Garbage Management System Using IoT and Machine Learning

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***Abstract*— Effective waste management is a critical component for sustainable development of society. This paper introduces an IoT-based Automated Garbage Management System that integrates machine learning, and cloud computing along with IoT to streamline waste segregation and monitoring processes. The system, powered by a Raspberry Pi 5 and a YOLOv8n object detection model, accurately identifies and categorizes waste into compost, recyclables, and trash. Sorted waste is directed into designated bins using stepper motors and arms, enhancing efficiency and reducing human intervention. An IR sensor-based monitoring system tracks bin fill levels and uploads real-time status data to an AWS S3 bucket once the bin is filled. A AWS Lambda function triggers email notifications via SES, ensuring timely waste management and preventing overflow. By combining all above technologies, this scalable solution promotes sustainability and demonstrates its potential to support smart city initiatives, contributing to improved waste management and ecological preservation.**

***Index Terms*—Internet of Things, Automated Waste Management, Raspberry Pi , AWS S3, AWS IoT, Machine learning, YOLOv8 Object Detection, Smart cities**

I. Introduction

THE rapid growth in populations of urban areas has significantly increased the volume of waste generated, causing substantial environmental challenges and pollution. The traditional ways of managing waste, like manual sorting and irregular collection schedules, are no longer adequate with the needs of current smart cities. These systems are prone to inefficiencies, such as poor segregation, delayed waste collection, and overflow situations, which can lead to environmental pollution and public health issues. Economic development is significantly boosted when pollution is reduced, and natural resources are conserved [1]. As populations grow, industries expand, and cities continue to develop, the amount of waste being generated is increasing rapidly. This surge not only harms the environment but also raises the risk of spreading diseases, creating serious health and ecological challenges [2]. Managing trash containers has become a major challenge in densely populated cities, leading to problems with waste accumulation and disposal. However, modern technologies offer innovative and effective solutions to address these issues.

The rise of Internet of Things, machine learning, and cloud computing has led to more innovative ways of managing waste, focusing on improving efficiency, supporting sustainability and reducing pollution. This approach introduces an Automated Garbage Management System designed to tackle these challenges by automating garbage sorting and monitoring process. The proposed system integrates advanced technologies, including a Raspberry Pi-based controller, a YOLOv8 object detection model for real-time waste classification, and AWS cloud services for data management and notifications.

Unlike traditional methods, the system automates the sorting of waste into categories such as compost, recyclables, and trash using a camera-enabled machine learning model. Stepper motors are employed to ensure precise sorting into designated bins. An IR sensor-based mechanism continuously monitors the bin fill level, and this data is uploaded to an AWS S3 bucket. Automated alerts are sent to waste management personnel via AWS Lambda and SES when bins are full, ensuring timely collection and preventing overflow.

This paper explores the system's architecture, implementation, and performance, emphasizing its potential to revolutionize waste management practices. By combining advanced technologies with practical design, the system offers a scalable and efficient solution to support the vision of smart and sustainable cities.

In addition to addressing inefficiencies in waste segregation and monitoring, the proposed system emphasizes ease of deployment and scalability, making it adaptable to various settings, from households to industrial facilities. The integration of machine learning allows for accurate identification of waste types, while the use of stepper motors ensures reliable mechanical operations for sorting. Furthermore, leveraging cloud services like AWS enhances the system's connectivity and automation, enabling real-time data storage and communication. Adding a notification system helps ensure timely action while connecting automated systems with human efforts, creating a seamless waste management process. This forward-thinking approach shows how technology can turn waste management into a proactive, data-driven solution that supports environmental sustainability.

II. Related Work

Many systems have been created to address waste management issues, using a variety of methods and sensors to make sorting more efficient. These systems can range from traditional mechanical solutions to more advanced technologies like machine learning and computer vision. However, most of these approaches focus primarily on industrial or municipal waste, where the sorting process usually centers on separating recyclable materials from non-recyclables. The main goal of these systems is to simplify waste segregation to make disposal and processing easier.

The paper by Ramakrishnan Raman and others, automates waste sorting and recycling using IoT, machine learning, and robotics. The camara will be collecting the data of the waste from garbage sites and is processed by Raspberry Pi. This data is later sent to cloud where a Support Vector Machine (SVM) algorithm classifies the waste into recyclable and non-recyclable categories based on a pre-trained dataset. Once classified, robotic arms or conveyor belts are used to segregate the waste into appropriate containers [4]. Although SVM's are good for small dataset, they are not efficient & accurate for large datasets.

Another paper by Rajapandian B and others presents a smart waste segregator designed to simplify waste disposal by automatically separating biodegradable and non-biodegradable materials. The system uses a conveyor belt, electromagnets to detect metallic waste, moisture sensors for wet waste, ultrasonic sensors for proximity and level detection, and a gas sensor for odor detection. A servo motor is used to rotate the bin for segregation, and the entire system is controlled by an Arduino UNO microcontroller [5]. However this system is efficient in the segregation of biodegradable and non-biodegradable sorting, this model is not suitable for all the waste types which are being generated in modern day.

Another Paper by R. Parvin and others presents a project which focuses on automating household waste segregation into biodegradable and non-biodegradable materials using machine learning and Raspberry Pi. The system uses various sensors, including an IR sensor, to detect waste in the bin. When waste is detected, the Raspberry Pi processes the signal and activates DC motors to rotate the conveyor belt. The waste is then identified by sensors positioned along the belt, and the system efficiently segregates. The system uses Random Forest algorithm to segregate the data [6]. Although this system is robust, there are a lot of better machine learning algorithms that can outperform Random Forest in classification and detection problems such as Convolution Neural Network (CNN) and You Only Look Once (YOLO).

While these projects offer advanced solutions for waste sorting, they often overlook the issue of bin filling and overflow after the segregation process. The primary goal of this project is to create a fully automated end-to-end system that minimizes the need for human intervention, addressing both waste sorting and bin management efficiently.

III. System Model, Problem Statement, and Analysis

A. *System Model*

The complete system model can be broken down into three major groups: physical devices, cloud resources, and machine learning model. The physical devices include the raspberry pi 5 which acts as processing unit for all the operations, camara module, infrared sensors, and conveyer belt built with stepper motors. The cloud resources include Amazon Web Services (AWS) Internet of Things (IoT) Core, AWS Lambda Function, AWS Simple Email Service (SES) and AWS S3. You Only Look Once (YOLO) is used as the machine learning algorithm. Figure 1 shows the outline of the whole system.

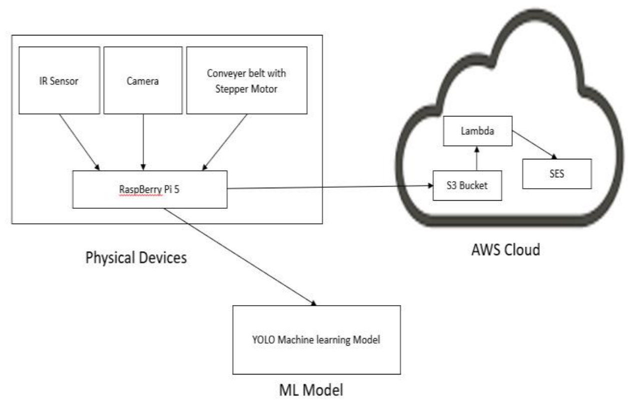

Figure 1: A System diagrams of the resources used in this project.

The Raspberry Pi is a small, affordable single-board computer created to make computing accessible for everyone, but most of all for educational and DIY projects. Initially, in 2012, this was designed to teach computer science; it has grown to become a very versatile platform applied today in areas such as IoT, robotics, home automation, and even artificial intelligence. It runs on a Linux-based operating system, with its official software being Raspbian, although it will also support other operating systems, such as Ubuntu. It contains an ARM-based processor, numerous USB ports, HDMI output, and GPIO pins that allow it to interact with external hardware, like sensors and motors.

In the years to come, the Raspberry Pi evolved through different models: improved in performance and enhanced in memory. The Raspberry Pi 4 and Raspberry Pi 5 give some decent boosts in processing power, support for as high as 8GB of RAM, and enhanced graphics capabilities, including dual 4K display support. Yet the Raspberry Pi has kept its affordable price, with some models costing as low as $5. Figure 2 shows the pinout of Raspberry Pi 5 which is being used by the project.

For the sensors IR sensor and camera module was used. IR sensor was used to sense the waste on the conveyer belt and bin fill. The IR sensors have three pins, VCC, Ground, Output. There will be emitter and receiver in the IR sensor. The emitter

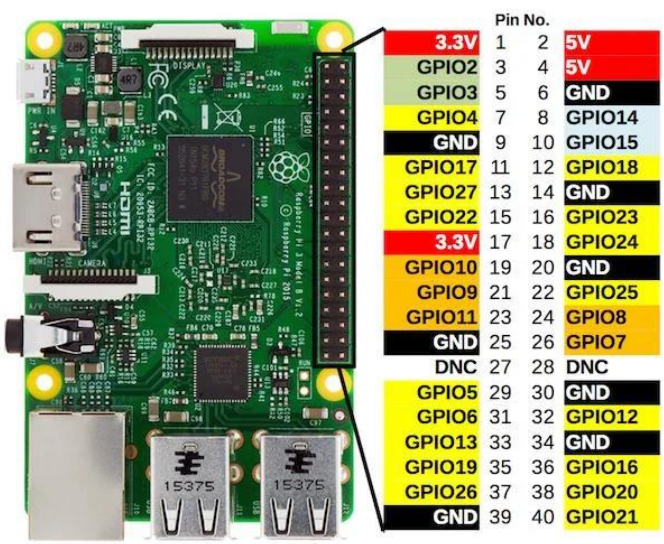

Figure 2: Raspberry Pi 5 GPIO Pins

emits the infrared rays and the reflected rays are received by the receiver. Once received the IR sensor gives False as output from the output pin. The camera used is a 5MP Raspberry Pi's official camera which is both affordable and suitable for the use case. Figure 3 shows IR Sensor and Raspberry Pi Camera.

Figure 3a: IR Sensor

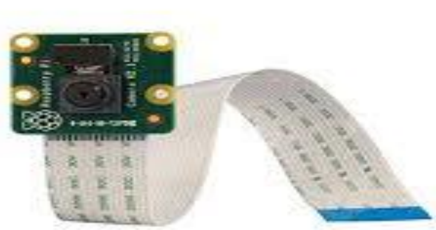

Figure 3b: Camera
Figure 3: Sensors used in the project

Stepper motors are used as actuators. After the classification, the stepper motors in the arm directs the waste into different categories. Stepper motors used here are Control 28BYJ-48 Stepper Motor with ULN2003 Driver. These have four inputs inc1 – inc4 which are used to activate the coils and turn the stepper motor. Additionally, these need the 5V power supply and ground. Figure 4 shows stepper motor with ULN2003 controller. I have used full steps for the motor to run. The inputs for Inc1-4 for full steps is given in the Figure 5.

Figure 4: Stepper motor with ULN2003

```
Full Step Activation Sequence:
[1, 0, 1, 0] # Step 1
[0, 1, 1, 0] # Step 2
[0, 1, 0, 1] # Step 3
[1, 0, 0, 1] # Step 4
```

Figure 5: Stepper Motor Full Activation Sequence

B. Problem Statement and Analysis

The problem we are addressing here is the inefficiency in the current waste management schemes, especially in urban zones. Traditional methods of segregation largely depend on manual intervention at various levels and are erroneous because segregating is not proper at different levels, leading to increasing expenses against lower economy-of-scale operations. In the case of traditional systems, monitoring of fill level usually failed while bins overflowed, consequently missing the scheduled collection. This leads to a lack of real-time data related to optimizing waste collection schedules and ensuring effective recycling.

Our project will develop an automated waste segregation system that incorporates machine learning, IoT sensors, and cloud integration. The model uses the YOLOv8 object detection model to classify waste into biodegradable and non-biodegradable categories. IR sensors monitor the fill level of the bin to avoid overflow. These data are sent to the cloud server for real-time analysis, and on detection of a full bin, a lambda function sends notifications. Then, motors and robotic arms sort the waste physically. Therefore, the proposed system automates both the sorting and monitoring processes, reducing human intervention, enhancing the efficiency of recycling, and improving overall waste management operations.

IV. Design And Implementation

A. Physical devices

This section provides an overview of how the physical components are interfaced with the Raspberry Pi, including details on the connections and pin configurations. The IR sensors are used for two purposes, waste detection where the pin used is GPIO 7 and for Bin fill detection where the pin used us GPIO 4. When some waste in put on the conveyer belt the IR sensor detects it. If there is a requirement of conveyer belt to run for initial camera view then that action will be activated using this. The second IR sensor once it detects the bin filling sends the data to S3 bucket.

Once the waste in the proper place, the camera takes the picture and sends it to the ML model. In raspberry pi there is a separate camera slot where the camera can be connected. Once the detection is done with ML model, the corresponding motors will be activated using the full step activation steps.

We are using three Motors. One for the conveyer belt and other two for both the arms. Based on the detection, the raspberry pi will activate the required motor. The motors are connected through the pins shown in the figure 6.

Motor 1:
5, 6, 13, 19

Motor 2:
12, 16, 20, 21

Motor 3:
4, 17, 27, 22

Figure 6: GPIO pins for each motor in Raspberry Pi 5

Motors require a 5V power supply to operate efficiently, and if this voltage is not provided, they may fail to function. The Raspberry Pi offers only two 5V outputs, which is insufficient to power three motors simultaneously. While motors can run on 3V, their performance is significantly reduced, resulting in slower speeds. To ensure optimal performance for this project, an additional 5V power source is necessary.

B. Cloud Services

It contains the code for automatically triggering events upon the detection of a full bin via the IR sensor attached to the Raspberry Pi. This updates the AWS S3 bucket with relevant data that signifies the filling of the bin. An update to this triggers an AWS Lambda function, a serverless compute service that can run code in response to such events. In processing the event, the Lambda function automatically invokes the Amazon Simple Email Service.

Using SES, an email is generated and sent to a designated recipient's email address, notifying them of the status of the bin. This setup ensures a seamless real-time alert system that reduces delays in waste collection. The system achieves a high level of automation, scalability, and reliability using AWS services like S3, Lambda, and SES, enhancing the efficiency of the operations of waste management.

The full workflow of the system is given in figure 7.

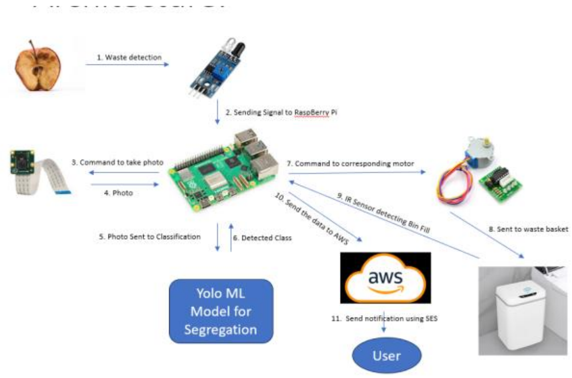

Figure 7: Workflow of the project

The sample of the data sent to the AWS S3 bucket is given in the figure 8.


```
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
{
    "bin_fill": "yes"
},
```


Figure 8: example data which is stored in S3

The example email that has been sent from AWS is shown in the figure 9.

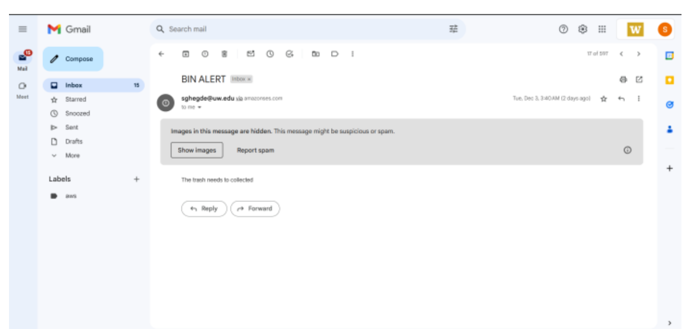

Figure 9: example email that is sent when the bin is full

The data from the raspberry pi will be stored in a file named bin_fill_data.json under garbagemanagementsystem bucket. We can see the custom message and subject which is sent from the AWS SES from figure 9. The email will come in with the configured email through amazonses.com.

C. Machine Learning Model

The machine learning (ML) component of the waste segregation system focuses on automating waste classification using the YOLOv8n model, a cutting-edge algorithm renowned for its real-time object detection capabilities. The model is trained on a diverse dataset containing labeled waste categories such as plastics, metals, cardboards, biological, trash, and glass. These are then divided into compost, trash, and recycled in the raspberry pi's code. During operation, images of waste are captured by a camera and processed by YOLOv8n to identify and classify items based on learned visual features like shape, texture, and color. This ML-driven approach ensures rapid and precise classification, which is critical for the subsequent sorting process. The use of YOLOv8 significantly enhances the system's efficiency compared to traditional methods, enabling accurate, scalable waste management.

V. Evaluation

The automated waste segregation system was evaluated across several parameters, including waste classification accuracy, hardware reliability, system efficiency, and scalability. The YOLOv8 model demonstrated high precision in identifying biodegradable and non-biodegradable materials, supported by robust training on diverse datasets. The integration of physical components, such as stepper motors and conveyor belts, ensured seamless sorting of waste with minimal errors. These components were tested extensively under different conditions to validate their operational consistency.

The bin fill detection mechanism, implemented through IR sensors, exhibited reliability in identifying when bins reached capacity, triggering real-time alerts via AWS services. This functionality was further validated by testing the cloud integration pipeline, which efficiently updated the S3 bucket and triggered Lambda functions to send email notifications through AWS SES. The end-to-end latency from detection to notification was minimal, demonstrating the system's responsiveness. Overall, the evaluation confirms that the system achieves its objectives of automating waste segregation and notification processes, with potential for scalability and adaptation to larger waste management frameworks.

VI. Conclusion

The automated waste segregation system developed in the project represents a holistic and effective solution to the growing problem of waste management in urban environments in the modern context. The integration of machine learning, IoT devices, and cloud computing facilitates the process of waste identification, classification, and monitoring smoothly and with a minimum share of human intervention, which reduces the inefficiency associated with traditional methods. At the core of the machine learning model, the YOLOv8 model makes sure the correct classification of waste is done with precision and in real time, based on the visual features such as texture, shape, and color. This enables proper segregation into biodegradable and non-biodegradable categories, which are of essence in sustainable waste processing.

The system relies on the use of IoT sensors, such as IR sensors for the detection of bin filling, and integrates AWS cloud services for real-time notifications, enhancing its utility and scalability. The application of AWS Lambda and SES services enables timely alerts, thus ensuring efficient disposal of waste without instances of overflow. Furthermore, the physical components comprising motors, conveyor belts, and sensors are in precise synchrony with the system's logic to provide a robust operational framework.

This work points out the potential of technology-driven waste management systems in solving environmental challenges. By automating the segregation process, the system reduces labor costs and operational delays but also encourages more systematic recycling and disposal practices. It opens the door to further innovations in waste management, such as expanding waste categories, improving classification accuracy with larger datasets, and improving energy efficiency. This will, in the end, greatly contribute to the vision of sustainable urban development through cleaner cities and the conservation of the environment.

VII. Future Work

The future work for this automated waste segregation system involves enhancing the machine learning (ML) model through advanced training and deployment techniques using cloud computing, specifically AWS services. Currently, the YOLOv8 model is trained locally on a dataset, but future improvements can include leveraging AWS services such as Amazon SageMaker to handle the model's training, fine-tuning, and deployment processes. SageMaker provides a scalable and efficient platform for training deep learning models with the ability to handle large datasets, which can significantly improve the classification accuracy and generalization of the system across different waste categories. Additionally, SageMaker's managed infrastructure would streamline the deployment of the model, ensuring updates and retraining can be done seamlessly without the need for manual intervention.

Furthermore, AWS Lambda and S3 could be utilized for more automated workflows. When a new dataset is uploaded to S3, a Lambda function can trigger the model's retraining process on SageMaker, ensuring that the system continually improves and adapts to new types of waste. After training, the updated model could be deployed using AWS Lambda for real-time predictions, providing a fully managed, scalable solution for waste segregation. This would reduce the reliance on local hardware, improving both the system's performance and efficiency.

Another area for future work includes the expansion of the dataset with additional types of waste, such as electronic waste or hazardous materials. By continuously feeding the model with more diverse data, the system's ability to accurately classify and segregate waste in real-time will improve. Integration with more advanced sensor technologies and machine learning models, such as Convolutional Neural Networks (CNNs) or Support Vector Machines (SVMs), can also enhance classification, especially for more complex waste types. This multi-layered approach will create a more robust waste management system, capable of handling various waste streams and contributing to more sustainable recycling processes.

The use of AWS's scalable and flexible architecture ensures that these future enhancements can be integrated with minimal disruption, allowing the system to evolve with advancements in both machine learning techniques and IoT technologies. By leveraging AWS, the system will become more adaptive, efficient, and ready for deployment on a larger scale, potentially benefiting smart cities and industrial waste management applications globally.

A novel future development could be the usage of blockchain technology for tracking and traceability of waste. Integrating blockchain into the system, each piece of waste can be tagged with a digital identity for more transparency and accountability in the process of waste management. Blockchain could provide a secure and immutable record of the waste's journey from segregation to disposal or recycling, which would be of great value for regulatory compliance and transparency.

Another important future direction might be the use of smart contracts besides the blockchain integration to allow automation of waste management processes. Smart contracts are self-executable contracts whereby the terms related to an agreement are directly written into lines of code. With the concept of smart contracts applied to waste management, these can be used in situations where certain conditions need to be met to automatically invoke a corresponding action, such as when waste bins are full and should be collected or payment released for recycling services once it has been confirmed that the wastes are correctly sorted out. It will automate the operations to make the process even less manpower-dependent, hence more efficient, transparent, and less expensive. By integrating blockchain with smart contracts, the entire waste management lifecycle—from waste generation to final disposal or recycling—could be monitored and optimized in a way that ensures accountability, reduces waste mismanagement, and encourages sustainability.

All the above methods will improve the model performance and gives it a new direction to collect and use more data and have more control over waste management procedures.

VIII. References

[1] K. Moirogiorgou et al., "Intelligent robotic system for urban waste recycling," 2022 IEEE International Conference on Imaging Systems and Techniques (IST), Kaohsiung, Taiwan, 2022.

[2] A. Nikhila, R. Mahato and B. Sudha, "Automatic Garbage Segregation and Management System", International Journal of Innovative Science and Research Technology, vol. 8, no. 5, 2023

[3] H. Azath, A. K. Velmurugan, K. Padmanaban, A. M. Senthil Kumar and Murugan Subbiah, "Ant based routing algorithm for balanced the 2023 Second International Conference on Smart Technologies for Smart Nation (SmartTechCon 2023) 231 load and optimized the AMNET lifetime", AIP Conference Proceedings, vol. 2523, pp. 1-9, 2023.

[4] R. Raman, C. J. Rawandale, R. Meenakshi, S. Jayaprakash, R. Latha and C. Srinivasan, "Real-Time Video Management System for Robotic Waste Sorting and Recycling Using IoT and Machine Learning," 2023.

[5] R. B, A. D, T. T, D. R. D and D. N, "Smart Solid and Wet Waste Management System," 2022 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), Chennai, India, 2022.

[6] R. Parvin, D. P. C, D. V and A. S. G, "Automatic Segregation of Household Waste using Machine Learning Approaches," 2022 International Conference on Edge Computing and Applications (ICECAA), Tamilnadu, India, 2022.

[7] T. M. N. Vamsi, G. Kalyan Chakravarthi, P. Lanka and B. Divakar, "An IoT Based Smart Garbage Monitoring and Disposal Support System," 2021.

[8] P. Chowdhury, R. Sen, D. Ray, P. Roy and S. Sarkar, "Garbage Monitoring and Disposal System for Smart City Using Iot," 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT), Bangalore, India, 2018