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Project Report

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Innovative System Design and Development 1

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ReSort

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Table of Contents

Abstract

The ReSort Intelligent Recycling System revolutionizes waste management by automating the sorting process with advanced IoT sensors and machine learning algorithms. The system efficiently classifies materials such as plastic, metal, paper, and organic waste with high accuracy, reducing human error and enhancing recycling rates. By integrating real-time feedback and analytics, ReSort empowers users to improve their waste disposal practices while providing detailed environmental impact metrics. Designed for scalability, the system caters to households, municipalities, and industrial facilities, adapting to various operational needs. Beyond its practical benefits, ReSort contributes to sustainability by lowering carbon emissions, reducing landfill waste, and promoting a circular economy. This innovative approach represents a significant step forward in achieving efficient and eco-friendly waste management solutions

Introduction

The ReSort Intelligent Recycling System offers a groundbreaking approach to waste management by addressing inefficiencies in traditional sorting processes. Utilizing advanced IoT sensors and machine learning algorithms, the system automates the classification of recyclable materials such as plastic, metal, glass, and organic waste with exceptional accuracy. This innovative system minimizes human error, optimizes recycling rates, and enhances operational efficiency, making it a sustainable solution for modern waste challenges. ReSort is designed to be scalable, serving a diverse range of users, from individual households to municipalities and industrial facilities. The system provides real-time feedback and analytics, helping users improve their recycling habits while contributing to environmental conservation efforts. By reducing carbon emissions, conserving resources, and promoting sustainability, ReSort represents a significant step forward in creating a cleaner and greener future.

Literature Review

Abstract

This project aims to develop an Intelligent Recycling System that leverages machine learning and sensor technologies to automate waste classification. By using deep learning models like CNN and YOLO alongside sensors such as inductive and moisture detectors, the system can accurately sort waste into metal, plastic, paper, and organic categories. Designed to improve efficiency and reduce manual labor, this system seeks to enhance recycling rates and lower environmental impact. Future research opportunities include advancements in sensor integration, AI-driven data analysis, and applications in smart city projects to create a more sustainable waste management solution.

1. Introduction

- **Importance of Recycling Processes and Current Challenges:** Efficient waste management is critical for environmental sustainability, yet traditional recycling systems remain largely dependent on manual processes, which are time-consuming and error prone. As cities continue to grow, the limitations of these systems, particularly low recycling rates and high contamination in recycling streams underscore the need for smarter, automated solutions.
- **Objective of ReSort:** Our team's project, ReSort, addresses these challenges by developing an intelligent recycling system that uses sensors and machine learning algorithms to automatically sort waste. By integrating this system with a user-friendly interface, we aim to optimize recycling processes, increase sorting accuracy, and ultimately contribute to more sustainable waste management practices.
- **Contribution to the Literature:** The ReSort project introduces a comprehensive, AI-powered approach to waste sorting. This system has the potential to provide valuable insights into automated recycling solutions and serves as a reference for researchers and practitioners interested in sustainable urban waste management.

2. Project Aim and Contributions

One of the biggest environmental challenges faced by modern societies is the efficiency of waste management and recycling processes. Traditional waste management systems mostly rely on manual processing, leading to wasted time and resources. Moreover, manual classification processes increase the likelihood of errors, resulting in recyclable materials being miscategorized and entering the wrong waste streams. Therefore, smarter and automated solutions for sustainable waste management are becoming increasingly essential. Our project, the Intelligent Recycling System, presents an innovative approach to addressing these environmental challenges. The project aims to develop a system capable of automatically detecting and separating waste into categories such as metal, plastic, paper, and organic materials and optimizing the recycling process. Using a series of sensors, image processing algorithms, machine learning models, and mechanical separation systems (conveyor belts, robotic arms), this smart system is designed to automatically classify and sort waste based on its type.

Project Aim

- **Improving Classification Accuracy:** The intelligent recycling system will reduce sorting errors by accurately classifying waste into categories like metal, plastic, paper, and organic materials. This minimizes potential waste stream contamination and ensures that each type of waste is directed to the most appropriate recycling process.
- **Saving Time and Labor Costs:** Traditional waste management processes are time-consuming and labor-intensive. Our project seeks to automate this process, saving time and reducing the need for manual labor, which is particularly beneficial in densely populated cities where efficiency is crucial.
- **Contributing to Sustainable Waste Management:** By offering smart solutions to achieve sustainability goals, our project will facilitate the transformation of waste into reusable materials, reducing environmental impact, conserving natural resources, and ultimately increasing recycling rates.
- **Data-Driven Improvement and Adaptation:** The system will continuously improve itself through data collected from sensors and machine learning algorithms. For instance, algorithms can adapt to variations in waste types generated by users, enhancing classification accuracy. Additionally, user habits and waste type data can be analyzed to make strategic decisions regarding recycling processes.

Project Contributions

Once implemented, our project will provide environmental, economic, and social benefits, including:

Environmental Contributions

- Reducing Classification Errors: Accurate waste sorting will ensure that recyclable materials are efficiently directed to the recycling process, increasing recycling rates and reducing the environmental burden on nature.

- Lowering Carbon Footprint: Higher recycling rates will reduce the amount of waste sent to landfills and cut down on carbon emissions from waste incineration.
- Conserving Natural Resources: By correctly sorting waste types, recycled materials can be reused in production, decreasing the consumption of natural resources.

Economic Contributions

- Reducing Labor Costs: Automated waste classification will reduce the need for manual sorting, saving on labor costs.
- Enhancing Efficiency: Faster recycling processes allow for more waste to be processed in a shorter time, increasing facility efficiency and economic gains.
- Creating Economic Value from Waste: Sorted waste can be processed into high-value recycled materials, benefiting the recycling industry.

Social Contributions

- Raising User Awareness: This project will help individuals better understand the importance of recycling and increase awareness of proper waste sorting. A user-friendly interface will also encourage the use of the system.
- Potential for Smart City Applications: Intelligent recycling systems can be integrated into smart city projects, enhancing the environmental performance of urban areas by increasing recycling rates.
- Educational Opportunities: The project can help users develop good waste-sorting habits, contributing to higher recycling rates in the long term.

Contributions to Research and Technology Development

- Advancements in Artificial Intelligence and Sensor Technologies: This project will serve as a valuable case study for integrating artificial intelligence and sensor technologies. The developed model and technologies can inspire other waste management projects, contributing to more advanced waste-sorting technologies.
- Academic Contributions: The project will serve as a significant reference in the literature on waste management and AI-powered recycling systems, guiding future studies and research in sustainable waste management.

3. Limitations of Current Systems

Traditional recycling and waste management systems rely on manual labor processes, which present several limitations in terms of sustainable waste management and environmental impact. These limitations result in low recycling rates, insufficient classification accuracy, lack of operational efficiency, and high labor costs. Particularly in large cities and densely populated areas, these issues become more prominent, emphasizing the need for more effective and intelligent systems.

- **Inefficiency of Manual Sorting:** In conventional waste management systems, sorting for recycling is largely done by hand. This method is prone to errors and leads to low classification accuracy. Users often misclassify waste, which disrupts the recycling process. Misclassification makes it challenging to recover recyclable materials and ultimately reduces overall recycling rates.

- **Time and Cost Inefficiencies:** Manual operations require significant labor resources when applied on a large scale, leading to substantial increases in waste management costs. Additionally, due to the slow pace of sorting processes, it becomes difficult to handle large quantities of waste within a short time frame. This decreases operational efficiency in waste management and hampers the effective management of high waste inflows.

- **Low Recycling Rates:** Misclassification by users and insufficient sorting processes lead to low recycling rates. Recyclable materials that mix with organic waste often become contaminated and unsuitable for recycling. This causes recyclable waste to blend into the general waste stream, negatively impacting the recovery rate.

- **Insufficient Technology and Lack of Automation:** Most current recycling systems are limited in terms of technology and have low levels of automation. These systems typically lack sensor and AI-driven solutions that could automate sorting and separation processes. The lack of automation restricts both the accuracy and speed of processes, which leads to performance issues, especially in large-scale facilities.

- **Environmental Impact and Sustainability Challenges:** The slow and error-prone nature of manual processes reduces the efficiency of the recycling process, increasing the environmental impact. Misclassification or loss of recyclable materials during processing results in more waste being left in nature. This leads to higher carbon emissions and greater consumption of natural resources, creating a major barrier to sustainable waste management.

4. Machine Learning and Sensor Technologies

In our Intelligent Recycling System project, we leverage machine learning algorithms and sensor technologies to accurately classify waste. Machine learning enables the quick and accurate categorization of waste using image processing-based classification algorithms, while various sensors detect the physical and chemical properties of the waste, supporting the machine learning algorithms. The integration of these two technologies aims to improve the efficiency and accuracy of waste management processes.

4.1. Machine Learning Technologies

Machine learning is primarily used in the waste sorting process for image classification and object recognition. Deep learning algorithms allow for the automatic recognition and classification of waste types, helping make the recycling process more efficient.

Convolutional Neural Networks (CNN)

- CNN algorithms are used to learn the visual features of waste, such as color, shape, or texture, to predict whether the waste is plastic, paper, or metal.
- Application Example: When analyzing an image of waste, the waste sorting system can use a CNN model to accurately determine the category of the waste.

YOLO (You Only Look Once)

- The YOLO algorithm is highly effective and fast for real-time object detection and classification. YOLO can simultaneously recognize multiple objects in an image, enabling real-time categorization of waste moving on a conveyor belt.
- Application Example: Using YOLO, multiple waste objects (such as plastic bottles, metal cans) in an image captured by the camera can be detected and accurately classified simultaneously.

Data Augmentation and Transfer Learning

- Data Augmentation: This involves applying transformations such as rotation, cropping, and zooming to diversify the training data. This helps the model recognize images from different perspectives**.**
- Transfer Learning: A pre-trained model is fine-tuned on a new dataset, which can accelerate training and improve accuracy for our project.

Optimization and Loss Functions

- Adam Optimization: This optimizer helps the model learn faster and improve classification accuracy.
- Loss Function: sparse_categorical_crossentropy is used as the loss function to minimize classification errors.
- These machine learning algorithms speed up the waste sorting process and improve classification accuracy, contributing to the efficiency of the recycling process

4.2. Sensor Technologies

Various **sensor technologies** are used to support machine learning algorithms. These sensors detect the physical and chemical properties of the waste, providing additional information to the machine learning models and enhancing the accuracy of the classification process.

Optical Sensors and Cameras

- Optical sensors: analyze the color and surface texture of the waste to predict its type.
- Camera modules provide data for image processing algorithms, allowing for object detection in the image. For example, plastic bottles, metal cans, and paper-based waste can be analyzed and classified with optical sensors.

Metal Sensors (Inductive Sensors)

- Inductive sensors detect metal-containing waste by generating a signal when they sense metal, allowing easy separation of metal from non-metal waste.
- Application Example: Metal cans moving on a conveyor belt can be detected by inductive sensors and classified as metal by the machine learning model.

Moisture Sensors

- Moisture sensors measure the water content of the waste, facilitating the separation of organic from inorganic waste. Organic waste typically has a higher moisture content, helping classify it accurately.
- Application Example: A waste item with high moisture content can be classified as organic waste.

Color Sensors

- Color sensors enable color-based classification, particularly for types of plastics.
- Application Example: Color sensors can differentiate green, blue, or transparent plastics to sort them into distinct categories.

Weight Sensors (Load Cell)

- Weight sensors measure the mass of waste, providing an additional attribute for classification. For example, large and heavy items can be classified into separate categories.
- Application Example: Heavy objects like full plastic bottles or metal cans can be detected and classified by weight sensors.

Ultrasonic Sensors

- Ultrasonic sensors are used to measure the size or height of the waste. These sensors measure the distance of waste on the conveyor belt, helping determine the type of waste.
- Application Example: Large-sized waste items can be detected by the ultrasonic sensor and tagged as bulk waste.

Machine learning algorithms and sensor technologies provide a complementary structure for the intelligent recycling system. While image processing algorithms (such as CNN and YOLO) categorize waste types quickly and accurately, various sensors like metal, moisture, and color sensors detect the physical properties of the waste, supporting the machine learning algorithms. This integration allows the system to operate with high accuracy and automate the classification process, significantly benefiting the environment and recycling processes.

This combination provides an effective solution for increasing recycling efficiency, reducing labor costs, and minimizing environmental impacts, especially in large facilities or densely populated cities.

5. Future Research Opportunities

Our Intelligent Recycling System project combines machine learning and sensor technologies to make recycling processes more efficient and sustainable. However, there are still many areas to explore in waste management to develop fully autonomous systems and enable these technologies to be applied on a larger scale. Future research can focus on reducing environmental impacts, increasing operational efficiency, and enhancing user experience by implementing more advanced technologies in recycling systems. Our Intelligent Recycling System project combines machine learning and sensor technologies to make recycling processes more efficient and sustainable. However, there are still many areas to explore in waste management to develop fully autonomous systems and enable these technologies to be applied on a larger scale. Future research can focus on reducing environmental impacts, increasing operational efficiency, and enhancing user experience by implementing more advanced technologies in recycling systems.

Advanced Sensor and Data Analytics Technologies

- In the future, recycling systems could incorporate sensors with more precise data collection and analysis capabilities. For example, smart sensors that detect the chemical composition of waste or near-infrared (NIR) spectrum analysis technologies could be explored. Such sensors would enable more detailed classification based on the chemical composition of waste types, enhancing accuracy in recycling processes.

Improvement of Deep Learning Models

- More complex and advanced learning models could be developed to improve classification accuracy. Specifically, transformer-based models and more sophisticated CNN architectures can more accurately identify waste types in recycling systems. Additionally, developing lightweight AI models that can operate on low-cost hardware would make these systems more widely applicable.

- IoT (Internet of Things) and cloud-based data management can enable remote monitoring and management of recycling systems. Data collected from recycling facilities could be stored in the cloud for analysis, allowing for customized reports for each facility. At the same time, system performance can be monitored, improving waste management processes at each recycling facility.

User Behavior and Educational Programs

- To increase recycling efficiency, more research could be conducted on user habits and behaviors. For example, educational programs or incentive systems could be developed to encourage users to adopt correct waste-sorting habits. Such research would enhance public contributions to recycling processes, allowing waste management systems to operate more effectively.

Research on Energy Efficiency in Recycling Systems

- Research can be conducted on improving energy efficiency in recycling processes to minimize energy consumption. For example, by developing low-energy-consuming sensors or algorithms, the carbon footprint of recycling facilities could be reduced. This could be a significant step toward achieving environmental sustainability goals.

Fully Autonomous Recycling Facilities

- Future research could focus on the development of fully autonomous recycling facilities that require no human intervention. In such facilities, AI-powered robotic systems and automated sorting systems could independently handle waste sorting, processing, and recovery. Such an autonomous system would reduce operational costs while increasing classification accuracy and recycling rates.

Smart City Integrations

- Intelligent recycling systems could be integrated into future smart city projects. In this way, waste management processes in each city could be interconnected and managed through a single system. Recycling systems integrated with smart city applications could increase recycling efficiency and minimize environmental impact.

AI-Driven Data Analysis and Prediction Models

- AI models capable of predicting waste amounts and types could be developed using data collected from recycling systems. Such data analysis could be used to optimize operational processes in recycling facilities and develop waste management strategies. Additionally, user behavior could be predicted to improve recycling rates, allowing for strategic decision-making.

These future research opportunities promote the use of innovative technologies in waste management and recycling processes. Research into topics such as advanced sensor technologies, machine learning, and user behavior analysis could increase the accuracy, efficiency, and sustainability of recycling systems. This, in turn, can help reduce environmental impact and conserve natural resources.

6. Conclusion

- **Contributions of ReSort:** Our project, ReSort, offers a unique approach to recycling that incorporates advanced sensor technologies and machine learning to enhance sorting accuracy. By making the recycling process more efficient and accessible, we hope to contribute to higher recycling rates and greater environmental sustainability.

- **Recommendations for Future Research:** Our findings suggest that further research should focus on improving public education around recycling practices, as well as developing more advanced sensor and data analytics solutions for waste management systems. ReSort serves as a foundation for these future explorations, with the goal of advancing both research and practical applications in sustainable waste management.

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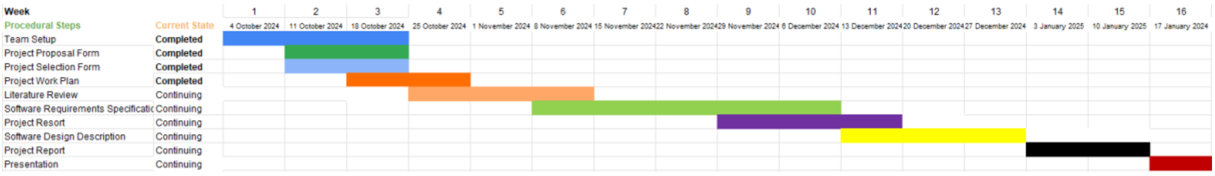
WORK PLAN



Step Name	Status	Date Range
Team Setup	Completed	October 4, 2024 - October 11, 2024
Project Proposal Form	Completed	October 11, 2024 - October 18, 2024
Project Selection Form	Completed	October 18, 2024 - October 25, 2024
Project Work Plan	Completed	October 25, 2024 - November 1, 2024
Literature Review	Completed	October 25, 2024 - November 8, 2024
Software Requirements Specification	Completed	November 1, 2024 - November 22, 2024
Project Resort	Completed	November 15, 2024 - November 29, 2024
Software Design Description	Completed	November 22, 2024 - December 6, 2024
Project Report	Completed	December 6, 2024 - January 3, 2025
Presentation	Completed	December 27, 2024 - January 17, 2025

SOFTWARE REQUIREMENTS SPECIFICATION

1. INTRODUCTION

1.1 Purpose

This document describes the specifications for the ReSort project, an intelligent recycling system designed to automate the sorting of recyclable materials using IoT devices, sensors, and machine learning algorithms. The purpose of this document is to define the system requirements for developers and stakeholders and to ensure alignment with project goals, including increased recycling efficiency and reduced waste misclassification.

This document also aims to highlight the environmental benefits of the ReSort system, such as reducing landfill dependency and minimizing resource wastage by promoting efficient recycling processes. Furthermore, the system aims to foster environmental awareness among users by providing insightful data on their recycling habits and encouraging sustainable practices. These objectives align with global efforts to combat climate change and promote a circular economy.

1.2 Scope of Project

ReSort aims to transform traditional waste sorting by implementing a smart, automated system. The project includes sensor and machine learning integration to accurately classify waste into predefined categories (e.g., plastic, metal, organic). It is designed for individual households, municipal recycling centers, and industrial users. The project aims not only to classify waste but also to increase recycling awareness of users. In addition, the system is planned to have an educational aspect. The system provides real-time feedback and analytics, offering environmental and operational benefits, including:

- Reduced human error in sorting.
- Increased recycling rates through accurate classification.
- Scalable deployment across urban and rural settings.

1.3 Glossary

- **IoT (Internet of Things):** Devices connected via the internet for data collection and communication.
- **Machine Learning:** Algorithms enabling the system to classify waste more accurately over time.
- **Sensors:** Devices that measure specific waste properties, such as material type, weight, and shape.
- **User Interface (UI):** Dashboard or app where users interact with the system.
- **Real-Time Feedback:** Instant notifications or results provided to users based on their interactions with the system.

1.4 References

1. Krizhevsky, A., et al. *ImageNet classification with deep convolutional neural networks*.
2. Redmon, J., & Farhadi, A. *YOLOv3: An incremental improvement*.

3. Al Mamun, M., et al. *IoT-based waste management system*.

1.5 Overview of the Document

The document is divided into high-level descriptions (Overall Description) and detailed technical specifications (Requirements Specification). These sections cater to stakeholders and technical teams, ensuring all aspects of ReSort's design and functionality are clearly defined.

2. OVERALL DESCRIPTION

2.1 Product Perspective

The ReSort Intelligent Recycling System is a comprehensive solution designed to revolutionize waste management through automation and intelligence. The system integrates IoT devices, machine learning algorithms, and a user-friendly interface to enhance recycling processes. ReSort replaces or complements traditional manual sorting systems by providing a scalable, accurate, and efficient method of waste classification.

Key Components:

1. **IoT Sensors and Cameras:**
    - Measure material properties (weight, dimensions, material type).
    - Capture images of waste for visual classification.
    - Examples: Weight sensors for organic vs. non-organic separation, cameras for identifying plastics vs. metals.
2. **Machine Learning Algorithms:**
    - Utilize advanced models (e.g., YOLO, CNN) for image-based classification.
    - Continuously improve through retraining using collected data.
    - Classify waste into categories such as plastic, metal, glass, and organic waste with >90% accuracy.
3. **Cloud-Based Analytics:**
    - Store historical waste data for trend analysis and reporting.
    - Use predictive analytics to forecast waste generation patterns.
4. **User Interfaces:**
    - **Mobile Application:** Offers real-time feedback on waste sorting, progress tracking, and recycling tips.
    - **Web Dashboard:** Allows municipalities or administrators to view system performance, manage devices, and generate reports.

Key Benefits:

- Reduces manual sorting effort and human error.
- Increases recycling rates by automating accurate waste classification.
- Provides users with actionable feedback and progress insights.

2.1.1. Development Methodology

The development of the ReSort Intelligent Recycling System will follow the Agile Scrum methodology, ensuring iterative progress and adaptability to evolving requirements. Scrum is chosen due to its flexibility and emphasis on regular feedback, which is essential for aligning the system's functionality with user needs and technological advancements.

Key Elements of the Methodology:

1. **Sprint Planning:**
    - Development will occur in 2-week sprin**ts**, with clear objectives set at the start of each sprint.
    - Deliverables will include functional prototypes for waste classification, IoT integration, and UI components.
2. **Daily Standups:**
    - The development team will conduct short daily meetings to discuss progress, identify blockers, and adjust tasks as needed.
3. **Incremental Delivery:**
    - Features such as real-time waste feedback, classification accuracy tracking, and report generation will be developed and delivered incrementally, ensuring regular testing and feedback.
4. **Backlog Management:**
    - The product backlog will prioritize high-impact features, including sensor integration, machine learning algorithms, and user feedback mechanisms.
    - Low-priority features (e.g., multi-language support, advanced analytics) will be addressed after the core functionalities are implemented.
5. **User Testing:**
    - Regular feedback will be gathered from pilot users, including households and municipal operators, during sprint reviews.
    - Insights from testing will inform refinements to the system's UI, classification algorithms, and data reporting tools.
6. **Continuous Integration and Deployment (CI/CD):**
    - Automated pipelines will be established to ensure rapid integration of new code and features.
    - Regular deployment to staging environments will allow early detection of bugs or performance bottlenecks.

7. **Energy Optimization Analytics:**
    - The system provides analytics on energy consumption patterns of IoT devices. Administrators can use these insights to optimize device usage and reduce overall energy costs.

Tools and Technologies:

- **Project Management:** Jira or Trello for sprint planning and backlog management.
- **Version Control:** GitHub for source code management and collaboration.
- **Collaboration:** Slack or Microsoft Teams for real-time communication.
- **CI/CD Tools:** Jenkins, CircleCI, or GitHub Actions for automated testing and deployment.

Advantages of Scrum for ReSort:

- **Adaptability:** Quick iterations enable adjustments to system requirements based on user feedback or technical discoveries.
- **Transparency:** Regular sprint reviews ensure stakeholders are aware of project progress and challenges.
- **Efficiency:** Continuous testing and integration minimize downtime and ensure the delivery of a high-quality product.
- **Early Identification and Mitigation of Risks:** Through regular sprint reviews and retrospectives, potential risks, such as integration challenges with IoT devices or delays in machine learning model training, are identified early and addressed proactively.

2.2 User Characteristics

2.2.1. Primary User Groups:

1. **Household Users:**
    - Individuals aim to improve personal recycling habits using automated systems.
    - No technical expertise required; simple, guided interfaces ensure ease of use.
2. **Municipal Operators:**
    - Professionals managing large-scale recycling processes in cities or towns.
    - Moderate technical knowledge needed for system monitoring and basic troubleshooting.
3. **Recycling Facility Administrators:**
    - Technical experts responsible for configuring and maintaining the system's hardware and software components.

- Require experience in IoT device management, machine learning model deployment, and data analysis.

4. **Educational Institutions:**
   - Schools, universities, and research institutions aim to educate students about sustainable waste management practices. The system can be used as a teaching tool in environmental science courses, providing hands-on experience with smart recycling technologies.
5. **Event Organizers:**
   - Organizers of large-scale events (e.g., festivals, sports events) are looking to manage waste effectively. ReSort can be temporarily deployed to sort and recycle waste generated during events.

User Needs and Preferences:

1. **Household Users:**
   - Real-time classification results and easy-to-understand recycling tips.
   - Monthly and yearly reports summarizing personal recycling impact.
2. **Municipal Operators:**
   - Performance metrics of all IoT-enabled bins and recycling units.
   - Ability to generate compliance reports for government regulations.
3. **Administrators:**
   - Centralized system management for all connected IoT devices.
   - Alerts and error reporting for quick resolution of system issues.
4. **Educational Institutions:**
   - Ability to tailor recycling scenarios and classifications to align with specific environmental science curriculums or research objectives.
   - Tools to monitor and evaluate the impact of different waste sorting methods during practical lessons.
   - Capability to export recycling data for academic analysis or reports.
   - A plug-and-play system that can be easily deployed in classrooms or labs without technical expertise.
5. **Event Organizers:**
   - A lightweight and easily transportable system that can be installed and removed quickly at event venues.
   - Ability to manage large amounts of waste generated during events with real-time sorting and notifications for bin replacements.

- Summary reports showing the amount of waste sorted, recycled, and overall environmental impact for post-event reviews.
- A simple interface for temporary staff to monitor and manage the system without extensive training.

2.3 Assumptions and Dependencies

1. **System Assumptions:**

   - Reliable internet connectivity is available for real-time data transmission between IoT devices and cloud storage.
   - All deployed sensors and cameras are maintained and calibrated periodically.
   - End-users have access to a smartphone or web-enabled device for using the ReSort interface.
   - Machine learning models used for waste classification assume a diverse and representative dataset is available for training and testing. The accuracy of classifications depends on the quality of these datasets.

2. **External Dependencies:**

   - **Cloud Storage:** The system relies on third-party cloud platforms for data storage and processing.
   - **Power Supply:** Continuous power supply is necessary for IoT devices to function effectively.
   - **Government Policies:** Compliance with local waste management regulations will affect system deployment and functionality.

3. REQUIREMENTS SPECIFICATION

3.1 External Interface Requirements

1. **User Interfaces:**

   - Web app with interactive dashboards.
   - Mobile app for real-time notifications.

2. **Hardware Interfaces:**

   - Weight sensors, ultrasonic detectors, and cameras integrated with IoT devices (e.g., Raspberry Pi).

3. **Software Interfaces:**

   - Integration with cloud platforms for storage and AI processing.

4. **Communication Interfaces:**

- Data transmitted via MQTT protocol over Wi-Fi.

3.2 Functional Requirements

3.2.1. Sensor Malfunction Detection and Resolution:

Use Case:

- Detect Sensor Malfunction
- Log Error
- Review and Resolve Issue

Diagram:

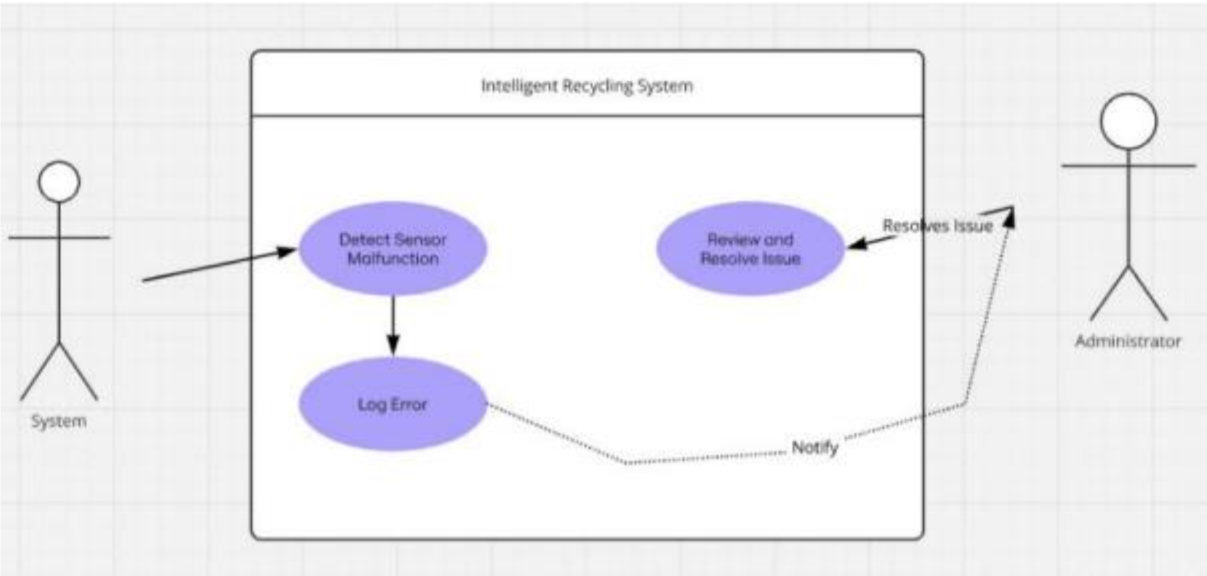


Figure 1 Sensor Malfunction Detection and Resolution

Brief Description:

This use case diagram outlines the processes involved in an Intelligent Recycling System, focusing on detecting sensor malfunctions, logging errors, and resolving issues. When the system detects a sensor malfunction, it logs the issue and notifies the administrator. The administrator reviews the reported problem and resolves it.

Initial Step by Step Description:

Detect Sensor Malfunction:

The system continuously monitors the functionality of sensors. If a malfunction is detected (e.g., no data received or incorrect data), the process is initiated.

Log Error:

The system logs the detected sensor malfunction as an error in the system's error log. The recorded log includes technical details such as the sensor ID, timestamp, and type of error.

Notify Administrator:

The system notifies the administrator when an error occurs. This notification could be delivered through a visual alert in the system interface or via email.

Review and Resolve Issue:

The administrator accesses a control panel to review the reported error. The administrator analyzes the sensor's condition and develops solutions. The resolution might involve manually fixing, restarting, or replacing the sensor.

Resolves Issue:

The administrator takes necessary actions to resolve the malfunction. Once the issue is resolved, the system updates the status to "active" and resumes monitoring.

3.2.2. Maintenance Scheduling and Approval Process:

<u>Use Case:</u>

- Predict Maintenance Needs
- Suggest Schedule
- Approve Schedule

<u>Diagram:</u>

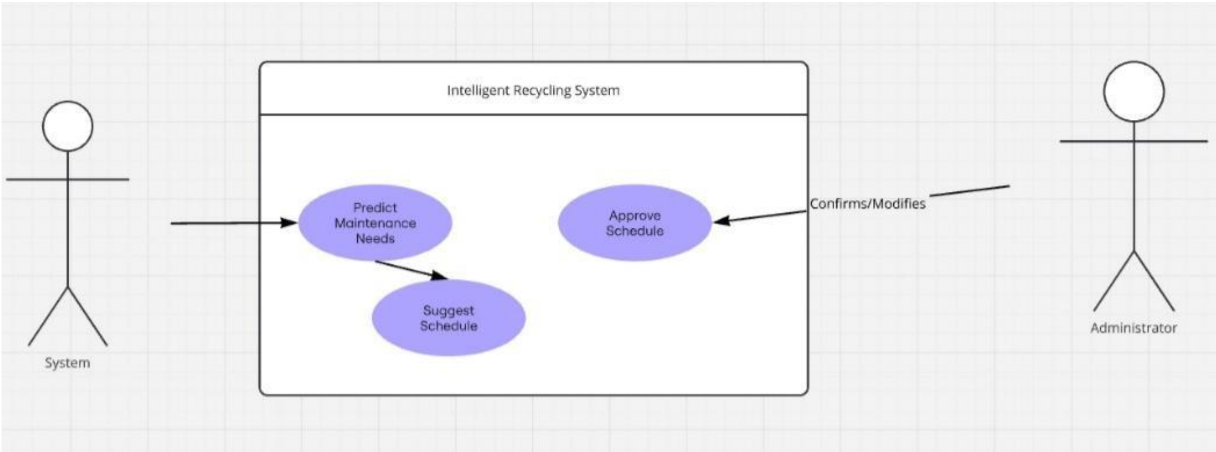


Figure 2 Maintenance Scheduling and Approval Process

<u>Brief Description:</u>

This use case diagram illustrates the Intelligent Recycling System's Maintenance Scheduling Process. The system predicts maintenance needs based on sensor performance or usage data, suggests a schedule for maintenance, and seeks administrator approval for the proposed schedule. The administrator can either confirm or modify the schedule.

Initial Step by Step Description:

Predict Maintenance Needs:

The system continuously monitors the operational status of the recycling components (e.g., sensors, conveyor belts, robotic arms). Based on data like performance logs, error rates, and usage duration, the system predicts when maintenance is required.

Suggest Schedule:

After identifying maintenance needs, the system generates a proposed schedule. The suggested schedule includes details such as date, time, and the components that require maintenance.

Approve Schedule:

The administrator reviews the suggested schedule. The administrator can: Confirm the schedule as it is. Modify the schedule (e.g., change the date or include additional components).

Confirm/Modify Schedule: Once the administrator finalizes the schedule, it is stored in the system's calendar for execution. The maintenance team is notified based on the approved schedule.

3.2.3. Recycling Workflow and System Monitoring:

Use Case:

- Deposit Waste
- Identify Materials
- Flag Non – Recyclable Items
- Provide Recycling Tips
- Monitor System Health
- Generate Efficiency Report

Diagram:

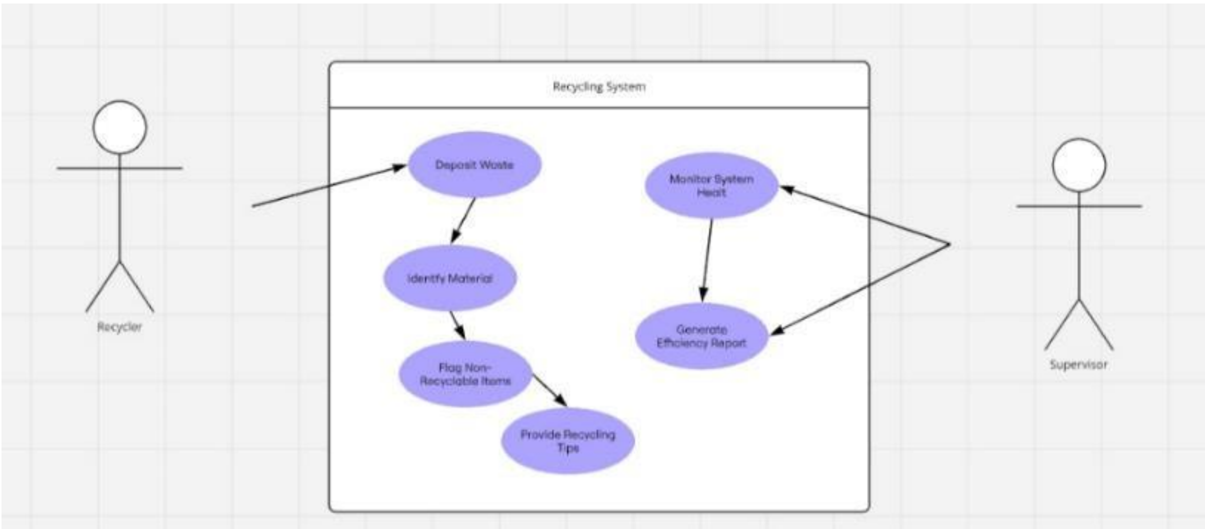


Figure 3 Recycling Workflow and System Monitoring

Brief Description:

This use case diagram represents the Recycling System Workflow. It involves two actors:

Recycler: Deposits waste and interacts with the system for recycling tips.

Supervisor: Monitors system health and generates efficiency reports. The system performs core tasks such as identifying materials, flagging non-recyclable items, providing recycling tips, and ensuring overall system functionality.

Initial Step by Step Description:

Deposit Waste:

Actor: Recycler The recycler deposits waste into the recycling system via an input panel or conveyor mechanism.

Identify Material: The system analyzes the deposited waste using IoT sensors, cameras, and machine learning algorithms. Materials are classified into categories (e.g., plastic, metal, paper, or organic).

Flag Non-Recyclable Items: If non-recyclable materials (e.g., hazardous waste) are detected, the system flags them. The flagged items are either separated or an alert is issued for proper disposal.

Provide Recycling Tips: The system provides real-time feedback to the recycler.

Example: "This item is not recyclable. Please dispose of it as hazardous waste."

Monitor System Health:

Actor: Supervisor The system continuously checks the performance of its components (e.g., sensors, conveyor belts, and robotic arms). Any anomalies are logged for further review.

Generate Efficiency Report:

Actor: Supervisor Based on collected data, the system generates detailed reports highlighting: Volume of materials processed.

Recycling efficiency.

Error rates and flagged items.

3.2.4. Comprehensive Recycling System Operations:

Use Case:

- Submit Waste
- Classify Waste
- Notify Hazardous Material
- Perform System Maintenance
- Manage User Data
- Generate Recycling Report

Diagram:

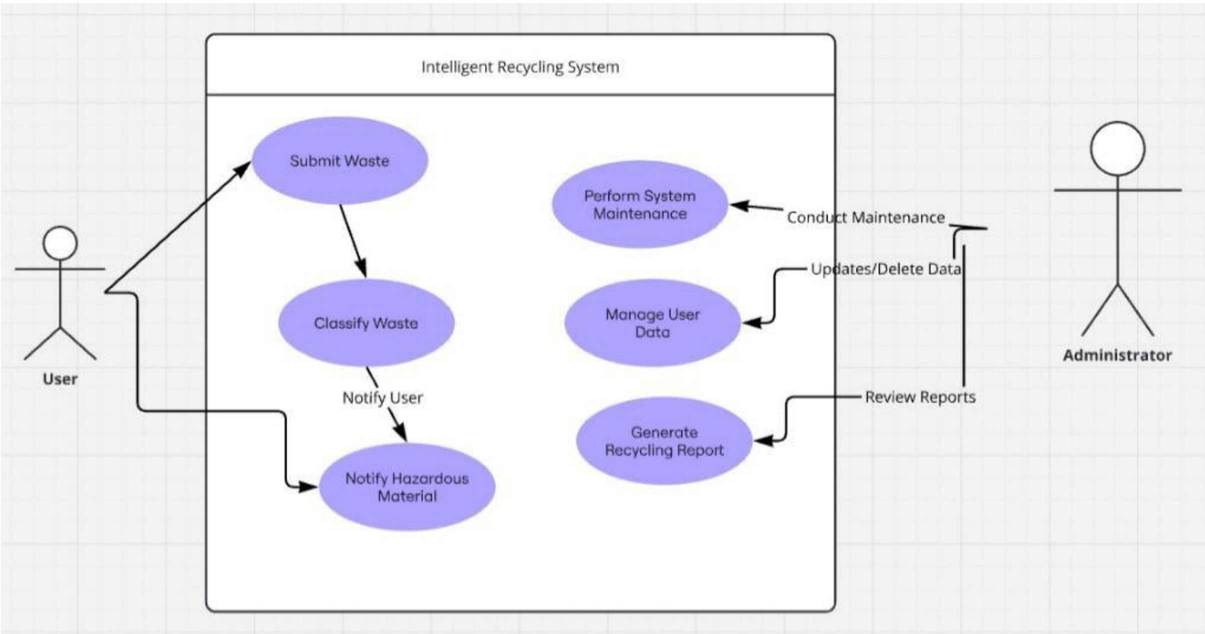


Figure 4 Comprehensive Recycling System

Brief Description:

This use case diagram illustrates the core functionalities of the Intelligent Recycling System, involving two main actors:

User: Submits waste for classification and receives feedback on hazardous materials.

Administrator: Manages system maintenance, user data, and generates recycling reports. The system handles waste classification, notifies users about hazardous materials, and allows administrators to maintain the system and analyze recycling data.

Initial Step by Step Description:

Submit Waste:

Actor: User The user interacts with the system by submitting waste for classification through a designated input interface.

Classify Waste: The system analyzes the submitted waste using sensors and machine learning algorithms. Waste is categorized as recyclable (e.g., plastic, metal, glass) and non-recyclable materials.

Notify User: The system informs the user about the classification results. Example: "The item you submitted is recyclable as plastic."

Notify Hazardous Material: If the waste contains hazardous materials (e.g., batteries or chemicals), the system alerts the user with proper disposal instructions. Example: "This is hazardous waste. Please dispose of it responsibly at a designated facility."

Perform System Maintenance:

Actor: Administrator The administrator ensures the system's hardware and software components are functioning correctly by performing regular maintenance tasks.

Manage User Data:

Actor: Administrator The administrator can update or delete user data stored in the system, ensuring compliance with data privacy regulations.

Generate Recycling Report:

Actor: Administrator

The system compiles and presents recycling statistics, such as:

Total waste processed.

Classification accuracy.

Recycling efficiency metrics.

These reports help the administrator evaluate system performance and identify areas for improvement.

3.2.5. Integrated Recycling and System Monitoring Workflow:

Use Case:

- Deposit Waste
- Identify Waste
- Flag Non – Recyclable Items
- Monitor System Health
- Generate Efficiency Report
- Provide Recycling Tips

Diagram:

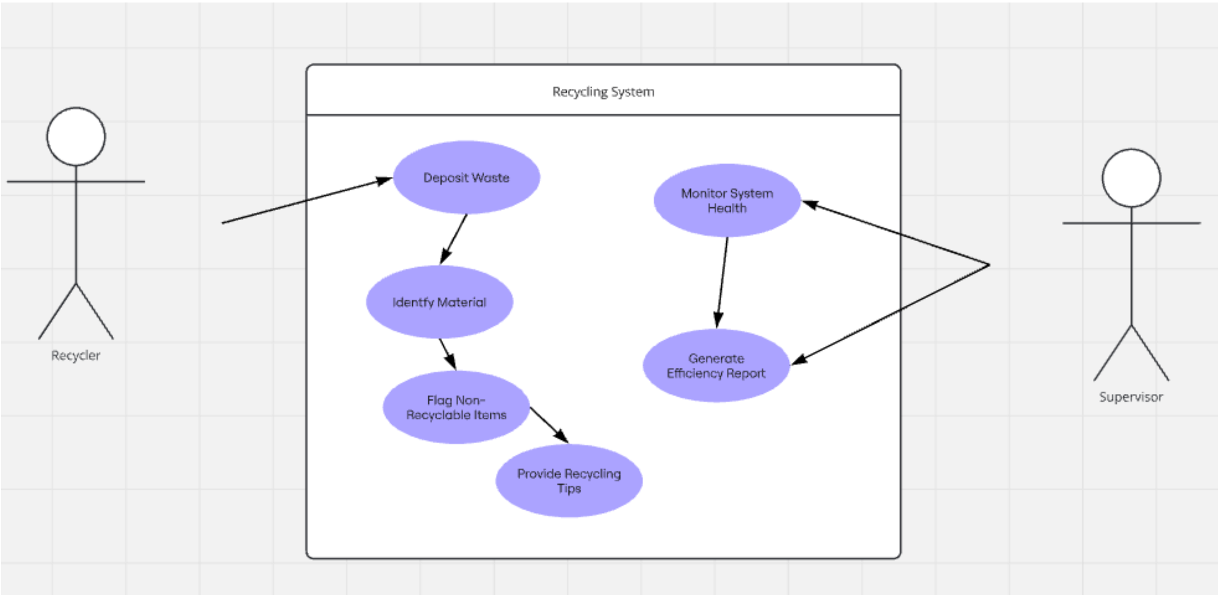


Figure 5 Integrated Recycling and System Monitoring Workflow

Brief Description:

This use case diagram showcases the Recycling System's Functional Workflow, involving three primary actors:

Recycler: Deposits waste and receives recycling feedback.

Supervisor: Monitors system health and reviews efficiency reports.

System: Manages the overall operations, including material identification and providing feedback. The system focuses on waste classification, recycling efficiency analysis, and user guidance for proper recycling.

Initial Step by Step Description:

Deposit Waste:

Actor: Recycler The recycler interacts with the recycling system to deposit waste into the input slot.

Identify Material: The system uses integrated sensors and AI-based algorithms to identify the material type (e.g., metal, plastic, organic). Proper classification ensures efficient recycling processes.

Flag Non-Recyclable Items: Non-recyclable items are flagged by the system, preventing contamination of recyclable materials. Example: "This item is non-recyclable. Please dispose of it responsibly."

Provide Recycling Tips: The system provides tips and feedback based on the material deposited by the recycler. Example: "You can reduce waste by rinsing recyclable containers before disposal."

Monitor System Health:

Actor: Supervisor The system continuously monitors its operational components (e.g., sensors, conveyors). Any anomalies or maintenance needs are logged for supervisor review.

Generate Efficiency Report:

Actor: Supervisor

The system generates periodic reports on:

Amount of waste processed.

Classification accuracy.

Percentage of flagged non-recyclable items.

These reports help the supervisor evaluate system performance and improve processes.

3.3 Performance Requirements

3.3.1. Accuracy:

- The classification system must achieve an accuracy rate of 90% or higher under optimal conditions.

3.3.2. Latency:

- The system should provide classification results within 2 seconds of waste detection.

3.3.3. Scalability:

- Must support up to 10,000 IoT devices operating simultaneously in municipal setups.
- Capable of handling up to 1 TB of daily data from sensors and cameras.

3.3.4. Reliability:

- Ensure 99.9% uptime for critical deployments in municipal waste management.

3.3.5. Energy Efficiency:

- IoT devices should consume no more than 5 watts of power during operation to ensure energy-efficient usage across large-scale deployments.

3.4 Software System Attributes

3.4.1. Portability:

- The system should run on multiple IoT platforms, including Raspberry Pi and Arduino.
- The mobile and web applications must be compatible with major operating systems (iOS, Android, Windows, and macOS).

3.4.2. Usability:

- User interfaces should be intuitive, requiring minimal training for household users and administrators.
- Include accessibility features such as voice assistance and high-contrast modes for visually impaired users.

3.4.3. Security:

- Protect user data using AES-256 encryption.
- Secure communication between IoT devices and cloud servers with SSL/TLS protocols.

3.4.4. Maintainability:

- The system must support over-the-air (OTA) updates for software patches and feature enhancements.
- Provide detailed logs for troubleshooting and system diagnostics.

3.5 Safety Requirements

3.5.1 Hardware Safety:

- IoT devices, including sensors and cameras, should be housed in tamper-resistant and weatherproof enclosures.
- Ensure electrical safety standards are met to prevent user injuries or equipment damage.

3.5.2 User Safety:

- Display warnings for hazardous materials, such as batteries or chemicals, to guide users on proper disposal methods.

3.5.3 Data Safety:

- Ensure user data privacy through GDPR-compliant practices.
- Allow users to view and delete their stored data upon request.

3.5.4 Emergency Shutdown:

- The system must include an emergency shutdown feature to deactivate all IoT devices in case of fire, electrical hazards, or other emergencies, ensuring user safety and preventing equipment damage.

3.6 Environmental Impact

The Intelligent Recycling System is designed to significantly reduce the environmental footprint associated with waste management by leveraging automation and advanced classification technologies. The system's impact can be measured in several key areas:

1. **Reduction in Landfill Waste:**
    - By accurately classifying and separating recyclable materials, the system reduces the volume of waste sent to landfills. This contributes to the preservation of natural ecosystems and minimizes the contamination caused by non-biodegradable materials.
2. **Increased Recycling Rates:**
    - The system improves the efficiency of recycling processes by minimizing human error in waste classification. Enhanced sorting accuracy ensures that more materials are directed toward appropriate recycling streams, reducing the demand for raw materials and energy-intensive production processes.
3. **Reduction in Landfill Waste:**
    - By accurately classifying and separating recyclable materials, the system reduces the volume of waste sent to landfills. This contributes to the preservation of natural ecosystems and minimizes the contamination caused by non-biodegradable materials.

4. **Increased Recycling Rates:**
    - The system improves the efficiency of recycling processes by minimizing human error in waste classification. Enhanced sorting accuracy ensures that more materials are directed toward appropriate recycling streams, reducing the demand for raw materials and energy-intensive production processes.
5. **Lower Carbon Emissions:**
    - By reducing the volume of improperly disposed waste, the system helps decrease greenhouse gas emissions from waste incineration and landfill decomposition. Additionally, increased recycling rates lower the carbon footprint associated with the production of new materials.
6. **Support for Circular Economy:**
    - By enabling efficient waste sorting, the system supports the transition to a circular economy, where materials are reused and recycled rather than discarded. This approach aligns with global sustainability goals and promotes long-term environmental balance.
7. **Educational Impact on Users:**
    - Through real-time feedback and recycling tips provided via the user interface, the system educates users on proper waste disposal practices. This awareness fosters more responsible waste management behaviors, contributing to broader environmental benefits.

Summary: The Intelligent Recycling System not only enhances operational efficiency but also plays a critical role in addressing environmental challenges. By reducing waste misclassification, supporting recycling efforts, and conserving resources, the system provides tangible contributions toward a more sustainable future.

4. REFERENCES

1. Krizhevsky, A., et al. *ImageNet classification with deep convolutional neural networks*.

2. Redmon, J., & Farhadi, A. *YOLOv3: An incremental improvement*.

3. Al Mamun, M., et al. *IoT-based waste management system*.

SOFTWARE DESIGN DESCRIPTION

1. INTRODUCTION

1.1 Purpose

The purpose of this Software Design Document is to provide a detailed framework for the development and implementation of the ReSort Intelligent Recycling System. This system aims to address inefficiencies in waste management by automating the sorting of recyclable materials using IoT sensors and advanced machine learning algorithms.

The system aims to achieve long-term goals, such as continuous performance improvement through iterative data analysis and machine learning. Additionally, it focuses on reducing carbon emissions and preserving natural resources by improving recycling rates. The scalable infrastructure allows the system to adapt to various waste management units, from small households to large municipalities.

The primary audience of this document includes developers, stakeholders, and technical experts involved in the creation and deployment of ReSort. The system is designed to serve the needs of individual households, municipalities, and industrial users by providing:

- Accurate Waste Classification: Sorting waste into predefined categories such as metal, plastic, organic, and glass with over 90% accuracy.
- Real-Time Feedback: Delivering instant results to users about their waste management practices.
- Environmental Impact Analytics: Tracking and reporting the environmental benefits of recycling, such as reduced carbon emissions and resource conservation.

ReSort's goal is to revolutionize waste management by reducing human error, increasing recycling rates, and providing a scalable, efficient, and user-friendly system for diverse operational environments.

1.2 Scope

The ReSort system benefits various user groups, including households, municipalities, and industrial facilities. Additionally, it serves as an educational tool for schools and universities, enabling students to gain hands-on experience with sustainable waste management practices. The system also supports interactive experiences to promote recycling habits.

This document contains a complete description of the design of the ReSort Intelligent Recycling System. The system integrates IoT sensors, machine learning algorithms, and user-friendly interfaces to automate waste sorting. ReSort is optimized for individual households, municipalities, and industrial recycling facilities.

Key Components:

1. IoT Sensors and Cameras:
    - Detect the weight, color, and material properties of waste.

- Use high-resolution cameras for image-based analysis.

2. Machine Learning Modules:
    - Utilize YOLO and CNN algorithms to categorize waste.
    - Aim for a classification accuracy rate of 90% or higher.

3. User Interfaces:
    - Provide real-time feedback via mobile and web dashboards.
    - Offer recommendations to improve users' recycling habits.

Development Environment:

The system will be developed using Python and TensorFlow for machine learning components, with Raspberry Pi as the preferred IoT platform. The design is modular to ensure scalability and ease of maintenance.

1.3 Glossary

Term	Definition
IoT (Internet of Things)	Devices connected via the internet to collect and share data.
CNN (Convolutional Neural Network)	A machine learning algorithm used for image-based classification.
YOLO (You Only Look Once)	Real-time object detection and classification algorithm.
User Interface (UI)	The interface (mobile or web) through which users interact with the system.
Raspberry Pi	A small, cost-effective computer platform used for IoT devices.
SDD (Software Design Document)	A document describing the technical design details of the software.

1.4 Overview of Document

This document provides a comprehensive design outline for the ReSort system, organized into the following sections:

- Section 1: Introduction - Describes the purpose, scope, and glossary of terms for this document.
- Section 2: Architecture Design - Explains the system's components, including class diagrams and data flow.

- Section 3: Use Case Realizations - Details user scenarios and activity diagrams that describe system interactions.
- Section 4: Environment - Specifies the development and deployment environments.
- Section 5: References - Lists all the resources and documents used in creating this system.

1.5 Motivation

We are a group of senior computer engineering students passionate about using innovative technologies to address environmental challenges. Through this project, we aim to contribute to sustainable waste management practices by leveraging modern technologies such as IoT and machine learning.

Our primary motivation stems from the increasing need for efficient recycling solutions in both urban and industrial settings. By automating waste sorting processes, ReSort aims to:

- Reduce Environmental Impact: Mitigate waste mismanagement and improve recycling rates, ultimately decreasing landfill overflow and resource depletion.
- Enhance Operational Efficiency: Minimize human error in waste classification, reduce costs, and optimize recycling workflows.
- Promote Technological Advancement: Integrate cutting-edge technologies such as Raspberry Pi, IoT-enabled sensors, and AI-driven classification algorithms to set a new standard for waste management systems.

Our team has utilized Raspberry Pi for IoT integration, which provides a cost-effective yet powerful platform for implementing our system. Additionally, we have employed TensorFlow and Python to develop the machine learning models that drive ReSort's classification engine. To further refine our skills and ensure the success of the project, we have studied various resources and sought guidance from professionals in the field of IoT and machine learning.

This project represents not only an academic challenge but also an opportunity to make a meaningful impact on global sustainability efforts.

2. ARCHITECTURE DESIGN

2.1 System Design Approach

The development of the ReSort project follows the Agile Scrum Methodology, ensuring flexibility and iterative progress throughout the project lifecycle. Scrum divides the work into sprints, each lasting two weeks, to deliver manageable increments of the system. This approach is particularly suited to ReSort due to its need for continuous feedback and adaptation to new challenges in waste management technology.

Scrum Implementation in ReSort:

1. Product Owner: Represents stakeholders and ensures that the system aligns with user requirements.

2. Scrum Master: Facilitates the development process by removing obstacles and ensuring adherence to the Scrum framework.
3. Development Team: Consists of engineers specializing in IoT, machine learning, and UI/UX design.

Sprint Workflow:

1. Project Backlog: All tasks and system requirements are listed here.
2. To Do Phase: Tasks selected for the sprint, prioritized based on importance.
3. In Progress Phase: Tasks actively under development.
4. In Review Phase: Tasks undergoing peer or stakeholder review.
5. To Deploy Phase: Tasks ready for integration into the main system.
6. Done Phase: Completed tasks that have been successfully implemented and tested.

This workflow ensures a clear division of tasks and efficient project management, making the system adaptable to evolving needs.

2.2 Architecture Design of ReSort

2.2.1 User Management

- Summary: The ReSort system allows users to register, log in, and manage their accounts. Administrative users can approve or delete user accounts and assign roles for system access.
- Actors: User, Administrator
- Preconditions: User must have access to the system.
- Basic Sequence:
    1. The user registers with their name, email, and password.
    2. The user logs into the system using their credentials.
    3. Users can update their account information via the user settings menu.
    4. Administrators can delete or approve accounts through the admin dashboard.
    5. Users can log out of the system at any time.
- Exception: Database connection may fail.
- Postconditions: User account data is stored or updated in the system database.
- Priority: Medium

2.2.2 Options Menu

- Summary: The options menu allows users to access system settings, such as adjusting notification preferences, reviewing system instructions, or logging out.
- Actors: User
- Preconditions: The user must be logged into the system.
- Basic Sequence:
    1. Users access the options menu from the dashboard.
    2. Users can enable or disable system notifications.
    3. Users can view system usage instructions.
    4. Users can log out of the system.
- Exception: No exceptions are expected for this functionality.
- Postconditions: Changes made by the user are saved in the system.
- Priority: Low

2.2.3 Waste Sorting Mode

The waste sorting process involves collecting data from IoT sensors, analyzing it using machine learning algorithms, and presenting real-time results on the user interface. Any errors or sensor failures are detected promptly, and classification results are delivered within 2 seconds.

- Summary: This mode allows users to sort waste materials into categories such as plastic, metal, and organic. The system utilizes sensors and machine learning models to identify and classify the waste.
- Actors: User, Administrator
- Preconditions: Sensors and machine learning modules must be operational.
- Basic Sequence:
    1. Users place waste into the designated input area.
    2. IoT sensors collect data such as weight and material properties.
    3. Cameras capture images of the waste.
    4. The machine learning module processes the data and classifies the waste.
    5. The results are displayed to the user in real time.
    6. Administrators can monitor sorting performance through the admin dashboard.
- Exception: Sensor malfunction or system downtime.
- Postconditions: Classification data is saved and displayed to the user.

- Priority: High

2.2.4 Activity Diagram

The following activity diagram illustrates the waste sorting workflow in the ReSort system:

1. User Places Waste: The user places waste material into the system.
2. Sensor Data Collection: IoT sensors measure weight and detect material properties.
3. Image Processing: Cameras capture images, and the machine learning model analyzes them.
4. Waste Classification: The system classifies the waste into predefined categories.
5. Feedback Display: The classification results are shown on the user interface.
6. Data Storage: The results are saved in the system database for future analytics.

2.3 Class Diagram

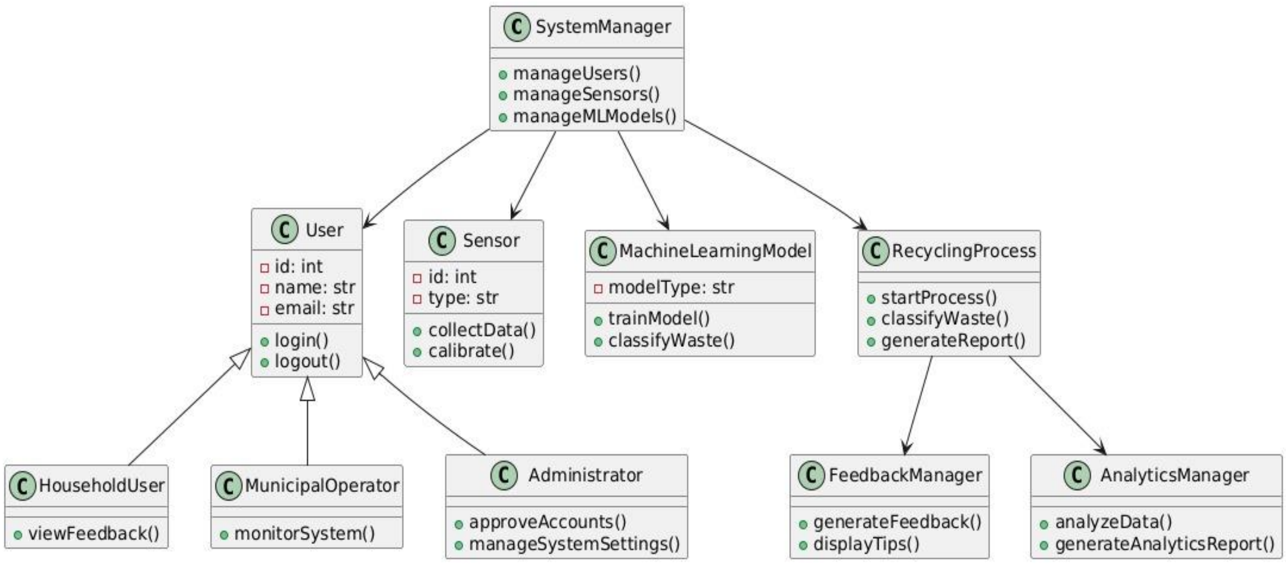


Figure 1 Class Diagram

2.4 Data Flow Diagrams

2.4.1 Level 0

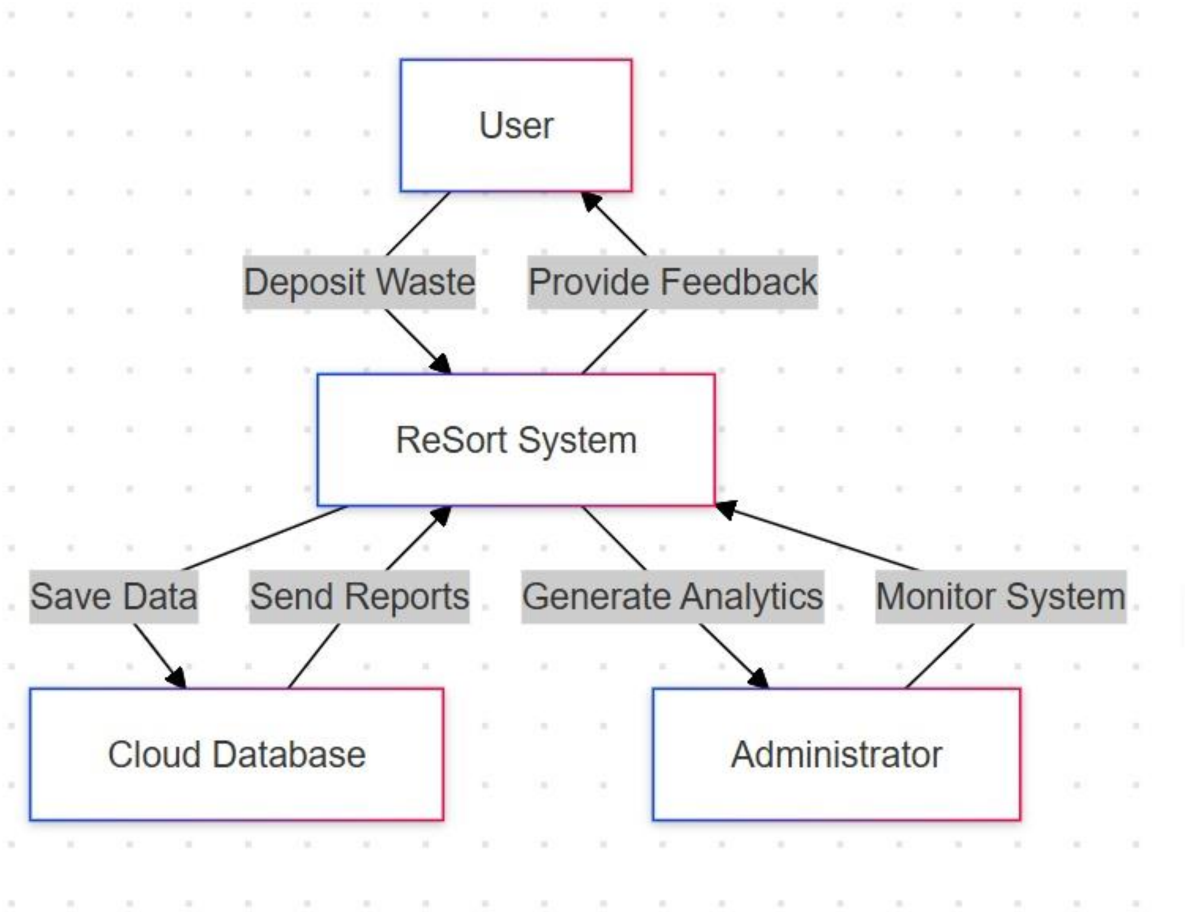


Figure 2 Level 0 Data Flow Diagram

2.4.2 Level 1

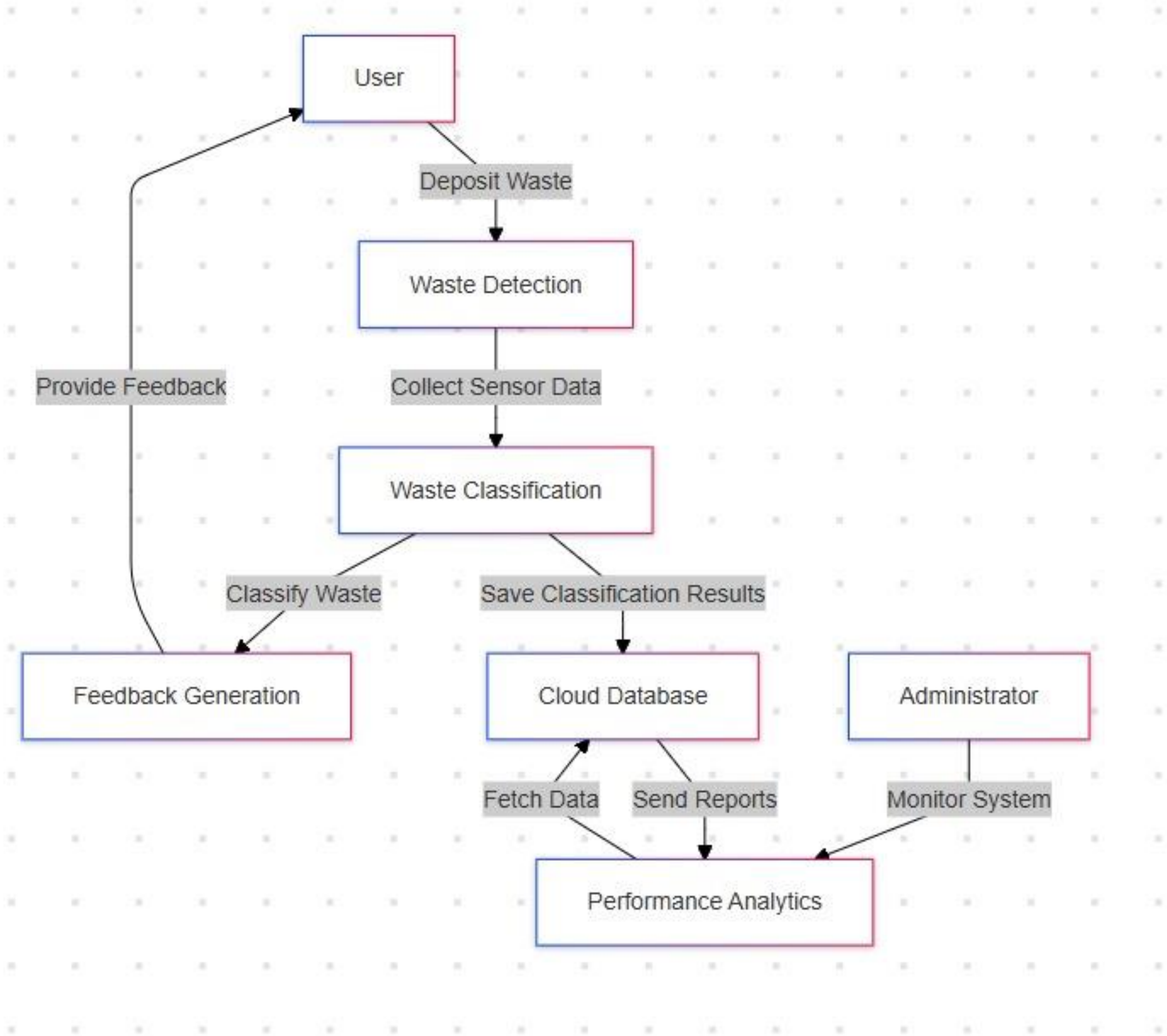


Figure 3 Level 1 Data Flow Diagram

2.4.3 Level 2

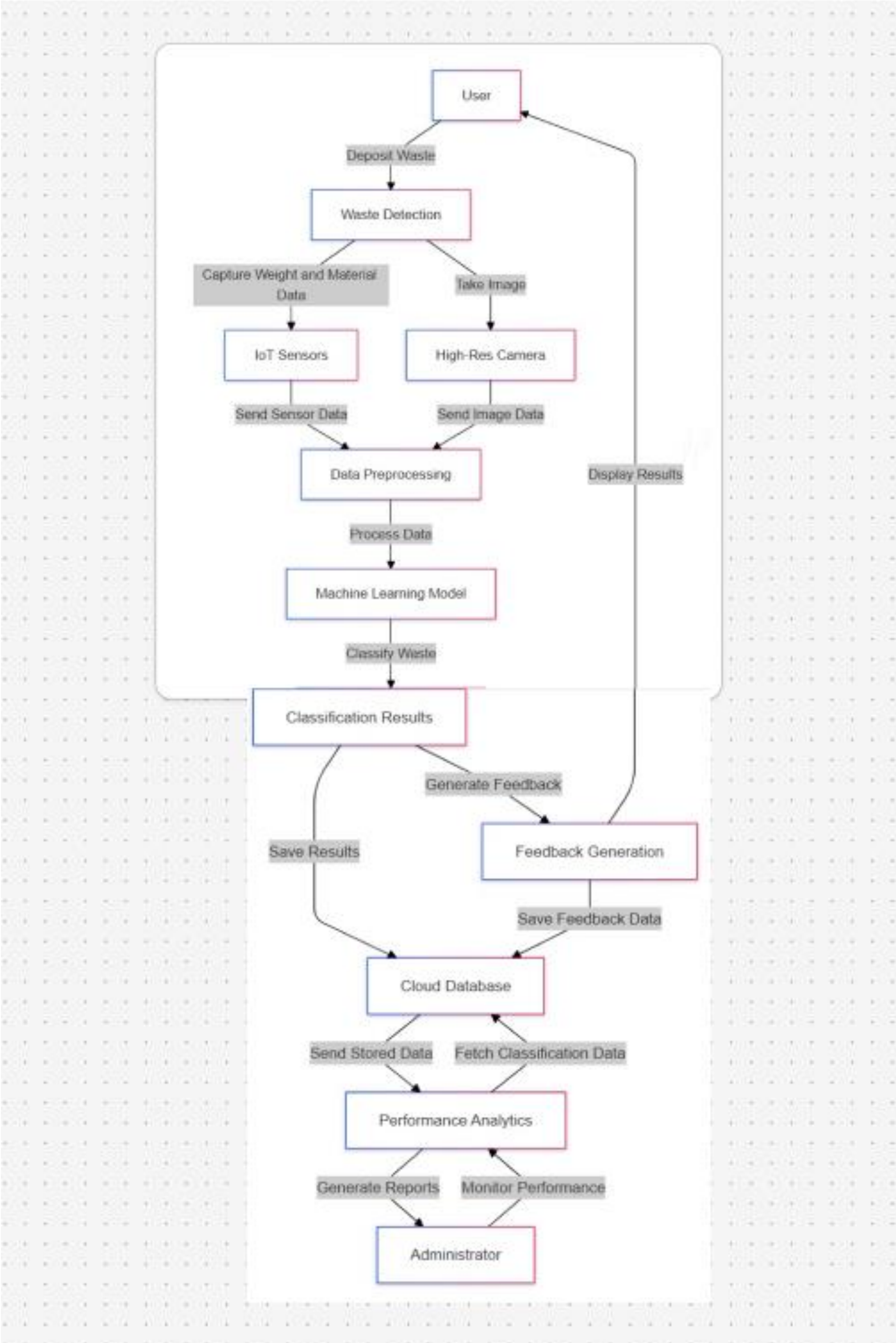


Figure 4 Level 2 Data Flow Diagram

3. USE CASE REALIZATIONS

3.1 Brief Description of the ReSort System

The components of the ReSort project can be categorized into five main modules, as shown in the block diagram. Each module serves a specific purpose in facilitating the waste sorting and recycling process. These modules include the User Interface (UI) Design, Waste Environment Design, Data and Feedback Design, Sensor and Machine Learning Integration, and System Analytics Design.

The UI Design is responsible for enabling user interaction with the system. It consists of various panels such as the main menu, options menu, progress panel, and feedback panel. The main menu serves as the entry point for users, allowing them to register, log in, and access key features of the system. The options menu provides access to system settings, notifications, and the logout option. Users can view their recycling progress and feedback in real-time via the progress and feedback panels.

The Waste Environment Design manages the physical and virtual spaces where users interact with the system. This includes the waste input area where users place their recyclable materials, the sorting mechanism where IoT sensors and machine learning models process the materials, and the processed waste output area where sorted results are displayed.

The Data and Feedback Design ensures that users receive actionable insights. Real-time feedback is provided immediately after waste is classified, helping users understand their recycling efforts. Additionally, the system offers performance analytics and environmental impact reports, detailing the amount of waste recycled and the ecological benefits achieved.

The Sensor and Machine Learning Design integrates various hardware and software components to automate waste sorting. IoT sensors measure the physical attributes of waste, such as weight, material type, and metal content. Machine learning models like YOLO and CNN process the captured data to classify the waste into predefined categories accurately.

Finally, the System Analytics Design is responsible for aggregating and analyzing all system data. This module securely stores user performance metrics and waste classification data, generating detailed reports for users. It also provides insights into recycling trends, enabling users to improve their practices and contribute to sustainability goals.

3.1.1 GUI Design

The GUI Design module is the central point of interaction between the user and the ReSort system. It incorporates several sub-systems, including the main menu, options menu, progress panel, feedback panel, and waste analysis panel. The main menu allows users to register, log in, and navigate through the system, while the options menu provides access to notification settings, system instructions, and the logout feature. The progress panel displays user recycling statistics, and the feedback panel offers real-time insights into waste classification and recommendations for improvement.

3.1.2 Waste Environment Design

The Waste Environment Design module is dedicated to managing the spaces where waste sorting occurs. Users interact with this environment by placing their waste in the input area, where IoT sensors and cameras analyze the materials. The sorting mechanism processes the waste based on the collected data, and the processed waste is displayed in the output area for validation.

Users interact with the system by placing waste in the designated input area, where sensors collect data on weight, material, and type. The system processes the data, categorizes the waste, and alerts users with visual and audio feedback if incorrect placement occurs.

3.1.3 Data and Feedback Design

The Data and Feedback Design module focuses on delivering valuable insights to users. The system provides real-time classification feedback, helping users identify and sort waste more effectively. Additionally, it tracks recycling performance metrics and generates environmental impact reports that highlight the ecological benefits of users' efforts, such as reduced carbon emissions and improved recycling rates.

Users can view recycling data and environmental impact metrics through mobile applications and web dashboards. Feedback reports are automatically generated weekly and monthly, providing insights into recycling habits and areas for improvement.

3.1.4 Sensor and Machine Learning Design

The Sensor and Machine Learning Design module integrates IoT sensors and machine learning models to automate waste sorting. IoT sensors detect physical properties such as weight, material composition, and metal presence. The system uses YOLO for real-time object detection and CNN for advanced image-based classification, ensuring high accuracy in waste categorization.

3.1.5 System Analytics Design

The System Analytics Design module aggregates and analyzes user and system data. It securely stores recycling performance metrics and classification results, providing users with comprehensive reports. This module also identifies recycling trends, offering users actionable insights to enhance their waste management practices and contribute to sustainability goals.

3.2 User Scenarios

3.2.1.1 Waste Sorting Process

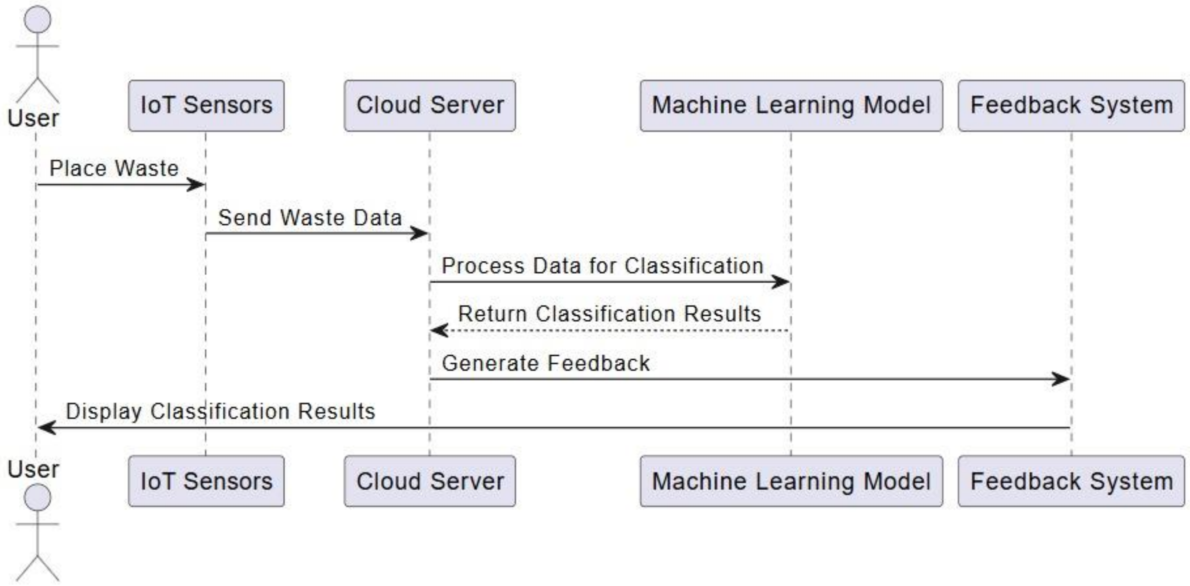


Figure 5 Waste Sorting Process

3.2.1.2 Waste Classification Process

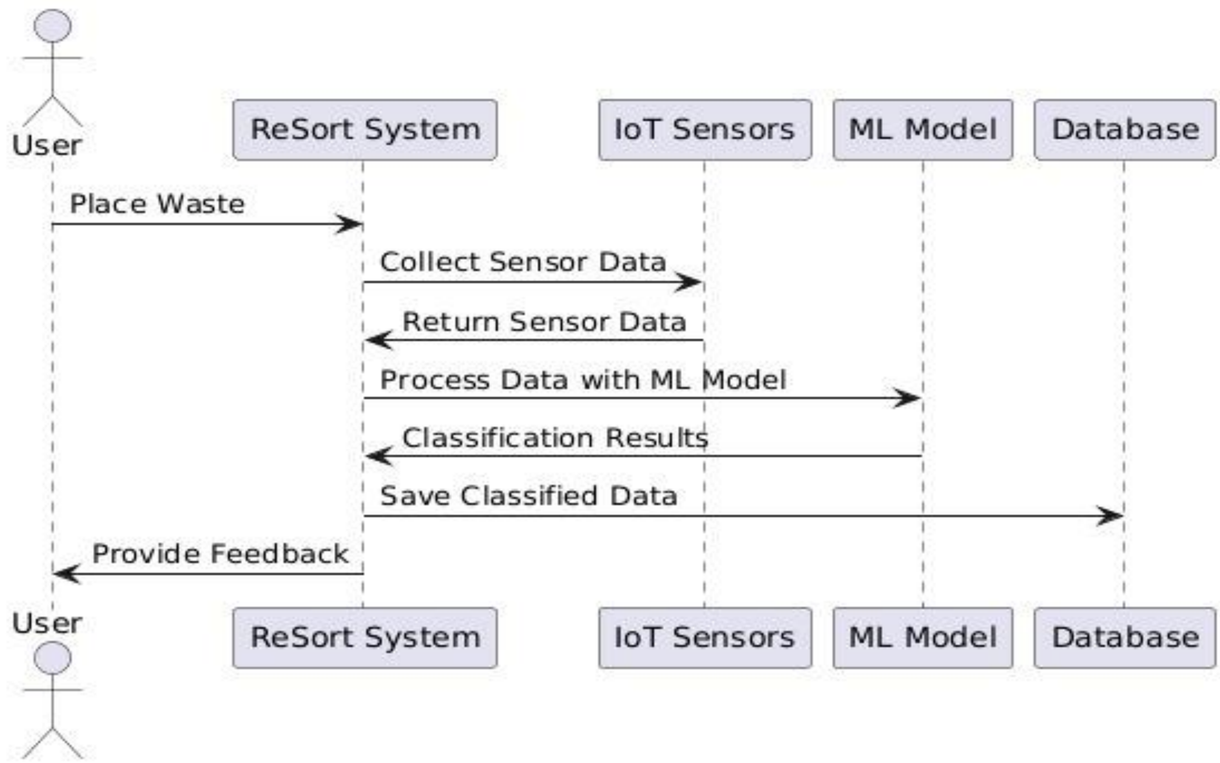


Figure 6 Waste Classification Process

3.2.2 Feedback and Logging Process

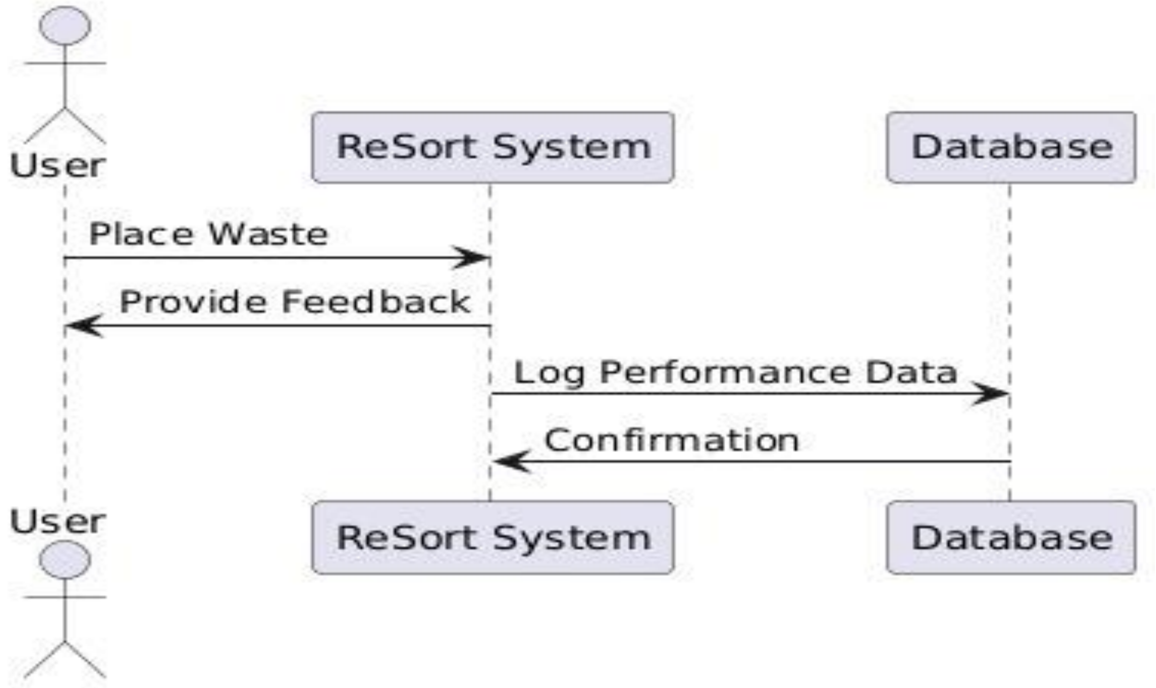


Figure 7 Feedback and Logging Process

3.2.3 Feedback and Analytics

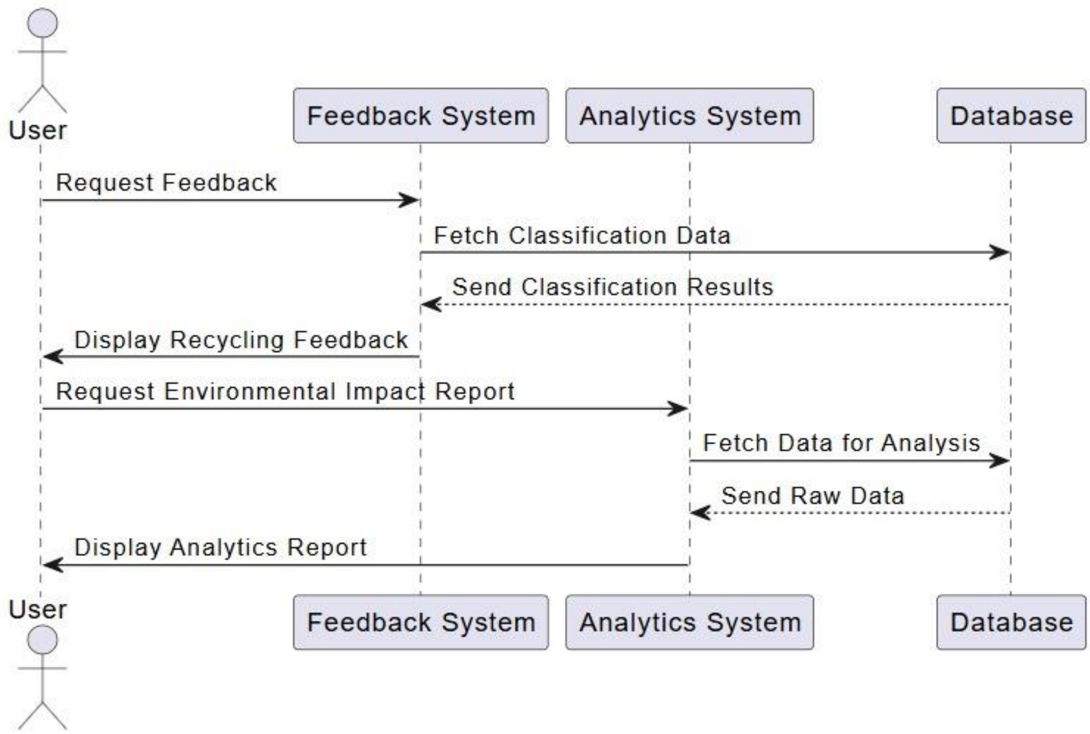


Figure 8 Feedback and Analytics

3.3 Activity Diagrams

3.3.1 Activity Diagram 1

Figure 9 Activity Diagram 1

3.3.2 Activity Diagrams 2

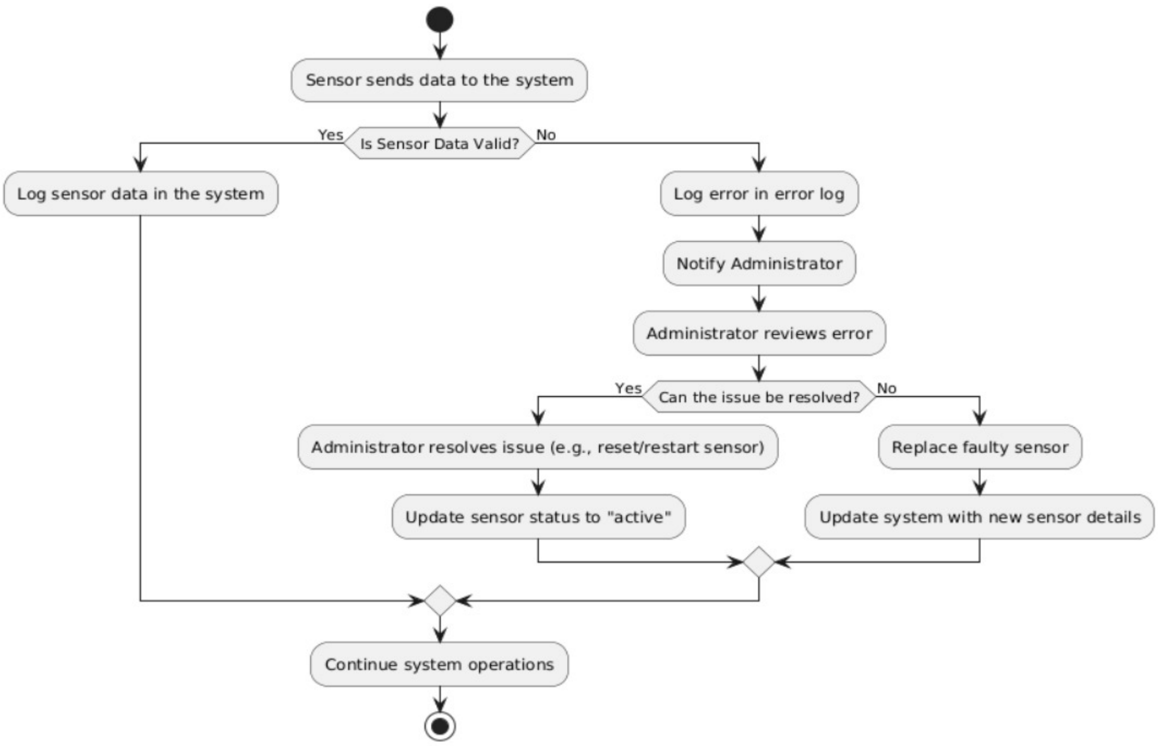


Figure 10 Activity Diagram 2

3.4 User Interface

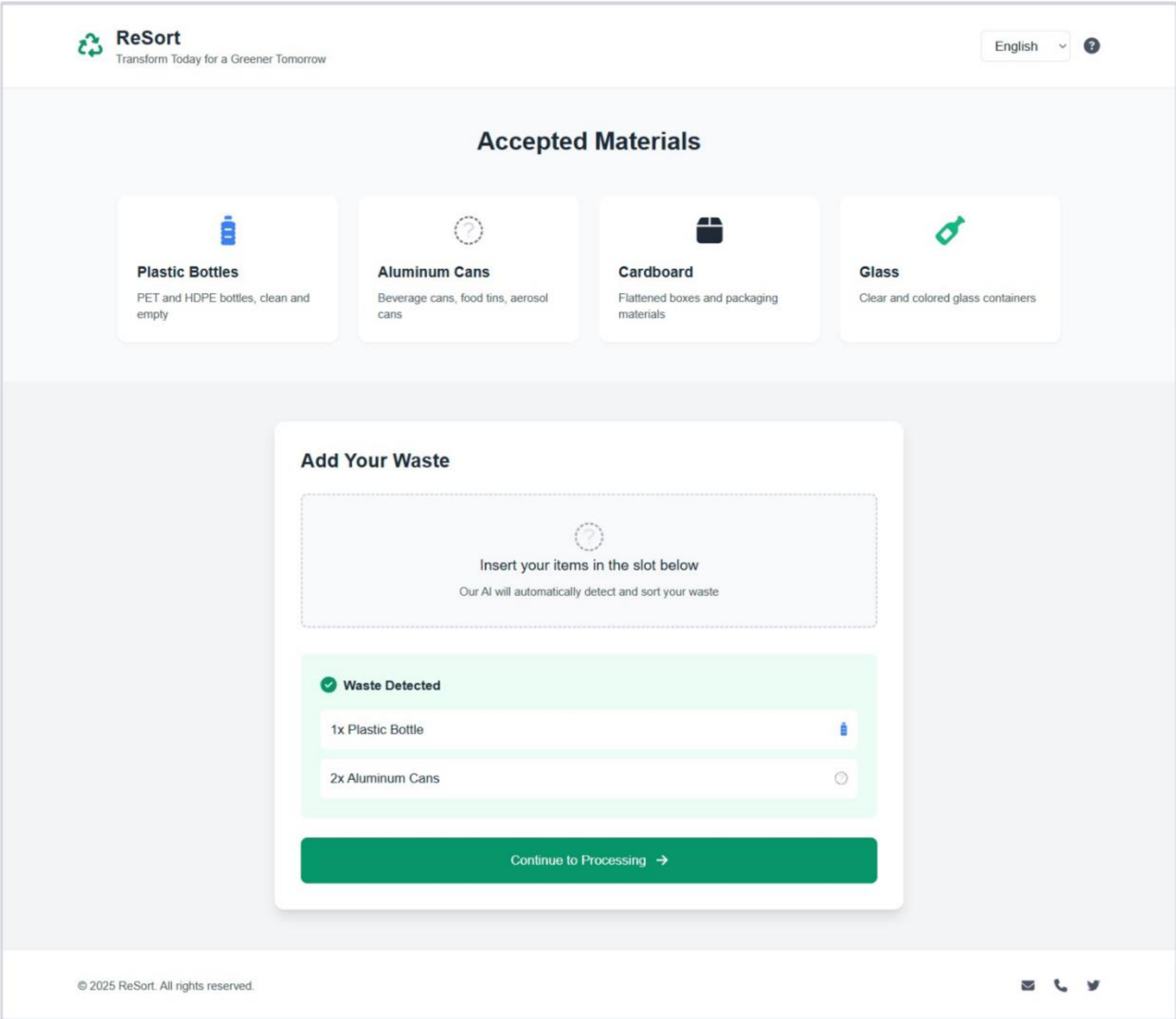


Figure 11 User Interface 1

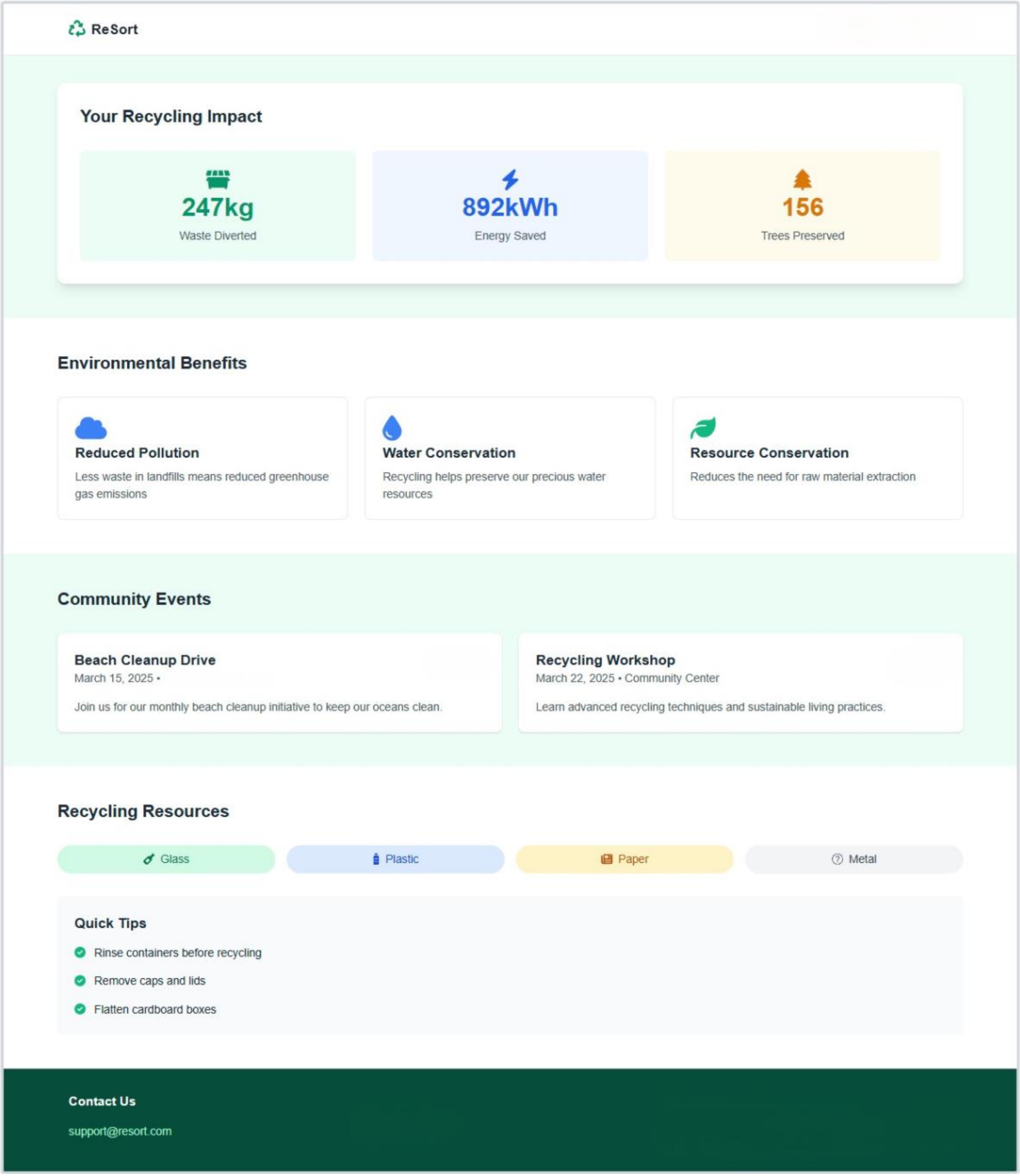


Figure 12 User Interface 2

4. ENVIRONMENT

4.1 Modelling Environment

The ReSort system incorporates advanced modelling environments to simulate real-world waste sorting processes. These environments are designed to provide users with an intuitive and interactive experience, combining visual representations and real-time system feedback.

In the Sorting Environment, users interact with the system by placing waste materials into the input area. This environment includes 3D models of recyclable materials such as plastics, metals, and organic waste, as well as virtual representations of the IoT sensors and sorting mechanisms. The inventory panel displays all detected waste items, categorized by their type, weight, and other physical properties. For example, when a user places a plastic bottle into the system, it is analyzed and classified by machine learning algorithms, and the results are shown on the feedback panel. This immediate feedback allows users to understand how their waste is being processed, promoting better recycling habits.

Additionally, the Visualization Environment provides detailed analytics to users, enabling them to track their recycling performance over time. This environment includes visualizations such as graphs, charts, and tables, which present metrics like total waste sorted, classification accuracy, and environmental impact. For instance, users can view how much waste they have recycled in a week and how their efforts have reduced their carbon footprint. These insights are designed to motivate users by showing the tangible benefits of their recycling activities.

The system also supports advanced simulations to handle mixed waste scenarios. These simulations test the system's capability to sort and classify complex waste combinations, ensuring robust performance under diverse conditions. By accurately simulating these scenarios, the ReSort system provides users with a realistic and educational experience, fostering greater understanding and engagement with the recycling process.

The modelling environment in ReSort is developed using modern 3D design tools such as Blender, which allows the creation of realistic models that integrate seamlessly with the system. This approach ensures that both the visual and functional aspects of the system are highly immersive and effective, making the recycling process more accessible and appealing to users of all backgrounds.

Conclusion

The ReSort Intelligent Recycling System successfully addresses the challenges of modern waste management by integrating automation, precision, and sustainability. Using IoT sensors and machine learning algorithms, the system ensures accurate waste classification, reduces human intervention, and enhances recycling efficiency across diverse settings. By offering real-time feedback, performance analytics, and a scalable architecture, ReSort not only promotes better recycling habits but also supports broader environmental goals, such as reducing landfill waste and lowering carbon emissions. This system underscores the importance of technological innovation in fostering sustainable practices, paving the way for smarter and more effective waste management solutions that contribute to global ecological well-being.