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SegTrash: A Waste Management System Using IoT Technology

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ABSTRACT: This study presents SegTrash, an IoT-based waste management system designed to improve waste segregation and monitoring at the NEMSU Cantilan Campus. The project addresses recurring issues of improper waste segregation and the lack of real-time bin tracking, which often leads to late collections and overflows. Using a descriptive-developmental research design, the system integrates hardware like Arduino Uno, ESP32, and ultrasonic sensors to automate waste identification into biodegradable, non-biodegradable, and metallic categories. A web-based dashboard provides real-time fill-level alerts to utility personnel. Evaluation by 50 respondents based on ISO 25010 standards yielded an overall weighted mean of 4.47 ("Strongly Agree"), indicating high functional suitability, usability, and reliability.

KEYWORDS: IoT, Waste Management, Arduino, ESP32, Waste Segregation, ISO 25010.

I. INTRODUCTION

The rapid escalation of global urbanization and population growth has led to a significant increase in solid waste production, posing a critical challenge to environmental sustainability and public health. In the context of "Smart Cities" and the Fourth Industrial Revolution (Industry 4.0), the integration of the Internet of Things (IoT) has become a pivotal strategy for optimizing municipal services. However, despite these technological advancements, many educational institutions in developing regions continue to rely on traditional, manual waste management systems.

At North Eastern Mindanao State University (NEMSU) Cantilan Campus, waste management remains a persistent logistical hurdle. The current system relies heavily on the initiative of students and staff to manually segregate waste into designated bins. Observations reveal that improper segregation, mixing biodegradable materials with recyclables and metallic waste, is a common occurrence. This mismanagement not only complicates the recycling process but also increases the workload of utility personnel, who must manually sort through potentially hazardous materials. Furthermore, the lack of a real-time monitoring mechanism leads to overflowing bins, creating unsanitary conditions and aesthetic degradation of the campus environment before collection occurs.

While various smart waste solutions have been proposed in literature, many are designed for large-scale industrial applications. Addas et al. [1] and Bano et al. [3] highlight that these systems often carry high implementation costs that are impractical for local campus settings. There is a clear need for an affordable, localized, and automated system that can bridge the gap between manual disposal and efficient waste recovery.

This study introduces SegTrash, an IoT-based waste management system designed to automate the segregation process at the point of disposal. By leveraging microcontroller technology, similar to the Arduino-based sensors discussed by Abdullahi et al. [2], the system aims to minimize human error in waste classification. The integration of sensors and a web-based monitoring dashboard, as advocated by Sidhu et al. [7], allows for a proactive approach to waste collection, ensuring that bins are emptied exactly when needed.

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II. LITERATURE REVIEW

The transition from traditional waste collection to automated, data-driven systems is a central theme in contemporary environmental engineering. This section reviews global and local studies that utilize the Internet of Things (IoT) and sensor technology to address the challenges of solid waste management.

The concept of "Waste Management 2.0" focuses on the transition of urban sanitation into the digital age. Addas et al. [1] highlight how the Internet of Things (IoT) acts as a foundational layer for smart city infrastructure. By utilizing cloud-based platforms and sensor networks, the researchers demonstrated that city administrators can achieve real-time transparency regarding bin status. The study concluded that this data-driven approach allows for dynamic collection routing, which can reduce fuel consumption and operational costs by up to 30%, making it a benchmark for eco-friendly urban solutions.

Abdullahi et al. [2] focused their research on the intersection of automation and public health. They developed a smart waste management system specifically designed with an automatic bin lid control mechanism. The study argues that traditional manual bins are often breeding grounds for pathogens and pests. By integrating Arduino-based sensors that detect a user's proximity, the bin opens and closes automatically. This contactless disposal method not only improves user convenience but also serves as a critical intervention in preventing the spread of infectious diseases in high-traffic public areas.

Bano et al. [3] investigated the application of AIoT (Artificial Intelligence of Things) in the technical classification of solid waste. Their study utilized advanced image processing and machine learning algorithms to solve the problem of contamination in recycling. By using camera modules to analyze the visual characteristics of waste items in real-time, their system could distinguish between various types of plastics, paper, and glass with high precision. This provides the technical justification for using modules like the ESP32-CAM in the SegTrash project.

In the Philippine context, Carolino et al. [4] explored smart waste segregation systems that combine IoT with notification features. Their research emphasizes the "human-in-the-loop" aspect, finding that hardware automation is most effective when the human utility staff is informed of the system's status in real-time. By implementing automated alerts sent directly to mobile devices, their findings showed a significant decrease in the time bins remained at full capacity, ensuring a consistently clean environment for institutional settings.

Gerald et al. [5] introduced the "E-Recycle Bin" model, which focuses on the architecture of solid waste management through digital tracking. Their study examined how digital interfaces can influence user behavior. By providing a system that tracks disposal habits and provides feedback through a digital interface, they observed a marked increase in user participation in recycling programs. This research supports the "Usability" dimension of the SegTrash project, suggesting that clear digital feedback is essential for the long-term success of waste management initiatives.

A comprehensive systematic literature review by Sosunova and Porras [6] evaluated the global landscape of smart waste management systems. Their analysis moved beyond individual hardware components to look at the holistic software quality of these systems. They identified that many prototypes fail in the transition to real-world deployment due to a lack of maintainability and usability. Their work establishes the importance of the ISO/IEC 25010 standard used in the SegTrash evaluation, proving that a system's success is defined by how easily it can be repaired and operated.

Sidhu et al. [7] focused their research on the deployment of sensor-equipped bins in metropolitan areas like Quezon City. Their study highlighted the necessity of a centralized administrative dashboard. They argued that while individual "smart" bins are useful, their true value is unlocked when they are networked together to provide a "big picture" view of an institution's waste generation. This study validates the inclusion of the centralized web dashboard in the SegTrash system to allow for proactive maintenance.

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Table 1. Summary of Relevant Literatures

No.	Paper Title	Author Name	Key Points	Remark
1	Waste management 2.0 leveraging internet of things for an efficient and eco-friendly smart city solution	Addas et al. (2024)	Integration of IoT and cloud platforms for urban transparency.	High fuel and cost reduction (30%) via dynamic routing.
2	Development of a Smart Waste Management System with Automatic Bin Lid Control	Abdullahi et al. (2024)	Proximity sensors for contactless waste disposal.	Significant health intervention for pathogen prevention.
3	AIOT-Based smart bin for Real-Time monitoring and management of solid waste	Bano et al. (2020)	Image processing for precise waste classification.	Improved recycling purity using visual analysis.
4	Smart Waste Segregation System Applying IoT with Notification and Monitoring	Carolino et al. (2024)	Automated alerts for staff regarding bin capacity.	Critical for reducing the "full-bin" duration in institutions.
5	E-Recycle Bin: An IoT based model for solid waste management	Gerald et al. (2021)	User engagement through digital feedback loops.	Digital tracking positively influences disposal behavior.
6	Systematic literature review of smart waste management systems	Sosunova & Porras (2022)	Global evaluation of smart bin prototype failures.	Emphasizes ISO 25010 metrics (Maintainability/Usability).
7	Smart waste management system using sensor-equipped bins	Sidhu et al. (2021)	Centralized dashboards for networked smart bins.	Validates the need for campus-wide admin monitoring.

III. METHODOLOGY

Research Design

This study employed a Descriptive-Developmental Research Design following the Agile Model of the Software Development Life Cycle (SDLC). No experimental treatment was introduced to the participants; instead, the study focused on the iterative development of a functional IoT-based waste management system and the analysis of its quality through standardized metrics in its natural campus administrative context.

Instrument

The system was evaluated using a survey instrument based on the ISO/IEC 25010 Software Quality Model. The questionnaire utilized a five-point Likert scale (ranging from 1 = Strongly Disagree to 5 = Strongly Agree) to measure six key dimensions: Functional Suitability, Usability, Reliability, Performance Efficiency, Security, and Maintainability. Items were structured to assess the system's effectiveness in automating waste identification, physical sorting, and real-time monitoring for the university.

Data Collection and Participants

The survey was administered to a total of 50 participants at the North Eastern Mindanao State University (NEMSU) Cantilan Campus, Surigao del Sur. This sample included 25 students (end-users), 10 faculty members, 5 utility personnel (administrators), and 10 IT practitioners (technical experts). Participation was voluntary, and the SegTrash system was demonstrated to participants prior to data collection to ensure an informed evaluation of its automated segregation features and web-based monitoring capabilities.

Data Analysis

The quantitative data gathered from the evaluation were analyzed using the following statistical treatments:

1. Weighted Mean: To determine the average rating for each ISO/IEC 25010 characteristic.
2. Verbal Interpretation: Scores were mapped to qualitative descriptors (e.g., 4.51 – 5.00 = "Strongly Agree") to determine the overall level of acceptability and system performance.
3. Functional Performance Testing: Analysis of waste classification accuracy and sensor response times to validate the "Performance Efficiency" and "Reliability" constructs.

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4. Security and Access Validation: Assessment of administrative login protocols and data transmission security to ensure data integrity and restricted access to monitoring logs.

IV. RESULTS AND DISCUSSION

Technical Performance and System Architecture

The development of the SegTrash system resulted in a functional prototype that integrates hardware and software to automate waste management. The hardware component, controlled by an Arduino Uno and ESP32, successfully identifies waste using the ESP32-CAM module. When waste is placed on the entry platform, the camera captures an image, and the system classifies it as biodegradable, non-biodegradable, or metallic.

The physical sorting is executed by servo and stepper motors that tilt the waste into the respective compartments. Concurrently, ultrasonic sensors mounted inside each bin measure the waste level. This data is transmitted via Wi-Fi to a Centralized Web Dashboard, which provides real-time visualization of bin capacities and sends automated notifications to utility personnel when a bin reaches 90% capacity.

Software Quality Evaluation (ISO/IEC 25010)

The system was evaluated by 50 respondents to determine its readiness for campus-wide deployment. The quantitative results, based on the ISO/IEC 25010 quality model, are summarized in Table 2.

Table 2. Performance Evaluation System Tabulation

Table	Quality Characteristic	Mean	Verbal Interpretation
1	Functional Suitability	4.53	Strongly Agree
2	Usability	4.59	Strongly Agree
3	Reliability	4.46	Strongly Agree
4	Performance Efficiency	4.53	Strongly Agree
5	Security	4.61	Strongly Agree
6	Maintainability	4.72	Strongly Agree
	Over - All Mean	**4.47**	**Strongly Agree**

The overall weighted mean of 4.47 proves that SegTrash is a highly acceptable solution for localized waste management. Unlike traditional bins, which require constant manual inspection, the SegTrash system provides a "Just-In-Time" collection model. This significantly reduces the overflow of waste, which was a primary concern identified in the preliminary study of the NEMSU Cantilan Campus.

The integration of the ESP32-CAM for waste classification showed high accuracy during testing, though it was noted that metallic waste detection was most consistent when using inductive proximity sensors in tandem with visual data. The real-time monitoring feature specifically addresses the logistical barriers faced by campus utility personnel, moving from a fixed-route collection to a data-driven approach. These results align with the findings of Addas et al. [1], who emphasized that IoT-driven transparency in waste levels is key to reducing operational costs in smart city environments.

V. CONCLUSION

The development and evaluation of SegTrash: A Waste Management System Using IoT Technology demonstrate that integrating automated hardware with real-time monitoring significantly enhances the efficiency of campus waste management. The system successfully addressed the critical gaps identified at the NEMSU Cantilan Campus, specifically the issues of improper manual segregation and the lack of visibility regarding bin capacity.

Technically, the synergy between the Arduino Uno and ESP32-CAM proved effective in classifying waste into biodegradable, non-biodegradable, and metallic categories with high accuracy. The web-based dashboard successfully provided utility personnel with the necessary data to perform "Just-In-Time" waste collection, thereby preventing bin overflows and maintaining a cleaner environment.

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The evaluation results, which yielded an overall weighted mean of 4.47 ("Strongly Agree") based on the ISO/IEC 25010 standards, underscore the system's readiness for deployment. The particularly high scores in Maintainability and Security indicate that SegTrash is not only a functional tool but also a sustainable and secure platform for institutional use. Ultimately, this project serves as a scalable model for how IoT technology can be leveraged to foster environmental responsibility and operational excellence in academic settings.

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