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Machine Learning Based Waste Sorting for A Sustainable Environment

Dr. M. Sayeekumar[1], S. P. Dhanasri[2], Attikapalli Krishna Priya[3], S. Devadharshini[4]
[1]Head of Department, Department of Computer Science and Technology
[2,3,4]Student(UG), Department of Computer Science and Technology
Vivekananda College of Engineering for Women (Autonomous), Tiruchengode, India
sayee.academic@gmail.com[1], dhanasrisivakumar245@gmail.com[2], attikapallikrishna2003@gmail.com[3], dharshinisakthivel520@gmail.com[4]

Abstract*: The fast pace of urbanization and consumption has made effective waste management a key challenge. This study presents a smart waste monitoring and management system designed to enhance waste segregation, improve operational efficiency, and promote sustainability.With the use of IoT-enabled sensors, I-based classification, and real-time monitoring, the system facilitates automated waste identification and also disposal with minimal manual intervention. The advanced sensors allow real-time evaluation of waste types, while automated systems ensure correct segregation. Intelligent monitoring elements offer round-the-clock that updates the bin status, avoids overflow and simplifies collection operations. Remote communication modules provide real-time alerts by allowing for prompt intervention and optimal resource deployment. This flexible and scalable solution is well suited to different environments, including cities, institutions, and business premises. By employing data-driven decision-making, predictive analysis, and automation, the system lends support to a more efficient and environmentally friendly waste management solution, in accordance with global sustainability endeavours*

Keywords: smart waste management, smart garbage bin

I. INTRODUCTION

The development in technology has generated great improvement in waste management with the combination of artificial intelligence and the Internet of Things (IoT). It includes the invention of the Smart Waste Segregation System, with the use of AI-based Image recognition and IoT sensors to sort and deal with waste in an efficient manner [1].
This revolutionary method facilitates real-time tracking which improves recycling and reduces environmental pollution. Through automated segregation of waste, this system overcomes the inefficiencies of manual methods and opens up the way to a more sustainable waste management system [2].

1.1 Smart Waste Management

Smart waste management employs technology to improve waste collection with segregation, and disposal. By combining AI and IoT, the smart waste management systems can sort the types of wastes, track the levels of bins, and alert authorities when it is time to collect waste. Smart waste management systems are responsible for minimizing landfill overflow, increasing recycling levels, and ensuring environmental sustainability [3]. As the urban population grows, intelligent waste management is a critical solution to ensure cleanliness and efficient use of resources in cities.

1.2 Artificial Intelligence for Waste Segregation

Artificial Intelligence (AI) has transformed industries across the globe which includes waste management. Machine learning-based waste segregation uses machine learning algorithms to sort waste in an efficient way. The convolutional Neural Networks (CNNs) and lean models like MobileNetV2 improve image-based waste sorting by minimizing reliance on manual sorting [4]. AI-based waste segregation enhances precision, minimizes labour expenses, and facilitates smooth recycling processes. In addition, AI models have the ability to learn and upgrade continuously, enabling them to be extremely versatile for different waste management purposes [5].

1.3 Internet of Things (IoT) in Waste Monitoring

The Internet of Things (IoT) has a critical contribution to make waste management through the collection and communication of real-time data. IoT-enabled smart bins incorporate sensors that measure waste levels and environmental parameters by sending data to waste management officials for on-time collection [6]. Bins fill levels are measured using ultrasonic sensors, while moisture and oil sensors aid in the distinction between wet and dry waste. IoT integration helps in effective disposal of waste by minimizing operation costs and avoids overflow issues [7].

1.4 Environmental impact of Smart Waste Segregation

Conventional waste disposal practices are major contributors to environmental contamination because of ineffective segregation and overutilization of landfill spaces. Smart waste segregation systems avoid these problems through effective waste classification at the point of generation [8]. AI and IoT-enabled waste management improves recycling, decreases greenhouse gas emissions, and reduces the environmental impact of waste disposal. Automated waste segregation through its adoption helps communities achieve a cleaner and greener environment while maximizing waste management processes.

II. LITERATURE REVIEW

R. Holanda Filho et al. (2024) advocated for a framework waste management model that increases the efficiency of recycling by employing a lot-based method. This system classifies waste into predetermined lots, reducing contamination and allowing accurate segregation [1]. The research identifies community involvement in waste management, mobilizing local people to participate in recycling activities. Although certain technologies were not widely covered, the system proposes the inclusion of automation and data analysis for enhanced efficiency. The results highlight the social and environmental advantages of organized waste management, providing a scalable approach for urban recycling systems.

Hussain et al. (2024) has suggested comparative analysis of IoT-based waste management frameworks through multi-agent simulation for comparing several waste disposal plans. The study examines the way smart bins work and sensor-based waste collection systems, as well as predictive analysis, propel urban waste management [2]. The results reveal that the implementation of IoT considerably enhances the efficiency of waste collection, minimizes operation expenses, and ensures the optimal utilization of resources. The research offers useful insights to inform policymakers and urban planners who are keen on adopting evidence-based waste management in smart cities.

P. Jiang et al. (2023) wrote about the use of blockchain technology in waste management, emphasizing transparency, accountability, and traceability. Blockchain's distributed ledger allows real-time monitoring of waste collection, transportation, and recycling with minimal fraudulent practices such as illegal dumping [3]. Smart contracts also automate transactions among waste generators, collectors, and recycling firms to achieve maximum efficiency. The research also identifies constraints such as high energy expenses, regulatory barriers, and integration issues. Nevertheless, blockchain is regarded as a game-changing technology in waste management, ensuring secure and effective waste treatment.

H. Patel et al. (2023) contrasted machine learning approaches to automated waste sorting. In the paper, rule-based systems are compared with deep learning models like CNN and MobileNetV2 with explicit mention of utilization of AI to enhance classification performance [4]. With Edge Impulse, wastes are sorted and classified with little or no human intervention, resulting in effective recycling.The paper further suggests possibilities of federated learning, where various waste treatment plants cooperate and train machine learning models collectively without sharing sensitive information. This decentralized approach improves model performance while maintaining data privacy. The findings bring into focus the importance of integrating real-time monitoring and AI-based classification to improve waste segregation and minimize environmental impact [5]

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R. Sharma et al. (2024) studied the use of IoT in optimizing waste collection logistics. The study suggests an ultrasonic sensor-based smart bin monitoring system to detect waste levels and notify collection agencies in real time [6]. Through the study of waste collection patterns, the system anticipates future patterns of waste generation and supports proactive scheduling of the collection. The research proves that IoT-based systems manage to curb waste overflow accidents and decrease operational expenses through optimization of the collection routes. The research identifies the use of GSM modules to support remote communication, in which authorities can be notified when bins are full [7]. The results emphasize the efficiency of IoT in contemporary waste management to ensure timely disposal and improved urban sanitation.

S. Gupta et al. (2024) investigated how Edge Impulse-based AI models enhance waste segregation through precise real-time classification of waste types. The research explores how sensor-based waste detection and AI-powered classification enhance recycling efficiency [8]. The continuous monitoring through IoT modules integrated for optimized waste collection according to real-time bin status avoids waste collection inaccuracies. Machine learning models also affect the waste sorting aspect, as stated in the paper, where light AI models were identified to hold the promise for implementation in settings with limited resources. The outcomes favour the implementation of AI-assisted segregation mechanisms for waste collection in smart cities, saving efforts and enhancing general waste processing precision.

2.1 EXISTING SYSTEM

Hand sorting is the heavily relied-upon traditional waste management infrastructure that is time-consuming, labour intensive, and full of mistakes. In most urban and rural communities, waste segregation at the source is not properly executed, and hence contaminates recyclables and hastens the rate of waste dumping in landfills. Existing mechanisms employ individual bins for wet and dry waste, but incorrect disposal through human negligence decreases recycling rates and adds load to waste treatment plants. There are some automated waste management systems, including conveyor belt sorting and image-based classification systems, however, entail high infrastructure investment and are more suitable for large-scale industrial use than for household or small-scale environments. Additionally, real-time tracking of waste is typically missing in conventional systems, resulting in overflow situations and inefficient collection frequencies. The absence of smart tracking infrastructure causes delayed collection of waste, which increases environmental hazards like pollution and unhygienic lifestyles. Moreover, existing waste classification models are typically not coupled with AI and IoT technologies, which can potentially improve sorting precision and operational efficiency to a great extent. In the absence of real-time monitoring via AI-based classification, traditional waste management systems cannot optimize resource allocation and do not provide scalable and sustainable solutions for growing urban populations.

III. PROPOSED SYSTEM

The proposed Smart Waste Segregation System leverages the usage of a blend of IoT sensors, image processing based on AI, and GSM technology for communication to segregate and dispose of waste efficiently. It has two compartments to differentiate between dry and wet waste, using various hardware devices to facilitate automatic notification and monitoring processes. When the system identifies unrecognizable waste, the ESP32-CAM module gets activated to take a photo, and the image is analysed through an AI model utilizing the MobileNetV2 algorithm to establish its classification.

For effective waste management, the SIM800L GSM module also sends alerts to the respective authorities when the bin is full or when there is unidentified waste. An OLED display also gives real-time status reports. This inclusion of smart technology helps in time-saving waste disposal, minimizes manual intervention, and maximizes waste collection operations, leading to a sustainable and automated waste management system.

The system also reduces landfill waste by increasing recycling efficiency. Its automated nature minimizes the contact of people with waste, thus making the environment cleaner and safer for waste management operations.

The requirements of the Smart Waste Segregation System are:

- **ESP32** (microcontroller processor)
- **ESP32-CAM** (capture of waste image for classification)
- **GSM 900 Module** (real-time alert & communication)
- **Ultrasonic Sensor** (sensing of waste level)
- **Soil Moisture Sensor** (segregation of wet and dry waste)
- **OLED Display** (status & feedback display)
- **Jumper Wires**
- **USB Cable**

IV. MODULE DESCRIPTION

The Smart Waste Segregation System automates the sorting and disposal of waste through IoT, AI, and GSM communication in order to manage with minimal human intervention.

4.1 Waste Detection and Classification

The system captures photos using an ESP32-CAM module where every time an unknown waste material is inserted into the bin. The images captured are processed by a classification model based on AI and trained on MobileNetV2, which establishes whether the waste is either dry or wet. Automated classification minimizes significant manual sorting work and promotes efficiency in handling waste.

4.2 Waste Level Monitoring

An ultrasonic sensor is embedded into the bin to monitor the fill level of dry and wet waste compartments continuously. The moment the waste exceeds a predetermined levelsthe system raises an alarm to ensure timely disposal and prevent overflow.

4.3 Environmental Condition Sensing

For enhanced waste classification accuracy, the system includes a soil moisture sensor that senses moisture levels in the waste. This differentiates between wet and dry waste and allows for more accurate segregation and efficient disposal of waste.

4.4 Automated Waste Management Notification

The SIM800L GSM module is used to communicate in real time with waste management authorities. The system automatically sends an SMS to the registered authority when the bin is about full or running low, enabling timely collection and avoiding waste mismanagement.

4.5 Real-time Monitoring OLED Display

An OLED display gives the users real-time system feedback and shows them essential information like results of waste classification tests, levels of bins filled, and system warnings. The feature makes the user more aware and make efficient use of the waste management system.

V. ALGORITHM DESCRIPTION

5.1 Mobile Net V2 Algorithm

MobileNetV2, one of the existing deep learning algorithms for image classification, is used in this paper because it is computationally efficient and an appropriate candidate for real-time waste classification in edge devices.It is light in weight and thus appropriate for real-time waste segregation on high-accuracy low-computational-expensive edge devices.It performs image processing with low latency through depth wise separable convolutions and inverted residuals with linear bottlenecks and is most suitable for IoT. Training on a diverse set of wet and dry waste increases

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accuracy, and data augmentation techniques enhance robustness under conditions.To make segregation of waste, MobileNetV2 can be trained from labelled images of dry and wet waste, so it can segregate waste in an efficient manner with less latency. The benefits of implementing this algorithm in the project are lesser computational complexity so it can be deployed on IoT devices, lower power usage than heavier models and quicker inference time so it can segregate waste in real time. MobileNetV2 offers great precision at low hardware requirements, accommodates on-device AI processing without depending on the cloud, and can seamlessly be integrated with microcontrollers such as ESP32-CAM for smart waste management solutions.

Architecture of the Proposed System

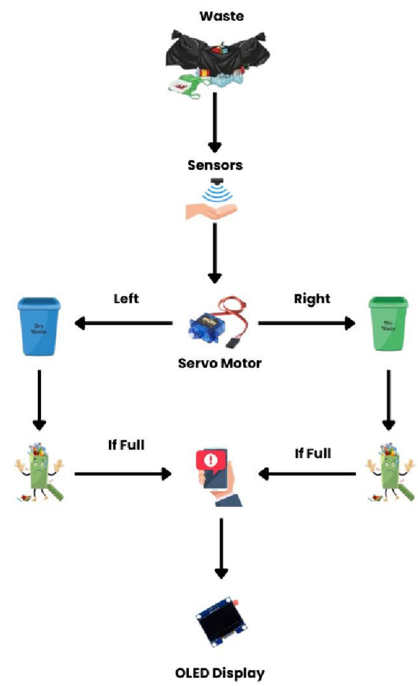

Figure 5.1 Architecture of the Proposed System

Figure 5.1 shows the architecture of the system, from waste input and image capture to waste classification and segregation through AI. The process involves image pre-processing, feature extraction through MobileNetV2, model inference for waste classification and automated waste segregation by guaranteeing efficient and accurate waste disposal.

VI. RESULT ANALYSIS

The Smart Waste Segregation System utilizes IoT and also Machine learning based automation to improve waste categorization and management. The ML model based on MobileNetV2 and ESP32-CAM accurately identifies the type of waste only triggering the camera when an unknown object is deposited. This optimizes efficiency with minimal unnecessary processing. Real-time monitoring of waste is done through an ultrasonic sensor, which monitors bin fill levels and avoids overflow. The soil moisture sensor also adds to segregation by separating dry and wet waste. If the bin is about to reach full capacity or is underutilized, the SIM800L GSM module automatically sends a notification to the registered authority, promoting timely collection of waste and avoiding accumulation. The OLED display of the system gives real-time feedback regarding classification outcomes and bin status, keeping users and waste management staff up to date. The system minimizes manual handling, maximizes efficiency, and reduces inappropriate disposal by automating segregation of waste. Real-time monitoring and notification feature further maximize collection schedules, cutting costs of operations and enhancing overall waste management.

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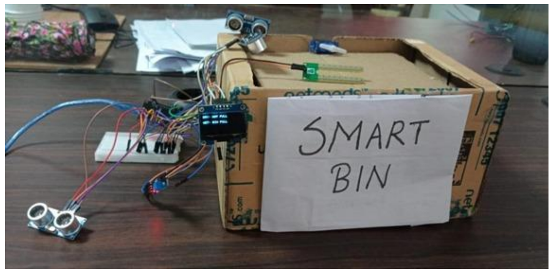

Figure 6.1 Output System

VII. CONCLUSION

The Smart Waste Segregation System not only makes waste classification easy but also enhances efficiency with the use of AI and IoT for proper and automatic disposal of waste. The ESP32-CAM captures images of waste, and the image-trained AI model classifies the waste into wet, dry, and unknown waste, making segregation proper. Ultrasonic sensors aid in waste volume measurement of bins to avoid overflows, and soil moisture sensors aid in identifying biodegradable and non-biodegradable waste. Use of GSM-based real-time messages helps in on-time waste collection, reducing health risks and making urban living clean.The technology can be coupled with cloud services to enable data analysis that can be utilized to optimize waste collection schedules based on patterns of waste bin usage. With additional improvement, the technology is likely to transform the urban waste management process by reducing landfill contribution, increasing recycling percentages, and providing environmentally friendly waste disposal options.With the growth of urbanization, artificial intelligence-driven waste management systems will be at the forefront of ensuring environmental balance, reducing pollution, and making the world cleaner and healthier.

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