SmartSort - Waste Segregation System Using Machine Learning and IoT

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***Abstract*—Waste management in Pakistan is a critical challenge due to rapid urbanization and population growth, resulting in 30 million tons of solid waste annually. Inefficient infrastructure leads to environmental degradation and public health risks. Lack of recycling exacerbates the issue, necessitating an effective waste segregation system. The proposed system helps increasing recycling of waste materials with the efficient identification and categorization of waste materials. The system utilizes object detection model for identifying wastes and categorizing into classes such as plastic, metal, paper, and trash. System utilizes CNN Model to identify waste classes, achieved 92.2% accuracy level. The system is integrated with an ESP32 and its camera module, enabling real-time detection and segregation into bins using Hardware setup made of wood using predefined angles of servo motor and actuators. This efficient approach tackles urban waste management challenges, promoting environmental sustainability and conserving resources. Its optimized methods contribute effectively to addressing urban environmental concerns.**

***Keywords*—Internet-of-Things(IoT), Machine learning, Monitoring system, Smart Bin, Arduino UNO, Waste Management, Waste Segregation, Automation, Sensors**

I. Introduction

Waste management in Pakistan, particularly in cities like Karachi and Lahore, faces significant challenges due to outdated infrastructure and a growing population of over 220 million people. With over 30 million tons of waste produced annually, the situation worsens day by day, leading to environmental degradation and public health issues. Manual waste sorting remains the primary method, highlighting the need for automated solutions. Our proposed system aims to automate waste sorting and classification, reducing reliance on manual labor and ensuring proper waste segregation. By categorizing materials and promoting recycling, we aim to contribute to a more sustainable waste management ecosystem in Pakistan. Current practices, reliant on manual sorting and inefficient infrastructure, contribute to contamination and pollution. Our proposed automated system seeks to address these challenges by streamlining waste management processes and reducing environmental impact.

Pakistan's current waste management system is inadequate for addressing the challenges posed by rapid urbanization, population growth, and industrialization. Manual sorting processes are time-consuming and prone to errors, hindering effective recycling efforts. The outdated infrastructure and lack of community engagement further exacerbate the problem. Integrating new technologies such as machine learning and IoT can offer a solution. Machine learning models can accurately classify waste types based on visual data, while IoT sensors enable automated monitoring and identification of waste, leading to significant resource savings. Additionally, IoT facilitates efficient waste collection, transportation, and disposal through real-time data analysis. By leveraging these technologies, Pakistan can transition towards a smarter and more efficient waste management system.

Our technology revolutionizes garbage disposal in Pakistan, using AI and IoT for waste collection. By combining sensors, cameras, and actuators, it sorts waste in real-time into plastic, paper, metal, and general trash. Machine learning predicts waste properties, optimizing resource retrieval and minimizing pollution. Fully automated, it eliminates human error, increasing efficiency and reducing landfill waste.

A. *Research motivation*

The motivation behind this study stems from the urgent necessity to tackle the escalating crisis of waste management in Pakistan, especially in densely populated urban centers such as Karachi and Lahore. The swift urbanization and population expansion have led to the alarming generation of approximately 30 million tons of solid waste each year. The lack of effective infrastructure for waste collection and disposal has resulted in environmental degradation, health hazards, and the inefficient utilization of valuable resources.

Currently, manual waste sorting by human labor remains the predominant method, underscoring the absence of technological solutions for efficient waste classification. In response to these challenges, our proposed system aims to revolutionize waste management by introducing an automated approach to waste sorting and classification. By eliminating the reliance on manual labor, our system ensures systematic segregation of waste into distinct categories and designated containers. The primary objective is to alleviate the burden of waste mismanagement in Pakistan, promoting efficient waste segregation at its source and making substantial contributions to improved recycling rates and minimized environmental impact.

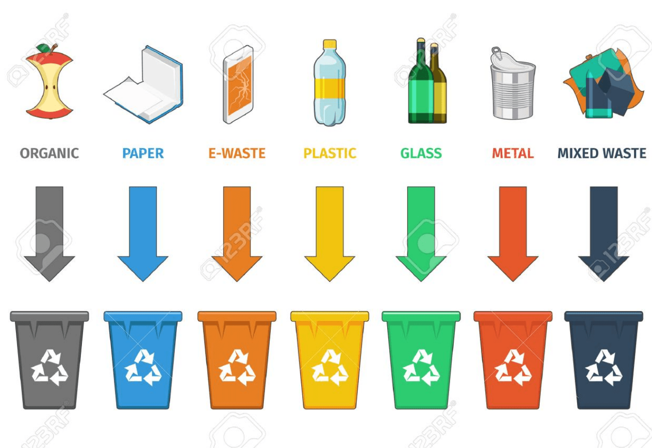

Fig. 1. Waste Management Process

II. Literature Review:

Fresh advancements in computer vision have been made possible in large part by recent advances in deep learning research. One of the most potent deep-learning algorithms, convolution neural networks (CNN) finds various uses in the classification, segmentation, and detection of images. CNN is therefore suggested to carry out garbage detection and recognition.[1-2] A deep neural network categorization model called RecycleNet was introduced in. Cardboard, paper, glass, plastic, metal, and rubbish are the six categories into which RecycleNet separated recyclable items. [3] Reference classified and localized street garbage using an OverFeat-GoogLeNet model. A high-resolution camera mounted on a moving truck that was driving on the streets captured photographs of trash. [4] The majority of the trash discovered were cigarettes butts and leaves. Reference examined the effectiveness of conventional machine learning classifiers (VGG-16 and AlexNet) with CNN-based classifiers for classifying garbage (KNN, SVM and RF). Classifiers built on CNN outperformed conventional ones. In addition to the study that was given, there are others like Adita Putri Puspaningrum [9] prepared a convolutional neural network using NVIDIA DIGITS, and trained a support vector machine using Matlab 2016. The study's limitation was the smaller number of descriptions and photos in the training and preparation set. The original 256 x 256 size of the training pictures was shrunk to 32 x 32. This decline introduced other pertinent challenges. On a Raspberry Pi 3, the research's final developed model was implemented on average in about 0.1 seconds.[4-5]

To automate the process, the IoT-enabled automatic waste segregation and management system uses a mechanical system [5]. Every household feels compelled to use two different trash cans and sort the garbage manually. This project helps the user to avoid the need for a second trash bin and human interaction during the waste separation process. Based on data gathered from the sensors the type of trash is also displayed on the LCD display. When the trash trays are full, ultrasonic sensors on the trays send data to the node MCU, which is then transmitted to the user's phone via an open-source app. The information detailing the integration of the different sensors to the Arduino microcontroller is proposed in [11-12]. The various types of wastes and segregation is discussed. The study focuses on the Municipal Solid Waste Management system and identifies the areas that require expansion. The garbage monitoring system study is described [6].

A number of methods have been used to examine and present the research and papers . The number of years it covers, the databases to search in, the search terms to use, and relevancy to the paper's focus were all taken into consideration. The database from two main databases, Scopus and Web of Science, was searched using keywords such machine learning, image processing, artificial intelligence, and a combination of waste segregation in order to be able to demonstrate certain advancements. They were selected as they offer the most comprehensive selection of scholarly papers and publications. [7]

III. Problem Statement

This project addresses the challenges in waste management through the implementation of an advanced waste segregation system. Focusing on accurate identification and categorization of materials like plastic, metal, paper, and trash, the system aims to enhance recycling rates and reduce environmental concerns.

IV. Purpose Statement

This project aims to create an efficient waste segregation system using advanced technologies, such as object detection models and raspberry pi integration. The objective is to improve recycling accuracy and promote sustainable waste management practices for environmental conservation.

V. Methodology

A. Proposed System

Our Proposed System is the combination of Hardware and Software System. In System Part, a CNN Object detection

Model with keras framework is selected. CNN Model is chosen for its efficiency, providing real-time object detection on computing devices. Its optimized architecture is perfectly balanced with speed and accuracy, making it suitable for lightweight and limited computational resources.The fine-tuning process involved training the model over 50 epochs with a learning rate of 0.001, adapting it specifically for object detection tasks. Hardware part is Structural Body made of wood to integrate it with software to display real time Waste Sorting.

B. Waste Dataset Collection

Famous waste datasets, including Openlittermap with multi-label annotations for outdoor waste, Trashnetnet focusing on indoor waste patterns, and WastePictures contributing to diverse outdoor waste types, serve as the foundation. These waste classes consist of plastic, metal, glass, paper and Trashnet[2]. There are some limitations of existing datasets and address them through modifications, including cleaning annotations, ensuring labeling consistency, and providing clear annotation for waste classification.[3-6]

The TRASHNET (common objects in context) dataset, comprising over 330,000 images, played a crucial role in training the model to recognize 91 object classes, each meticulously labeled and annotated. The annotations in the Trashnet dataset 11 provided information on object bounding boxes, enabling the model to learn spatial relationships and characteristics of various objects.

We collected dataset for this research Observations is completely organic with nowadays waste objects and materials. The total of 2000 images are collected for the dataset. Per class images are 500. The Python script is used to label the classes using an array of objects starting from 0 to 4. 0 is defined for plastic, 1 for metal, 2 for paper, 3 for trash, and 4 for none. below are images of collected dataset as four classes such as plastic, paper, trash and metal.

C. Hardware Setup and Design

The hardware body of the system is designed using wood as material for enabling real time Sorting and Segregation. The Hardware setup includes Entry point of 12*15 inches, for putting waste into, a 6 inch stand for placing camera module with ESP32, an opener below the entry point, with servo motor attached. Another Stand of 5 inches is placed at surface of the body for placing servo motor for enabling sorting functionality. Servo Motor is attached with an actuator of cardboard material to help in placing the waste objects to the dustbin. At last. we placed 4 dustbins as we have four classes in software model,near and infront of the hardware body to display fully functional system of waste sorting & segregation.

D. System Algorithm

The System start with live stream Camera feeding of ESP32 Camera Module. It constantly observe the input image, placing in the Entry Point. When Object is detected, it enables ESP32 and sends a signal of object being detected. Esp32 send the signal to CNN model to get result of object being detected. In mean time, CNN model detects the object and sends result to ESP32 for further operations. Using C language script, we have defined angles for each class to move into the dustbin. Figure 2 shows the flowchart of system architecture in more good way. The system algorithm defined are as follows:

1)Start
2)Drop waste object
3)ESP32 Cam enabled
4)if object==detected:
Enable ESP32
Model Predicts waste object
result send to ESP32
ESP32 changes Servo Motor Angle as:
If Object==Plastic
Angle=0
else If Object==Metal
Angle=90
else If Object==Paper
Angle=180
else If Object==Trash
Angle=270
else If object==none:
Nothing happens

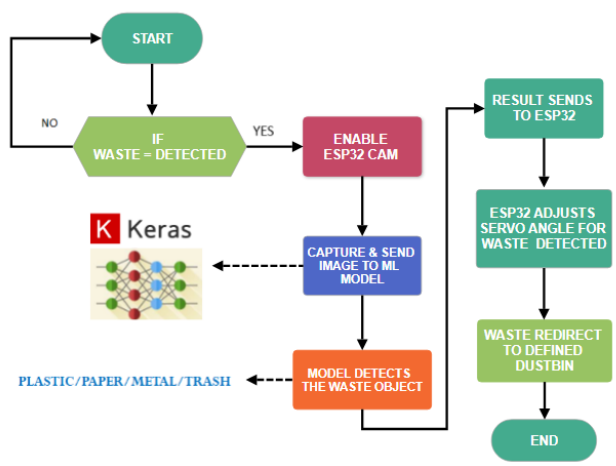

Fig. 2. System Algorithm Flowchart

VI. Findings

A. Findings

1) Model Execution Process: The Model was trained on Google Colab with dataset of 2000 images having four unique classes. The dataset was uploaded on a google drive and was accessed through it. firstly, dataset is splitted into training, validation and testing sets. The splitting contained 70% of training set and 30% of testing set respectively. After dataset splitting, data augmentation was performed to resize,scale images for training the model. Batch size is set to 16 and epoch number is set to 50 as it was enough for better model accuracy and predictions for wastes. Model was trained and observed accuracy of 92.2% overall.

2) Model Deployment: The Model with weight file ".h5" is deployed on ESP32 using C Language code in Arduino IDE. This systen implements a web server on an ESP32-CAM microcontroller, facilitating real-time control System. Through a WiFi connection, users can access a web interface hosted by the ESP32-CAM to manipulate the camera's orientation remotely. The HTML-based interface provides intuitive buttons for commanding the camera to move up, down, left, or right. Upon receiving these commands, the microcontroller adjusts the positions of attached servos accordingly, enabling smooth and precise control over the camera's movements. Additionally, the code enables live streaming of camera images, enhancing the user experience by providing visual feedback during camera manipulation. With its straightforward setup and responsive interface, this project offers a versatile solution for remote surveillance, monitoring, or exploration applications.

VII. Result

A. Model Training & Deployment

The result of training the model for detection of all types of waste specifically plastic, metal, paper and trash is observed thoroughly. The model required 50 epochs of training and took 2-3 hours to complete the training depending of internet speed and connection. The estimated loss value is approximately 0.11 and overall accuracy of the model is 92.21%.

B. Accuracy Per Class

Model have four classes as Plastic, Paper, Metal, & Trash. Each Class was trained with several Sample dataset to observe Model Accuracy for object detection and classification. Below is attached Accuracy Per Class table attcahed.

Accuracy per class

CLASS	ACCURACY	# SAMPLES
plastic	1.00	15
metal	1.00	11
paper	0.93	15
trash	1.00	15
none	0.75	4

Fig. 3. Accuracy Per Class

C. Accuracy Per Epoch

The overall result of the graph demonstrates the progression of accuracy per epoch during the training process. Both the training and test accuracies show an increasing trend over time, indicating that the model is learning and improving its performance. Initially, both the training and test accuracies start at a low value, reflecting the early stages of model training where the algorithm is learning from the data. As the epochs progress, both accuracies steadily increase, signifying that the model is becoming more adept at correctly classifying the data. The training accuracy reaches at 92.2%, indicating that the model has learned the training data perfectly. However, the test accuracy, while showing improvement, reaches a maximum of 80%, slightly lower than the training accuracy.

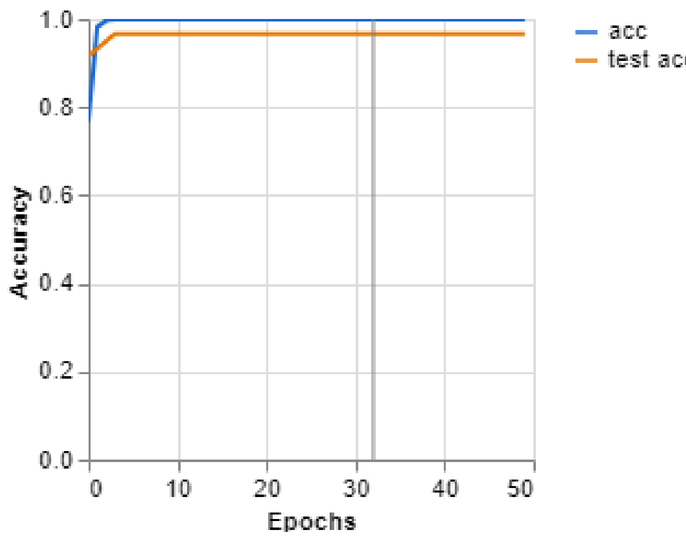

Fig. 4. Accuracy Per Epoch

VIII. Conclusion

Our Study has outlined a vision for the Waste Segregation System using Machine learning and IoT, driven by the aim of Transforming waste management practices. By Using cutting-edge technologies such as the ESP32, ESP32 camera, Keras model for object detection, and servo motors, we have laid the groundwork for an innovative waste sorting solution. Our mission is clear: to streamline waste segregation processes and promote sustainability by efficiently categorizing different types of waste materials. With defined angles for four bins catering to plastic, paper, metal, and miscellaneous waste, our system is composed to transform waste management practices.

The advantages of our proposed system are manifold. Firstly, it offers a more efficient and accurate method of waste segregation, reducing the burden on traditional waste management systems. Secondly, by automating the sorting process, our system minimizes the risk of human error and improves overall efficiency. Additionally, our system promotes environmental sustainability by facilitating proper disposal and recycling of waste materials. Moreover, the simplicity and accessibility of our design make it scalable and applicable in various settings, from households to commercial establishments.

IX. Recommendations and future work

A. Integration of Computer Vision Techniques

We propose the integration of computer vision techniques to enable detection and classification of various objects, thereby improving previous methods.

B. Additional Classes

We also advocate expanding accepted waste to include an additional classes, making them easier to identify and recycle.

C. Uses Sensor Technology

We also encourage the use of a full detection system that uses sensor technology to alert waste management agencies when containers are full so that waste can be disposed of in a timely manner.

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