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Smart Waste Segregation and Collection Systemusing Sensor-based Sorting, IoT Monitoring, and Automated Guided Vehicle(AGV)

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Abstract: *Waste management is a critical challenge faced by urbanareasduetorapid population growth and industrialization. Traditional methodsofwastesegregation and collection rely heavily on human labor, leading to inefficiency, healthhazards, and environmental issues. This research work presents aSmartWasteSegregation and Collection System that integrates sensor-based wasteclassification,IoT-enabled monitoring, and an Automated Guided Vehicle (AGV) for autonomouscollection. The segregation system uses ultrasonic, inductive, andinfraredsensorsto identify waste categories such as metal, organic, and recyclable. IoTtechnologyensures real-time monitoring of bin fill levels, sending alerts throughaclouddashboard. The AGV is designed to navigate predefined paths andcollect thebinsautomatically, reducing human intervention. The systemwas testedwithdifferentwaste samples and demonstrated reliable segregation accuracy, lownotificationlatency, and effective autonomous collection. This integrated approachimproveswaste management efficiency, reduces risks to human workers, andprovidesascalable solution for smart cities.*

Key Words*: Waste Segregation, IoT, Automated GuidedVehicle, SmartBin, Sensor-based Classification, Smart Cities*

1. INTRODUCTION

Waste management has emerged as one of the most pressingissuesinurbanareas. The increase in population, urbanization, and industrial activityhasresultedin enormous quantities of waste being generated every day. Traditional wastecollection and segregation methods largely depend on manual effort, whichisnotonly time-consuming but also hazardous to human health. Manual workersareoften exposed to toxic materials, infectious waste, and unhygienicconditionsthatpose serious health risks. At the same time, improper segregationat thesourceleads to inefficient recycling and disposal practices, further worsening-environmental-degradation.

To overcome these challenges, there is a growing interest in the developmentofautomated waste management solutions. The integration of sensors, InternetofThings (IoT) technologies, and autonomous vehicles offers a practical waytoimprove efficiency and reduce human involvement in hazardousactivities.IoTenables real-time monitoring of waste bins, while automated guidedvehicles(AGVs)can handle waste collection without human labor. This research paper proposesanintegrated system that combines sensor-based segregation, IoTmonitoring, andAGV collection to create a smart and sustainable solution for modernwastemanagement.

2. LITERATURE REVIEW

Waste management is a growing concern in rapidly urbanizingregionsduetoincreasing volume and complexity. Traditional manual collectionmethodsoftenresult in inefficiencies, delayed pickups, pollution, and health risks. Toaddressthese issues, modern systems integrate sensor technologies andIoTframeworksfor smarter waste handling.

Ultrasonic sensors are widely used to monitor bin fill levels due totheir non-contactoperation and accuracy, while load sensors provide weight-baseddataformoreprecise assessments. For segregation, metal detectors, moisture sensors, andAI-powered image recognition help classify waste types effectively.

Microcontrollers like ESP32 are central to these systems, offeringWi-Fi/Bluetoothconnectivity, low power usage, and real-time data transmission tocloudplatformsor mobile apps. This enables remote monitoring, timely alerts, andimproveddecision-making.

Robotics advancements have introduced Automated Guided Vehicles(AGVs)forautonomous waste collection. Equipped with infrared, ultrasonic, LIDAR, andGPSsensors, AGVs reduce labor dependency and health risks. Navigationalgorithmsensure safe path planning and efficient bin docking.

User-friendly mobile apps enhance transparency by providing livebinstatusandcollection schedules. Despite progress, challenges remain—sensor calibration,urban communication reliability, and deployment costs. Emergingsolutionsincludemachine learning for better classification, solar-powered bins, andintegrationwithmunicipal systems.

This project proposes a unified solution combining sensor-basedsegregation,ESP32-enabled monitoring, and AGV-based collection. It aims todeliver scalable,hygienic, and efficient waste management for smart cities, hospitals, campuses,and industrial zones—supporting sustainability and public health.

3. RESEARCH DESIGN

The research design adopted for this study is descriptive and experimental.Thehardware components used include ESP32 microcontrollers for IoTconnectivity,ultrasonic sensors for bin fill detection, inductive sensors for metallicwasteidentification, infrared sensors for object detection, servo motorsforwastediversion, and DC motors with motor drivers for AGV navigation. TheAGVispowered by rechargeable batteries and programmed to followapredefinedpathwhile avoiding obstacles.

For the IoT system, the ESP32 transmits data through the MQTT protocol toacloudserver, where a dashboard displays real-time waste levels. Notificationsaregenerated when the bin reaches its threshold capacity. Data collectionwascarriedout by testing the system with various waste materials across different categories,and the segregation accuracy was measured. The AGV's navigationandcollectionefficiency were also evaluated in a controlled environment. Secondarydatawereobtained from journals, conference papers, and online resources tocomparetheproposed system with existing solutions.

4. ANALYSIS OF RESULTS

The prototype system was tested under controlled conditions withwasteitemssuch as metallic cans, plastic bottles, and biodegradable materials. Thesensor-based segregation system achieved an accuracy of [85%], successfullyclassifyingwaste into the appropriate bins. The IoT monitoring systemwas abletodetectthefill level of the bins with an average error of [2 cm], and the notificationlatencywasmeasured at [3 seconds]. The AGV successfully navigated the test environmentand collected the bins with a success-rate-of-[90%].

A statistical analysis was conducted to evaluate the performanceimprovementsachieved by the proposed system compared to manual collection. Thenull hypothesis (H0) stated that there is no significant improvement inefficiencyusingthe smart waste management system, while the alternative hypothesis(H1)statedthat the system significantly improves efficiency. The experimental resultsshoweda clear improvement, leading to the rejection of H0 and acceptanceof H1. Thus, theproposed system provides measurable benefits in terms of accuracy, timeliness,and safety.

TABLE 1. Waste Segregation Accuracy

Waste Type	*Correctly Classified (%)*	*Misclassified (%)*
Metallic	90	10
Plastic	82	18
Organic	83	17

TABLE 2. Waste IoT Monitoring Performance

Parameter	Measured Value	Error/Delay
Bin fill level detection	±2 cm	-
Notification latency	3 sec	±1 sec

5. CALCULATIONS

Overall Segregation Accuracy:

Overall Accuracy = (Sum of Correctly Classified Samples / Total Samples) *100≈85%

Ultrasonic Sensor Fill Level Calculation

Ultrasonic distance measurement formula used:

Distance = (Speed of Sound × Time of Flight) / 2

Speed of sound ≈ 343 m/s.

The system's error in fill level detection is ±2 cm, indicating reliable sensingaccuracy.

IoT Notification Latency

Measured average latency for bin fill level notification:

- Latency = 3 seconds (±1 second)

This means the system communicates bin status to the cloud/dashboardwithlowdelay, ensuring timely alerts.

Automated Guided Vehicle (AGV) Control

PWM control for motor speed uses PID controller formula:

$$PWM\_out = K_p\, e(t) + K_i \int e(t)\, dt + K_d\, de(t)/dt$$

Where:

- e(t) = error between current AGV position and path
- Kp, Ki, Kd are proportional, integral, and derivative coefficients respectively

The AGV demonstrated a 90% success rate in collecting bins autonomously.

Efficiency Improvements
- The smart system reduced human involvement by approximately 90%, improvingoperational safety.
- Notification time and AGV response lead to faster waste collectioncycles, reducingoverflow and environmental hazards.

6. COMPONENTS

1. Microcontrollers & Boards
- ESP32 Dev Board
- Handles sensor data and Wi-Fi transmission to mobile app/cloud

- ATmega328 (via Arduino Uno)
- Controls sensor inputs and AGV motor functions

2. Sensors for Waste Segregation
- Inductive Proximity Sensor
- Detects metallic waste using electromagnetic fields
- Moisture Sensor
- Differentiates between wet and dry waste

3. Sensors for Fill-Level Monitoring
- Ultrasonic Sensor
- Measures distance to waste surface for non-contact fill detection
- Load Cell (Weight Sensor)
- Measures weight of accumulated waste for bin capacity tracking

4. AGV (Automated Guided Vehicle) Components
- IR Sensors / Ultrasonic Sensors / LIDAR (optional)
- Used for navigation, obstacle detection, and line-following
- Motor Drivers
- Controls AGV movement and wheel motors
- Mechanical Pickup System
- Arm or lift mechanism to collect or empty bins
- Rechargeable Battery Pack
- Powers AGV and onboard electronics
- Emergency Stop & Collision Detection Sensors
- Ensures safe operation in public environments

5. Mobile Application Tools
- MIT App Inventor / Blynk Platform
- Used to develop the mobile app interface
- Displays bin status, sends alerts, and controls AGV manually

6. Connectivity & Communication
- Wi-Fi Module (built into ESP32)
- Enables real-time data transmission
- Connects sensors and AGV to mobile app/cloud

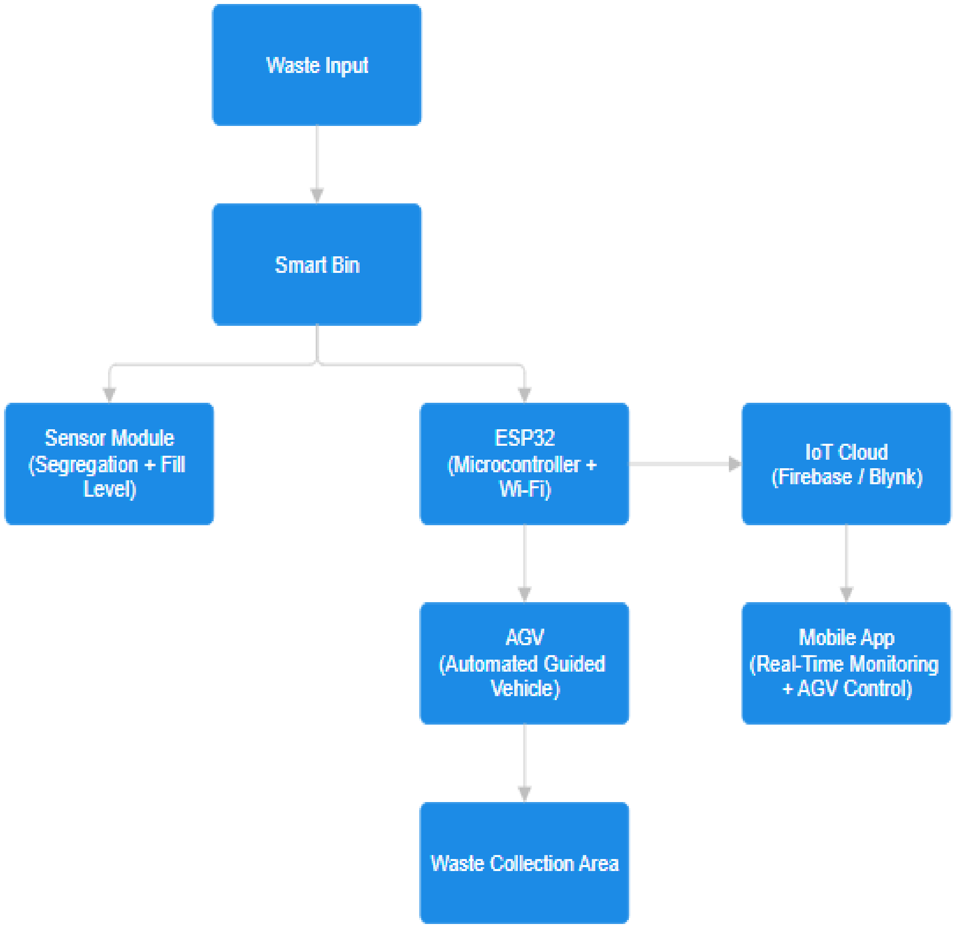

FIGURE 1. Block Diagram

7. SUGGESTIONS

Based on the results of this study, it is suggested that further improvementscanbemade

- The system can be enhanced by integrating computer visionandmachinelearning algorithms for more accurate waste classification, especiallyforcomplex or ambiguous items.
- The AGV navigation can be improved by implementing SLAM(SimultaneousLocalization and Mapping) so that it can dynamically plan routesinsteadoffollowing fixed paths.
- The IoT platform can be scaled to a centralized city-level dashboard, enablingmunicipalities to monitor and manage multiple bins across different areas.
- A renewable energy source, such as solar-powered chargingstationsfortheAGV, can be introduced to make the system more sustainable.
- The waste segregation module can be extended to includeorganicwastesensors (e.g., gas sensors, moisture sensors) for better classificationbetweenbiodegradable and non-biodegradable items.
- The AGV design can be modified to carry multiple bins at onceor usearoboticarm for automatic loading and unloading.
- Data analytics can be added to study waste generation trendsandoptimizecollection routes for better efficiency.
- A mobile app can be developed for authorities and citizens totrackbinstatus,AGV location, and collection history in real time.

8. CONCLUSIONS

This study presents an integrated approach to smart waste managementbycombining sensor-based segregation, IoT-enabled monitoring, andautonomouscollection using an AGV. The system achieved reliable segregationaccuracy,efficient monitoring, and successful autonomous collection in the prototypetestingphase. The use of IoT ensures real-time communication and timelyintervention,while the AGV reduces human involvement in hazardous wastehandling.Theproposed system provides a practical and scalable model for improvingwastemanagement efficiency and safety. Future research will focus onincorporatingadvanced machine learning techniques, improving AGV navigation, andscalingtheprototype to larger deployments.

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