ÇANKAYA UNIVERSITY

Software Requirements Specification

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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 centres, 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 aiming 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 aiming 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) 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:

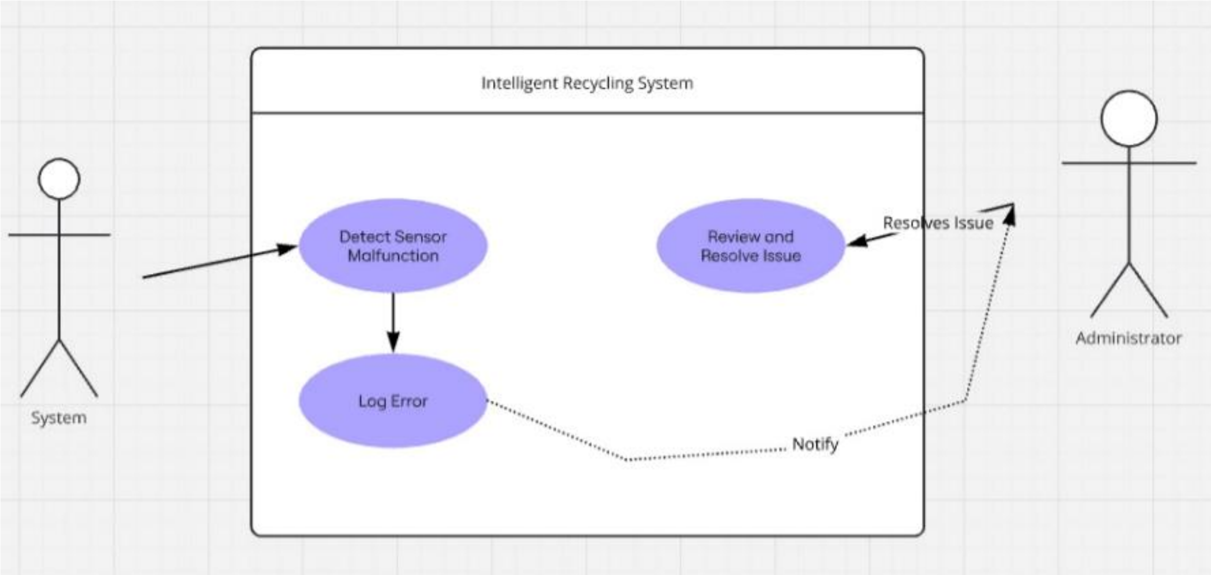

Figure 1 Sensor Malfunction Detection and Resolution

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:

Use Case:

- Predict Maintenance Needs
- Suggest Schedule
- Approve Schedule

Diagram:

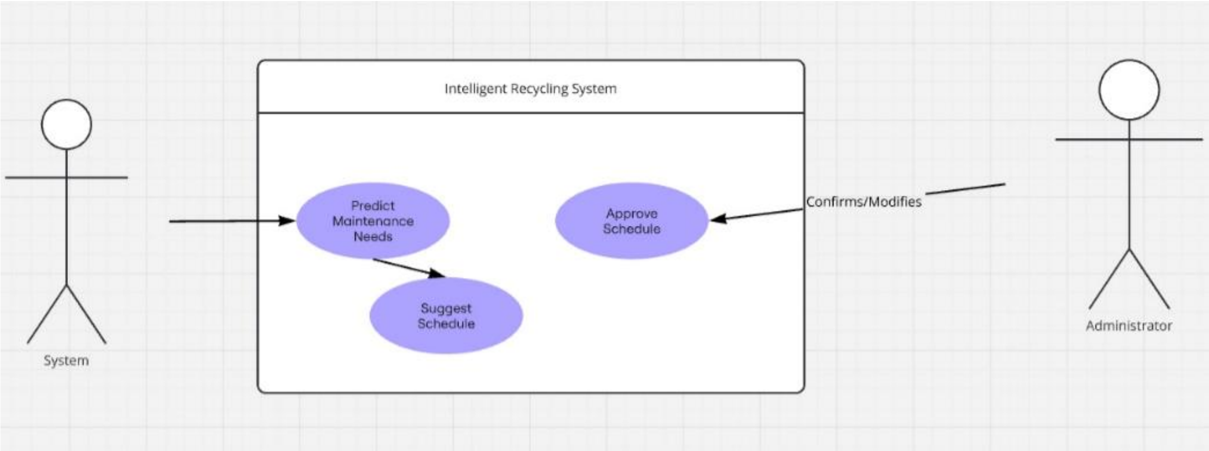

Figure 2 Maintenance Scheduling and Approval Process

Brief Description:

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:

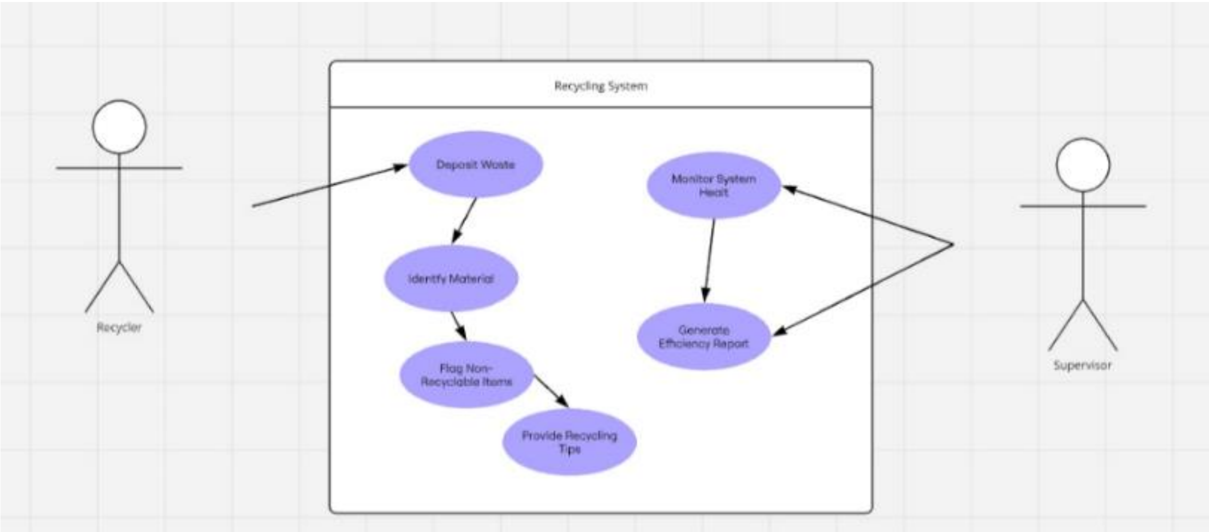

Figure 3 Recycling Workflow and System Monitoring

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:

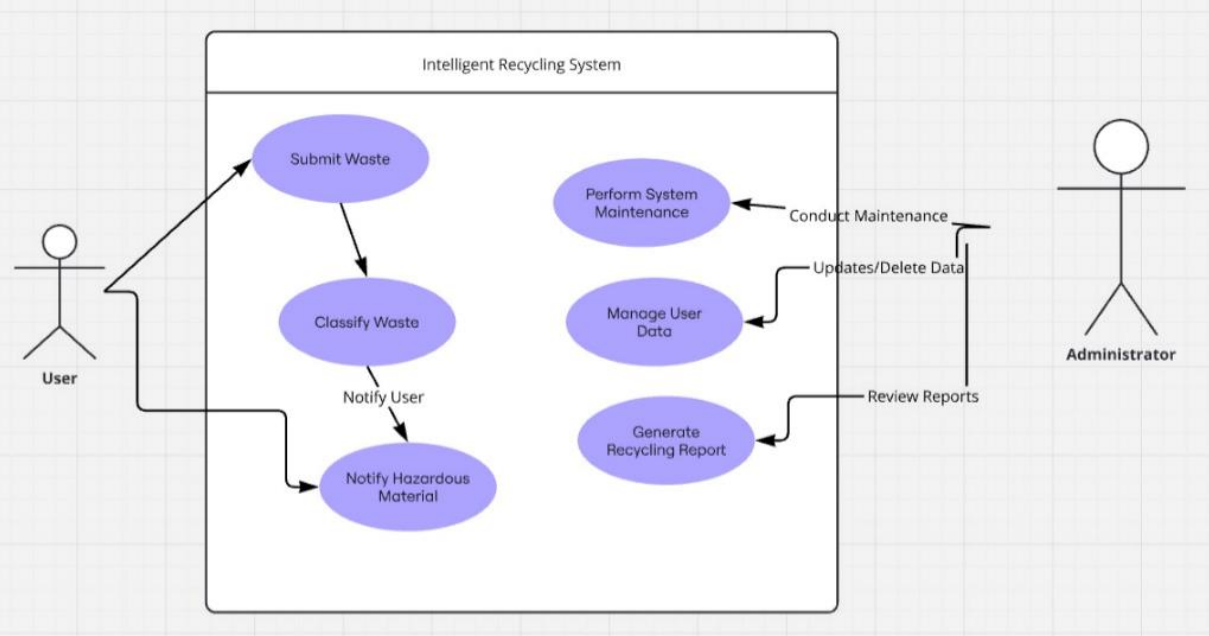

Figure 4 Comprehensive Recycling System Operations

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 into 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:

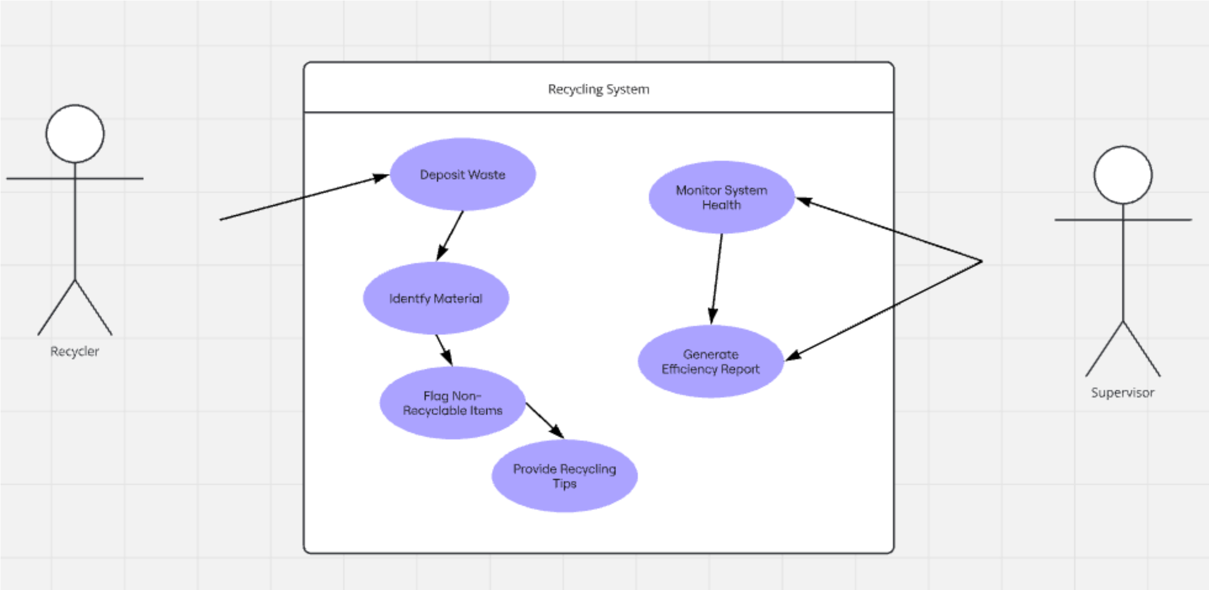

Figure 5 Integrated Recycling and System Monitoring Workflow

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. **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.
4. **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.
5. **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*.