Arab Academy for Science, Technology, and Maritime Transport

College of Computing and Information Technology - Cairo

Department Of Computer Science

B. Sc. Final Year Project

SORTIFY

Intelligent Waste Management System

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DECLARATION

I hereby certify that this material, which I now submit for assessment on the program of study leading to the award of Bachelor of Science in Computer Science is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Our dedication, hard work, and collaborative spirit were instrumental in the success of this project.

SORTIFY

Waste Sorted, Earth Supported

Marketing Name: Sortify

Slogan: Waste Sorted Earth Supported

ABSTRACT

"Sortify" introduces a revolutionary paradigm shift in waste management, merging IoT and AI to transform the narrative around waste. By seamlessly blending cutting-edge technology, it redefines how we perceive and handle waste. Imagine a future where waste ceases to be a problem, but instead becomes a catalyst for positive change. "Sortify" embodies this vision by sorting waste into specific categories like paper cups, cans, plastic bottles, glass bottles, and others. Through IoT camera, real-time images of waste items feed into an AI system that rapidly classifies each item with precision.

This innovative system intricately weaves together hardware and software, offering a user-friendly mobile app for registration, insightful statistics, and a repository for earned points. The AI model acts as the backbone, ensuring accurate waste classification. "Sortify" doesn't just simplify waste disposal; it also reshapes recycling into a rewarding and engaging experience. It serves as a beacon, inviting users into a realm of responsible waste management, nurturing a greener future. This amalgamation of IoT and AI technologies not only streamlines waste classification but also fosters a cleaner and more sustainable environment, marking "Sortify" as a testament to the potent synergy of technology and environmental consciousness.

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INTRODUCTION

1.1 Purpose

An intelligent waste management system has several goals in mind. It aims to bring about various benefits, such as boosting recycling rates and recovering valuable resources, saving money, reducing harm to the environment, creating cleaner and more attractive communities, and raising public awareness. It does this by using technology and data-driven methods to make waste management more sustainable and efficient, all while being eco-friendly.

1.2 Motivation

The motivation behind developing "Sortify" lies in addressing the pressing need for efficient and effective waste management in an increasingly waste-conscious world. By integrating IoT and AI, "Sortify" aims to alleviate the burden of waste disposal and recycling, transforming it from a mundane chore into an engaging, rewarding experience. This system seeks to eliminate the stress and confusion often associated with waste sorting by ensuring precise, real-time classification of waste items, thereby fostering a sense of responsibility and accomplishment among users. "Sortify" provides peace of mind to individuals and communities, empowering them to manage waste effortlessly and contribute to a cleaner, more sustainable environment. By enabling remote oversight and intervention, "Sortify" strengthens the bond between technology and environmental stewardship, demonstrating how innovative solutions can drive positive change in waste management practices.

1.3 Problem Statement

Current intelligent waste management systems using IoT and AI face challenges regarding economic feasibility, scalability, environmental impacts, and accessibility, creating barriers to their broad adoption. This research seeks to address these issues and develop solutions for more efficient and sustainable waste management practices

Despite advancements in intelligent waste management systems that leverage IoT and AI technologies to enhance waste collection and recycling, there exist critical challenges and uncertainties that hinder the widespread adoption of these systems. Issues such as the economic viability and scalability of these technologies in smaller municipalities, the potential environmental impacts, and questions of accessibility need to be addressed. Additionally, a lack of comprehensive assessment of these factors creates a gap in understanding how these systems can be implemented effectively and sustainably.

1.4 Scope

The Intelligent Waste Management System is designed to address the following challenges and achieve specific objectives.

1.4.1 Benefits

The "Sortify" Intelligent Waste Management System employs AI for accurate waste categorization, reducing contamination and improving recycling. Integrated IoT cameras allow real-time monitoring, providing quick decision-making insights. The user-friendly mobile app simplifies recycling, offering easy registration and a points system for increased user engagement. Overall, "Sortify" actively contributes to a cleaner, more sustainable environment by promoting responsible waste disposal practices.

1.4.2 Objectives

a. Improve Waste Collection Efficiency: Reduce collection time and fuel consumption by optimizing routing and minimizing unnecessary trips.
b. Increase Recycling Rates: Enhance recycling effectiveness by accurately sorting waste and facilitating efficient collection for recycling facilities.
c. Promote Responsible Waste Disposal: Encourage conscious waste sorting and disposal behaviors among community members.

1.4.3 Goals

The Intelligent Waste Management System aims to reshape waste management with five ambitious goals: boosting recycling and recovering resources, saving money through efficient operations, protecting the environment by reducing emissions and pollution, creating cleaner and more beautiful communities, and raising public awareness for responsible waste disposal. This system also aspires to gather insightful data and foster collaboration between residents, waste companies, and policymakers for a future of sustainable waste management.

1.5 Definitions

1.5.1 System Explanation

"Sortify" system groundbreaking solution that integrates IoT and AI technologies to revolutionize waste management. Using strategically placed IoT cameras, the system captures real-time images of waste items, swiftly and precisely classified by a trained AI model into categories like paper cups, cans, plastic bottles, glass bottles, and others. This innovative system seamlessly merges software and hardware, with the user-friendly mobile app serving as a central hub for easy registration, access to insightful statistics, and a points repository. The sophisticated AI model acts as the system's brain, ensuring efficient waste classification and enhancing the overall user experience. "Sortify" not only streamlines waste management but also encourages responsible practices, making recycling a rewarding and enjoyable experience for a cleaner and more sustainable environment.

1.5.2 System Features and Functionality

"Sortify" system is a comprehensive waste management solution that operates through several key steps. It begins by gathering a diverse dataset of waste items, annotated with specific categories. This data is then used to train a deep learning model, enabling the system to classify waste items based on their features. Integrated into the system, this trained model performs real-time classification by processing images captured and feeding them into the AI for predictions. The results, along with images and timestamps, are stored in a database for analysis and user feedback, accessible through a user-friendly mobile app. "Sortify" encourages user engagement by rewarding correct waste sorting with points redeemable for various rewards and offers educational content to promote awareness of recycling practices. The system continuously improves through a feedback loop, collecting data on classification results and user interactions to refine the AI model's accuracy and optimize waste management processes. Ultimately, "Sortify" aims to automate waste classification, incentivize recycling, and contribute to a cleaner, more sustainable environment.

1.5.3 Mitigation Strategies

a. Redundant Sensor Deployment: Employing multiple sensors per bin to provide redundancy and compensate for potential failures.
b. AI Model Validation: Regularly validating AI models against real-world data to monitor accuracy and identify and address potential errors.
c. Mobile App Testing: Conducting rigorous testing of the mobile application to identify and resolve bugs or usability issues.

1.5.4 Challenges

a. Sensor Accuracy: Ensuring the accuracy of infrared sensors in determining bin fullness and waste levels.
b. Image Classification Precision: Maintaining high accuracy in image processing and AI-based waste classification.
c. Mobile Application Usability: Designing a user-friendly and engaging mobile application that facilitates waste sorting and rewards.
d. Public Acceptance: Encouraging community adoption of the system and promoting trust in its effectiveness.

1.5.5 Risks

a. Sensor Failures: Mitigating the potential for sensor malfunctions that could affect bin monitoring and waste collection schedules.
b. AI Model Errors: Ensuring robustness of AI models against potential errors that could lead to misclassification of waste items.
c. Mobile App Functionality: Maintaining the stability and security of the mobile application to ensure seamless user experience.
d. Community Engagement: Addressing potential resistance or skepticism towards the system and fostering widespread adoption.

1.5.6 Mitigation Strategies

d. Redundant Sensor Deployment: Employing multiple sensors per bin to provide redundancy and compensate for potential failures.
e. AI Model Validation: Regularly validating AI models against real-world data to monitor accuracy and identify and address potential errors.
f. Mobile App Testing: Conducting rigorous testing of the mobile application to identify and resolve bugs or usability issues.

1.6 Intended Audience and Usability

The Intelligent Waste Management System targets urban communities facing challenges of inefficient waste disposal, overflowing bins, and the need for increased recycling. It aims to engage residents, waste management companies, and policymakers in a collaborative effort to optimize waste management and minimize its environmental impact.

1.6.1 Intended Use

a. The Intelligent Waste Management System is designed to automate and optimize waste collection, sorting, and recycling processes. It utilizes intelligent bins, image processing, artificial intelligence, and a mobile application to achieve these goals
b. Effortless Waste Sorting: Intelligent bins with infrared sensors and image capture technology automatically categorize waste items, ensuring proper sorting for recycling.
c. Smart Bin Routing: AI-powered routing algorithms direct waste items to their designated recycling streams, minimizing transportation and maximizing recycling efficiency.
d. User Engagement and Rewards: A mobile application encourages responsible waste disposal by rewarding users with points for proper waste categorization. This fosters a culture of environmental stewardship.

1.7 Project Description

"Sortify" revolutionizes waste management by using IoT and AI to accurately classify waste in real-time. It sorts items like paper cups, cans, and plastic bottles, offering a mobile app for user registration, statistics, and points tracking. This innovative system makes recycling rewarding and promotes a cleaner, more sustainable environment.

Chapter Two

LITERATURE REVIEW

Criteria	SORTIFY	YUTA (IshTva)	Intelligent Garbage Sorting System (IGSS)	AI Waste Sorting (Univ. of Malaya)	AI Robotics in Recycling (Univ. of Colorado Boulder)
Mobile App	Yes (✓)	No (✗)	No (✗)	No (✗)	No (✗)
Effective AI Model (Accuracy)	High (✓)	High (✓)	Moderate (✗)	Moderate (✗)	High (✓)
Camera Type	-IoT Camera	-Machine Vision Camera	-Webcam	-Image Analysis Camera	-Advanced Robotics Camera
Waste Specialization	cardboard, cans, plastic & glass bottles, others	Industrial waste	General waste	General waste	General recycling
Environmental Impact	-Helps people recycle more &protect the environment.	-Works well without causing harm to nature.	-Reduces trash & manages it better.	-Makes recycling easier & more effective.	-Makes recycling safer & better for everyone.
Cost Effectiveness	High (✓)	Moderate(✗)	High (✓)	Very High (✓)	Low (✗)
Scalability & Flexibility	High (✓)	High (✓)	High (✓)	Moderate (✗)	High (✓)

Table 1 Literature review

2.1 Related Systems

These systems highlight advancements in waste management through technology such as AI machine vision, modular design, AI classification, and IoT integration, aimed at tackling various types of waste, from industrial to general and recyclables. Each project showcases a unique approach to enhancing sorting efficiency, from robotic automation to user engagement via mobile apps, all contributing to a more sustainable and efficient waste management ecosystem.

Table 2 Related systems

System	Features	Advantages	Disadvantages	Place of Origin
Bin-e Smart Waste Bins	AI-powered sorting, sensor technology for fill levels, data analytics	Precise waste classification, real-time monitoring, user engagement	High initial cost, requires regular maintenance	Poland
Compology Smart Containers	Camera-based sensors, contamination detection, route optimization	Detailed monitoring, improves recycling quality, reduces contamination	Initial setup cost, relies heavily on camera accuracy	USA
NetBin by FarSite Communications	Bin fill-level sensors, wireless data transmission, cloud-based analytics	Real-time monitoring, efficient waste collection routes	Does not include AI-based sorting, limited user interaction	UK
Evreka Smart Waste Collection	Sensors for bins, route optimization, real-time monitoring	Comprehensive waste management, efficient route planning	No AI-based sorting, minimal user engagement features	Turkey

Bin-e Smart Waste Bins :

Bin-e reward is a system designed to collect and recycle empty packaging and reward customers in return. It's an efficient and automated way to collect empty containers, streamlining the recycling process and providing a tangible incentive for consumers to adapt eco-friendly habits.

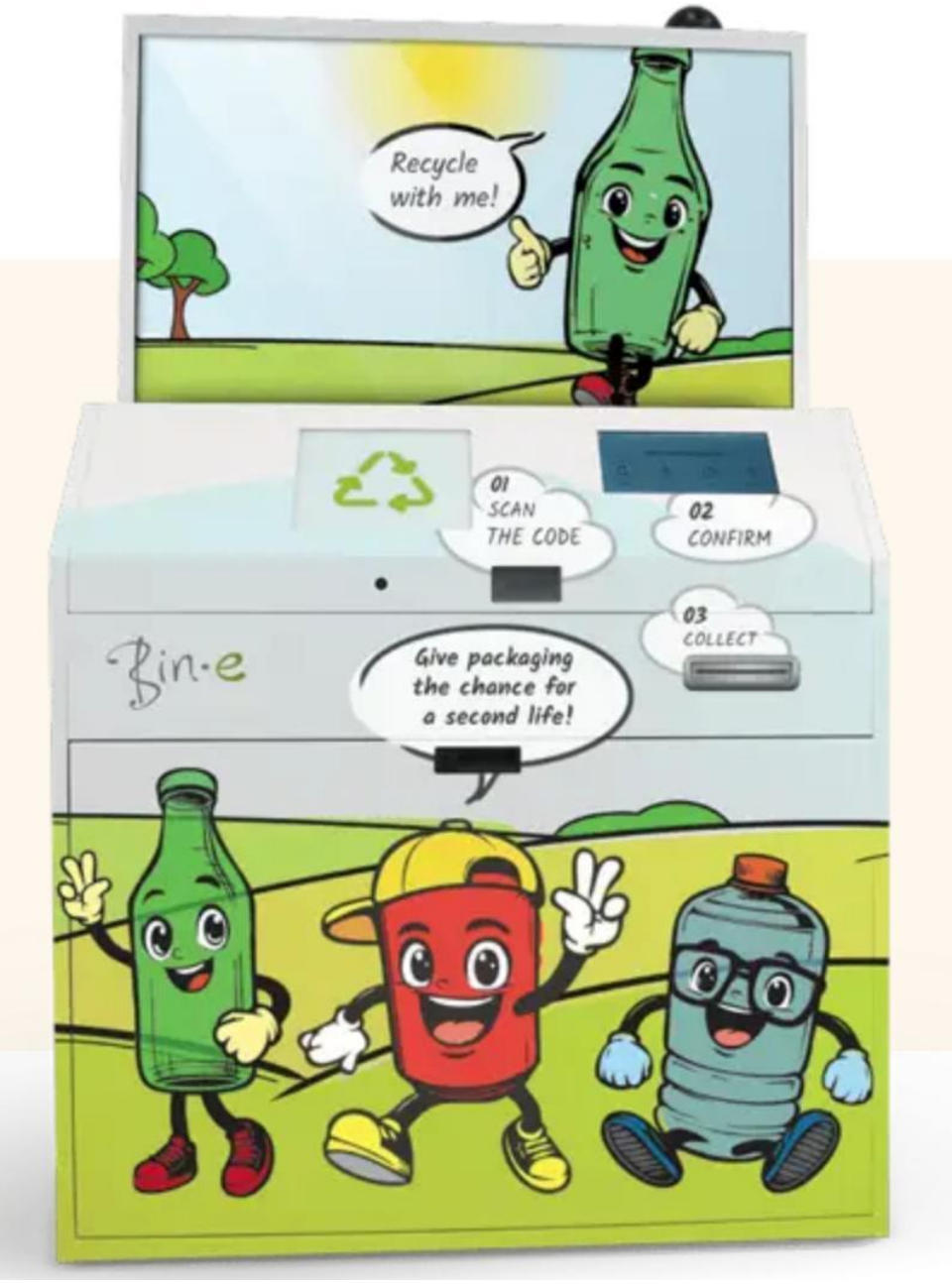


Figure 1 Bin-e smart Waste Bins

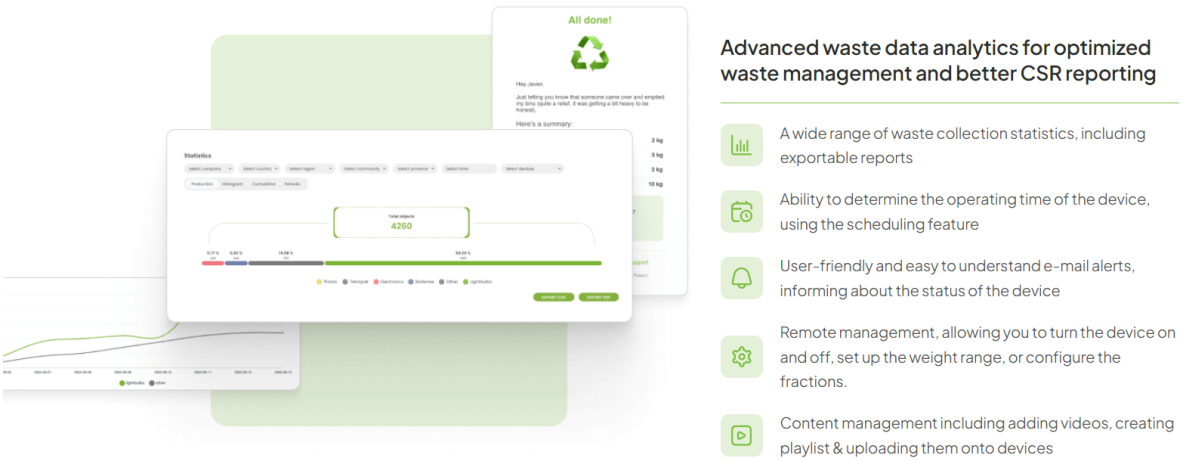


Figure 2 Bin-e smart Waste Bins (app)

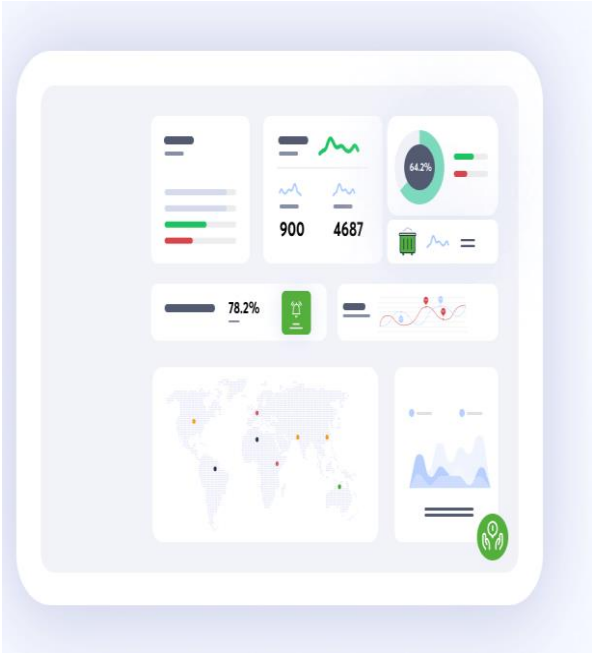


Figure 4 Evreka Smart Waste Collection

Figure 3 Compology Smart Containers

2.2 SWOT Analysis

2.2.1 Strengths

a. Improved efficiency: Streamlining waste processes leads to reduced waste and optimized operations
b. Increased recycling rates: Emphasizing sustainability promotes higher recycling practices.
c. User engagement: Involving users fosters a culture of responsible waste disposal
d. Cleanliness: Promotes hygienic and visually appealing communities.
e. Scalability: Potential for growth and adaptation to varying needs or sizes of communities

2.2.2 Weaknesses

a. Technical complexity: Complexity in understanding and implementing sophisticated technologies.
b. Initial investment costs: High upfront expenses might limit immediate adoption
c. Data privacy concerns: Risks associated with handling user data, requiring robust privacy measures
d. Dependence on electricity: Vulnerability due to reliance on consistent power sources

2.2.3 Opportunities

a. Expansion to new locations: Potential growth avenues by tapping into different markets
b. Integration with smart city initiatives: Aligning with larger urban development plans
c. Development of additional features: Enhancing offerings to cater to evolving needs
d. Data monetization: Leveraging collected data for additional insights or revenue.

2.2.4 Threats

a. High implementation costs: significant expenses might deter widespread adoption.
b. Privacy and security concerns: Risks related to data handling might hinder trust and acceptance.

2.3 PESTLE Analysis

2.2.1 Political

a. Opportunities: Collaboration with governments for waste management regulations and support.
b. Challenges: Adherence to varying regulations across regions affecting system implementation.

2.2.2 Economic

a. Opportunities: Potential for economic growth through partnerships and funding avenues.
b. Challenges: Initial high implementation costs impacting system adoption and scalability.

2.2.3 Social

a. Opportunities: Community engagement, raising awareness, and fostering responsible waste management behavior.
b. Challenges: User adoption, behavioral change, and the need for widespread participation.

2.2.4 Technological

a. Opportunities: Integration of AI, IoT, and smart tech for efficient waste classification and user interaction.
b. Challenges: Ensuring tech reliability, potential malfunctions, and data privacy concerns.

2.2.5 Legal

a. Opportunities: Adherence to waste management laws and regulations, potentially facilitating system acceptance.
b. Challenges: Diverse legal frameworks across regions impacting system implementation and operations.

2.2.6 Environmental

a. Opportunities: Contribution to sustainability, waste reduction, and promoting eco-friendly practices.
b. Challenges: Environmental impacts of tech components, energy consumption, and ensuring actual waste reduction.

2.3 IEEE standards

It is a set by the Institute of Electrical and Electronics Engineers, to offer crucial guidelines for technology projects. Adhering to these standards in our graduation project ensures alignment with industry best practices, enhances credibility, and showcases a commitment to excellence.

Table 3 Application of IEEE Standrads

IEEE standards	Description	Checklist	Satisfied in
730 (Software Quality Assurance)	defines a set of best practices for ensuring that software is created and maintained with high quality in mind. It's like a roadmap for software development.	✓	By addressing [1.3] scope, defining [1.4] challenges, proposing solutions, and considering a comprehensive approach to waste management. It also acknowledges potential [1.4] risks and seeks strategies for mitigation
830 (Software Requirements Specification)	1, Describe the overall product, including its functions, features, and characteristics. 2. Discuss the context within which the software will be used. 3. Define any relevant terminology or acronyms.	✓	Detailed system functionalities, waste categorization, intelligent bin operations, user engagement via the mobile app, and overall system behavior. Addresses [3.2] user requirements and system privileges.
1012 (Software Verification and Validation)	outlines guidelines for effective verification and validation (V&V) processes throughout the life cycle of systems, software, and hardware.	✓	Focus on real-time waste classification accuracy and effectiveness of the AI model in identifying and categorizing waste items. Includes validation against real-world data to monitor accuracy and address errors.
1016 (Software Design Descriptions)	1. Introduce the design description document. 2. Identify the software for which the design is being described. 3. Include any relevant background information or context.	✓	Integration of IoT and AI technologies within the system, ensuring alignment with intended functionalities and technologies. Covers software and hardware integration, highlighting the mobile app's central role and the significance of the AI model.

7000-2021 (Addressing Ethical Concerns During System Design)	Addresses the process for integrating ethical considerations into AI system design, particularly relevant for managing ethical implications in waste categorization and decision-making processes.	✓	Ensuring ethical framework integration into AI model design and operation, addressing potential ethical implications of AI-based decision-making in waste categorization and management.
802.15.4 (Low-Rate Wireless Personal Area Networks)	Specifies standards for Low-Rate Wireless Personal Area Networks (LR-WPANs), ensuring robust and reliable wireless communication capabilities within the waste management system's hardware infrastructure.	✓	Implementing reliable wireless networking capabilities within the hardware infrastructure of the waste management system, facilitating seamless communication between IoT devices like sensors and controllers.
828-2012 (Software Configuration Management Plans)	Defines guidelines for Software Configuration Management Plans (SCMPs), ensuring effective management of software configurations throughout the Sortify app's development lifecycle.	✓	Implementing effective software configuration management practices in the Sortify app's development process, ensuring systematic control over changes, versioning, and configuration items to maintain consistency and reliability.
1219 (Software Maintenance) Though superseded by ISO/IEC 14764:2006	1. Define a repeatable and predictable process for maintaining software. 2. Improve the quality and efficiency of software maintenance activities. 3. Address issues and problems commonly encountered in software maintenance.	✓	Continuous improvement through user feedback, data collection on classification results, and interactions for enhancing AI model accuracy and optimizing waste management processes.

2.5 System Prototype

Figure 5 System Prototype

Table 4 total cost

Items	Prices
Raspberry pi 4	7500
servo motors (x4)	185*4=740
infrared sensors(x2)	145*5=725
LCD	400
DC step down	175
DC geared motor	1000
Wood frame	1500
Hardware martials	3000
Conveyor belt	3000
Keypad	100
Servo driver	300
Totalcost	18,440

Chapter Three

System Analysis and Design

3.1 Use Case

The diagram is a use case diagram for a system with different actors: user, admin, and operators. It outlines various actions each actor can perform, such as 'Login', 'Register', and 'View Profile' for users, 'Maintain System' and 'View Bins' for admins, and 'Confirm Points' and 'View Notification' for operators. The diagram also shows the relationships and interactions between these actors and the system's functions.

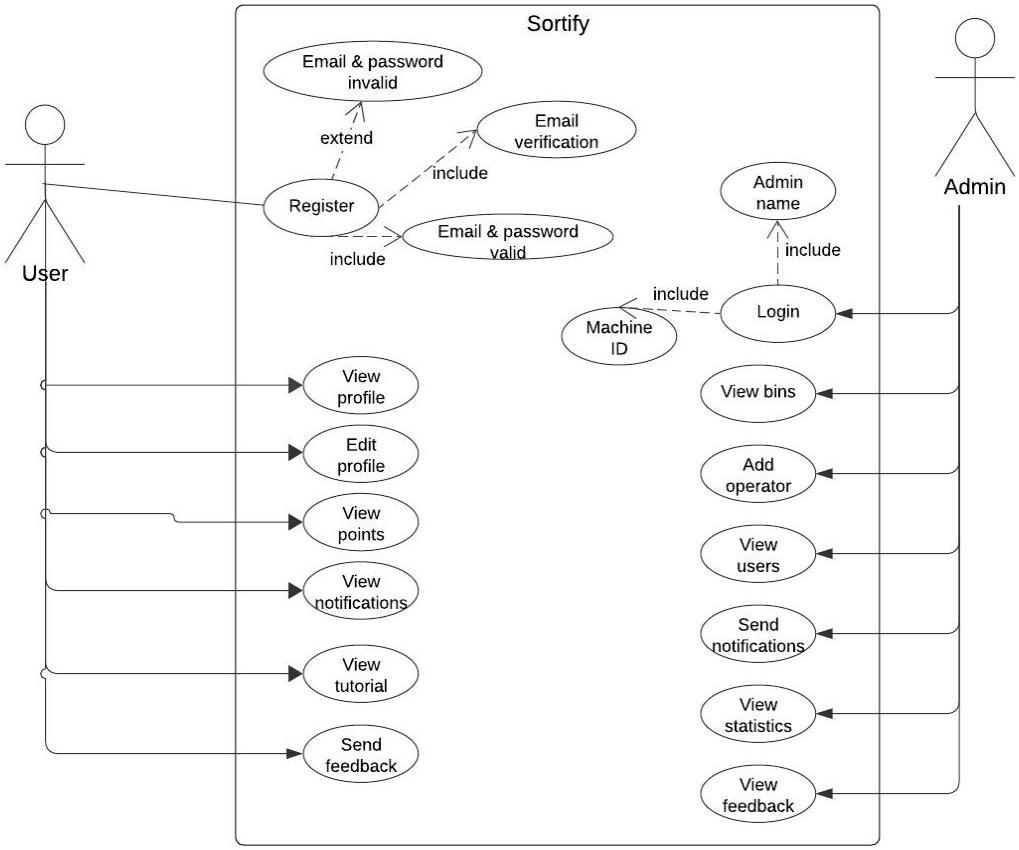


Figure 6 Use Case

3.2 Sequence Diagram

The diagram is a sequence diagram showing interactions between admins, an application, a database, a machine, and operators. It details the process of checking bin status, confirming bin status, and sending notifications. When a bin check is initiated by an admin, the application retrieves bin information from the database, which also communicates with a machine to determine the bin's status. If the bin is not full, a confirmation is sent back; if it's full, a notification is sent to operators.

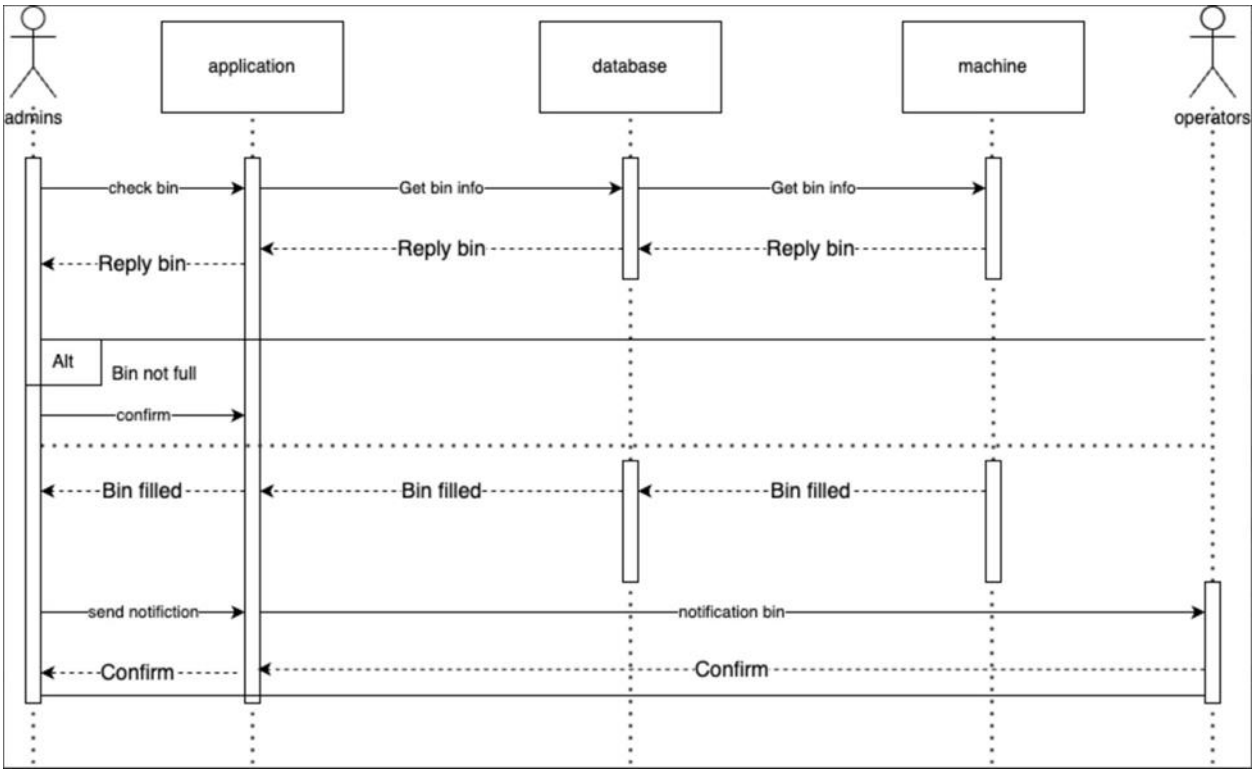


Figure 7 Sequence Diagram

The diagram depicts a sequence diagram for an interaction between a User and a waste management system involving an application, a database, and a machine. The user starts by signing in to the application, which checks credentials against the database. If the user doesn't have an account, there's an alternate flow to create one. Once logged in, the user can scan a QR code at the machine to throw away waste. After this, the machine sorts the waste and sends point information back to the application, which then shows the updated points to the user.

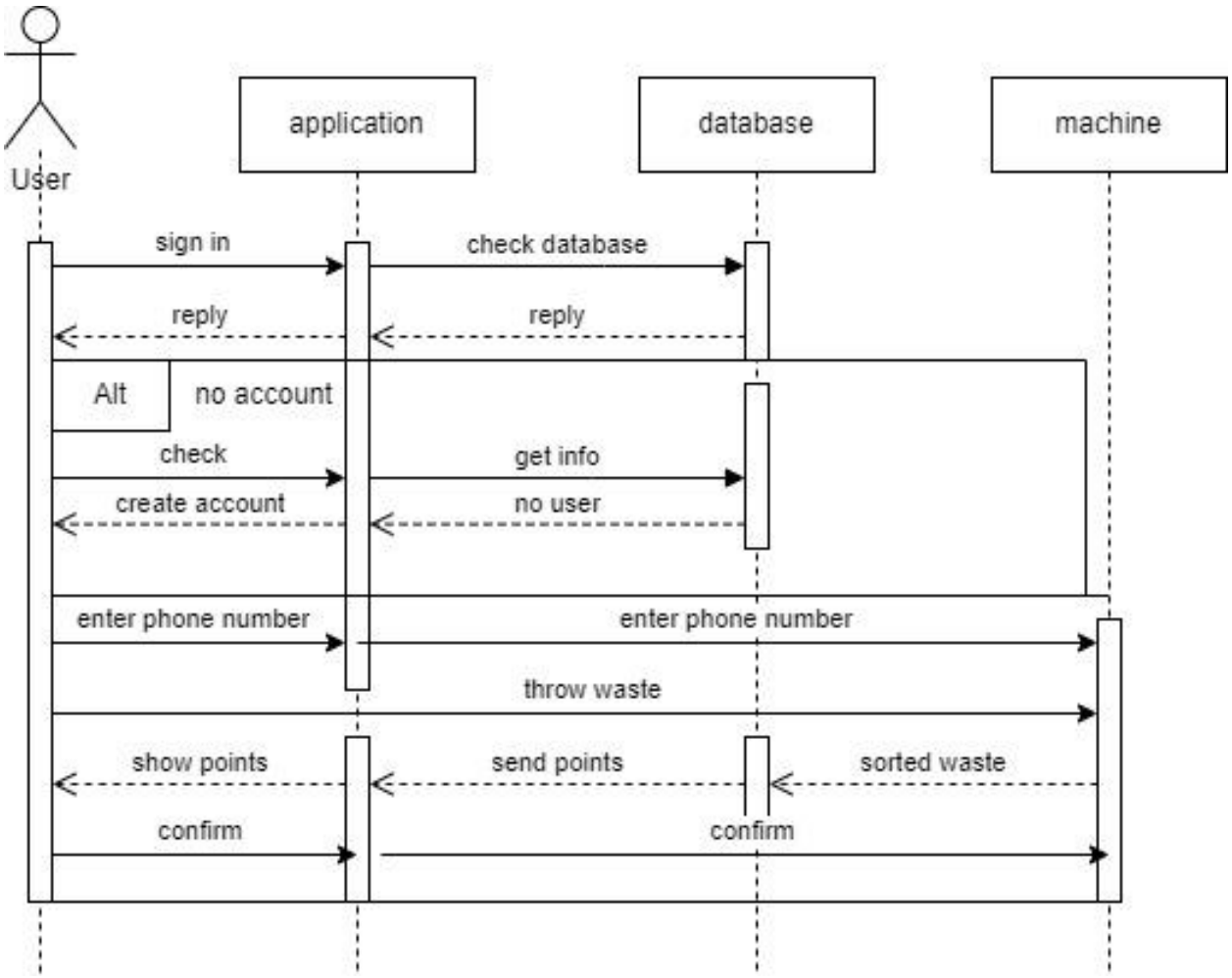


Figure 8 Sequence Diagram

3.3 State Machine Diagram

The diagram displays a state machine diagram for a recycling process. The system begins in an 'Idle' state and transitions to active when a person interacts with it. The person can either 'generate QR code' for item acceptance or 'scan bins'. If the bin is full, the system will 'Close pin' and 'Send notification', otherwise it will 'Accept items', 'capture picture', process the picture, 'Categorize trash', 'Count item', and finally 'Put it in'. After inserting the item, the system regenerates, likely to return to the 'Idle' state.

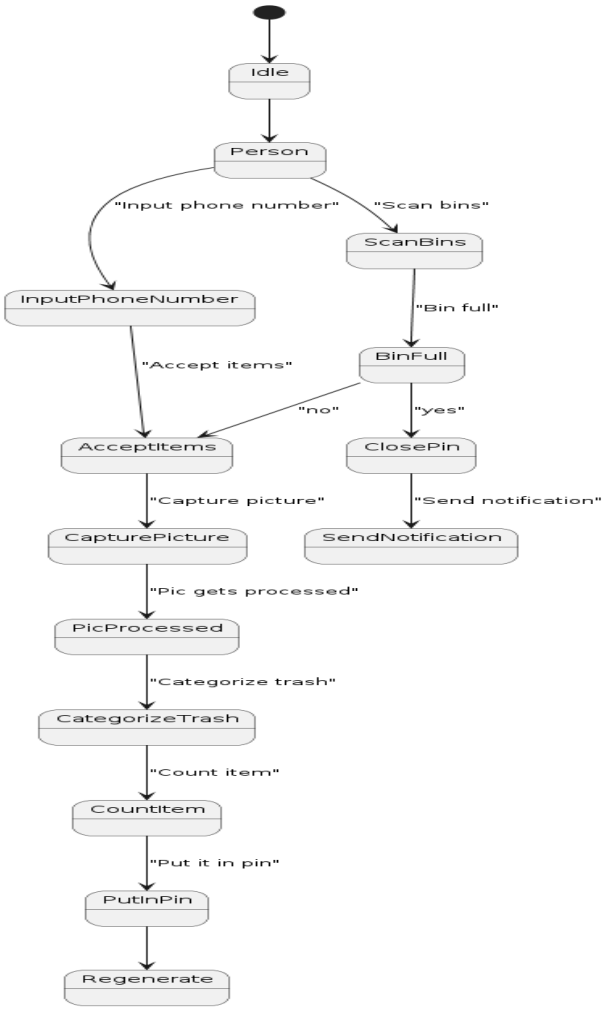


Figure 9 State Machine Diagram

3.4 Activity Diagram

The diagram is a class diagram for a waste management system. It defines the system's structure with classes for User, Profile, Points, Waste Type, Machine, Sorting Activity, and Admin. The User class includes methods for login, registration, profile viewing, and editing. Users have Profiles and accumulate Points, which are linked to specific Waste Types. Machines are associated with Sorting Activities, which are confirmed by an Admin. The admin class is noted to be similar to the User class.

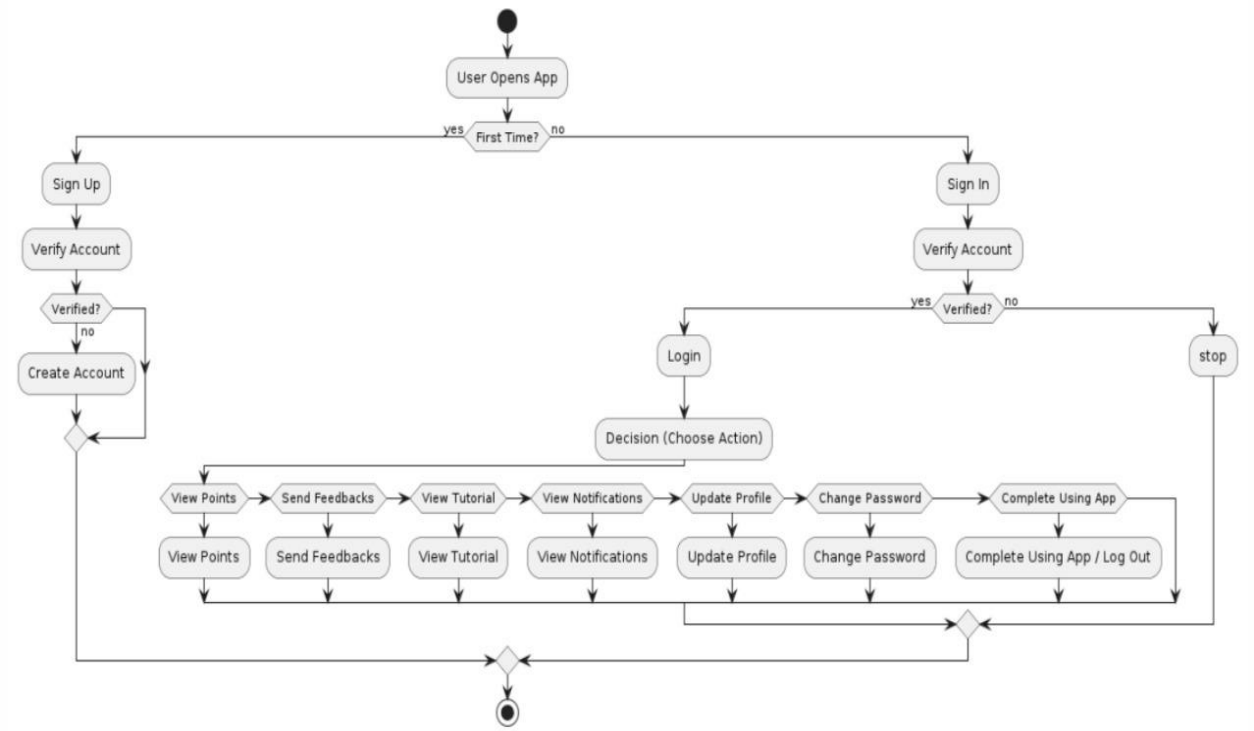


Figure 10 Activity Diagram

3.5 Class Diagram

The diagram is a class diagram for a recycling system. It features classes for User, Profile, Points, Waste Type, Machine, Sorting Activity, and Admin. The User class, with attributes like name and password, is linked to Profile and Points, indicating that each user has a profile and accrues points. Points are further broken down by type and are associated with Waste Type. The Machine class is linked to Sorting Activity, which an Admin can confirm. The admin class is noted to have similarities with the User class, suggesting shared attributes or methods.

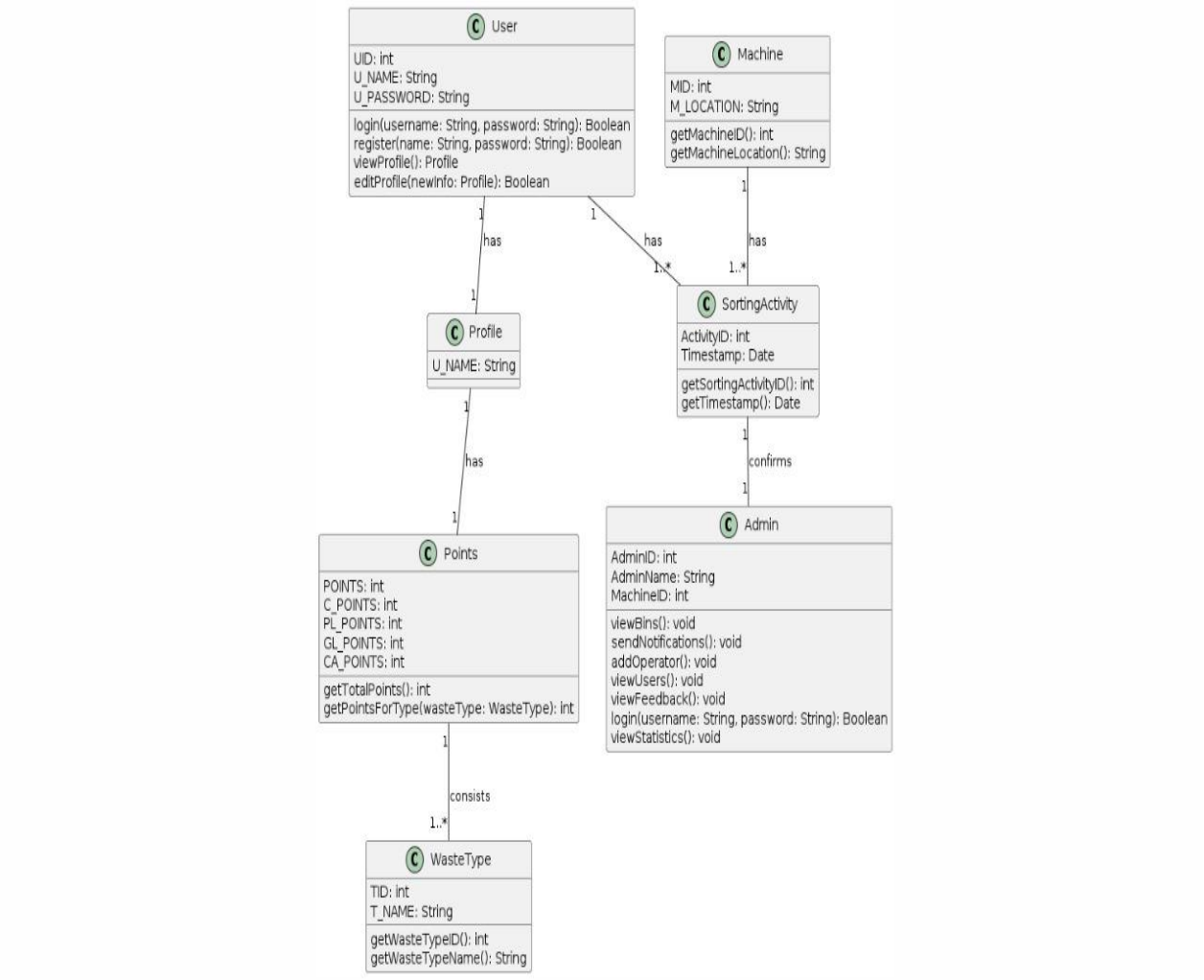


Figure 11 Class Diagram

3.6 Detailed Use Case

Table 5 Registration

Use Case Name	**Registration**
Primary actor	User (Operator/Admin/User)
Pre-condition	Access to the registration section of the platform.
Postcondition	Upon successful registration, the user receives a confirmation message and gains access to their account dashboard.
Normal flow	1. User Requests Registration. 2. User Enters Personal Information. 3. User Creates Login Credentials (username, password). 4. System Validates Information: Ensures completeness and 5. Account Creation. 6. User Accesses Dashboard.
Alternative Flow	1. Username Availability Check. 2. Email Verification. 3. Error Handling: In case of system errors or connection issues, notify the user and advise them to try again later or contact support.

Use Case Name	**View Waste Statistics**
Primary Actor	User (User/Admin)
Pre-condition	Successful Login
Post-conditions	Access to Waste Statistics
Normal Flow	1. User Requests to View Waste Statistics 2. User Navigates to the Statistics Section 3. System Displays Waste Statistics: Includes data on waste collected, categorized or any relevant waste management metrics.

Table 8 Edit Profile

Alternative Flow	No Statistics Available: If there's no recorded data or no data matches the search criteria, display a message indicating the absence of relevant statistics.
Use Case Name	**Edit Profile**
main Actors:	User, Admin, Operator
Pre-condition:	Successful login
Post-conditions:	Updated profile information
Normal Flow:	1. User/Admin/Operator navigates to Profile Settings or Edit Profile Section. 2. Edits personal details as required. 3. Confirms and saves the changes.
Alternative Flow:	1. Invalid Changes: If the entered information doesn't meet validation criteria, prompt an error message. 3. System Errors: In case of technical issues, notify the respective user/admin/operator.

Table 6 View Waste Statistics

Table 7 View Profile

Use Case Name	**View Profile**
Primary Actor	User (Registered), Admin, Operator
Pre-condition	Successful login as respective roles (user, admin, operator)
Post-condition	Display of respective profile information
Normal Flow	1. Actor (User/Admin/Operator) Navigates to Profile Section. 2. System Displays Respective Profile Information.
Alternative Flow:	Profile Data Unavailability scenario addressed. Technical issues or data unavailability might hinder profile display. System shows an error message indicating the unavailability of profile data.

Table 9 View Points

Use Case Name	**View Points**
Primary Actors	User
Pre-condition	Successful login as a user
Post-conditions	Ability to view accumulated points
Normal Flow	1. User Requests to View Points. 2. User Navigates to the Points Section. 3. System Displays User's Accumulated Points.
Alternative Flow	-No Points Earned Yet: If the user hasn't earned any points, the system displays a message indicating zero points and encourages them to engage in waste disposal for points.

Table 10 Maintain System

Use Case Name	**Maintain System**
Primary Actor	Admin
Pre-condition	Successful login as an admin
Post-conditions	Ability to maintain system functionalities
Normal Flow	1. Admin Requests System Maintenance. 2. Admin Navigates to the Maintenance Section. 3. System Displays Maintenance Options: Provides access to various system maintenance features. 4. Admin Executes System Checks: Runs diagnostics, software updates, and and performs system health checks. 5. Monitoring System Health: Regularly monitors system health to ensure smooth operation.
Alternative Flow	1. Technical Errors: If there are technical issues during maintenance, the system notifies the admin about the problem and suggests alternative actions or contacts technical support. 2. System Registers Successful Scan. 3. User Disposes of Waste into the Designated Bin. 4. System Validates Proper Disposal. 5. User Earns Points.

Table 11 Send Notifications

Use Case Name	**Send Notifications**
Primary Actor	Admin
Pre-condition	Successful login as an admin
Post-conditions	Sent notifications to designated recipients
Normal Flow	1. Admin Requests to Send Notifications 2. Admin Composes and Sends Notifications: Provides options to select recipients, draft messages, and send notifications.
Alternative Flow	1. Technical Issues: In case of system errors or connection issues, notify the admin and advise them to try again later or contact support.

Table 12 View Bins

Use Case Name	**View Bins**
Primary Actor	Admin
Pre-condition	Successful login as an admin
Post-conditions	Access to real-time bin status
Normal Flow	1. Admin Requests to View Bins. 2. Admin Navigates to the Bin Monitoring Section. 3. System Displays Real-time Bin Status: Provides a visual representation or list of bins, indicating their status (full, partially filled, or empty). 4. Admin Analyzes Bin Status: Checks for any issues, identifies locations needing attention or additional collections.
Alternative Flow	Delayed Update: If there's a delay in updating bin statuses due to technical issues, display a message indicating the delay and advise the admin to refresh or contact technical support.

Table 13 View and Edit Operator Profile

Use Case Name	**View and Edit Operator Profile**
Primary Actor	Admin
Pre-Condition	Logged in as an admin
Post-Condition	Operator profile updated
Normal Flow	1. Admin selects "Manage Operators" from the dashboard. 2. System displays a list of registered operators. 3. Admin selects a specific operator from the list. 4. System shows the operator's profile details. 5. Admin edits the necessary information (e.g., personal details, permission 6. Admin saves the modifications.
Alternative Flow	1. Restricted Access: Certain fields may be restricted based on permissions permissions. Admin can't modify certain information. 2. Technical Issues: System displays an error message if there are technical problems preventing edits.

Table 14 View Notifications

Use Case Name	**View Notifications**
Primary Actors	Operator
Pre-condition	Successful login as an operator
Post-conditions	Access to received notifications
Normal Flow	1. Operator Requests to View Notifications. 2. Operator Navigates to the Notification Section 3. System Displays Notifications: Provides a list of notifications received by the operator.
Alternative Flow	1. No Notifications Available: If there are no new or unread notifications, display a message indicating the absence of notifications. 2. Technical Issues: In case of system errors or connection issues, notify the operator and advise them to try again later or contact support.

Table 15 Send Confirmation

Use Case Name	**Send Confirmation**
Primary Actors	Operator
Pre-condition	Successful login as an operator
Post-conditions	Confirmation sent to the relevant recipients
Normal Flow	1.Operator Requests to Send Confirmation. 2.Operator Selects the Pending Confirmation 3.System Provides Confirmation Options: Allows the operator to choose and send confirmations for pending tasks or notifications.
Alternative Flow	1.No Pending Confirmations: If there are no pending confirmations or tasks, display a message indicating the absence of pending items. 2.Technical Issues: In case of system errors or connection issues, notify the operator and advise them to try again later or contact support.

Table 16 Login

Use Case Name	**Login**
Primary Actor	User (Operator/Admin/User)
Pre-condition	Registration (Sign-Up)
Post-conditions	Access to the System
Normal flow	1. User Requests Login. 2. User Inputs Credentials (username, password). 3. System Authenticates Credentials. 4. User Accesses Dashboard: View waste statistics, manage profiles, or actions available based on their role.
Alternative Flow	1. Invalid Credentials: Show error message prompting re-entry or account 2. Forgot Password: Provide options for password recovery. 3. Account Lockout: After multiple failed login attempts, provide account recovery options or contact support.

3.7 Methodology

The methodology involves several key steps. First, a diverse dataset of waste items is collected and annotated with corresponding categories. Next, a deep learning model is trained using the annotated dataset to classify waste items based on extracted features. The trained model is integrated into the system for real-time waste classification. The process involves capturing images, preprocessing them, and feeding them into the AI model for prediction. The classification results, along with the image and timestamp, are stored in a database for further analysis and user feedback. The mobile application allows users to view their points, track their progress, and engage with the system.

The "Sortify" system promotes user engagement and awareness by rewarding users for correctly sorting recyclable waste. The points accumulated can be redeemed for various rewards. Additionally, the system provides educational content to raise awareness about waste management and recycling practices. Continuous improvement is achieved through a feedback loop, where data on classification results and user interactions are collected to enhance the AI model's accuracy and optimize waste management processes.

By implementing the "Sortify" intelligent waste management system, we aim to automate waste classification, incentivize recycling, and contribute to a cleaner and more sustainable environment

3.8 User Requirements and System Privileges

3.8.1 User Requirements

"Sortify" caters to a diverse array of users, including municipalities, environmental organizations, businesses, community members, investors, homeowners, public events, and festivals. Each user segment holds unique demands, from streamlined waste control for municipalities to educational tools for community members, creating a multifaceted approach to waste management. Environmental organizations seek data demonstrating eco-impact, while businesses prioritize efficient waste disposal methods. Investors, entrepreneurs, and community associations all find utility in different facets of the system, from growth predictions to home waste management guidance.

3.8.2 System Privileges

The system offers distinct privileges tailored to administrators, users, and operators. Administrators possess comprehensive control, managing profiles, overseeing system maintenance, analyzing statistics, sending notifications, and managing points. Users are empowered with profile management, access to statistics, functionalities, and point-related actions. Operators, on the other hand, view modifications within the system and send confirmations for bin servicing.

3.9 Assumptions, Constraints, Limitations, and Dependencies

3.9.1 Assumptions

a. Accurate image capture by IoT cameras.
b. Diverse and representative training data for the AI model.
c. Reliable and consistent performance of the AI model.
d. Continuous internet connectivity for data transmission.
e. User awareness and active participation in responsible waste disposal.

3.9.2 Constraints

a. Hardware limitations affect image capture, processing, and data storage.
b. Software limitations affecting image processing, waste classification, and model accuracy.
c. Environmental factors impacting performance, such as lighting and contaminants.
d. Limited waste categories currently identified (five).
e. Initial investment costs for hardware, software, and infrastructure development.

3.9.3 Limitations

a. Potential for misclassification of unusual or poorly presented waste items.
b. Data privacy concerns regarding user data collected through the mobile app.
c. Vulnerability to disruptions due to reliance on technology and internet connectivity.
d. Limited scalability for large-scale waste management needs without further development.
e. Dependence on user engagement for effectiveness.

3.8.3 Dependencies

a. Cloud infrastructure for data storage, processing, and model training.
b. Reliable internet connectivity for communication between sensors, bins, the central server, and the mobile app.
c. Existing waste management infrastructure for collection and recycling of classified waste.
d. Ongoing maintenance and updates for optimal performance and issue resolution.
e. User feedback for AI model improvement and system optimization.

Chapter Four

IMPLEMENTATION & TESTING AND RESULTS

4.1 AI Implementation Details

4.1.1 Comparison Between Yolo and Other Ai Models

Table 17 Comparison Between Yolo And Other Ai Models

Model	Speed	Device Compatibility	Ease of Use	Application
YOLO (You Only Look Once)	Fast	Works on small devices like Raspberry Pi	Easy to set up	Real-time object detection
SSD (Single Shot MultiBox Detector)	Slower	Requires more powerful devices than YOLO	Moderate ease of use	General object detection
Faster R-CNN (Region-based Convolutional Neural Network)	Slowest	Requires a powerful computer	Complex setup	Detailed object detection

- **Conclusion**

  - YOLO is fast, works on small devices, easy to use, and ideal for real-time applications.
  - SSD is slower than YOLO, needs more power, and is moderately easy to use.
  - Faster R-CNN is the slowest, requires a big computer, and is more complex to set up compared to YOLO and SSD.

4.1.2 Dataset Collection and Preparation

We collected 1,400 images for each category using a combination of images from a Kaggle dataset and images we captured and filtered. All images were resized to 416x416 pixels. The dataset was then divided into training, validation, and test sets using a 60-20-20 split, resulting in

a. Training set: 3,360 images (840 per category)
b. Validation set: 1,120 images (280 per category)
c. Test set: 1,120 images (280 per category)

We labeled the images using Labelmg, ensuring each label file matched its corresponding image file by name. The dataset was structured into folders for images and labels, each containing subfolders for training, validation, and test sets. This dataset was uploaded to Kaggle along with a .yaml file that specifies the directory paths for training, validation, and test data.

4.1.3 Model Training

We used a Kaggle notebook for training, validation, and testing processes, utilizing the Ultralytics YOLO package, specifically the YOLOv8s model, which is known for its speed and suitability for deployment on devices like the Raspberry Pi 4.

(a) Cardboard

(b) Cans

(c) Glass

(d) Plastic

Figure 12 categories, (a) Cardboard, (b) cans,(c) Glass, and (d) Plastic

4.1.4 Training Configuration

First, we installed the Ultralytics package and imported the YOLOv8s model. The training command was as follows
“!yolo train model=yolov8s.pt imgsz=416 --batch=8 --epochs=200 --data=/kaggle/input/customdata3/custom_data3.yaml --cache --augment=False --close_mosaic=0 --patience=20” This command specifies

a) Operation: Train the model
b) Model: YOLOv8s
c) Image Size: 416x416 pixels
d) Batch Size: 8
e) Epochs: 200
f) Data Path: Path to the .yaml file specifying the dataset directories
g) Cache: Use caching to speed up data loading
h) Augmentation: Disabled
i) Close Mosaic: Set to 0 to avoid augmentation in the last 10 epochs
j) Patience: Set to 20 to implement early stopping if no improvement is observed over 20 consecutive epochs

4.1.5 Model Evaluation

During training, the model's performance was evaluated using validation data after each epoch. Metrics such as mean Average Precision (mAP), Precision, and Recall were calculated to monitor the model’s learning progress. This evaluation helps in saving the best-performing model weights, ensuring effective learning and good generalization to unseen data.

4.1.6 Model Validation and Testing

The validation process ensured that the model was not overfitting and could perform well on unseen data. The final test phase provided an unbiased evaluation of the model's performance, confirming its ability to accurately detect and classify objects in new images.

This structured approach ensures a robust training pipeline, leading to a reliable and efficient object detection model suitable for deployment on edge devices. We successfully achieved a high accuracy of 95%.

4.1.7 Challenges and Solutions

- **Problem Encountered**

  The model faced challenges in accurately distinguishing between certain categories. Specifically, it struggled with misclassifying plastic images as glass and some cans as plastic. Moreover, it occasionally misidentified human faces as categories like cans, plastic, cardboard, or glass.

- **Solution Implemented**

  To mitigate these issues, additional images of plastic items were captured within the specific deployment environment. This targeted approach significantly improved the model's accuracy and reduced misclassifications.

4.1.8 Recommendations for Model Improvement

Despite achieving a high accuracy of 95%, continuous enhancement of the model's performance can be pursued through the following strategies

- **Increase Dataset Size**

  Expand the dataset by acquiring more images for each category to enhance diversity and further refine the model's ability to generalize.

- **Experiment with Batch Sizes**

  Increase the number of training epochs beyond 200 and employ early stopping techniques to prevent overfitting and improve model generalization.

- **Extend Training Epochs and Employ Early Stopping**

  Increase the number of training epochs beyond 200 and employ early stopping techniques to prevent overfitting and improve model generalization.

- **Explore Different Image Sizes**

  Experiment with varying image dimensions, such as 640x640 pixels, to determine if larger images enhance object detection accuracy and localization.

- **Fine-Tune with Gradually Decreasing Learning Rates**

  Implement a fine-tuning strategy that progressively reduces learning rates to fine-tune model parameters and achieve higher precision in object detection tasks.

  Implementing these strategies will further optimize the YOLOv8s model's performance, ensuring robustness and reliability across different environmental conditions. This approach facilitates effective deployment of the model on edge devices like the Raspberry Pi 4 while maintaining high standards of accuracy and efficiency in object detection tasks.

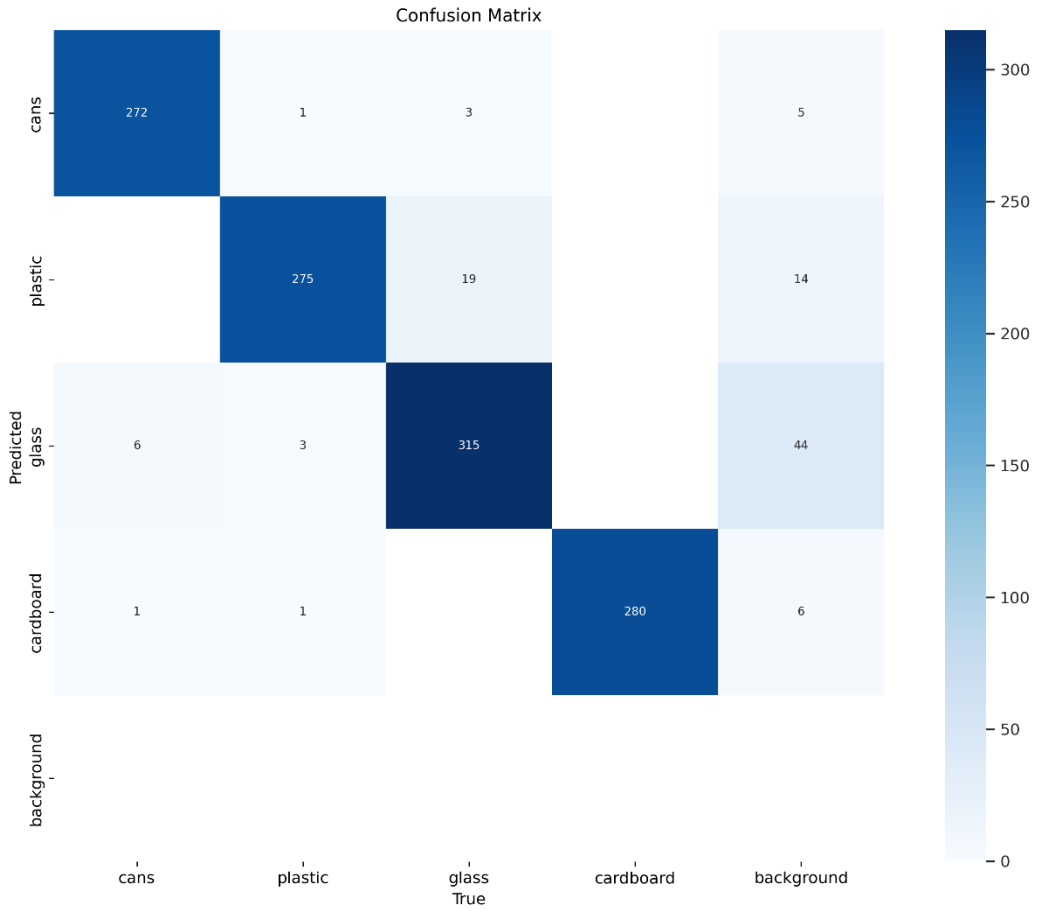


Figure 13 Train confusion matrix

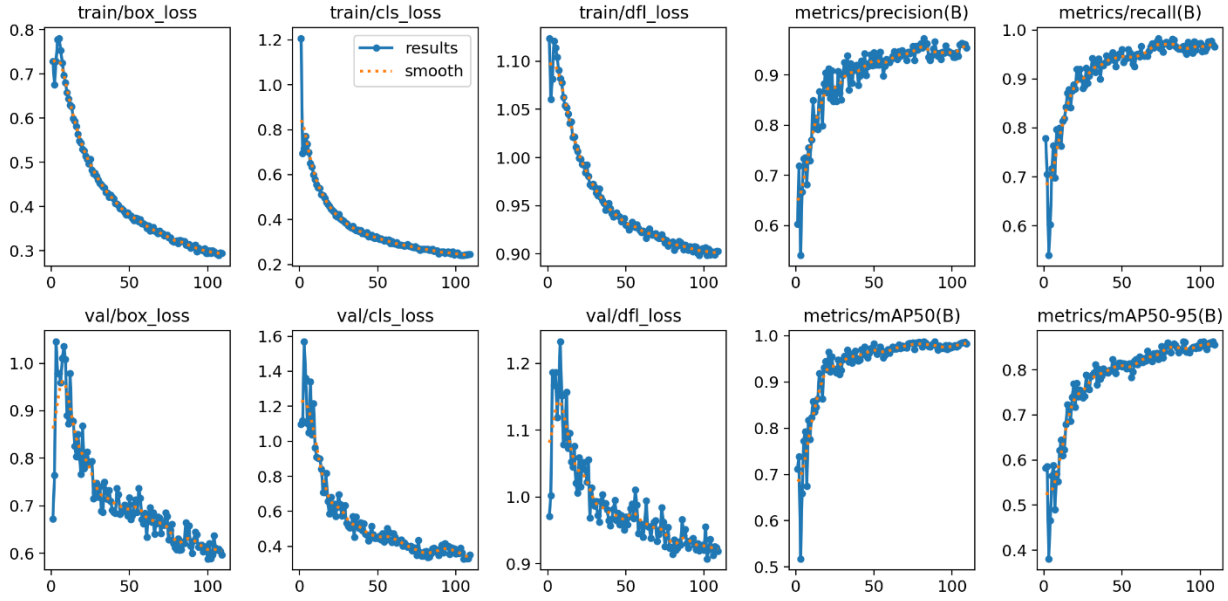


Figure 14 Train results

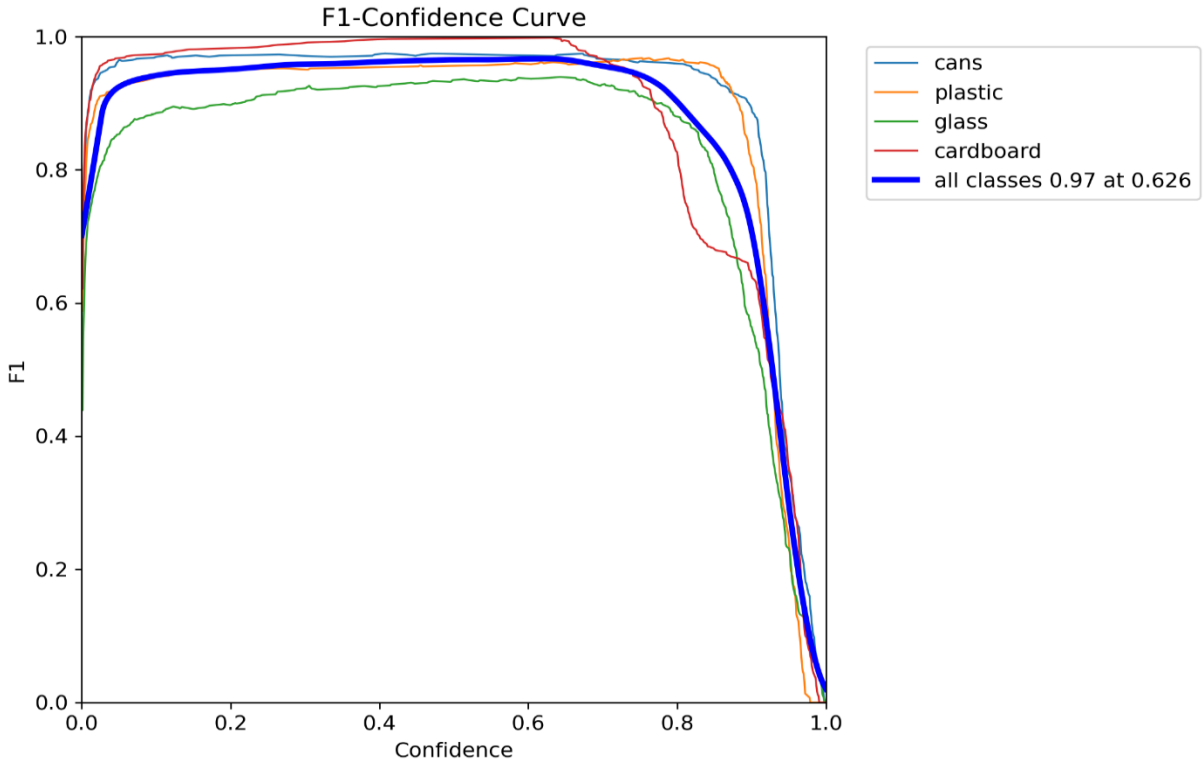


Figure 15 Train F1_curve

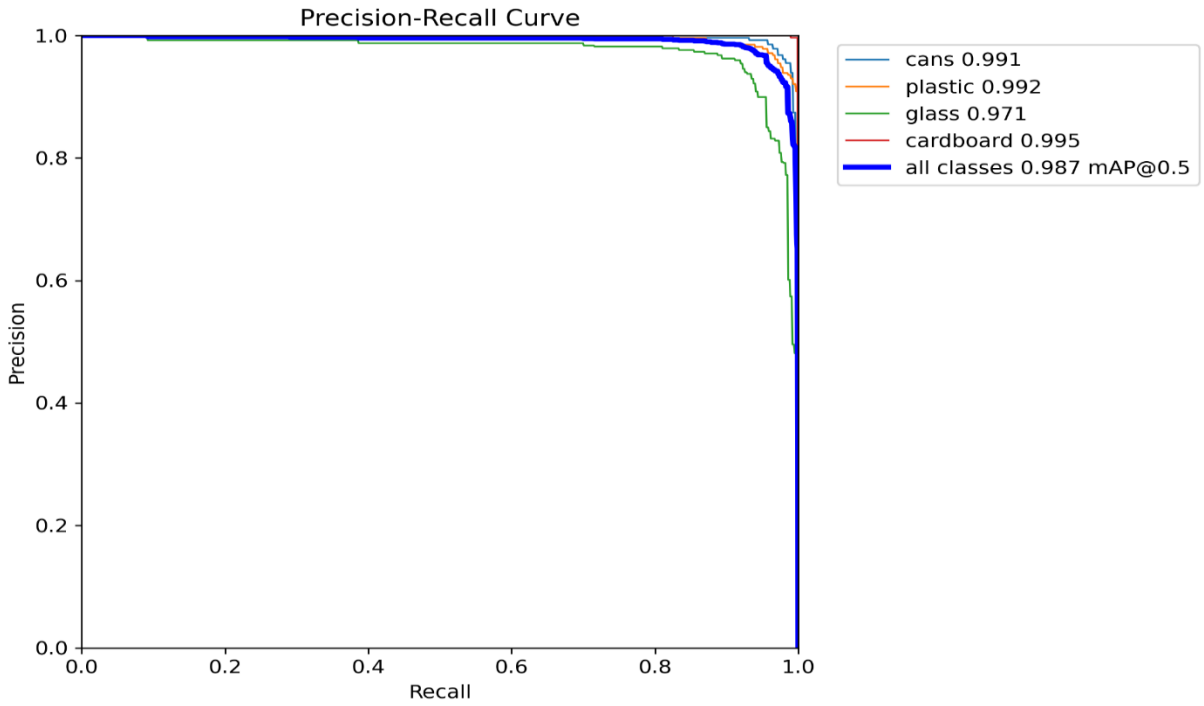


Figure 16 Train PR_curve

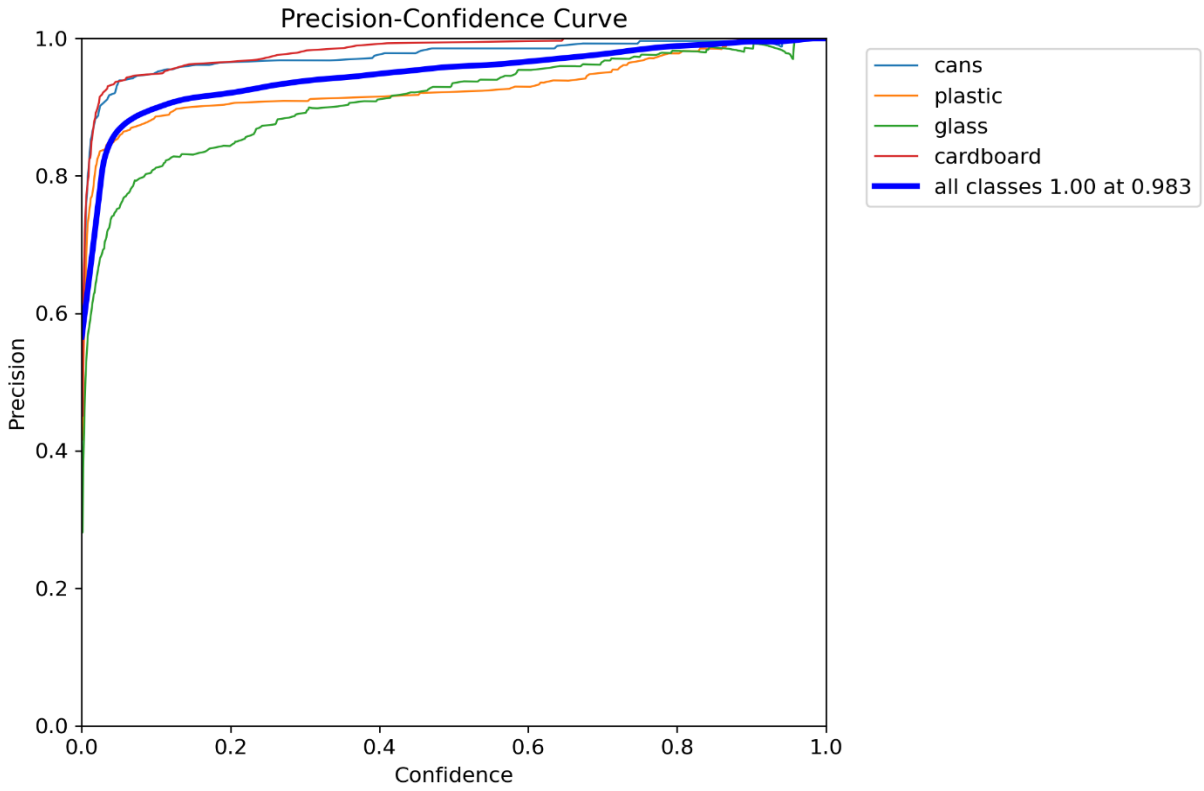


Figure 17 Train P_curve

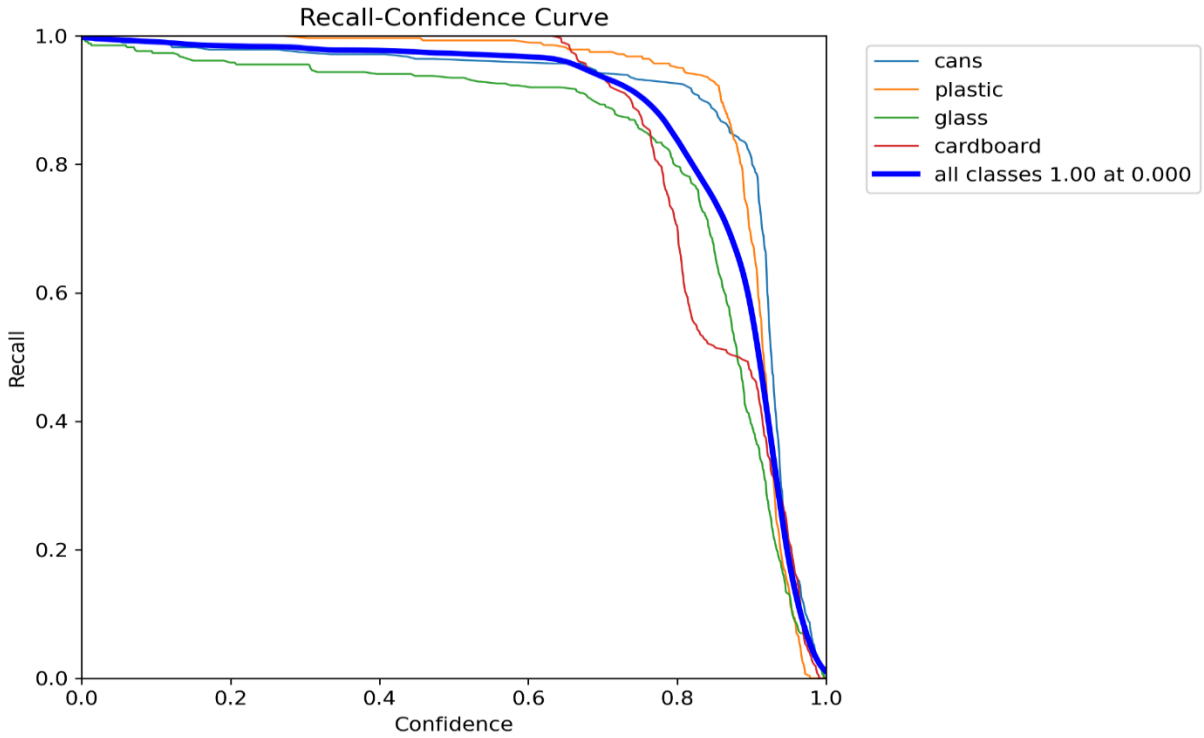


Figure 18 Train R_curve

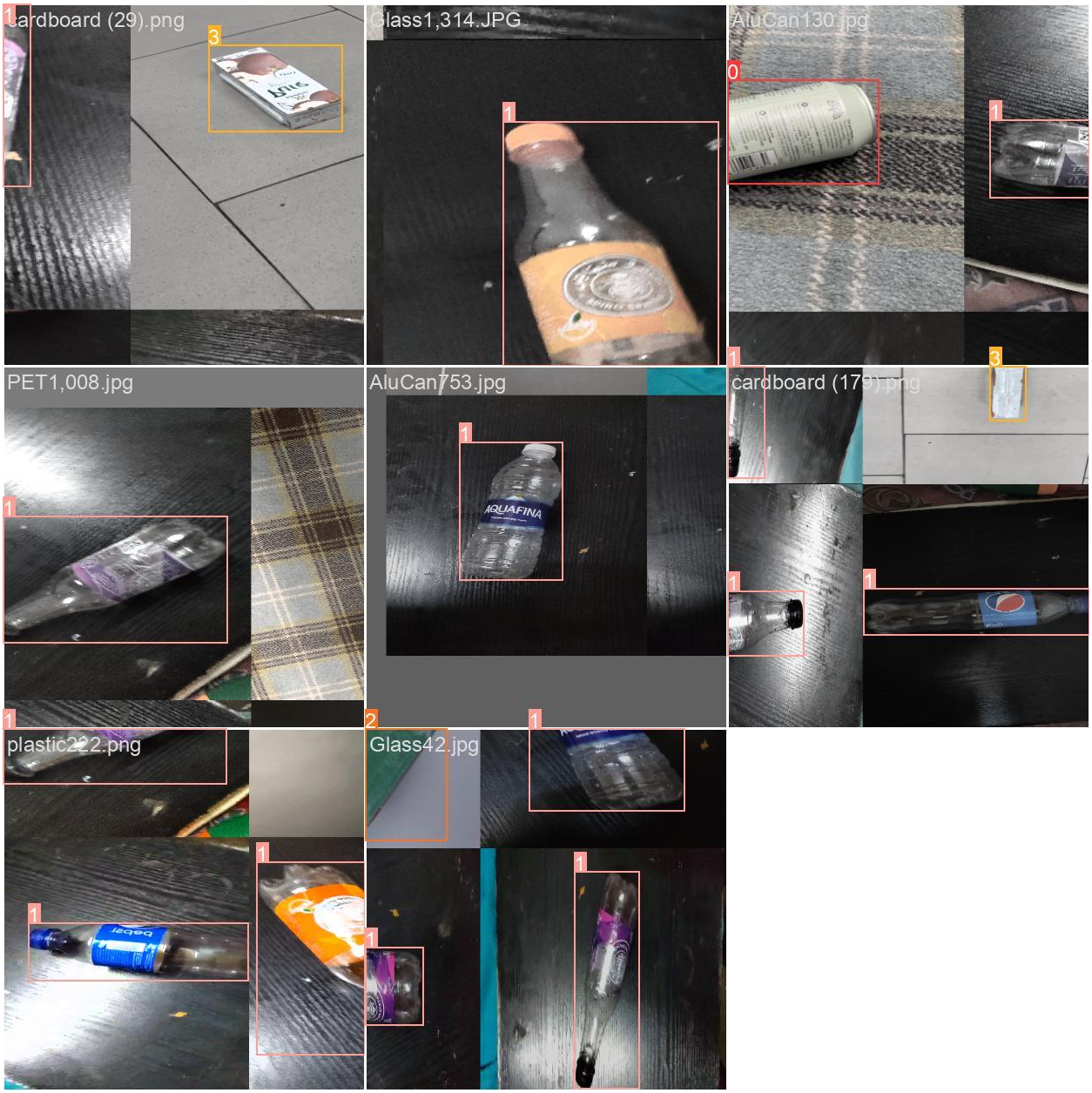


Figure 19 train_batch1

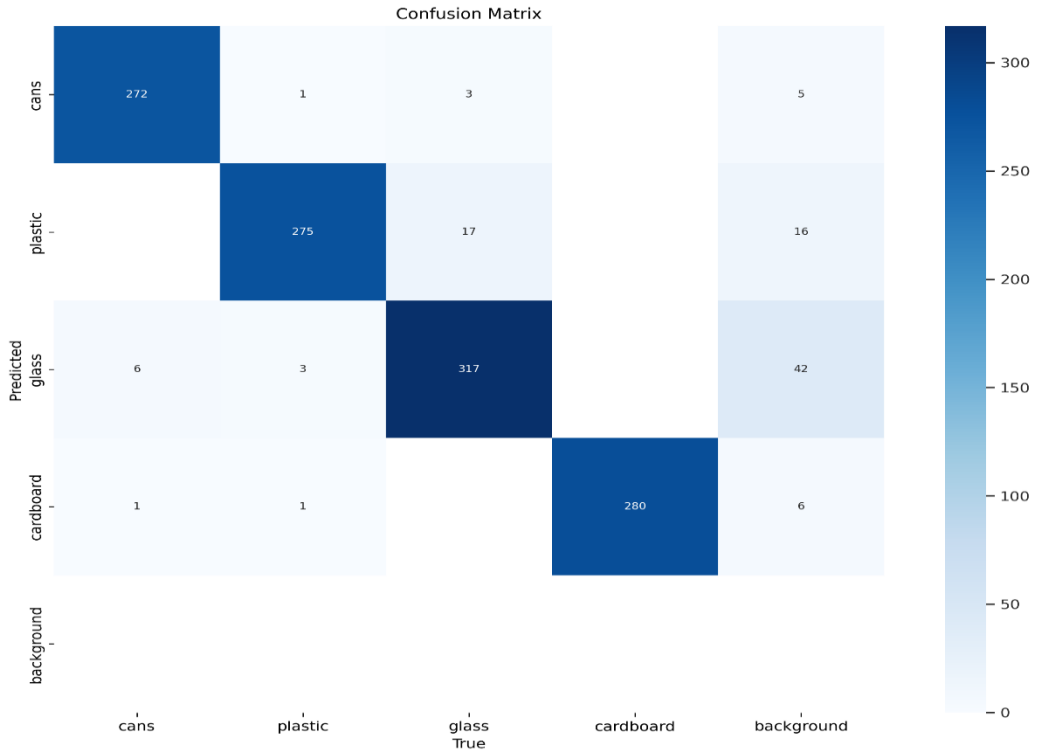


Figure 20 Validation confusion matrix

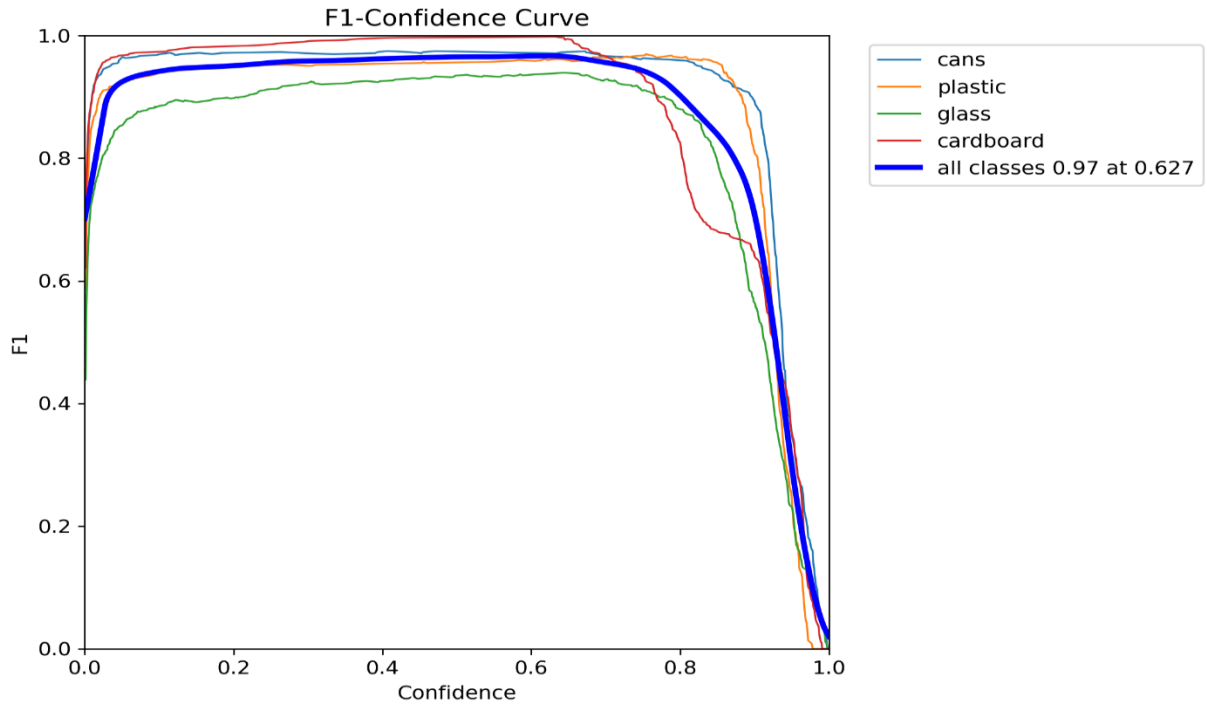


Figure 21 Validation F1_curve

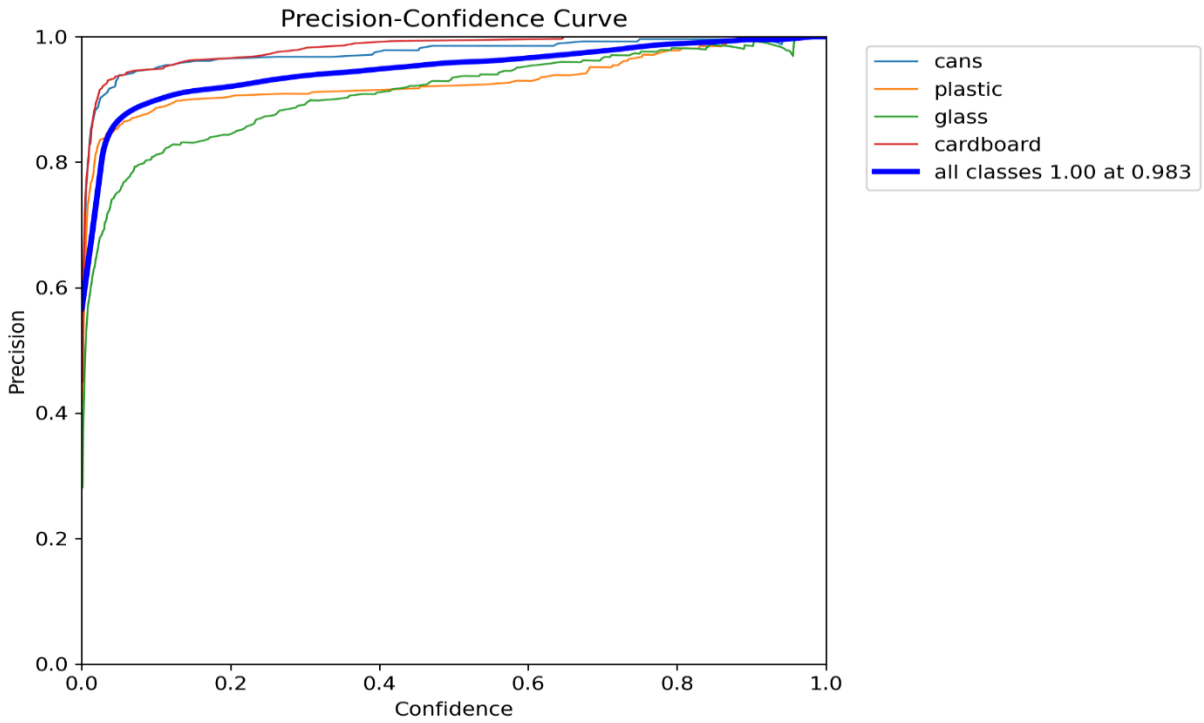


Figure 22 Validation P_curve

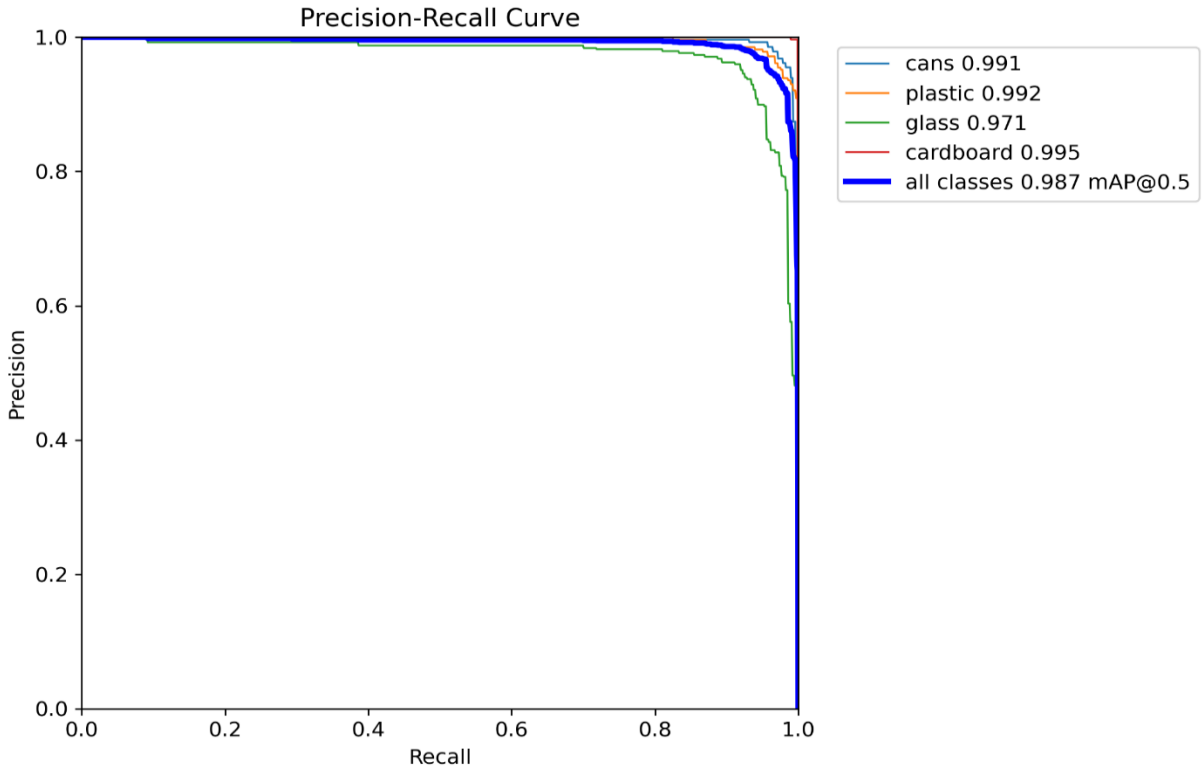


Figure 23 Validation PR_curve

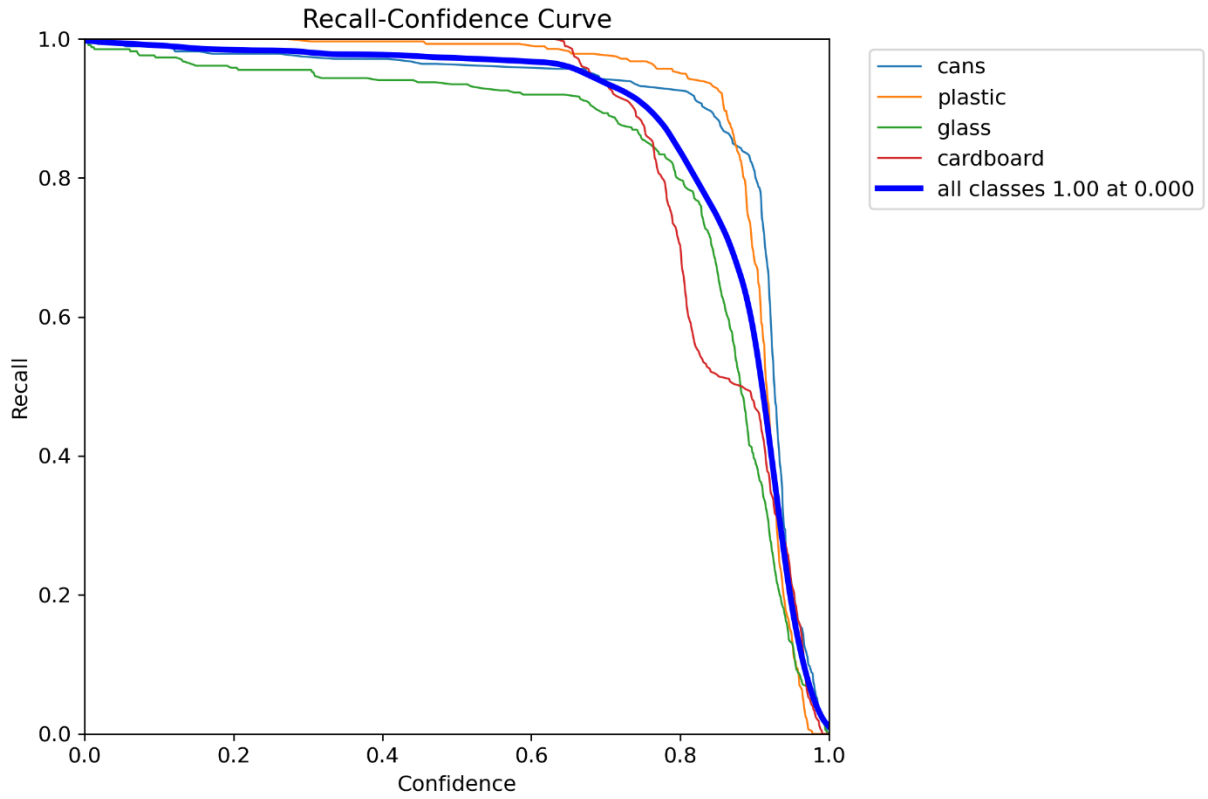


Figure 24 Validation R_curve

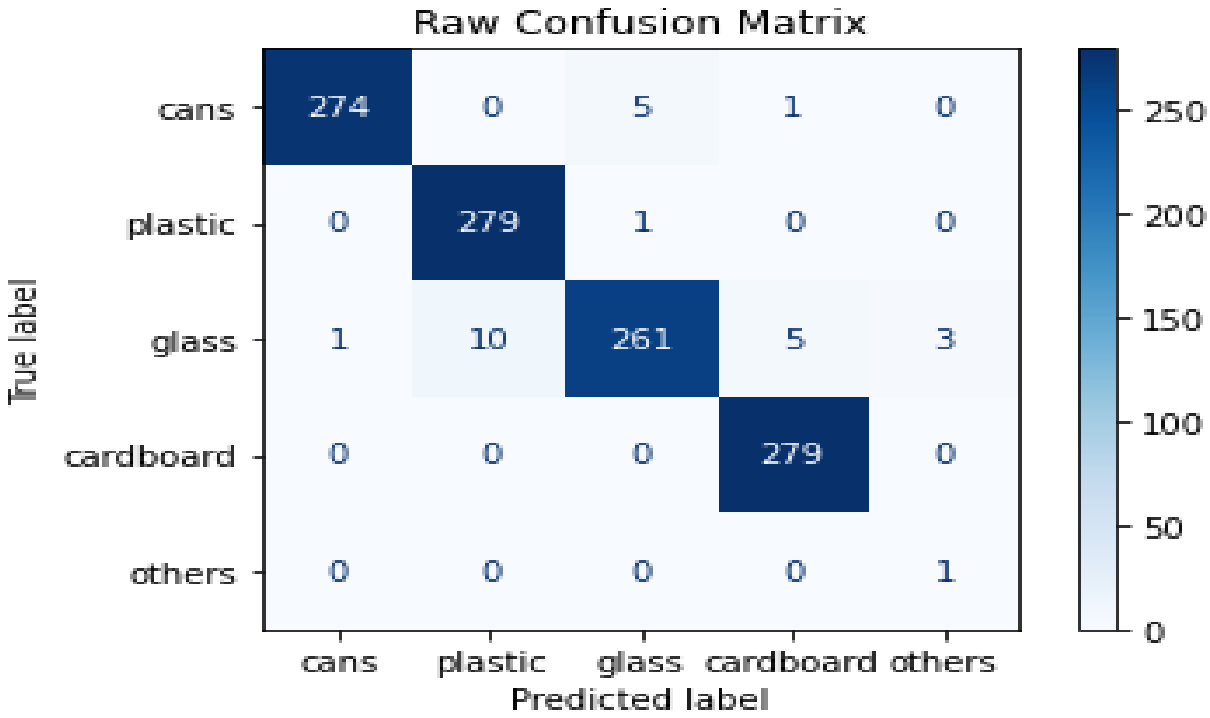


Figure 25 Test confusion matrix

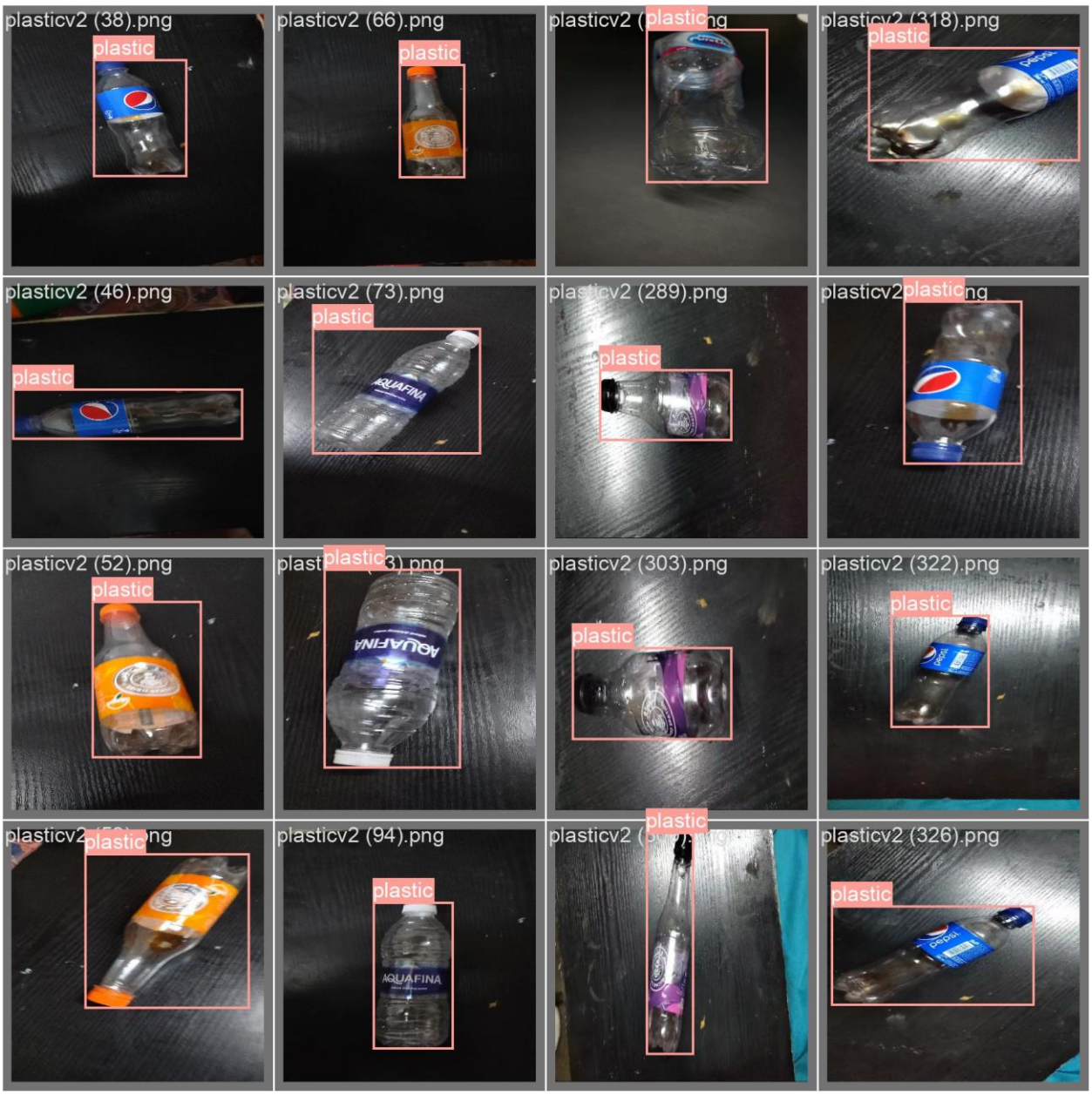


Figure 26 val_batch0_labels

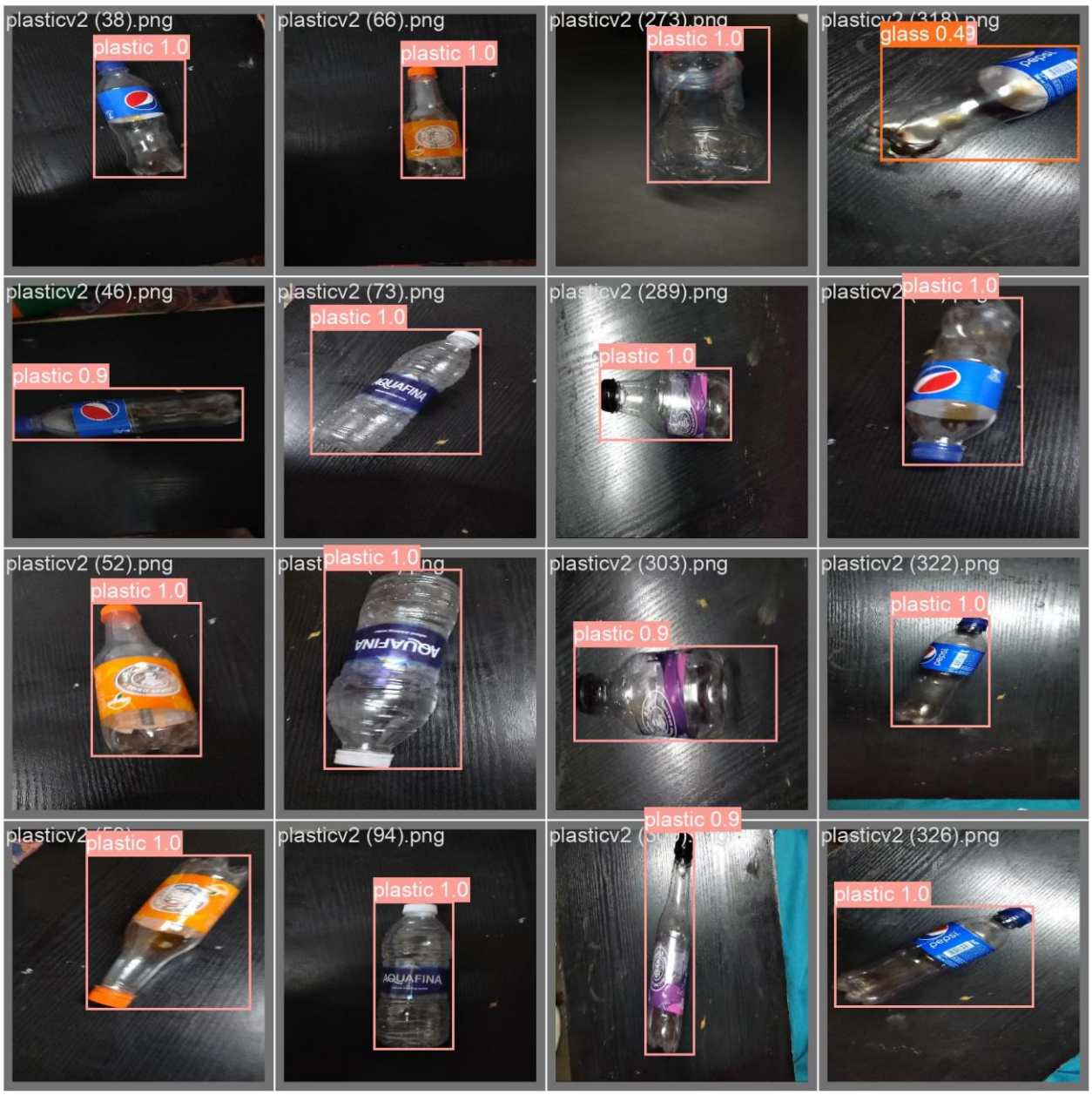


Figure 27 val_batch0_pred

4.2 Application Implementation

4.3.1 Development Tools

- Frontend : Flutter Flow
- Backend : Firebase

4.3.2 Styles and Design

- UI : Modern, Intuitive, And User-Friendly
- Color Scheme : Green And Blue Tones to Represent Eco-Friendliness and Technology
- Icons & Images : High-Quality Icons and Images to Enhance User Experience
- Typography : Clear And Readable Fonts to Ensure Accessibility

4.3.3 General Features

- Registration : Provides User Registration (For Users) and Registration with Machine Id (For Admins).
- Real-Time Feedback : Users Receive Real-Time Feedback on Their Waste Sorting.
- Points System : Users Accumulate Points Based on Their Activities.
- Rewards Management : Users Can Redeem Points for Rewards.
- Waste Sorting Instructions : Offers Instructions for Sorting Waste Correctly.

4.3.4 Admin Features

- Login : Login Using Name and Machine Id [48]
- Statistics Viewing : Access to Detailed Statistics Related to Machine Usage.[43]
- Notification Sending : Ability to Send Notifications to Users or Machine Operators.[40]
- Bin View : Has The Ability to Access to View the Bins and Know If the Bin Is Full or Not [44]
- Assign Operator : The Admin Has the Ability to Assign the Operator [42]
- Feedback View : The Admin Can View the Feedback of The Users [39]
- View Users : The Admin Can View the Users That Are in The System [47]

4.3.5 User Features

- Login : The User Login with The Email and Password [30]
- Registration : Users Can Securely Register Securely with Email Verification Send , Log In, And Log Out. [46]
- Profile Management : Users can manage and update their profile information.[36]
- Password Reset : The User Will Receive an Email to Reset His Password [45]
- Write Feedback : User Has the Ability to Write His Feedback [37]
- Points Management : Track Accumulated Points and Engage in Activities to Earn Rewards and The Ability to Redeem the Points with Rewards
- Tutorial Video : User Can View the Tutorial Video to Know How to Use the Machine
- Receive Notification : The User Receives Notification of the Points That He Has Given and Can Receive Nonfiction from The Admin [38]

4.3.6 Firebase Configuration

- Firebase Authentication : Used for user sign-up and log-in, with email verification.
- Fire store : Utilized for real-time database management and data storage.

4.3.7 Data Management

- Authentication : When A User Enters Their Email, A Verification Message Is Sent.
- Screen Navigation : Each Screen in The Flutter Flow Storyboard Is Connected to The Next Screen, And Each Button Is Linked to The Appropriate Action or Screen.
- API Call for Feedback : Uses A POST Method to Submit Feedback.
- Media Assets : Includes Every Logo, Image, And Bin Design Used in The App.
- Button Actions : Each Button Has an Associated Action, Including Validations and Error Messages.
- Phone Number Validation : Ensures Phone Numbers Are Exactly 11 Digits and Contain Only Numbers. Displays An Error Message for Incorrect Inputs.

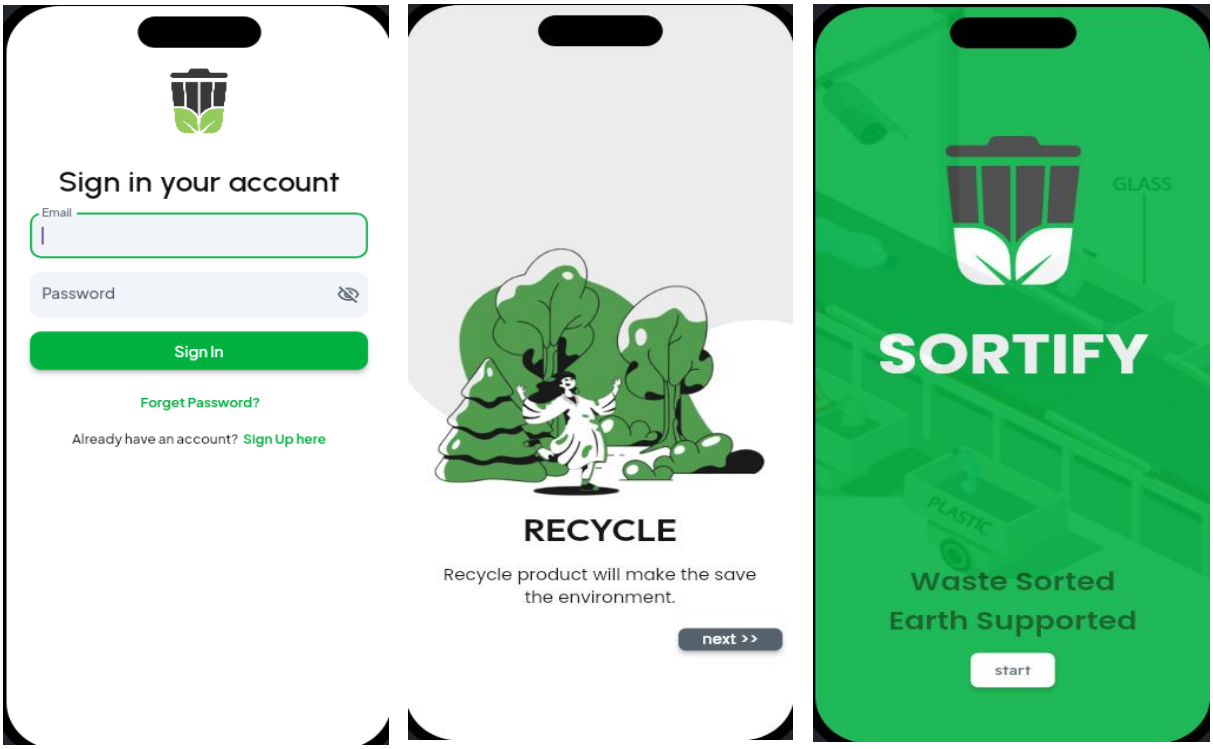


Figure 28 user sign in ,user splash screen , and user start screen

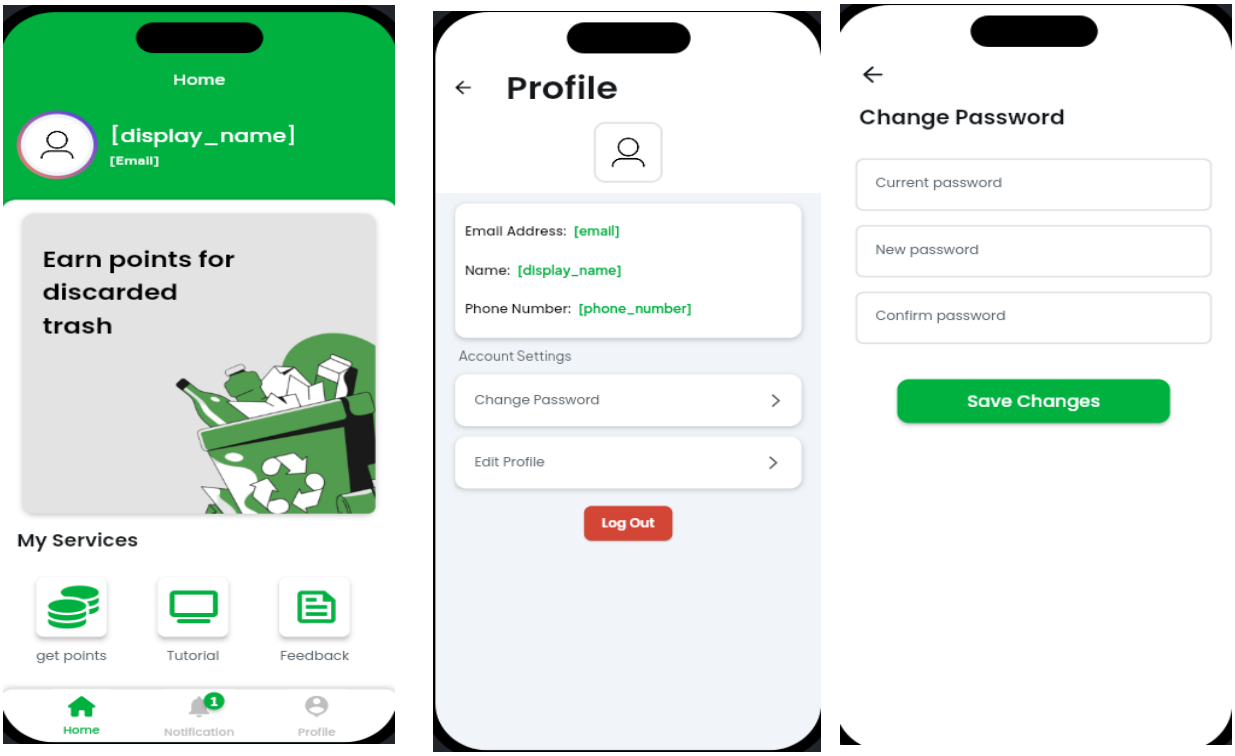


Figure 29 user home page, user view profile , and user change password

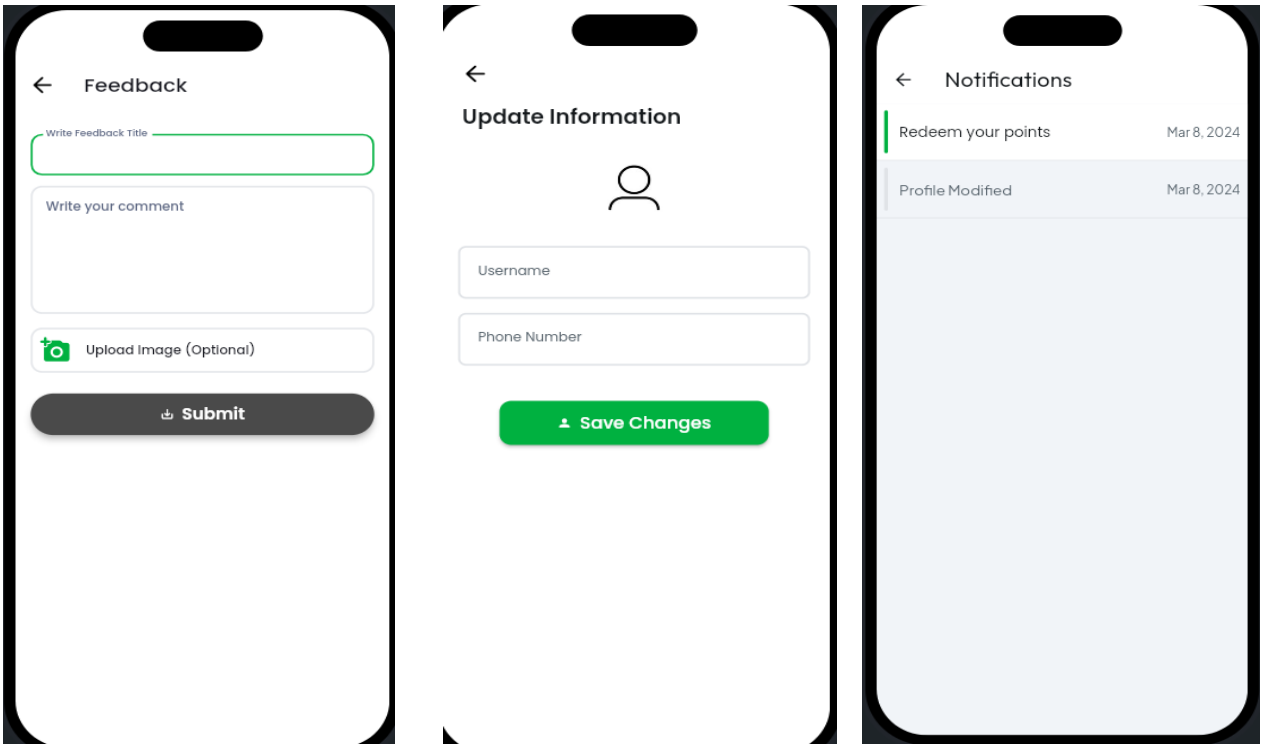


Figure 31 user feedback, user update information ,and user notifications

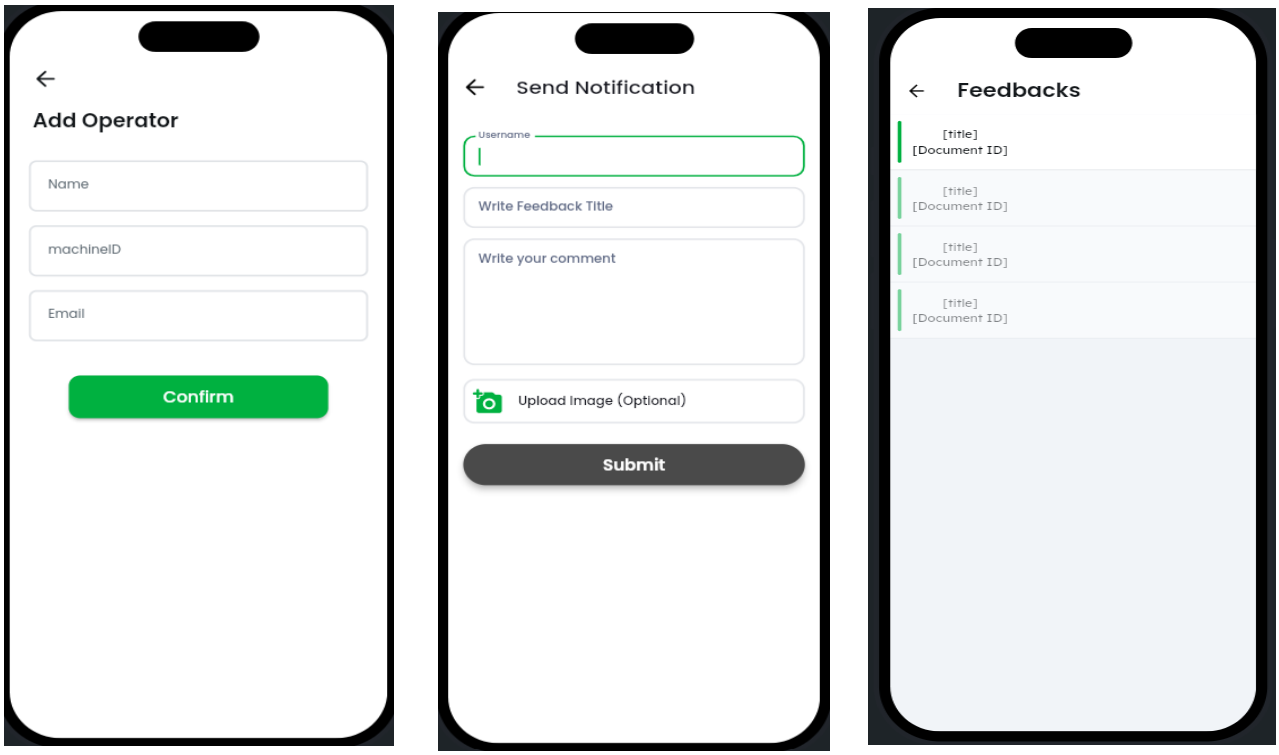


Figure 30 admin add operator , admin send notification , and show feedback

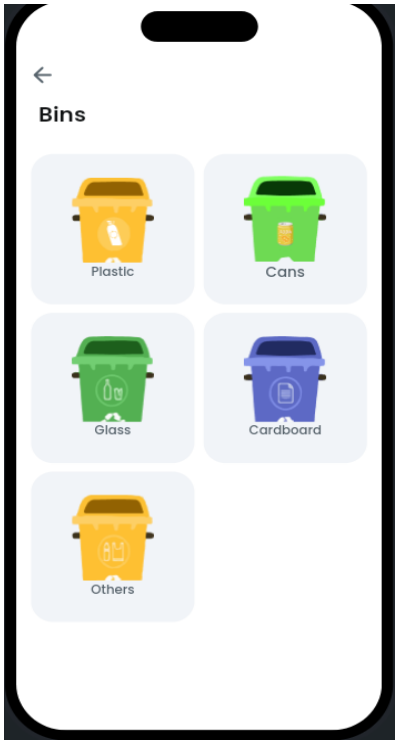


Figure 332 admin shows bins

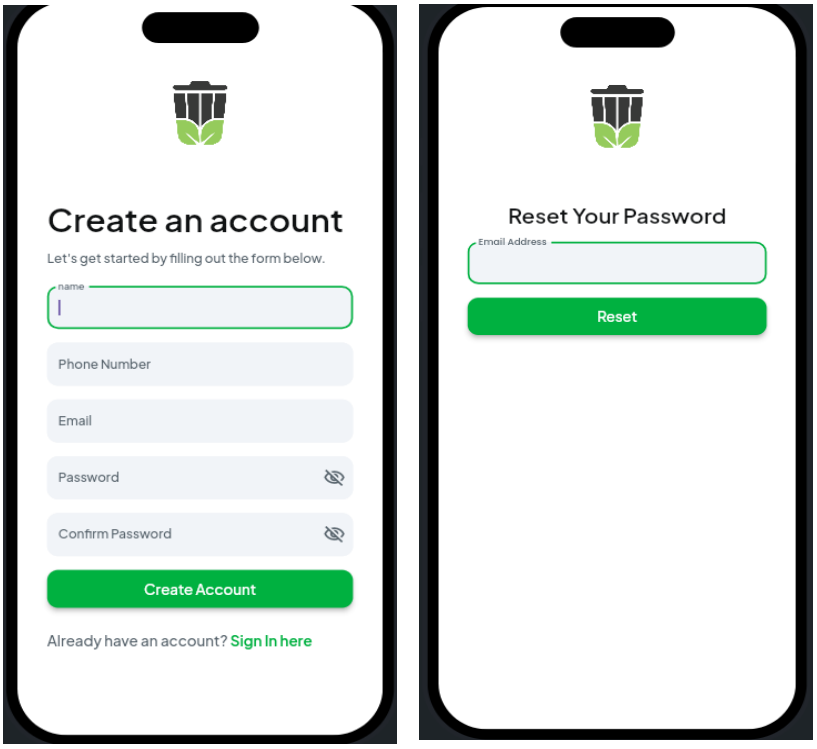
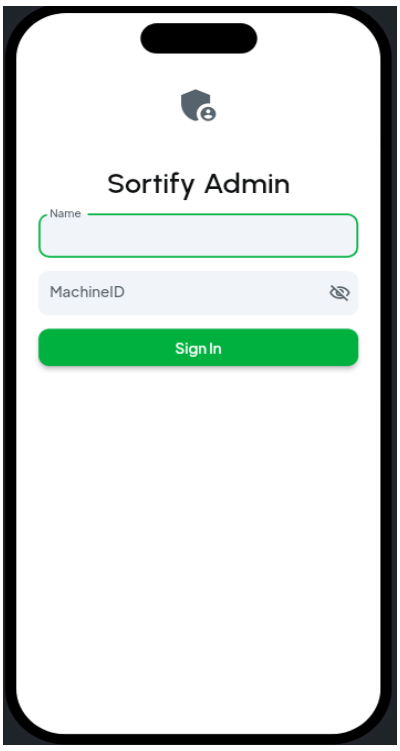


Figure 33 user create account and user reset password



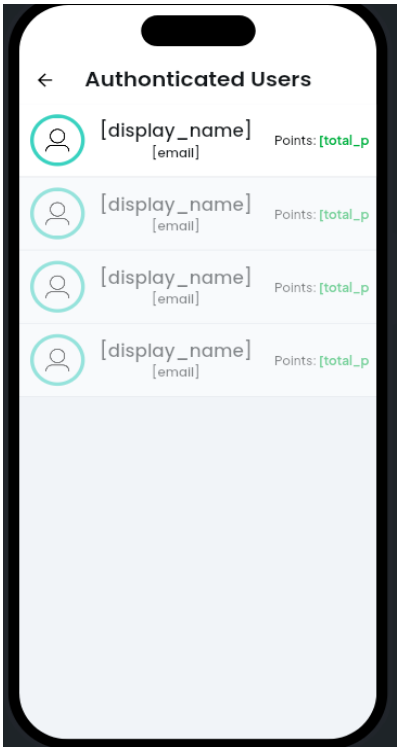


Figure 32 admin sign in and admin show system users

4.6 Hardware Implementation

4.6.1 Servo Motors (4 units)

- Description: High-torque servo motors with arms for precise movement control.
- Specifications:
    - Torque: 10 kg/cm
    - Speed: 0.1 sec/60°
    - Operating Voltage: 4.8-6.0V
    - Interface: PWM
- Function: Used for precise positioning and movement within the machine.

4.6.2 DC Motor

- Description: A motor for providing rotational power to the machine.
- Specifications:
    - Voltage: 12V
    - Current: 2A
    - Speed: 3000 RPM
- Function: Drives the rollers and treadmill.

4.6.3 L298N Motor Driver

- Description: Dual H-Bridge motor driver for controlling the DC motor.
- Specifications:
    - Operating Voltage: 5-35V
    - Max Current: 2A per channel

4.6.4 Raspberry Pi 4

- Description: A single-board computer for controlling the machine.
- Specifications:
    - CPU: Quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
    - RAM: 4GB LPDDR4-3200 SDRAM
    - Ports: 2 x USB 3.0, 2 x USB 2.0, HDMI, Ethernet, GPIO

4.6.5 PCA9685 Servo Driver

- Description: 16-channel PWM driver for controlling servos.
- Specifications:
    - Channels: 16
    - Voltage: 2.3V-5.5V
    - Frequency: 40-1000 Hz
- Function: Drives the servos with precise PWM signals.

4.6.6 Power Supply

- Description: Provides power to all components.
- Specifications:
    - Output Voltage: 5V, 12V
    - Max Current: 10A
- Function: Ensures stable power delivery to the system.

4.6.7 GPIO Extension Board

- Description: Expands the GPIO capabilities of the Raspberry Pi.
- Function: Provides additional GPIO pins for connecting sensors and other peripherals.

4.6.8 IR Sensor

- Description: Infrared sensor for detecting objects.
- Specifications:
    - Range: 2-30 cm
    - Voltage: 3.3V-5V
- Function: Detects obstacles or objects in the path of the treadmill.

4.6.9 Keypad

- Description: Input device for user interaction.
- Specifications:
    - Type: 4x4 matrix
    - Voltage: 3.3V-5V
- Function: Allows user to input commands.

4.6.10 Rollers

- Description**: Cylindrical components to support the treadmill.**
- **Function: Enable the** Conveyor belt **to roll smoothly.**

4.6.11 Conveyor belt

- Description: Conveyor belt for movement.
- Specifications:
    - Length: 3 meters
    - Width: 45 cm
- Function: Moves objects from the start to the end of the machine.

4.6.12 Camera

- Description: Camera for capturing images or videos.
- Specifications:
    - Resolution: 1080p
    - Interface: USB/CSI
- Function: Provides visual feedback and monitoring.

4.6.13 Machine Layout and Configuration

- Frame Dimensions: Height: 150 cm, Width: 50 cm
- Treadmill Dimensions: Height: 3 meters, Width: 45 cm
- Camera Mounting: A square frame at the start of the machine, 50 cm high, with the camera hanging from it.
- Servo Placement: Four servos equipped with arms, paired with a distance of 40 cm between each pair.

Figure 34 servo motor

Figure 35 DC motor mecha 130168

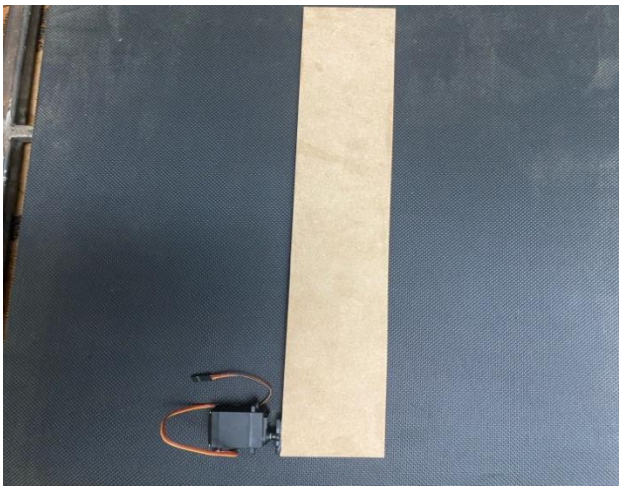


Figure 36 Arm for categorization

Figure 37 power supply

Figure 38 Raspberry Pi 4

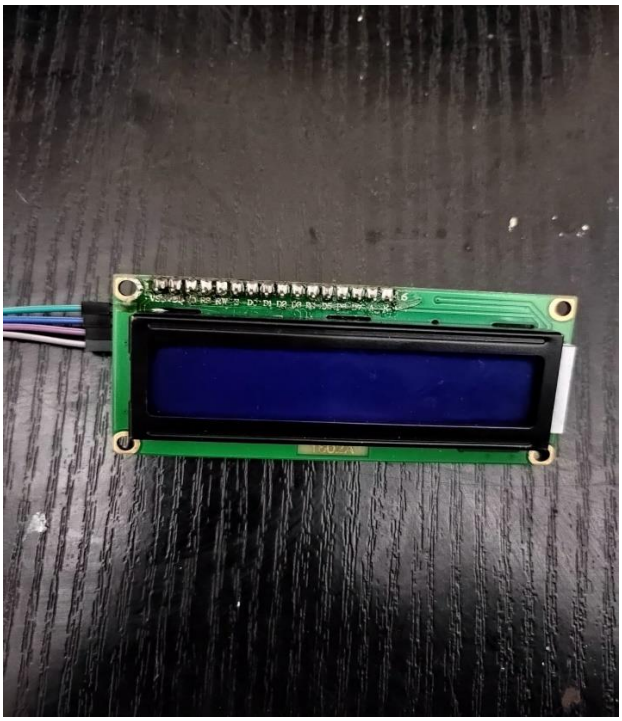


Figure 39 LCD for show user phone number

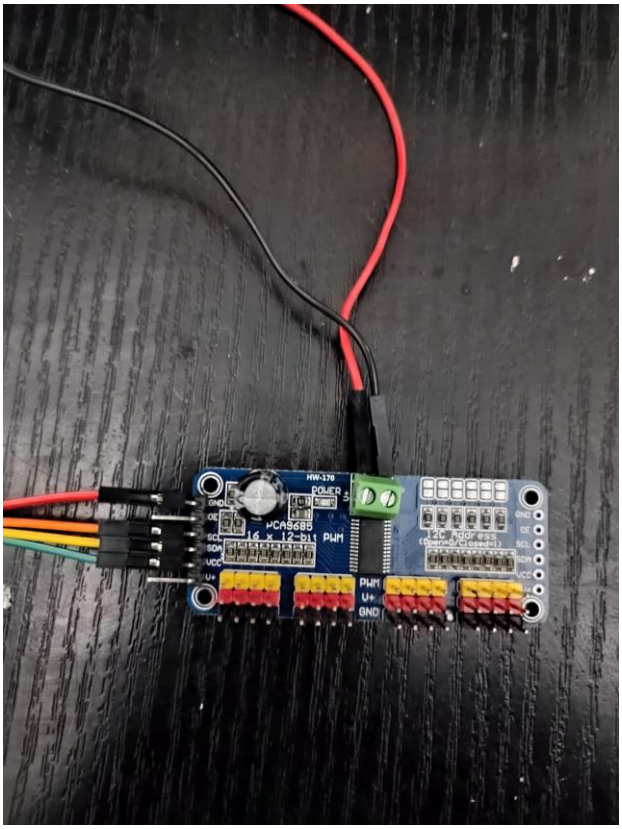


Figure 40 Servo Driver PCA9685

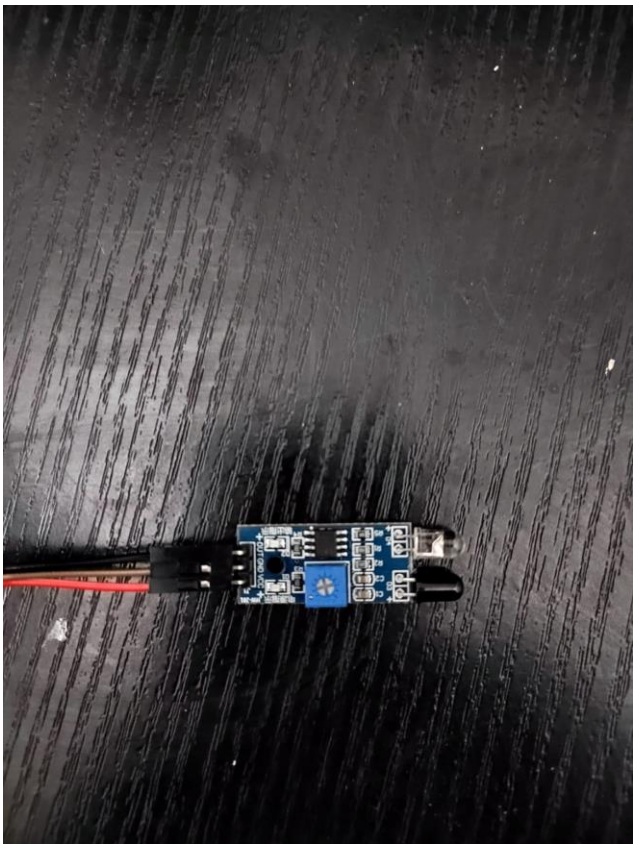


Figure 41 IR sensor

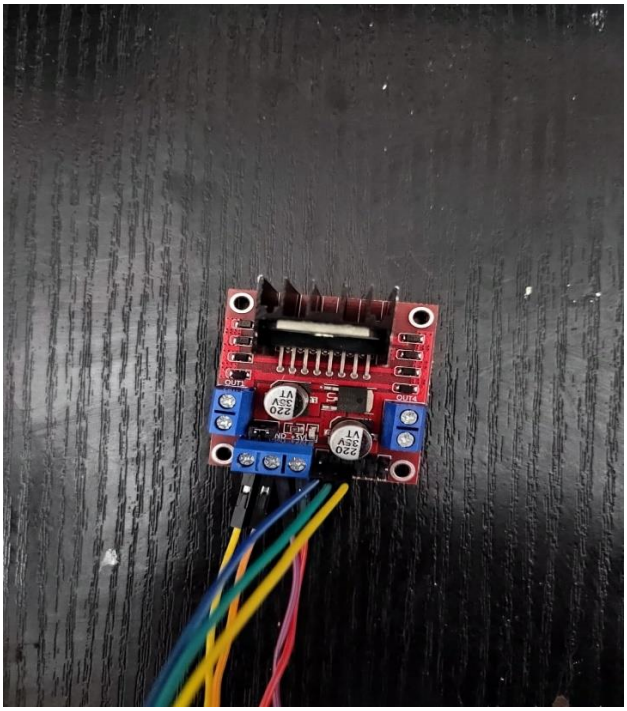


Figure 42 L298N to control dc motor

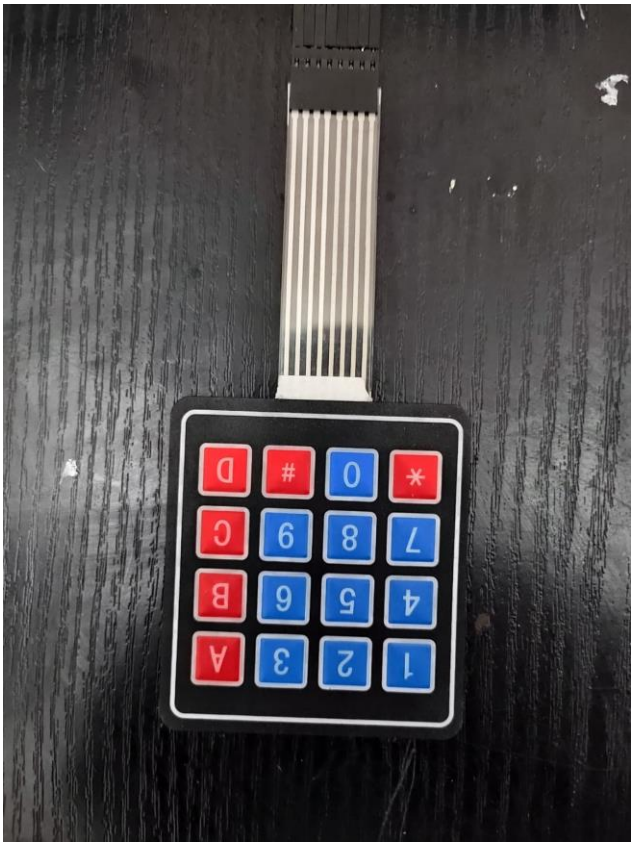


Figure 43 Key pad

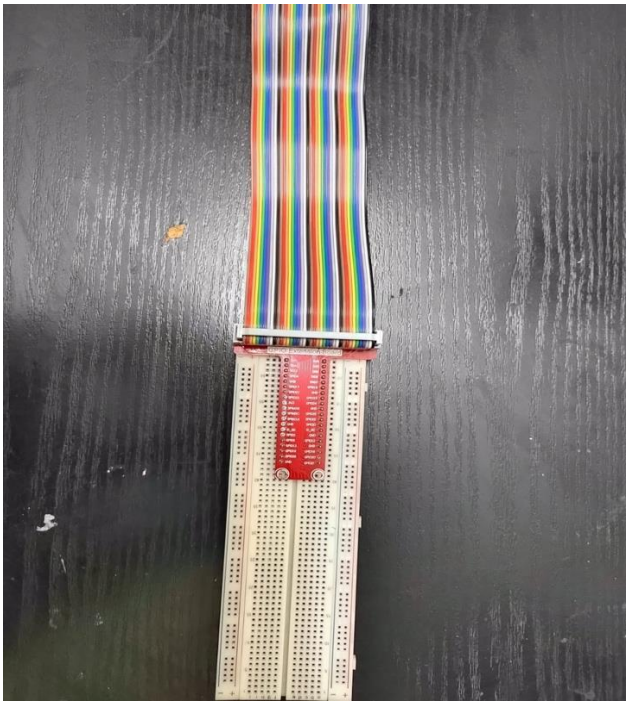


Figure 44 GPIO Extension Board

Chapter Five

Conclusions & Future Work

5.1 Conclusions

In conclusion, Sortify is a substantial advancement in addressing urban waste issues. This system combines AI and IoT technologies to streamline and enhance the efficiency of waste sorting and recycling processes. The integration with a mobile application ensures user engagement and promotes responsible recycling habits among the community.

Sortify automates the waste sorting process, identifying different types of waste and ensuring they are correctly categorized. This not only reduces human error but also increases the overall efficiency of recycling efforts. Users can easily connect with the system by entering their mobile number, which links the app to the machine, facilitating a seamless user experience.

Despite facing challenges such as initial costs and technical difficulties, the benefits of improved recycling, sustainability, and scalability are clear. Adhering to IEEE standards has ensured the system's reliability and quality, demonstrating how hardware and software can work together to deliver an effective solution for waste management.

5.2 Future Work

- **Enhance AI Accuracy**

  Continuously improve the AI's waste-sorting capabilities to recognize and categorize a broader range of waste materials more accurately.

- **Gather User Feedback**

  Collect and utilize user feedback to refine and enhance the system, ensuring it meets user needs and expectations effectively.

- **Expand Deployment**

  introduce Sortify to more cities and regions to broaden its impact on waste management practices.

- **Smart City Integration**

  Collaborate with smart city projects to integrate the system with existing infrastructure for optimized waste collection and management.

- **Strengthen Data Security**

  Improve data privacy measures to protect user information and safeguard against potential cyber threats.

- **Reduce Environmental Impact**

  Focus on minimizing the system's carbon footprint by incorporating renewable energy sources and environmentally friendly materials in its construction.

- **Collaborate With Educational Institutions**

  Partner with schools and universities to promote recycling education and use the system as a tool for research and learning about sustainable practices.

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