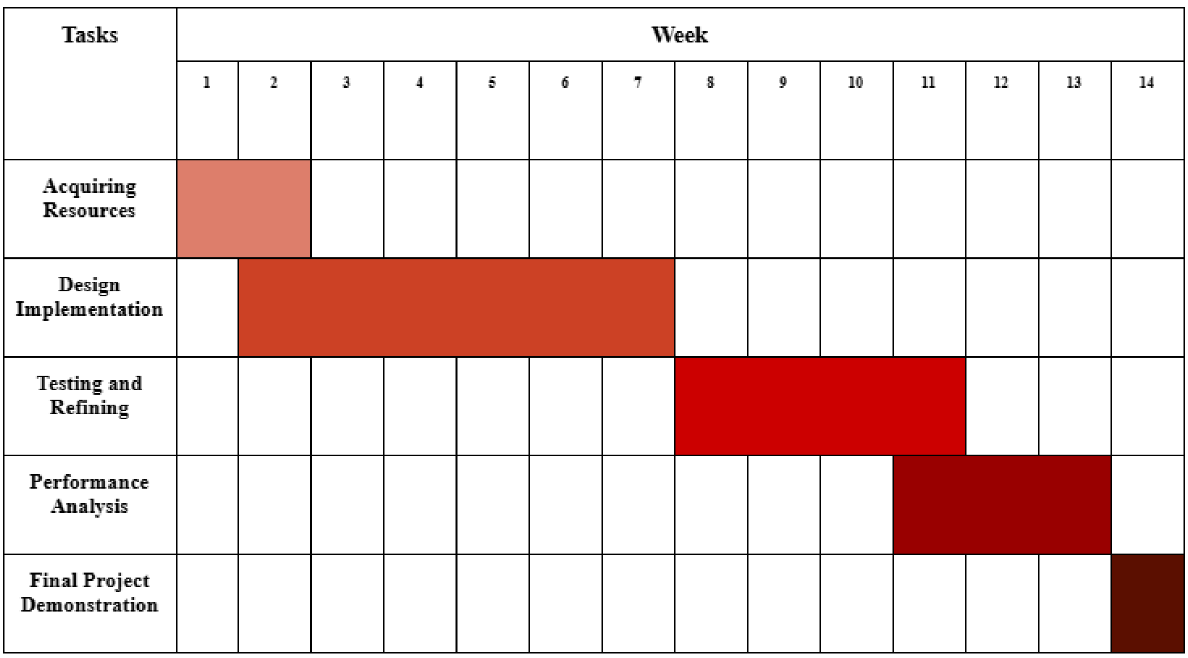


Fig-36 : Gantt Chart for FYDP-C

7.3 Evaluate Project Progress

7.3.1 Schedule Adherence

The project progress was closely monitored using the Gantt chart and planned milestones. The initial proposal and design phases were completed on time. The literature survey, design approach evaluation and component selection were selected according to the project's requirements. During the implementation phase, there were minor delays in hardware procurement because of supply chain issues. Those issues were swiftly addressed by preparing a revised timeline. Which included progresses like simulation and dashboard development. Which kept the overall progress on track. Despite these challenges, the Integrating and testing phase period came up early by reaching every milestone in the dedicated time deadline for the project system.

7.3.2 Budget and Risk Management

The project stayed within the pre-calculated and allocated total budget. Costs were broken down accordingly and monitored continuously to prevent overruns and expenses that might impact in the cost benefit analysis for the project. Smart procurement choices were made by opting for reliable and affordable components from the ideology of building a cheaper solution for smart city waste management [22]. Multiple risks which include sensor malfunctions, classification errors and IoT connectivity problems were managed by keeping backup hardware units and preparing contingency plans. As an example, offline storage modes and retraining the ML model. Those are financially beneficial backups as well. This prevented risks from significantly impacting the overall progress or performance of the system.

7.3.3 Technical Progress

Through the integration of all working parts together, the subsystem-level testing was completed. Object detecting IR sensor based lid control and ultrasonic fill-level monitoring is the sensor level integration. Additionally, waste classification with the trained model and IoT connectivity with dashboard giving alerts to the monitoring body were verified and tested simultaneously. This helped to keep track of the project progress monitoring. The continuous testing and verification ensures overall system functionality. The full structured hardware was integrated with the Raspberry Pi and cloud dashboard. It all together enabled real-time monitoring and feedback systems.

7.3.4 Team Collaboration

Teamwork was one of the key aspects in the progressive path walking of the project. Everyone's duties and roles were clearly assigned for each member in different subsystem testing and verification. The building structure or hardware prototyping, then the software simulations,working on the feedback IoT integration, overall documentation and simplifying the budgeting. Each and every one of these works were distributed according to the expertise to prevent the slow pace of progress. Weekly meetings kept everyone on the same page with the scope of finding the lackings of the project. Everyone had shared cloud folders where data and progress reports were uploaded, online updating through social media and formal logbooks for tracking everyday work lists, which helped to keep the pace of communication among the team. Collaborative presentations and peer evaluations confirmed equal participation. Mutual feedback further improved the quality of deliverables and presentations.

7.5 Conclusion

In conclusion, the ideology of project management processes were applied vastly throughout the project. Resulting in a successful application of the process as well. All the basic theoretical and conceptual aspects were clearly managed along with the detailed planning with the help of resource allocation. Progress reports were presented and reviewed within time to time that helped the update for the overall project. The main task for all these progressive works was to overcome challenges and mitigate possible risks. Additionally, the team operated highly in terms of a collaborative body. Each member stood out uniquely to fulfil their assigned duties with calmness, composure and maintained responsive communication with the other members of the team. The short timed, economically beneficial and successful compilation of a complex engineering solution was compiled by this complete approach to project management.

Chapter 8: Economical Analysis.

8.1 Introduction

Economic aspect evaluation and breakdown is always considered as one of the key and crucial aspects of an engineering project. It guarantees and clarifies whether a suggested solution is actually technically possible and financially viable or simply not. The whole concept is mainly important in the context of waste management because conventional collection methods often carry out most of the costing of the system. The deployment of physical labor and untimed scheduling is another fact as well . These inefficient observations result in public health risks by not following the SDG goals, resulting in an unhygienic situation through overflow incidents and an immense amount of fuel consumption. All of that combined adds to the hidden costs that are charged by the stakeholders or investors. Mainly organizations and local governments. By making and availing a real time smart waste management system in the needed areas, it is possible to solve these problems and operating costs while can be reduced effectively through maintaining safety standards.

Through recycling optimization, coin-based disposal, and integration of renewable energy, the intelligent IoT- and ML-based method all together for the system not only lowers operating costs but also adds value. It reduces unnecessary collection trips and avoids overflows while potentially increasing revenue from recyclables by facilitating accurate sorting and real-time monitoring. The system is scalable and affordable when deployed in large quantities. As a result, it strikes a balance between affordability and sustainability. It also solidifies a quantifiable return on investment with a long term societal advantage.

8.2 Economic analysis

In case of breaking down and analysing the economic aspect in component level, sensors, microcontrollers, and power adapter units as well as mechanical enclosures, cloud storage, and machine learning training materials were necessary for the prototype's development. These upfront costs were required to develop the fully functional system that could monitor in real time and make decisions based on data. The system provides a more intelligent and effective approach than conventional waste collection techniques, which mainly rely on manual inspections and set collection schedules. This lessens reliance on manual labor, reduces needless fuel consumption from collection vehicles. Which reduces other external costs except the prototyping phase costs.

Furthermore, the system’s functionality that sends out alerts at the appropriate moment because the ultrasonic sensors measure bin fill levels accurately, constantly updates the monitoring aspect. By introducing a revenue model, the coin dispenser unit encourages users to use the bins responsibly while enabling them to pay for specific disposal services in one time buying option. At the same time, data-driven scheduling is supported and management inefficiencies are decreased due to the cloud communication. All together it enables the system to be scaled for implementation on campuses or office places resulting in long-term cost savings and new revenue streams.

8.3 Cost benefit analysis

The total prototype development cost was approximately 29,000–30,000 BDT with sensors, microcontrollers, communication units, batteries, fabrication, and testing were all included in developing the prototype. Among the many advantages that make the system attractive for institutional and municipal adoption are decreased manual labor and collection frequency saving fuel and transportation costs that improves waste management on campus. With the potential for revenue from recyclables and coin-based disposal with positive contribution to sustainability development goals (SDG).

Design Approach 1: (Image classification based sorting)

Table-12: Cost analysis of Design Approach-1

Component	Cost	Benefit	Drawback
Microcontroller (Raspberry Pi 4)	15215	High processing power which also supports ML and multiple interfaces	Higher cost and power consumption

Camera Module (8 MP, 1080p)	650	Accurate image capture for ML-based sorting	Requires good lighting, higher data processing load
Waste Sorting Classifier (ML model)	–	High classification accuracy and flexible for updates	Needs training data and computationally intensive
Hand Detection Sensor (IR LM393)	398	Reliable proximity detection	Sensitive to ambient light in limited range
Bin Level Sensors (HC-SR04)	150	Accurate distance measurement and easy to integrate	Susceptible to interference which needs calibration
Entry Flap Actuator (MG996R)	264	Precise flap control	Limited torque that may struggle with heavier lids
Sorting Flap Actuator (MG996R)	1100	Strong torque for heavy flaps	Higher power consumption and larger size
Coin Dispenser Actuator (MG90S)	264	Precise coin dispensing	Limited torque that slows operation for heavy coins
Flame Detection Sensor (LM393)	262	Quick flame detection for analog/digital output	False positives possible in bright light
Gas Detection Sensor (MQ-2)	180	Detects multiple gases	Slow recovery time
Buzzer	50	Simple alert mechanism	Limited feedback type which is audible only
LED (5 mm RED)	50	Low-power visual indicator	Small and may be hard to see in bright light
WiFi Communication (MQTT via Raspberry Pi)	–	Real-time remote monitoring	Requires stable internet connection
Dashboard (Node-RED)	–	Visualizes data in real-time	Needs server setup and maintenance

LCD Module Display	525	User-friendly interface	Limited display area with extra power consumption

Design Approach 2: (Sensor based sorting)

Table-13: Cost analysis of Design Approach-2

Component	Cost	Benefit	Drawback
Microcontroller (ATmega328P)	1200	Low-cost, low-power	Limited processing power that cannot run ML models
Hand Detection Sensor (IR Proximity)	300	Simple and reliable	Limited range that is sensitive to ambient light
Bin Level Sensors (Ultrasonic)	700	Accurate distance measurement	Interference possible needs calibration
Waste Sorting Classifier (Color Sensor RGB)	1200	Simple and low-cost	Less accurate than ML-based image classification
Entry Flap Actuator (DC Gear Motor 12V, 100 RPM + Limit Switches)	2500	Strong torque and reliable with limit switches	Less precise than servo that is more complex control
Sorting Flap Actuator (DC Gear Motor 12V, 100 RPM + Limit Switches)	2100	Handles heavy loads	Requires more space and noisier
Gas Detection Sensor (Smoke, LPG, Methane)	640	Detects multiple gases	Slower response and calibration needed
Power Source (12V 7Ah SLA Battery)	1750	Portable, reliable for offline operation	Heavy that limits runtime and requires maintenance
User Feedback (LEDs + Buzzer)	180	Simple notifications	Limited information; visual/audible only

8.4 Evaluate economic and financial aspects

The financial evaluation of the overall system explains the clear aim for sustainability and profitability of the project. The base prototype cost was approximately 29,000–30,000 BDT. Including the sensors, microcontroller, communication modules and power systems. The system is aimed to achieve a significant ROI of about 21.2% annually per unit. When deployed in larger numbers (10–50 units), projected profits range from 70,000–350,000 BDT annually. This only focuses on the ROI based on prototyping. This will vary for a product based market approach with other financial costs to officially launch the product in the market. Where the consideration of the refilling currency in the coin dispenser and maintenance cost is also included. Factors such as less power requirements, integrating with renewable power sources and ensuring financial feasibility over the long term is a foreseeable future economic aspect.

Table-14: Initial Prototype Cost for finalized Design Approach

Component	Unit	Unit Cost	Total Cost
Microcontroller (Raspberry Pi 4)	1	15215	15215
Camera Module (8 MP, 1080p)	1	650	650
Waste Sorting Classifier (ML model)	-		
Hand Detection Sensor (IR LM393)	1	398	398
Bin Level Sensors (HC-SR04)	2	150	300
Entry Flap Actuator (MG996R)	1	264	264
Sorting Flap Actuator (MG996R)	1	1100	1100
Coin Dispenser Actuator (MG90S)	1	264	264
Flame Detection Sensor (LM393)	2	262	525
Gas Detection Sensor (MQ-2)	1	180	180
Buzzer	1	50	50
LED (5 mm RED)	1	50	50
WiFi Communication (MQTT via Raspberry Pi)	-		
Dashboard (Node-RED)	-		
LCD Module Display	1	525	525
Hardware components and miscellaneous	-	9979	9979
Total cost			29500

With the total costing of 29500, the estimated ROI calculation-

Table-15: Total Product Level Cost

Cost Component	Cost (BDT)
Prototype Hardware	29500
Product Marketing and Promotion	3000
Packaging and Distribution Setup	1500
Maintenance and Servicing (annual)	1500
Total Product Cost (Per Unit)	**36000**

Annual ROI Projection-

Table-16: Product Level ROI projection and Calculation

Deployment Scale	Total Investment	Annual ROI%	Projected Profit
1	36000	21.2%	7632
10	360000		76320
25	900000		190800
30	1800000		381600

8.5 Conclusion

The overall IoT and ML incorporation to the system shows that the entire interface is proven durable and cost-effective.Which was conducted economically and in social terms, the system is in conclusion beneficial for long term investment based on the collaboration with the NGOs and government organizations [23]. Aside from operational deficiencies, the system also adjusts costs from the extent of system functionality disposal placed by and through the system. It not only opens up the path towards the smart city project, but also fulfills multiple sustainable development goals. By presenting more innovative and flexible approaches for the field gains that are targeted. Overall, the premise set stands economically. Along with instant operational costs. Financially, the base system is remarkably sustainable and for future aspects can be economically scalable.

Chapter 9: Ethics and Professional Responsibilities CO13, CO2

9.1 Introduction

For projects like smart waste management systems, ethics and professional responsibilities play an important role. In today's world, engineers and professionals are required to design systems that solve complex problems as well as abide by the safety of society and environment. This includes transparency, accountability, fairness and compliance with the established standards and codes. Also prioritizing global sustainability and greater good of the environment. From selection of materials to implementation, every decision made has its own ethical importance that can further influence society and environment.

9.2 Identify ethical issues and professional responsibility

Constructing the smart waste management system, transparency and fairness in designing is the key part for ethical consideration. Insufficient resources and over-laborious methods could trick the stakeholders into believing in the system. One way to overcome this fact is to provide clearly documented methods and systems that are constructed according to the principles and ethics codes. In addition, directly linked stakeholders will be informed and regularly updated if any changes are made to the project in time. Students, faculty, and other university staff can engage in regular feedback sessions to ensure that the system meets the needs of all involved stakeholders ethically and lawfully. Identifying the issue of transparency is also necessary to eliminate any further transparency problems. A very important ethical consideration involved in creating a smart waste management system is to be ethical with the data management process, since the use of camera and sensor features might lead to the identification of the bin users. Therefore, the predictions and usages will be anonymized and stored within the system administration to ensure confidentiality. Machine learning models collecting waste will be used to watch for biases and systematically allocate resources evenly across the campus. The system is designed to scale up as environmental concerns arise: increasing waste production or stricter regulations. All IoT devices, sensors, and batteries are to be recycled properly following current e-waste regulations at the end of the system's lifespan. All material used in this project is manufactured according to ethical labor practices and environmental criteria, so guaranteeing supply chain respects the long-term aim of the project. Educational modules like signage, digital notifications will be included in the system to guide users in how to properly separate trash and reduce the health hazards involved in improper disposal. Environmental impact analysis has to be carried out to develop a system that will contribute to the environmental protection and sustainability of society.

9.3 Apply ethical issues and professional responsibility

For ethical consideration, environmental safety is also an obligatory one in relation to the general environmental safety consideration and the impact of our project.

Table-17: Ethical impact analysis table

Impact Area	Potential Impact	Mitigation Measures
Air Quality	Emissions from waste decomposition in bins	Use of gas sensors (MQ-135) to detect harmful gases
Water Quality	Contamination from liquid waste leakage	Design waterproof and leak-proof bins
Soil Quality	Leakage of hazardous waste into soil	Implementation of sealed bins and regular maintenance checks
Energy Consumption	Use of IoT devices and sensors increases power usage	Using energy-efficient components and rechargeable batteries
Noise Pollution	Alerts and alarms may cause noise disturbance	Using adjustable volume settings for alerts
Waste Generation	E-waste from sensors and electronic components	Partnering with certified e-waste recycling companies
Biodiversity	Risk to the surrounding flora and fauna from waste spills	Ensuring proper waste containment and regular monitoring
Climate Impact	Reduced carbon footprint from optimized waste collection	Using ML to schedule efficient waste collection
Public Health	Exposure to hazardous waste poses health risks	Implementing safety features like flame sensors and alerts
Campus Aesthetics	Overflowing waste bins create unsightly campus areas	Real-time monitoring and timely waste collection
User Awareness	Lack of awareness may lead to improper use of the system	Proper usage is promoted by educational campaigns and workshops
Data Privacy	Unauthorized access to user data	Use encryption and access control, and consider security regularly.

9.4 Conclusion

Ethics and professional responsibility together ensures that the smart waste management system is technologically advanced and also environmentally sustainable. This project upholds the professional responsibility of engineers to act in the best interest of society and nature by addressing the above issues like privacy, environmental concerns, transparency, awareness and thoroughness. This approach reflects the ethical and professional duties of engineers by reinforcing ethical awareness, professional accountability and the role of engineers as a responsible innovator of a sustainable future.

Chapter 10: Conclusion and Future Work.

10.1 Project Summary / Conclusion

The project also dealt with the longstanding inefficiencies of the conventional methods of waste management by creating a smart bin system that is real-time and intelligent in university campuses. With the help of IoT sensors, machine learning classification and cloud connectivity, the system was able to automate waste sorting, track fill levels, and hazard detection. The machine learning-based design was found to be more accurate and robust than a more basic sensor-based model through simulations and prototype implementation. The prototype was able to produce reliable classification of biodegradable and non-biodegradable waste, less carbon emissions as it minimized unnecessary collection trips, and hygiene in the campus setting. The reward system fostered user responsibility socially, and economically, the system was able to save on fuel and labor and also provided the chances of recycling. In general, the project serves as an example of how the engineering solutions based on data may be converted into sustainable practices, in line with the global aims regarding a cleaner and more efficient urban lifestyle.

10.2 Future Work

Although the project has met its major goals, there are still a number of opportunities that can be improved. To start with, it can be integrated with renewable energy sources, e.g., solar panels, to become more sustainable and avoid relying on external power. Second, the classification model should be extended to cover more types of waste so that it would allow finer separation and promote recycling efforts. Third, predictive analytics may be included to enable the collection schedules to be dynamically optimized according to the usage trends in various locations. Fourth, the system would be able to be connected with municipal waste management networks in order to expand its influence outside campus settings. Lastly, user engagement and behavioral change studies over a long period would be beneficial in terms of improving the reward system and enhancing participation. By responding to these guidelines, the project could be developed into a campus prototype that is realized at a city-level to develop sustainable urban infrastructure.

Chapter 11: Identification of Complex Engineering Problems and Activities.

11.1: Identify the attribute of complex engineering problem (EP)

Table 18: Attributes of Complex Engineering Problems (EP)

	Attributes	Put tick (√) as appropriate
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	
P3	Depth of analysis required	√
P4	Familiarity of issues	√
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and needs	√
P7	Interdependence	√

11.2: Provide reasoning how the project address selected attribute (EP)

- **P1: Depth of knowledge required**

This project integrates multidisciplinary knowledge from electronics, embedded systems, machine learning and IoT communication. Therefore requiring interdisciplinary understanding.

- **P3: Depth of analysis required**

The design of this project required detailed analysis of sensor behaviour, ML model performance, durability of multiple boards, power usage and system integration through various simulations and prototyping.

- **P4: Familiarity of issues**

Waste management is familiar but incorporating automation, ML classification and IoT makes this project less familiar and more complex in implementation as well as making the whole system work together.

- **P6: Extent of Stakeholder Involvement and Needs**

Stakeholder's active involvement was fully throughout the analysis, design and testing part. Certain stakeholders' needs such as usability, safety and real world applicability was maintained as per their needs and demands.

- **P7: Independence**

This whole system depends upon interaction between hardware components like sensors, motor actuators and software components like classification, alerting as well as network communication. This creates an interdependent subsystem.

11.3 Identify the attribute of complex engineering activities (EA)

Table 19: Attributes of Complex Engineering Activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	√
A2	Level of interaction	√
A3	Innovation	
A4	Consequences for society and the environment	√
A5	Familiarity	

11.4 Provide reasoning how the project address selected attribute (EA)

- **A1: Range of resource**

This project has a wide range of resources, including hardware and software integration. With the use of those engineering and IT resources the project is managed simultaneously.

- **A2: Level of Interaction**

This project involved a high level of interaction between hardware-software parts, team members and real time data exchange between edge devices and cloud monitoring systems.

- **A4: Consequences for society and the environment**

This system improves campus cleanliness along with it reduces environmental pollution. This aligns with sustainability goals and promotes eco-friendly behaviour.

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Appendix

Logbook

	Final Year Design Project (C) Spring 2025		
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ATC Details:			
ATC 1			
Chair	Dr. Md. Mosaddequr Rahman	mosaddeq@bracu.ac.bd	
Member 1	Aldrin Nippon Bobby	nippon@bracu.ac.bd	
Member 2	Mohaimenul Islam	mohaimenul.islam@bracu.ac.bd	

Table 20: FYDP (P) Summary of Team Log Book

Date/Time/ Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
29.10.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.FYDP initiation 2.Presented numerous problem statements	All	N/A as it was an introductory meeting. Task 1: completed. Task 2: not started.
05.11.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Choosing a suitable problem statement	All	Task 1: Partially Completed
12.11.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Chosen topic discussion 2.Working on literature review 3.Deciding what to include in draft concept note	All	Task 1: Completed Task 2: Completed Task 3: Partially Completed
19.11.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Determining what to incorporate in progress presentation slides 2.Getting ideas to include budget and another design approach	All	Task 1: In Progress Task 2: Completed
26.11.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Valuable suggestions by ATC about what changes to make in the final concept note	All	Find better papers to make the work easier. Task 1: Completed
03.12.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.ATC indicated some restraints in the topic and what to encompass	All	ATC gave fundamental ideas about the topic. Task 1: Partially Completed

10.12.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Additional background research on the topics	All	Task 1: In Progress
17.12.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.Prominent ideas by ATC in order to do well in final presentation	All	Was instructed to add more details. Task 1: Completed
24.12.2024 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1.ATC giving feedback on the project proposal 2. Finishing and polishing the report and making the slides based on feedback	All	Task 1: Completed Task 2: Completed

Table 21: FYDP (D) Summary of Team Log Book

Date/Time/ Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
13.02.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Breaking down the design phase work of finalized model from the proposal	All	
15.02.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Dividing the design work among the groupmates	All	
16.03.2025 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Valuable suggestions from ATC regarding the insights of the design work and background research	All	Was instructed about how to proceed with the simulation part of the project. Task 1: In Progress
25.03.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Meeting session on background research and conducting an open survey for response analysis of waste management system	All	
18.04.2025 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Knowledge about functional verifications including the requirement of a 3D modelling for the system 2. Suggestions of verification tools for simulations 3. Progress presentation on the functional verification and simulation	All	Need to learn about how to make 3D models. Task 1: In Progress Task 2: Completed Task 3: Completed
24.04.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Building the 3d model and completing every other part of functional verification	All	

03.05.2025 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Final insights and suggestions on design approach comparison and finalized approach idea	All	ATC gave essential information about comparing the design approaches. Task 1: Partially Completed
05.05.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Compiling and concluding the final presentation and the report work	All	

Table 22: FYDP (C) Summary of Team Log Book

Date/Time/ Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
12.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Brainstorming and came up with an architecture that is better suited for the project	All	
17.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Constructing and manufacturing the required bin model	All	
20.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Ordering the necessary components via online platform	All	
22.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Buying the lid of the bin and taking essential measurements for the waste management system 2. Working on the necessary coding part	All	
24.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Generating ideas about how to fit a lid operated via a servo motor in this structure 2. Testing ultrasonic and infrared sensors	All	
26.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Preparing the two front doors of the bin 2. Colouring the lid 3. Testing the servo motors' rotational speed and angle	All	
29.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Attaching the lid to the top part of the structure with enough accuracy and precision 2. Implementing the required code	All	
31.07.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Connecting wires 2. Troubleshoot Pi-related issues	All	

02.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Building the inside bins with PVC	All	
04.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Securing the wires and prominent components to the walls of the structure 2. Placing the pi inside the bin	All	
07.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Constructing a tray which will hold the waste temporarily before rotating 2. Setting up the rest of the sensors	All	
09.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Mounting four wheels below the structure, making it portable 2. Building the pvc rod which will hold the tray and help it rotate	All	
11.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Placing the camera below the lid, at the top of the tray 2. Testing the trained model to detect appropriate types of waste	All	
14.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Running the pi model to spot any errors 2. Encountering problems related to the maximum height of the waste	All	
16.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Final report writing task split	All	
17.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Setting up the LCD display 2. Attaching the two servo motors, MG996R, to the tray and the bin consecutively	All	
18.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Executing code to run the partially completed program automatically on boot to test if it's operating correctly or not 2. Facing difficulties involving ultrasonic sensors 3. Introducing IoT based system to the project and utilizing pushbullet successfully	All	
19.08.2025 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Showing video clips of the project to ATC 2. Got useful feedback and generated new concepts	All	ATC gave an idea regarding the coin dispenser system. Task 1: Completed Task 2: In Progress
21.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Re-evaluating the program's boot-time functionality 2. Experiencing challenges regarding gas sensor and ultrasonic sensor	All	

		3. Running diagnosis to find a suitable solution		
24.08.2025 (Weekly ATC Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Exhibiting the project to ATC	All	Received positive remarks from ATC. Task 1: Completed
26.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Gas and ultra sensor issue re-emerges 2. Fixing issues related to wiring also	All	
28.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Installing the PVC panel permanently as a front door 2. Purchasing additional 3mm PVC boards	All	
31.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Building the coin dispenser system 2. Attaching the coin dispenser to MG90S servo motor	All	
02.09.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Preparation of poster 2. Connecting the coin dispenser system to the structure	All	
06.09.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Preparing the final report writing draft 2. Updating code to carry out the purpose of providing coin to user if two non biodegradable wastes are placed inside the bin	All	
07.09.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Preparation of poster 2. Printing high-impact visual stickers to adhere to the bin	All	
08.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Prototype testing to see if the bin is operating properly 2. Fixing wiring complications	All	
09.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Running the completed program to check for errors 2. Encountered some problems related to coin dispenser's servo motor 3. Resolving the issue of the motor's speed	All	
10.08.2025 (Weekly Members Meeting)	1.Hamin 2.Afrida 3.Yasir 4.Ikram	1. Made a working video for the exhibition day 2. Final prototype testing before demonstration day	All	

Related code/theory

Model training

```
import os
```

```
from ultralytics import YOLO
from PIL import Image
import random

# ======================
# 1. Dataset Verification
# ======================
dataset_path = r"C:\Users\USER\Downloads\garbage"  # Using raw string for Windows paths
b_dir = os.path.join(dataset_path, "B")  # Biodegradable
n_dir = os.path.join(dataset_path, "N")  # Non-Biodegradable

# Check if folders exist
if not os.path.exists(b_dir) or not os.path.exists(n_dir):
    raise FileNotFoundError("Missing 'B' or 'N' folder in dataset directory")

# Check class balance (only count image files)
image_extensions = ('.jpg', '.jpeg', '.png', '.bmp', '.tif', '.tiff')
b_count = len([f for f in os.listdir(b_dir) if f.lower().endswith(image_extensions)])
n_count = len([f for f in os.listdir(n_dir) if f.lower().endswith(image_extensions)])
print(f"Image counts - B: {b_count}, N: {n_count}")

# ======================
# 2. Training with Fixes
# ======================
model = YOLO("yolov8n-cls.pt")  # Load model

# Train with augmentation (cls_weight removed as it's not supported in newer versions)
```

```
results = model.train(
    data=dataset_path,
    epochs=30,
    imgsz=160,
    augment=True,  # Enable augmentations
    hsv_h=0.2,  # Color variation (0-0.5)
    translate=0.1,  # Random shifts (0-0.2)
    fliplr=0.5,  # Horizontal flips (0-1)
    seed=42,  # Reproducibility
    name="waste_classifier",
    batch=10,  # Reduce if you get CUDA out of memory
    patience=10,  # Early stopping if no improvement
    workers=4,  # Number of data loading workers
    # Newer versions handle class imbalance automatically
)



# =====================
# 4. Prediction Test
# =====================
def predict_test_image(model, image_path):
    try:
        results = model.predict(image_path)
        probs = results[0].probs.data.tolist()
        print(f"\nPrediction for {image_path}:")
        print(f"Biodegradable (B): {probs[0]:.2%}")
```

```
        print(f"Non-Biodegradable (N): {probs[1]:.2%}")

        # Display image
        img = Image.open(image_path)
        img.show()
    except Exception as e:
        print(f"Error processing {image_path}: {str(e)}")


# Test on known examples
test_images = [
    r"C:\Users\USER\Downloads\testsex\66.jpg",  # Should be B
    r"C:\Users\USER\Downloads\testsex\12.jpg"  # Should be N
]

for img in test_images:
    if os.path.exists(img):
        predict_test_image(model, img)
    else:
        print(f"\nTest image not found: {img}")

print("\nTraining complete! Model saved to:", model.save_dir)
print(f"Best model path: {os.path.join(model.save_dir, 'weights', 'best.pt')}")
```

Main Script

```
#!/usr/bin/python3
import cv2
```

```
from ultralytics import YOLO

import torch

import os

import pigpio

import time

from rpi_lcd import LCD

from pushbullet import Pushbullet

import threading


# Pushbullet setup

API_KEY = "o.jYUm4mZcjy4qdjgQNWZwT6ULoy1R82VV"  # Replace with your
Pushbullet access token

try:

    pb = Pushbullet(API_KEY)

    print("Pushbullet initialized successfully")

except Exception as e:

    print(f"Pushbullet initialization failed: {e}")

    pb = None  # Continue without Pushbullet if initialization fails


# Initialize LCD

lcd = None

try:

    lcd = LCD(address=0x27)

    lcd.clear()

except Exception as e:

    print(f"LCD initialization failed: {e}")
```

```
# Initialize pigpio
pi = pigpio.pi()

# GPIO Setup (all pigpio)
IR_SENSOR_PIN = 17
TRIGGER_PIN_1 = 24    # Bin 1 ultrasonic
ECHO_PIN_1 = 25
TRIGGER_PIN_2 = 8      # Bin 2 ultrasonic
ECHO_PIN_2 = 7
BUZZER_PIN = 22
MG90_SERVO_PIN = 23    # 270° servo (lid)
MG996R_SERVO_PIN = 18  # 270° servo (sorting)
COIN_SERVO_PIN = 19    # 180° servo (coin dispenser)
FLAME_SENSOR_1 = 5     # GPIO5 (Pin 29)
FLAME_SENSOR_2 = 6     # GPIO6 (Pin 31)
MQ135_DO_PIN = 26      # GPIO26 for MQ135 gas sensor

# Configure GPIO (pigpio)
pi.set_mode(IR_SENSOR_PIN, pigpio.INPUT)
pi.set_pull_up_down(IR_SENSOR_PIN, pigpio.PUD_UP)

for trigger, echo in [(TRIGGER_PIN_1, ECHO_PIN_1), (TRIGGER_PIN_2,
ECHO_PIN_2)]:
    pi.set_mode(trigger, pigpio.OUTPUT)
    pi.set_mode(echo, pigpio.INPUT)
    pi.write(trigger, 0)
```

```
pi.set_mode(BUZZER_PIN, pigpio.OUTPUT)
pi.write(BUZZER_PIN, 0)

# Configure servo pins
for servo_pin in [MG90_SERVO_PIN, MG996R_SERVO_PIN, COIN_SERVO_PIN]:
    pi.set_mode(servo_pin, pigpio.OUTPUT)
    pi.set_PWM_frequency(servo_pin, 50)

# Configure flame sensors (pigpio)
for flame_pin in [FLAME_SENSOR_1, FLAME_SENSOR_2]:
    pi.set_mode(flame_pin, pigpio.INPUT)
    pi.set_pull_up_down(flame_pin, pigpio.PUD_DOWN)

# Configure MQ135 (pigpio)
pi.set_mode(MQ135_DO_PIN, pigpio.INPUT)
pi.set_pull_up_down(MQ135_DO_PIN, pigpio.PUD_DOWN)  # Pull-up for active LOW

# Servo Setup
MG90_MIN, MG90_MAX = 500, 2500  # 270° servo
MG996R_MIN, MG996R_MAX = 500, 2500  # 270° servo
COIN_MIN, COIN_MAX = 500, 2000  # 180° servo

def set_servo_angle(servo_pin, angle, min_pulse, max_pulse, stepped=True):
    """Move servo to specified angle, with optional stepped movement."""
    max_angle = 180 if servo_pin == COIN_SERVO_PIN else 270
    angle = max(0, min(max_angle, angle))
```

```
try:
    current_pulse = pi.get_servo_pulsewidth(servo_pin)
    if current_pulse == 0:  # If not initialized
        pi.set_servo_pulsewidth(servo_pin, min_pulse)
        current_pulse = min_pulse
        time.sleep(0.3)
except pigpio.error:
    pi.set_servo_pulsewidth(servo_pin, min_pulse)
    current_pulse = min_pulse
    time.sleep(0.3)

target_pulse = min_pulse + (angle / max_angle) * (max_pulse - min_pulse)

if stepped:
    step_size = 3
    step_delay = 0.02
    current_angle = ((current_pulse - min_pulse) / (max_pulse - min_pulse)) * max_angle

    if current_angle < angle:
        steps = range(int(current_angle), int(angle) + 1, step_size)
    else:
        steps = range(int(current_angle), int(angle) - 1, -step_size)

    for step_angle in steps:
        pulse = min_pulse + (step_angle / max_angle) * (max_pulse - min_pulse)
        pi.set_servo_pulsewidth(servo_pin, pulse)
        time.sleep(step_delay)
```

```
    pi.set_servo_pulsewidth(servo_pin, target_pulse)
    time.sleep(0.3)

# Initialize servos
set_servo_angle(MG90_SERVO_PIN, 180, MG90_MIN, MG90_MAX, stepped=True)
set_servo_angle(MG996R_SERVO_PIN, 135, MG996R_MIN, MG996R_MAX,
stepped=True)
set_servo_angle(COIN_SERVO_PIN, 180, COIN_MIN, COIN_MAX, stepped=True)

# Ultrasonic Functions
def get_distance(trigger_pin, echo_pin):
    pi.write(trigger_pin, 1)
    time.sleep(0.00001)
    pi.write(trigger_pin, 0)

    timeout = time.time()
    while pi.read(echo_pin) == 0:
        if time.time() - timeout > 0.04: return None

    pulse_start = time.time()
    while pi.read(echo_pin) == 1:
        if time.time() - timeout > 0.04: return None

    return round((time.time() - pulse_start) * 17150, 2)

# Buzzer Control
```

```
def buzz(duration_sec):
    try:
        pi.set_PWM_dutycycle(BUZZER_PIN, 128)
        pi.set_PWM_frequency(BUZZER_PIN, 2000)
        time.sleep(duration_sec)
    finally:
        pi.set_PWM_dutycycle(BUZZER_PIN, 0)

# Async Pushbullet Notification
def send_pushbullet(title, message):
    if pb:
        print(f"Sending Pushbullet notification: {title} - {message}")
        try:
            pb.push_note(title, message)
            print("Pushbullet notification sent successfully")
        except Exception as e:
            print(f"Failed to send Pushbullet notification: {e}")
    else:
        print("Pushbullet not initialized, cannot send notification")

# Flame Detection
def check_flames():
    f1 = pi.read(FLAME_SENSOR_1) == 0  # Active LOW
    f2 = pi.read(FLAME_SENSOR_2) == 1  # Active LOW
    if f1 or f2:
        if lcd:
            lcd.clear()
```

```
            lcd.text("FIRE DETECTED!", 1)
            lcd.text(f"Sensors:{int(f1)}{int(f2)}", 2)
        threading.Thread(target=send_pushbullet, args=("Smart Bin Alert", "FIRE DETECTED in waste bin!")).start()
        return True
    return False


# MQ135 Gas Detection
def wait_until_stable(pin, state, seconds):
    t0 = time.time()
    while time.time() - t0 < seconds:
        if pi.read(pin) != state:
            return False
        time.sleep(0.1)
    return True


def check_gas(last_alert, warmup_complete):
    if not warmup_complete:
        return last_alert  # Skip gas checks during warmup
    if pi.read(MQ135_DO_PIN) == 0:  # Active LOW
        if wait_until_stable(MQ135_DO_PIN, 0, 3):
            start = time.time()
            while pi.read(MQ135_DO_PIN) == 0:
                elapsed = time.time() - start
                if elapsed >= 1:
                    time_since_alert = time.time() - last_alert
                    if time_since_alert >= 1:
```

```
                if lcd:
                    lcd.clear()
                    lcd.text("Toxic Gas Detected", 1)
                threading.Thread(target=send_pushbullet, args=("Smart Bin Alert", "Toxic Gas Detected in waste bin!")).start()
                return time.time()
            return last_alert
        time.sleep(0.1)
    return last_alert


# System Parameters
FILL_ALERT_CM = 35
ultrasonic_interval = 10
countdown_sec = 20
bin1_full = False
bin2_full = False
last_ultrasonic_time = time.time()
last_gas_alert = 0
countdown_start = 0
is_processing = False
gas_warmup_start = time.time()
gas_warmup_duration = 120  # 2 minutes
gas_warmup_complete = False


def update_bin_status():
    """Show both bin statuses on LCD"""
    status1 = "FULL" if bin1_full else "OK"
```

```
    status2 = "FULL" if bin2_full else "OK"
    if lcd:
        lcd.text(f"Bin1:{status1}", 1)
        lcd.text(f"Bin2:{status2}", 2)


def check_fill_level():
    global bin1_full, bin2_full, last_ultrasonic_time


    dist1 = get_distance(TRIGGER_PIN_1, ECHO_PIN_1)
    if dist1 is not None and dist1 <= FILL_ALERT_CM:
        if not bin1_full:
            if lcd:
                lcd.clear()
                lcd.text("Bin1 FULL!", 1)
                lcd.text("Check capacity", 2)
            buzz(2.0)
            threading.Thread(target=send_pushbullet, args=("Smart Bin Alert", "Bin 1 is FULL!
Please empty it.")).start()
        bin1_full = True
    else:
        if bin1_full:
            if lcd:
                lcd.clear()
                lcd.text("Bin1 Cleared", 1)
            time.sleep(2)
        bin1_full = False
```

```
    dist2 = get_distance(TRIGGER_PIN_2, ECHO_PIN_2)
    if dist2 is not None and dist2 <= FILL_ALERT_CM:
        if bin2_full:
            if lcd:
                lcd.clear()
                lcd.text("Bin2 FULL!", 1)
                lcd.text("Check capacity", 2)
            buzz(2.0)
            threading.Thread(target=send_pushbullet, args=("Smart Bin Alert", "Bin 2 is FULL!
Please empty it.")).start()
        bin2_full = True
    else:
        if bin2_full:
            if lcd:
                lcd.clear()
                lcd.text("Bin2 Cleared", 1)
            time.sleep(2)
        bin2_full = False

    last_ultrasonic_time = time.time()
    update_bin_status()

# Load YOLO model
model_path = "/home/rbd/yolo/best.pt"
if not os.path.exists(model_path):
    if lcd:
        lcd.clear()
```

```
        lcd.text("Model missing!", 1)
    pi.stop()
    exit()

try:
    model = YOLO(model_path)
except Exception as e:
    if lcd:
        lcd.clear()
        lcd.text("Model error", 1)
    pi.stop()
    exit()

# Initialize camera with retry
while True:
    cap = cv2.VideoCapture(0)
    cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)
    cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)
    if cap.isOpened():
        break
    if lcd:
        lcd.clear()
        lcd.text("Camera error", 1)
        lcd.text("Retrying...", 2)
    print("Camera initialization failed, retrying...")
    time.sleep(1)
```

```
try:
    while True:
        # Check if gas sensor warmup is complete
        if not gas_warmup_complete and time.time() - gas_warmup_start >=
gas_warmup_duration:
            gas_warmup_complete = True

        # Gas sensor check (only after warmup)
        last_gas_alert = check_gas(last_gas_alert, gas_warmup_complete)

        if countdown_start > 0 and time.time() - countdown_start >= countdown_sec:
            countdown_start = 0

        if check_flames():
            buzz(0.1)
            time.sleep(0.1)
            buzz(0.1)
            continue

        if time.time() - last_ultrasonic_time > ultrasonic_interval:
            check_fill_level()

        if bin1_full or bin2_full:
            time.sleep(1)
            continue

        if not is_processing and pi.read(IR_SENSOR_PIN) == 0:
```

```
        is_processing = True
        if bin1_full or bin2_full:
            if lcd:
                lcd.clear()
                lcd.text("Cannot process", 1)
                lcd.text("Bin FULL", 2)
            buzz(2.0)
            time.sleep(1)
            update_bin_status()
            is_processing = False
            continue

        if lcd:
            lcd.clear()
            lcd.text("Processing...", 1)
        set_servo_angle(MG90_SERVO_PIN, 260, MG90_MIN, MG90_MAX,
stepped=True)
        time.sleep(3)
        set_servo_angle(MG90_SERVO_PIN, 180, MG90_MIN, MG90_MAX,
stepped=True)
        time.sleep(1)

        # Flush camera buffer
        for _ in range(5):
            cap.grab()

        ret, frame = cap.read()
        if ret:
```

```
capture_time = time.time()
print(f"New image captured at {time.strftime('%Y-%m-%d %H:%M:%S',
time.localtime(capture_time))}")
cv2.imwrite("/home/rbd/yolo/captured.jpg", cv2.resize(frame, (224, 224)))
results = model("/home/rbd/yolo/captured.jpg")
class_name = model.names[results[0].probs.top1]
print(f"YOLO detected class: {class_name}")


if class_name == "B":
    set_servo_angle(MG996R_SERVO_PIN, 230, MG996R_MIN, MG996R_MAX,
stepped=True)
    time.sleep(2)
    set_servo_angle(MG996R_SERVO_PIN, 135, MG996R_MIN, MG996R_MAX,
stepped=True)
    if lcd:
        lcd.clear()
        lcd.text("Sorted to Bin1", 1)
    if countdown_start > 0:
        countdown_start = 0
elif class_name == "N":
    set_servo_angle(MG996R_SERVO_PIN, 40, MG996R_MIN, MG996R_MAX,
stepped=True)
    time.sleep(2)
    set_servo_angle(MG996R_SERVO_PIN, 135, MG996R_MIN, MG996R_MAX,
stepped=True)
    if lcd:
        lcd.clear()
        lcd.text("Sorted to Bin2", 1)
    if countdown_start > 0 and time.time() - countdown_start < countdown_sec:
```

```
                if lcd:
                    lcd.clear()
                    lcd.text("Please collect coin", 1)
                set_servo_angle(COIN_SERVO_PIN, 40, COIN_MIN, COIN_MAX,
stepped=False)
                time.sleep(1)
                set_servo_angle(COIN_SERVO_PIN, 180, COIN_MIN, COIN_MAX,
stepped=False)
                countdown_start = 0
            else:
                countdown_start = time.time()
                if lcd:
                    lcd.clear()
                    lcd.text("Add another plastic", 1)
                    lcd.text("for coin", 2)

        buzz(1.0)
        try:
            os.remove("/home/rbd/yolo/captured.jpg")
            print("Captured image deleted successfully")
        except OSError as e:
            print(f"Failed to delete captured image: {e}")
        time.sleep(1)
        update_bin_status()
        time.sleep(0.5)
    else:
        print("Failed to capture image from camera")
    is_processing = False
```

```
        time.sleep(0.1)

except KeyboardInterrupt:
    if lcd:
        lcd.clear()
        lcd.text("Shutting down", 1)
finally:
    cap.release()
    cv2.destroyAllWindows()
    pi.set_servo_pulsewidth(MG90_SERVO_PIN, 0)
    pi.set_servo_pulsewidth(MG996R_SERVO_PIN, 0)
    pi.set_servo_pulsewidth(COIN_SERVO_PIN, 0)
    pi.write(BUZZER_PIN, 0)
    if lcd:
        lcd.clear()
    pi.stop()
```

Assessment Guideline for Faculty

Assessment Tools and CO Assessment Guideline

	Distribution of assessment points among various COs assessed in different semesters														
PO	l	c	f	g	c	b	d	c	e	l	k	k	h	i	j
CO	CO1	CO2	CO3	CO4	CO5	CO6	CO7	CO8	CO9	CO10	CO11	CO12	CO13	CO14	CO15
EEE 400C/ ECE 402C (Out of 100)							30	24	6	4	4	6	7	7	12
Project Final Report/ Project Progress Report							x	x	x	x	x	x	x		x
Demonstration of working prototype							x								x
Progress Presentation/ Final Presentation								x			x				
Peer-evaluation*													x	x	
Instructor's Assessment*													x	x	

Demonstration at FYDP Showcase								x							x

Note: The star (*) marked deliverables/skills will be evaluated at various stages of the project.

Mapping of CO-PO-Taxonomy Domain & Level- Delivery-Assessment Tool

Sl.	CO Description	PO	Bloom's Taxonomy Domain/Level	Assessment Tools
CO7	**Evaluate** the performance of the developed solution with respect to the given specifications, requirements and standards	d	Cognitive/ Evaluate	• Demonstration of working prototype • Project Progress Report on working prototype
CO8	**Complete** the final design and development of the solution with necessary adjustment based on performance evaluation	c	Cognitive/ Create	• Project Final Report • Final Presentation • Demonstration at FYDP Showcase
CO9	**Use** modern engineering and IT tools to design, develop and validate the solution	e	Cognitive/ Understand, Psychomotor/ Precision	• Project Final Report
CO10	**Conduct** independent research, literature survey and learning of new technologies and concepts as appropriate to design, develop and validate the solution	l	Cognitive/ Apply	• Project Final Report
CO11**	**Demonstrate** project management skill in various stages of developing the solution of engineering design project	k	Cognitive/ Apply Affective/ Valuing	• Project Final Report • Project Progress

				presentation at various stages
CO12	**Perform** cost-benefit and economic analysis of the solution	k	Cognitive/ Apply	• Project Final Report
CO13	**Apply** ethical considerations and professional responsibilities in designing the solution and throughout the project development phases	h	Cognitive/ Apply Affective/ Valuing	• Peer-evaluation, • Instructor's Assessment • Final Report
CO14**	**Perform** effectively as an individual and as a team member for successfully completion of the project	i	Affective/ Characterization	• Peer-evaluation • Instructor's Assessment
CO15**	**Communicate** effectively through writings, journals, technical reports, deliverables, presentations and verbal communication as appropriate at various stages of project development	j	Cognitive/ Understand Psychomotor/ Precision Affective/ Valuing	• Project Final Report • Progress Presentations, • Final Presentation • Demonstration at FYDP Showcase

Note: The double star (**) marked CO will be assessed at various stages of the project through indirect deliverables.