Cost-Efficient AI-Driven Waste Segregation System Utilizing Image Processing

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Abstract—Efficient waste management is crucial to minimizing environmental impact and improving recycling rates. This paper presents a smart bin system designed to automate waste segregation through image processing and machine learning techniques. The system captures images of waste using a camera module, processes these images using OpenCV, and employs a TensorFlow-based classification model to categorize waste into plastic, metal, organic, paper, and unidentified categories. A processing unit like the ESP32 or Raspberry Pi is used to control the motorized bin system, which automatically directs waste into the appropriate container. The system is further enhanced with sensors that monitor bin levels and provide real-time feedback through LEDs. By automating the waste segregation process, this project aims to reduce human intervention and accelerate recycling efforts.

I. INTRODUCTION:

In recent years, urbanization and population growth have exacerbated the global waste management crisis. Manual sorting of waste is not only time-consuming but also prone to errors, which leads to improper segregation and, subsequently, contamination of recyclable materials. Automation in waste segregation can address these issues by providing an efficient and reliable method for sorting materials at the source. The smart bin system proposed in this paper uses image processing and machine learning techniques to automatically classify waste and direct it into the appropriate bin, reducing reliance on manual labor and ensuring more accurate waste disposal.

To tackle this problem, we propose a waste segregation system that uses image processing to classify industrial dry waste, such as paper, plastic, organic, and fabric waste. The system functions as a smart bin, integrating a camera, microcontroller, sensors, and motors to facilitate accurate sorting.

The system starts by using a camera to capture images of the waste, which then sends signals to the microcontroller to determine the type of waste. The microcontroller then directs motors to move the waste into the correct compartments. Sensors monitor how full each compartment is and relay this information using color-coded LEDs—red, yellow, and green—to indicate the compartment's status, ensuring efficient sorting.

II. SYSTEM DESIGN AND ARCHITECTURE:

A. The smart bin system integrates several key components, which work together to achieve automatic waste segregation. The design is modular and adaptable, making it suitable for various environments and waste management needs. Maintaining the Integrity of the Specifications.

B. Image Capture:

A camera module, such as the ESP32-CAM or Raspberry Pi Camera, captures images of the waste placed near the bin. The selection of the camera module depends on the project's requirements, such as resolution, processing speed, and environmental factors like lighting.

C. Image Processing:

Using OpenCV, the captured images are pre-processed to ensure uniformity. This step includes operations like resizing, normalization, and filtering, which help to prepare the images for classification. Pre-processing ensures that the machine learning model can operate efficiently under different conditions, such as varying lighting and background noise.

D. Waste Classification:

A TensorFlow-based machine learning model, trained on a dataset containing images of various types of waste, classifies the waste into five categories: plastic, metal, organic, paper, and unidentified. This model is built using convolutional neural networks (CNNs) and is trained on labeled data from publicly available datasets and custom-generated images using tools like Google Teachable Machine.

E. Automated Bin Selection:

Based on the classification result, a processing unit such as an ESP32 or Raspberry Pi is responsible for sending control signals to the motorized bin system. The processing unit interprets the classification output and rotates the corresponding bin into position for disposal. This modular design allows for flexibility in choosing processing units based on system requirements, such as processing power, memory, and connectivity.

D. Level Monitoring:

Sensors are integrated into the system to monitor the fill levels of the bins. When a bin reaches a certain capacity, the system triggers an LED indicator. A green LED signals that the bin has ample space, a yellow LED indicates that the bin is nearing full capacity, and a red LED signals that the bin is full and needs to be emptied. This feedback loop ensures that the system operates efficiently without overflow or maintenance issues.

III. WASTE CLASSIFICATION MODEL:

The waste classification model is a critical component of the system, built using TensorFlow and Keras. The model is trained to identify common types of waste encountered in everyday use. To ensure high accuracy, the training process involves augmenting the dataset with various image transformations, such as rotation, flipping, and brightness adjustments. This allows the model to generalize well across different conditions.

IV. Implementation: Given the modular nature of the system, its implementation can vary depending on the specific project requirements.

A. Hardware Implementation:

a) Processing Units: Depending on processing power and energy efficiency needs, the system can use either an ESP32 microcontroller or a Raspberry Pi. The ESP32 is suited for low-power applications, while the Raspberry Pi offers more processing power for complex tasks.

b) Camera Modules: The system supports camera modules like ESP32-CAM and Raspberry Pi Camera, allowing flexibility in image capture quality and integration with the processing unit.

c) Motorized Bin Control: The motor responsible for rotating the bins is controlled by signals from the processing unit. The motor is programmed to rotate in discrete steps, aligning each bin with the waste disposal area.

B. Software Stack:

OpenCV for Image Processing: OpenCV is used for tasks like image resizing and filtering, which prepare the captured images for classification.

TensorFlow for Waste Classification: The pre-trained TensorFlow model classifies waste in real-time. The model is optimized for low-latency inference to ensure that the bin rotation mechanism operates without delay.

Firmware for Processing Units: Custom firmware is written for the processing unit (ESP32 or Raspberry Pi), which handles image input, classification output, and motor control.

V. PROPOSED WORK

A. *Research:* Waste segregation is main problem in today's world and to reduce this manual segregation problem the entire process has been made automatic. This system developed with help of reference. Some drawbacks found in the reference these terms are waste type, image-based sensor, industry waste segregation. To counter this problem, it is thought to Add paper waste type. Considering the industry problem, it was suggested that waste segregation process should be developed there.

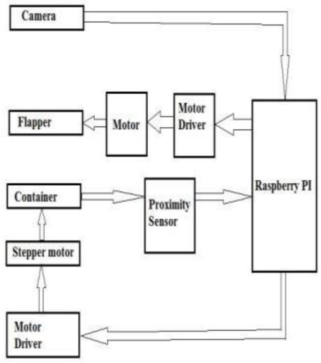
B. Design consideration: -

After recovering all issue related to reference, started create model design of solid waste system. This system is being designed to save manual time and also cost. Conceptual 3D design of Hopper, Containers, Motors, Steel Rods, Wheels, Flapper and Shell are drawn with the help of solid works. Calculate the load carrying capacity of motor.

C. Component specifications: -

In this system, have used acrylic containers. The main purpose of which is the container will look better and it will also be possible to measure the level filled with them.

VI. BLOCK DIAGRAM



VII. CONCLUSION

The development and implementation of an AI-based waste segregation system offers a significant advancement in waste management practices. This system helps to minimizing human effort with the help of AI also, reduce mix waste in landfill and cost for segregation. We can reduce the environmental impact of waste and help move toward circular economy.

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