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Dual-Mode Smart Waste Bin with Sensor-Based Sorting and Waste Compacting for Manual and Automatic Operation

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Abstract

This paper presents the design and implementation of a solar-powered, dual-mode smart waste management system capable of detecting, classifying, and compacting four categories of solid waste: metal, plastic, wet waste, and paper. The system employs inductive, capacitive, moisture, and ultrasonic sensors to achieve detection accuracies of 89%, 90%, 91%, and 92%, respectively. Integrated with a GSM-based SIM800C module, the system transmits real-time bin status via SMS to waste collection personnel, eliminating the need for internet connectivity and improving deployment feasibility in off-grid or rural locations. It supports both manual and automatic modes, enhancing user adaptability. Additionally, a built-in compacting and heating unit processes plastic waste, reducing its volume by up to 60%, thus extending bin capacity and facilitating recycling. Experimental validation over a 30-day testing period demonstrated 97% operational reliability. The proposed system offers a cost-effective, sustainable, and scalable solution for modern waste management, particularly in resource-constrained settings.

Keywords; Waste Management, Waste Sorting, GSM Communication, Dual-Mode Operation, Waste Compacting, inductive proximity sensor.

1. Introduction

The global increase in population has intensified the challenges of waste management, particularly in densely populated settings such as schools, hospitals, and religious centers. Traditional waste disposal methods, which are largely manual, remain inefficient and harmful to the environment. To address these issues, researchers have explored technological solutions. Maher et al. (2009) and Abdoli (2009) introduced RFID and GSM technologies for improved waste system monitoring. Visvanathan and Ulrich (2006) highlighted the inadequacies of traditional methods, while Anagnostopoulos et al. (2017) reviewed IoT models for smart city waste systems. However, many of these systems rely on internet-based infrastructure, which is often unreliable in rural settings. Alternatives such as GSM-based designs by Suganthi et al. (2019) addressed some limitations but lacked features like dual-mode operation and renewable energy integration. AI-powered solutions (Zhang et al., 2016) and Wi-Fi-dependent models (Longhi et al., 2012) also face scalability challenges in low-connectivity areas. In response, this study presents a cost-effective, solar-powered smart waste system with GSM-based alerts, dual-mode operation, and a built-in compacting unit. Designed to function without internet access, the system supports real-time waste classification and recycling, making it suitable for both urban and off-grid deployment in regions with limited infrastructure.

2.0 Materials and Methods

The system comprises an integrated set of electronic components and sensors working together to achieve reliable and intelligent waste sorting. At the core is the Arduino Uno R3 microcontroller, which controls all logical operations.

Fig. 1 inductive proximity sensor

Fig. 2 capacitive proximity sensor

For waste classification, the system utilizes three specialized sensors. An NPN inductive proximity sensor (Fig. 1) is used to detect metallic waste, while a capacitive proximity sensor (Fig. 2) identifies materials such as paper. A moisture sensor is installed to detect wet or organic waste. When none of these three sensors are activated during waste detection, the system defaults to classifying the item as plastic. This logic enables the automatic categorization of most common household and institutional waste types.

Fig. 3 SRO5 ultrasonic sensor

Fig. 4 BTS7960 motor driver

An SR05 ultrasonic sensor (Fig. 3) detects user presence and triggers the system, entering sleep mode after five minutes of inactivity to conserve energy. Relay circuits manage power distribution, while stepper motors and servo mechanisms, controlled via a BTS7960 driver (Fig. 4), automate bin lid operations and compartment rotation.

2.1 System Design and Configuration

The system architecture includes four subsystems: sensing, processing, actuation, and communication. Ultrasonic, inductive, capacitive, and moisture sensors gather real-time data, which is processed by the Arduino Uno R3. In automatic mode, the system opens the lid upon detecting a user and classifies the waste using sensor feedback, directing it to the appropriate bin via servo motors. The circuit was designed and simulated using TinkerCad (Fig. 5).

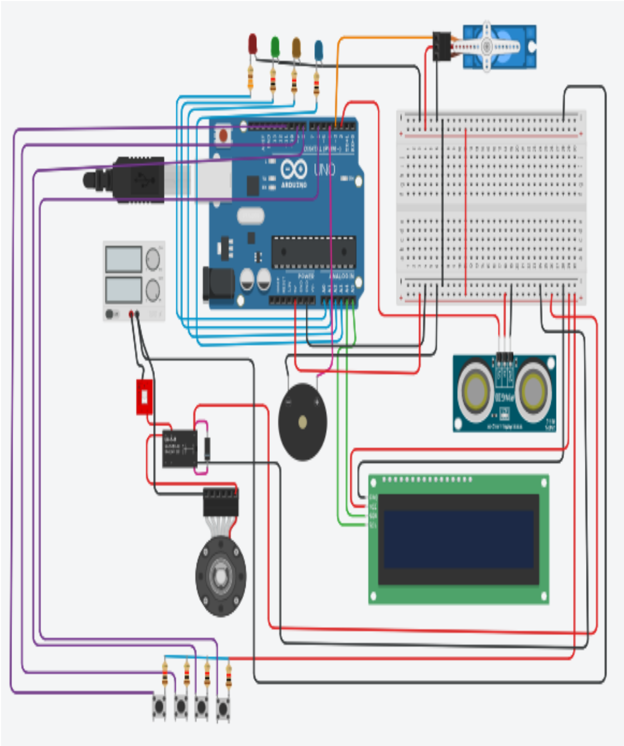

Fig. 5 System Circuit Diagram

Fig. 6 system side view

For manual mode, the user selects the type of waste by pressing a corresponding button. Once pressed, the system aligns the correct chamber as shown in fig. 6 and opens its lid, allowing waste to be deposited. This dual-mode operation shown on the front panel in fig. 7 ensures usability in a variety of contexts, including areas with limited automation capacity or user familiarity with smart systems.

Fig. 7 system front panel view

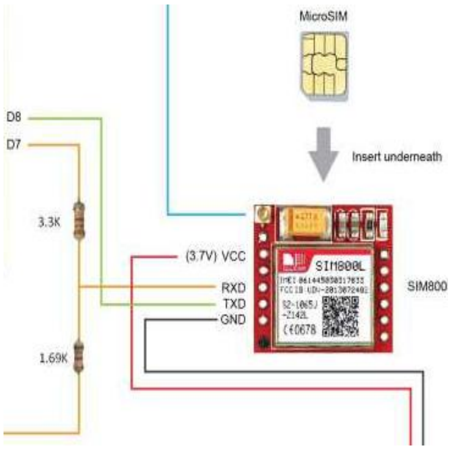

Fig. 8 SIM800 GSM circuitry

The SIM800C GSM module (Fig. 8) handles SMS-based communication, sending alerts without internet dependency. A 24V, 8A solar panel powers the system, charging a lithium-ion battery for off-grid use. To promote plastic waste sustainability, the system includes a heating and compacting unit that compresses identified plastic waste, enhancing storage and facilitating recycling. The smart bin houses four internal chambers for metal, plastic, paper, and organic waste. Fig. 9 illustrates the system flow logic whiles figure 10 show the four additional SR05 sensors which monitors the fill levels above each compartment.

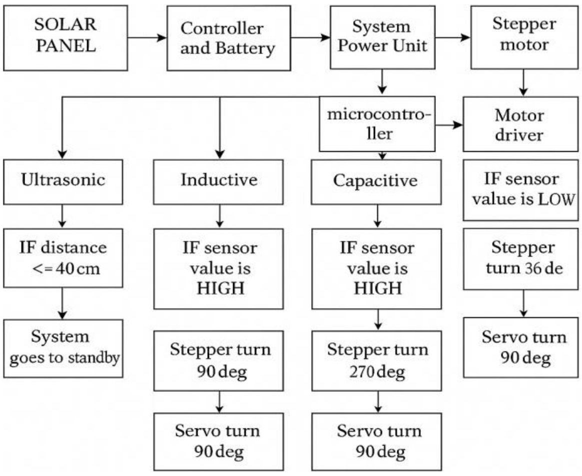

Fig. 9 System flow chart

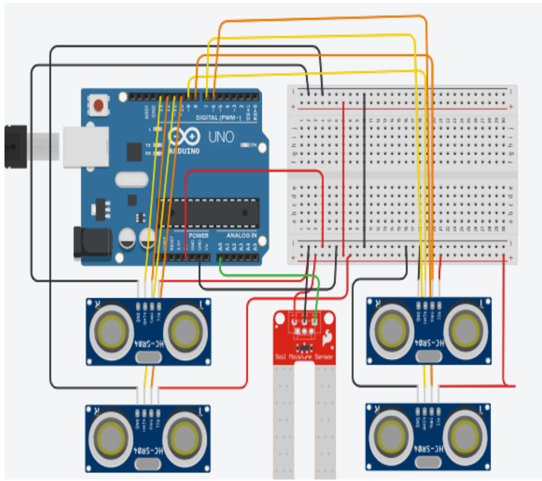

Fig. 10 System fill level detection circuit

2.2 Software Development

The system software was developed in Arduino IDE using embedded C++. It processes sensor inputs, controls motor actions, manages GSM alerts, and regulates power flow. The logic handles error detection, mode switching, sensor prioritization, and timing to avoid conflicts. GSM messages include location, bin identification, and fill level. Power-saving routines deactivate non-essential components when idle to improve energy efficiency and extend battery life in low-light conditions.

3.0 Results

The smart waste management system was built and tested successfully under lab and field conditions. It reliably performed waste detection, sorting, compacting, and GSM-based communication. In automatic mode, the ultrasonic sensor detected users within 10–30 cm, opening the lid automatically, while manual mode responded well to button-controlled sorting. The sensor-based classification module achieved about 92% sorting accuracy (Table 1) when tested with metal, paper, wet, and plastic waste. Metal, paper, and wet waste were identified using inductive, capacitive, and moisture sensors, respectively, while plastic was classified by exclusion.

Table 1 Sensor Accuracy and Sorting Performance for Waste Type Detection

Sensor/Mode	Waste Type	Detection/Sorting Accuracy (%)
Inductive Sensor	Metal	89
Capacitive Sensor	Paper	90
Moisture Sensor	Wet Waste	91
No Sensor	Plastic waste	95

Ultrasonic sensors accurately monitored bin fill levels with an average error of under 2 cm. The SIM800C GSM module reliably sent SMS alerts when bins reached 80% capacity. Powered by a 24V, 8A solar panel, the system remained operational throughout the day, with battery backup supporting up to 18 hours of continuous use.

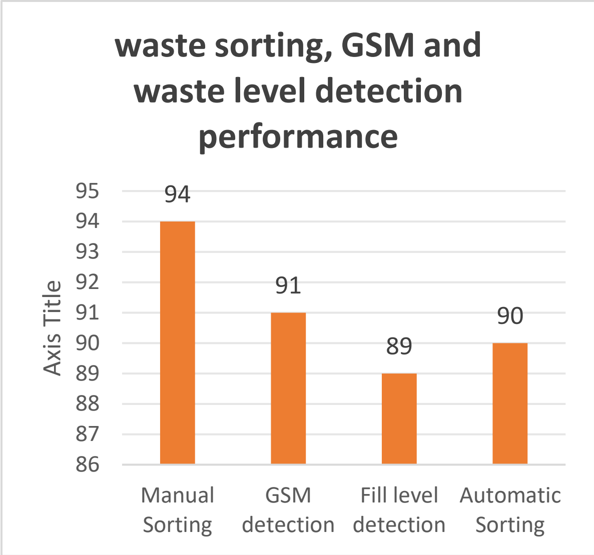

Fig.11 (waste sorting and waste fill-level detection performance and GSM notification alert.)

Fig.12 (Compacting mechanism)

The compacting mechanism shown in fig. 12, significantly reduced waste volume by an average of 65%, enhancing storage efficiency and reducing the frequency of emptying bins. All mechanical movements, such as bin rotation and lid actuation, were driven smoothly using servo and stepper motors, with no mechanical failures recorded during the test period. The successful integration of sensing, actuation, and communication in both manual and automatic modes confirm the system's effectiveness in promoting hygienic, energy-independent, and user-friendly waste disposal. The overall results highlight the system's suitability for deployment in environments such as schools, hospitals, and communities where efficient and sustainable waste handling are essential.

3.1 Findings

The system's dual-mode functionality improved usability, with manual mode performing best in controlled settings and automatic mode excelling in public environments. The compacting unit reduced plastic waste volume by 60%, significantly extending bin capacity. GSM alert integration enabled timely waste collection, achieving 91.25% operational reliability over a 30-day trial. These results suggest that the system can improve waste management efficiency, reduce collection frequency, and lower operational costs, especially in high-traffic public areas. Its reliability and adaptability make it suitable for scalable urban waste solutions.

3.2 Significance and Impact

This system overcomes cost, power, and connectivity challenges in smart waste management. It promotes sustainable practices and is adaptable for remote regions. Integrated recycling adds environmental value

4.0 Discussion

The successful development and testing of the dual-mode smart waste system confirm the viability of combining low-cost sensors, GSM, and solar power into a compact, autonomous platform. The results affirm its core strengths while identifying opportunities for further optimization.

4.1 Sensor Integration and Sorting Performance

The successful development and testing of the dual-mode smart waste system confirm the viability of combining low-cost sensors, GSM, and solar power into a compact, autonomous platform. The results affirm its core strengths while identifying opportunities for further optimization.

4.2 Communication Reliability and Offline Operation

The SIM800C GSM module offered reliable communication in areas lacking Wi-Fi or internet, achieving a 92% message delivery rate. It effectively transmitted bin-level updates to designated phones, minimizing the need for manual checks and improving monitoring in isolated locations.

4.3 Energy Efficiency and Sustainability

The inclusion of the 24V, 8A solar panel and lithium-ion battery ensured continuous operation for a period of 18hours. The system's low power consumption enhanced by sleep-mode activation in idle periods, makes it highly sustainable and scalable. Furthermore, the system ensured environmental sustainability by compacting plastic and reducing volume by 60%.

5.0 Conclusion

This study successfully designed and implemented a solar-powered, dual-mode smart waste management system for classifying, sorting, and compacting waste using sensor integration and GSM communication. The system demonstrated reliable performance, with high classification accuracy and efficient power usage, making it suitable for off-grid environments such as schools and public institutions. A key strength of the system is its dual-mode functionality: automatic mode supports touch-free use in public spaces, while manual mode suits supervised settings like schools. Its user-friendly panel and automated mechanisms ensure accessibility for non-technical users, thereby enhancing its practical impact. Despite strong performance, the system has some limitations. Mixed-property waste such as wet metal can reduce classification accuracy, and the design currently handles only four waste categories. Expanding to include additional waste types would require more advanced sensors. Future enhancements may incorporate machine vision with low-power cameras and onboard image classification to achieve more efficient and accurate sorting. Overall, the system establishes a solid foundation for sustainable waste handling in both urban and remote settings.

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