

Artificial Intelligence Based Waste Segregation System

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Abstract— The surge in urban population has led to a significant rise in municipal solid waste, making effective waste management increasingly important. Conventional methods that rely on manual sorting are often slow, unsanitary, and susceptible to mistakes. To address these challenges, this paper introduces an AI-driven smart waste segregation system that leverages computer vision, deep learning techniques, and IoT technologies to automatically identify and categorize waste materials.

The proposed system employs a raspberry pi 4b as its main controller integrated with a USB camera moisture detection sensor and ultrasonic sensor a convolutional neural network built on the mobilenetv2 framework is trained using a dataset of around 3153 images to distinguish between two types of waste biodegradable wet and non-biodegradable recyclable after identification the waste is automatically sorted into the correct container using a mechanism that combines servo and stepper motors ensuring accurate placement and better operational control the model demonstrated a testing accuracy of 92 additionally the system supports real-time monitoring of bin levels and sends notifications when bins are full through the Blynk IOT mobile application.

The proposed system reduces human intervention, improves segregation accuracy, and supports sustainable waste management, making it suitable for smart cities and public institutions in alignment with the Swachh Bharat Abhiyan and UN Sustainable Development Goals.

Keywords: Waste Segregation, CNN, MobileNetV2, Raspberry Pi, IoT, Blynk, Stepper Motor, Servo Motor, Smart Waste Management.

1. Introduction:

Managing waste has emerged as a major concern in today's urban settings, driven by rapid industrial development, increasing population, and higher consumption levels. Inadequate disposal practices contribute to environmental damage, pose serious health risks, and accelerate the exhaustion of natural resources. Conventional waste sorting approaches, which largely depend on human effort, tend to be slow, unsanitary, and susceptible to errors. As a result, there is an increasing demand for an automated solution capable of accurately identifying and separating waste in an efficient manner without relying on manual involvement.

The AI-based smart waste segregation system is developed to tackle this problem by combining Artificial Intelligence (AI), the Internet of Things (IoT), and embedded hardware. In this setup, a Raspberry Pi serves as the primary control unit and is connected to sensors such as a moisture sensor and an ultrasonic sensor, along with a camera module for capturing waste images. The collected images are then analyzed by a trained model that identifies and sorts the waste into categories like biodegradable or wet waste and non-biodegradable or dry waste. After detection, servo motors and a stepper motor work together to move and place the waste into the correct bins with greater accuracy and control.

The system also incorporates IoT capabilities through the Blynk application, enabling continuous monitoring of bin status in real time. Once a bin becomes full, an alert is automatically sent to the responsible personnel to ensure timely waste collection. This functionality helps prevent overflow and maintains cleaner, more hygienic surroundings. The primary aim of this project is to streamline waste segregation, minimize manual effort, and improve classification accuracy, ultimately

supporting sustainable waste management practices. Such a system can be deployed in smart city infrastructures, public areas, academic institutions, and industrial environments to encourage recycling and reduce the burden on landfills.

2. System Design:

2.1 Hardware Overview:

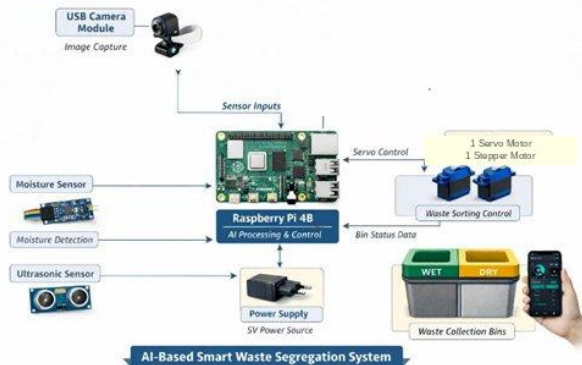


Figure 1: Circuit Diagram of Waste Segregation

The system hardware integrates the following key components onto a compact chassis platform:

| Component | Description |
|--------------------|---|
| Microcontroller | Raspberry Pi 4B – Main processing unit |
| Distance Sensing | Ultrasonic Sensor HC-SR04 – Detects bin level |
| Vision Module | USB Camera – Captures waste images |
| Moisture Detection | Identifies wet/dry waste |
| Actuation | Servo Motor – Controls waste direction. Stepper Motor – Provides precise positioning and rotation of the bin/mechanism |
| Waste Storage | Compartment Bin – Stores separated waste |
| Power Supply | 5V Adapter – Supplies power |

Table 1: Hardware Overview

2.2 Functionality:

The AI-based smart waste segregation system operates by capturing images of waste materials using a USB camera, which are then analyzed by a Raspberry Pi running a trained convolutional neural network to determine whether the waste is wet or dry. To enhance classification reliability, additional inputs from sensors such as a moisture sensor are used to validate the result. Based on the combined analysis, servo motors and a stepper motor mechanism are triggered to guide and accurately place the waste into the appropriate bin. Bin levels are continuously tracked using ultrasonic sensors, and once a bin reaches its capacity, an alert is sent via the Blynk application. This approach enables precise, efficient, and automated waste sorting while significantly reducing the need for manual intervention.

3. Methodology:

3.1 Image Acquisition:

In this stage, the system captures images of the waste material using a USB camera connected to the Raspberry Pi. The camera is positioned such that it clearly views the waste placed in front of the system. Whenever an object is detected, the camera captures its image in real-time. This image serves as the primary input for further processing and classification.

3.2 Image Processing:

After capturing the image, it is processed to prepare it for input into the AI model. The image is first adjusted to a fixed size, usually 224x224 pixels, to meet the model's input requirements. Furthermore, the pixel values are scaled through normalization to enhance the model's efficiency. This preprocessing stage helps maintain consistency and minimizes unwanted variations, resulting in improved prediction accuracy.

3.3 A-I Based Classification:

The processed image is then provided as input to a trained convolutional neural network (CNN). This model has been developed using a dataset comprising various waste images. It analyzes key characteristics such as texture, shape, and color to determine the type of waste, classifying it as either biodegradable (wet) or non-biodegradable (dry). The final classification output is subsequently transmitted to the Raspberry Pi for further processing and control actions.

3.4 Sensor Assistance:

To enhance the reliability of the system, a moisture sensor is used alongside the AI model. The sensor detects the moisture content present in the waste material. If the moisture level is high, the waste is identified as wet (biodegradable). This helps in improving accuracy, especially in cases where image classification alone may be uncertain.

3.5 Waste Segregation Mechanism:

Once the waste is identified, the Raspberry Pi interprets the classification result and issues appropriate signals to control the servo motor. The servo motor then turns to a predetermined angle based on the identified waste type. At the same time, a stepper motor is utilized to achieve precise movement and proper positioning of the bin or mechanism, ensuring accurate alignment during disposal. This coordinated action guides the waste into the correct section of the bin, whether wet or dry. The entire operation is automated, eliminating the need for manual involvement.

3.6 Bin Level Monitoring:

An ultrasonic sensor is employed to regularly track the level of waste inside the bins. It works by calculating the distance between the sensor and the surface of the waste material. As more waste accumulates, this distance gradually reduces. Once the measured distance drops below a set limit, the system recognizes that the bin has reached or is close to its maximum capacity.

3.7 IoT Monitoring and Notification:

The system is connected to the Blynk IoT platform to enable real-time tracking of bin status. Once a bin

reaches its maximum capacity, an alert is automatically delivered to the user via the mobile application. This feature helps ensure prompt waste collection and avoids overflow situations. Additionally, users can remotely check and monitor the system's condition through the app.

4. Construction:

The development of the AI-based smart waste segregation system involves the organized integration of mechanical structures, electronic components, sensing devices, and image processing modules into a compact and functional prototype. A strong frame or casing is used to hold and support all hardware elements securely. At the core of the system, the Raspberry Pi 4B serves as the main controller, placed strategically to efficiently manage image processing tasks, sensor data, and motor operations.

A USB camera is positioned at an optimal height and angle to capture clear images of the waste material placed before the system, providing real-time input for AI-based classification. Near the input section, a moisture sensor is installed to identify the presence of moisture, assisting in distinguishing between wet and dry waste. An ultrasonic sensor is mounted at the top of the bin to continuously monitor the fill level by measuring the distance between the sensor and the accumulated waste.

The bin is divided into separate compartments to store different types of waste accordingly. A servo motor is connected to a flap or rotating mechanism that directs the waste into the correct section based on the classification outcome. In addition, a stepper motor is incorporated to ensure precise movement and accurate positioning of the bin or mechanism during operation. All electronic parts are connected using jumper wires and supplied with power through a regulated source.

The system is programmed in Python, combining image processing libraries with a trained AI model for effective waste classification. IoT capabilities are also integrated using the Blynk platform, allowing real-time monitoring of bin levels and sending alerts when the bin becomes full. Overall, the design results in a compact, automated, and efficient waste segregation solution suitable for practical, real-time use.

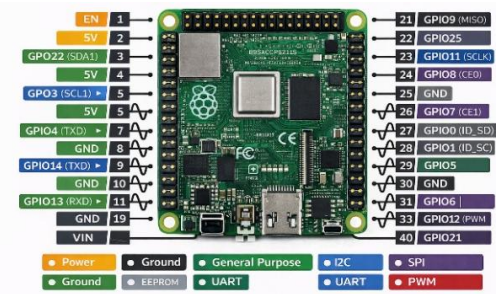


Figure 2: Prototype Model of the Waste Segregation

A detailed overview of each component used in the system is provided below to explain their specific roles and interconnections:

Raspberry Pi: The Raspberry Pi 4B functions as the central control unit of the system, managing all operations. It acquires images from the USB camera and analyzes them using the trained AI model to categorize the waste as either wet or dry. In addition, it gathers data from sensors such as the moisture and ultrasonic sensors to support decision-making. Based on the classification outcome, it operates the servo motor to guide the waste into the appropriate bin. It also communicates system data to the Blynk application for real-time monitoring. In this way, it coordinates all components and enables a fully automated waste segregation process.



Figure 3: Raspberry Pi

USB Camera Module: The USB camera is responsible for capturing images of the waste placed within the system. These images are then transmitted to the Raspberry Pi for further analysis. It supplies real-time visual data to the AI model, which examines the images to determine the type of waste. Based on this evaluation, the system categorizes the waste as either wet or dry. This component is essential for enabling automated waste segregation using artificial intelligence.



Figure 4: USB Camera

Moisture Sensor: The moisture sensor is utilized to identify the presence of water content in the waste. It assists in differentiating between biodegradable wet and non-biodegradable dry materials. The data collected by the sensor is transmitted to the raspberry pi for further evaluation. This additional input enhances the overall accuracy of the classification process when used alongside the ai model. As a result it serves as a supportive element in achieving more effective waste segregation

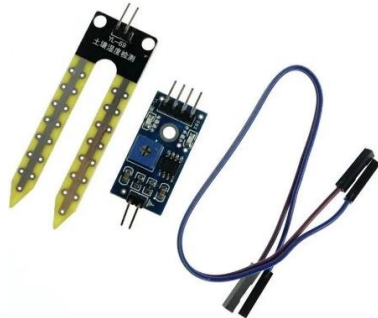


Figure 5: Moisture Sensor

Ultrasonic Sensor: The ultrasonic sensor is employed to monitor the waste level inside the bin by determining the distance between the sensor and the accumulated waste using ultrasonic signals. As the bin gets filled, this distance gradually reduces. Once it reaches a predefined limit, the system recognizes that the bin is full or near full. This data is then forwarded to the Raspberry Pi for further action. It plays an important role in tracking bin status and enabling timely alerts for waste collection.



Figure 6: Ultrasonic Sensor

Servo Motor: The servo motor is responsible for driving the motion of the waste sorting mechanism. It operates based on control signals sent from the Raspberry Pi once the waste has been classified. Depending on the detected category, it turns to a designated angle to guide the waste accordingly. This controlled movement ensures that the waste is accurately dropped into the appropriate compartment, whether wet or dry, supporting fully automated and precise disposal.



Figure 7: Servo Motor

Stepper Motor: The stepper motor enhances the precision and control of the waste segregation system. It operates in discrete steps, allowing accurate positioning without the need for feedback. In this project, it is used to provide controlled rotation and alignment of the bin or mechanism. After classification, the Raspberry Pi sends signals to both motors, where the servo directs the waste and the stepper ensures correct positioning. This improves the overall accuracy, efficiency, and reliability of the system.



Figure 8: Stepper Motor

5. Working:

The proposed AI-based smart waste segregation system combines image processing, sensor data, and automated control mechanisms to enable effective classification and sorting of waste. When a waste item is introduced into the system, a USB camera captures its image in real time. This image is then prepared for analysis by resizing it to a fixed resolution and normalizing its pixel values to make it compatible with the model.

The preprocessed image is then passed through a trained convolutional neural network (CNN), which evaluates visual features such as color, texture, and shape to categorize the waste as either biodegradable (wet) or non-biodegradable (dry). To improve reliability, a moisture sensor is also used to detect water content in the material, supporting the final decision.

After classification, the Raspberry Pi interprets the output and sends appropriate control signals to the actuators. The servo motor moves to a specific angle based on the predicted class, ensuring the waste is directed into the correct section of the bin. A stepper motor further assists by providing controlled and accurate positioning of the mechanism, allowing smooth and precise segregation without manual assistance.

At the same time, an ultrasonic sensor keeps track of the bin's fill level by calculating the distance between the sensor and the waste inside. Once this distance drops below a defined limit, the system recognizes that the bin is nearly full and sends an alert through the Blynk IoT platform. This real-time monitoring helps ensure timely collection and prevents overflow, maintaining overall cleanliness and efficiency.

6. Results and Observations:

6.1 Functional Testing

Functional testing of the proposed AI-based smart waste segregation system was conducted to ensure that all components operate correctly, including image recognition, sensor inputs, motor control, and IoT connectivity. The USB camera was able to capture real-time images effectively, which were then processed by the trained CNN model to classify waste as wet or dry with good accuracy under standard lighting conditions. The moisture sensor was also examined and proved useful in supporting the detection of wet waste, thereby enhancing the reliability of the classification process.

The performance of the actuation mechanism was assessed by checking the synchronized operation of the servo motor and stepper motor. Based on the output generated by the Raspberry Pi, the servo motor accurately guided the waste into the designated bin, while the stepper motor helped maintain precise alignment and controlled movement of the system. In addition, the ultrasonic sensor successfully tracked the bin's fill level and sent alerts via the Blynk IoT application once the bin reached its set limit. Overall, the system performed effectively, enabling automated and accurate waste segregation with very little human involvement.

| Test Scenario | Result | Observation |
|---------------------------------|--------------------------------|---|
| Response Time | ~1-2 seconds | Fast detection with slight processing delay |
| Object Detection | High (with stable frame logic) | Accurate after frame stabilization |
| Empty Detection | Reliable (with trained class) | Prevents unnecessary motor movement |
| AI Classification | Good (Wet vs Dry vs Empty) | Improves with better dataset |
| Moisture Detection | Binary (0 = Wet, 1 = Dry) | Helps correct AI misclassification |
| Hybrid Decision System | AI + Sensor Fusion | More reliable than AI alone |
| Motor Control (Stepper + Servo) | Smooth rotation & tilt | Accurate bin alignment |

| | | |
|----------------------------|----------------------------------|------------------------------------|
| False Trigger Prevention | Stable frame count (5 frames) | Avoids continuous motor activation |
| Live Camera Feed (USB Cam) | ~20-30 FPS | Real-time monitoring |
| Power Efficiency | Moderate (~20-30 min continuous) | Stable for demo-level usage |

Table 2: Functional Testing Results

6.2 Performance Matrix

The effectiveness of the proposed AI-based smart waste segregation system was assessed using parameters such as classification accuracy, processing speed, sorting efficiency, and overall system dependability. The convolutional neural network (CNN) model delivered an average accuracy of around 92%, successfully differentiating between biodegradable and non-biodegradable waste even under different environmental conditions. The addition of a moisture sensor also helped enhance decision-making accuracy by minimizing errors in ambiguous cases.

The system showed a quick operational response, typically taking about 1-2 seconds from image acquisition to final waste sorting, enabling real-time functionality. The combined operation of the servo motor and stepper motor provided smooth and precise control, ensuring proper placement of waste into the designated bins and resulting in efficient segregation. Moreover, the ultrasonic sensor reliably tracked bin fill levels with very little deviation. Overall, the system maintained stable and consistent performance during continuous use, without noticeable delays or malfunctions.

7. Conclusion

The AI-Based Smart Waste Segregation System successfully demonstrates an efficient and automated approach to waste management by integrating image processing, machine learning, and sensor-based validation. The use of a CNN model enables accurate classification of waste into wet and dry categories, while the combination of moisture sensing enhances decision reliability. The Raspberry Pi effectively controls the overall operation, and the coordinated action of the servo motor and stepper motor ensures precise and smooth waste segregation. Additionally, real-time monitoring using the ultrasonic sensor improves system efficiency by preventing bin overflow. Overall, the system reduces human effort, promotes proper waste disposal, and offers a scalable solution for smart and sustainable waste management.

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