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Automated Waste Bin Utilizing Machine Learning for Waste Categorization

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Abstract: - Proper waste management and disposal are crucial for maintaining a healthy and sustainable environment. Many developing countries like Nigeria are faced with such challenges for an effective waste management due to improper disposal practices. This paper aimed to address this issue by developing an automated waste bin system that utilizes machine learning techniques for waste classification. The system comprises of hardware that would accept the waste from the disposers and machine learning model that would predicts and classifies the waste. The system hardware was designed with camera and implemented using bottom-up approach. The waste images were gathered using smart phone's camera and properly labelled empty, organic and inorganic images to build up the dataset. A Teachable Machine platform embedded with deep learning algorithm was used to upload images and trained. The trained model with an accuracy of 98% was stored in the automated waste bin system's memory and tested. During testing, an organic or inorganic material is brought close to the camera, the system senses the object and captures a real-time image of the waste material using attached camera and sends to the controller. The controller calls the model that processes the image. The model accepts the image and compares it with the ones stored in the dataset. If it matches, it accurately classifies the waste into organic or inorganic categories and activates light emitting diode (LED) ON, then sends signal to the disposer to drop it in the exact waste bin. The test was conducted successful and is encouraged to be deployed in strategic waste places to ensure healthier environment always.

Key-Words: - waste bin, organic, inorganic, CNN, machine learning, waste classification, dataset

1 Introduction

Regardless of a nation's level of development, waste management is one of the most important problems the globe is currently confronting. The main problem with this waste segregation is that the garbage can in open areas fills up with water long before the cleaning procedure even starts. The cleaning procedure entails isolating waste that might have been caused by inexperienced personnel, which is less efficient, takes more time, and is implausible given the volume of waste that actually exists. The waste dump emits hazardous gases, which have negative effects on human health. In metropolitan places in Nigeria, managing waste is a daily chore that impacts positively in the social, economic, and environmental wellbeing of the country. Numerous strategies, including the nearest neighbour search, colony optimization, genetic algorithms, and particle swarm optimization techniques, have been put forth to optimize waste management [1]. Global population growth has resulted in improper waste management practices in many nations, causing health problems and environmental contamination. The garbage trucks only pick up waste once or twice every seven days. Waste collection is a crucial component of smart city services, and smart technology has enormous potential to improve the effectiveness and caliber of rubbish collection globally. An automated system for sorting and recycling waste is increasingly necessary for sustainable waste management due to the expanding waste problem brought on by modernization and industrialization. The field of picture classification has greatly advanced with deep learning, which makes it perfect for applications like waste sorting. For this application to work, a suitable deep learning model that can reliably classify different types of garbage must be developed.

2 Reviewed Works

In [2], Household Waste Management System Using IoT and Machine Learning was presented. Their system focused on segregation of the house hold waste and recycling of biodegradable waste. The model was achieved using K nearest neighbour algorithm (KNN). An Automated Machine Learning Approach for Smart Waste Management Systems was presented in [3]. They deployed Random Forest classifier to detect, classify, and manage waste. The detection and classification accuracy of the waste was improved from 86.8% and 47.9% to 99.1% and 98.2%.

In [4-5], an intelligent waste management system using deep learning with Internet of Things (IoT) was developed. A smart trash bin made up of microcontroller and multiple sensors was designed to capture the digestible and indigestible wastes. The CNN, deep learning architecture deployed to sort the wastes accordingly with integrated IoT and Bluetooth technology for monitoring. The classification accuracy of the proposed architecture based on the CNN model is 95.3125%, and the SUS score is 86%. Machine Learning (ML) and IoT-Based Waste Management Model was developed in [6]. The authors developed hardware prototypes which consists of Arduino UNO microcontroller, ultrasonic sensor, and moisture sensor and used it to take waste images. The ML processed the images and measured the waste index of a particular dumping ground which help established clean and pollution-free cities. A machine learning approach for a circular economy with waste recycling in smart cities was proposed in [7]. The researcher developed an IoT and machine learning-based waste recycling framework (AMLWRF) that classify and separate materials in a mixed recycling application for improved separation of complicated waste. In [8-9], Waste Management Using Machine Learning and Deep Learning Algorithms were presented. They gathered dataset and arrange it into six classes consisting of glass, paper, metal, plastic, cardboard, and waste. Three Machine Learning algorithms (Support Vector Machine (SVM), Random Forest, and Decision Tree, and one Deep Learning algorithm called Convolutional Neural Network (CNN) deployed to find the optimal algorithm that best fits for the waste classification solution. CNN outperformed the other models with percentage accuracy of 90%, SVM indicated an excellent transformation to various kinds of waste, with 85% classification accuracy, and Random Forest and Decision Tree accomplished 55% and 65% classification accuracy respectively.

A Reliable and Robust Deep Learning Model for Effective Recyclable Waste Classification was developed in [10]. A novel deep learning model was designed for classifying six distinct waste categories using the TrashNet dataset of 2,527 images. The proposed model outperformed several state-of-the-art models with a remarkable overall percentage accuracy rate of 95.01. The system received high F1-scores for each of the six waste categories namely 97.24% for cardboard, 96.18% for glass, 94% for metal, 95.73% for paper, 93.67% for plastic, and 88.55% for litter. The reliability of the model was demonstrated qualitatively through the saliency maps generated by Score-CAM (class activation mapping) model, which provide visual insights into its performance across various waste categories. Their results highlight the model's accuracy and demonstrate its potential for effective automated waste classification and management solution.

In [11], an Automatic Waste Segregator Based on IoT & ML Using Keras model and Streamlit was built. Their system showcased Internet of Things (IoT) Waste Segregator system that combined real-time data collection and machine learning approach with the help of Streamlit. The system consists of sensors and cameras integrated in locations for waste collection, allowing for the monitoring the level and classification of waste materials in real time. A deep learning (CNN-ResNet 101) model deployed in the Keras framework processed the data gathered by these sensors. The system is able to successfully learn and distinguish between different types of garbage based on visual signals. Automated waste-sorting and recycling classification using artificial neural network and features fusion: a digital-enabled circular economy vision for smart cities was presented in [12]. A digital model that automatically sorts the generated waste and classifies the type of waste as per the recycling requirements based on an artificial neural network (ANN) and features fusion techniques was developed. The developed model was validated by extracting relevant information from the dataset containing 2400 images of possible waste types recycled across three categories. Based on the analysis, it was observed that the proposed model achieved an accuracy of 91.7%, proving its ability to sort and classify the waste as per the recycling requirements automatically.

In [13], Smart Waste Management with Classification System for Smart Cities using Deep Learning (DL) was developed. They deployed IoT and DL techniques for waste gathering, rubbish categorization and sorting. Waste Classification for Sustainable Development Using Image Recognition with Deep Learning Neural Network Models was presented in [14]. They deployed EfficientNet-B0 to categorize bio, plastic, glass, metal, paper, etc. of the targeted garbage bin. The model was pre-trained using ImageNet with accuracy between 74% and 84%. In [15], Smart Waste Management with Classification Systems Using Cutting Edge Approach was developed. The system uses the Internet of Things (IoT), deep learning (DL), and cutting-edge techniques to classify and segregate waste items in a dump area. A camera captures the waste yard image and sends to an edge node to create a waste grid. The deep-learning algorithm deployed was Visual Geometry Group with 16 layers (VGG16). The algorithm trained on a cloud server and deployed at the edge node to minimize overall latency. The overall accuracy of the model is over 90%, which is quite effective.

3 System Design Approach

The design approach employed is bottom-up whereby the whole system is broken into smaller units, design and tested before integrating all together. The system consists of hardware and software as shown in fig. 1.

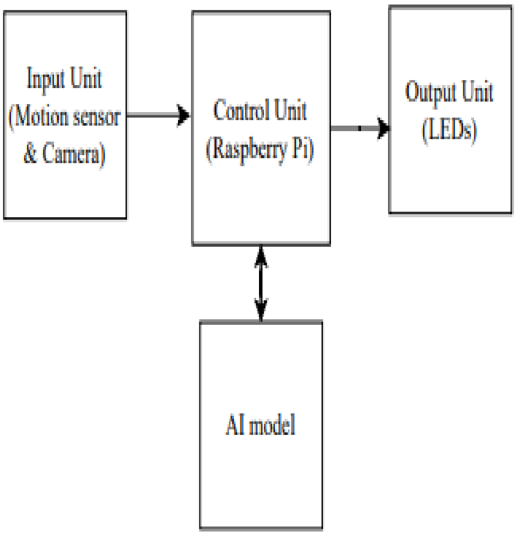

Fig.1. Block diagram of the automated waste bin classification

3.1. Input Unit.

Raspberry Pi camera is used to capture the waste image for classifications. The PIR motion sensor senses the object when it is kept on the surface of the system and triggers the controller to take the image and process for prediction. Fig.2. shows the components as discussed.

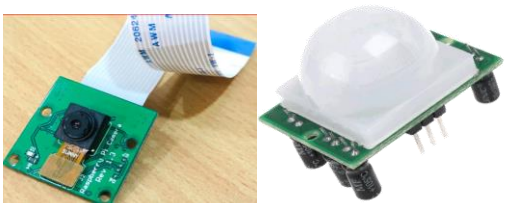

Fig.2. Raspberry Pic camera and PIR sensor

3.2. Control Unit.

Raspberry Pi 3 model B (fig.3.) is used as a control of the system. This unit receives data from the input components, processes and output the results. This component was chosen because of its capability to process machine learning programs.

Fig.3. Raspberry Pi 3 model board

3.3. Output Unit.

Three Lights emitting diodes (LEDs) were used for output device to give an indication of system response based on results of waste identification and classification process. Each LED (fig.4.) is characterized to emit green, blue or red light which indicates the result of the process. Green LED for organic, blue LED for inorganic and red for power input.

Fig.4. LEDs used for output

3.4. System circuit and Operations

When the system is switched ON, the controller is put to sleep and the system goes to the standby mode. In this mode, the camera is made to sleep in order to reduce the amount of power drawn from the battery which prolongs the battery life. Once triggered, the motion sensor senses any waste dropped on the base and sends signal to the controller if any to trigger the camera to take a video shot of the waste. The waste image is sent to the control unit that triggers the stored model to run for waste classification. The model predicts whether the waste image is organic or Inorganic. If the prediction is organic, then the green LED is switched ON and instructs the waste be placed in container A. If the prediction is inorganic, then the blue LED is switched ON and instructs the waste be placed in container B. Fig.5 shows the system circuit diagram used to achieve it.

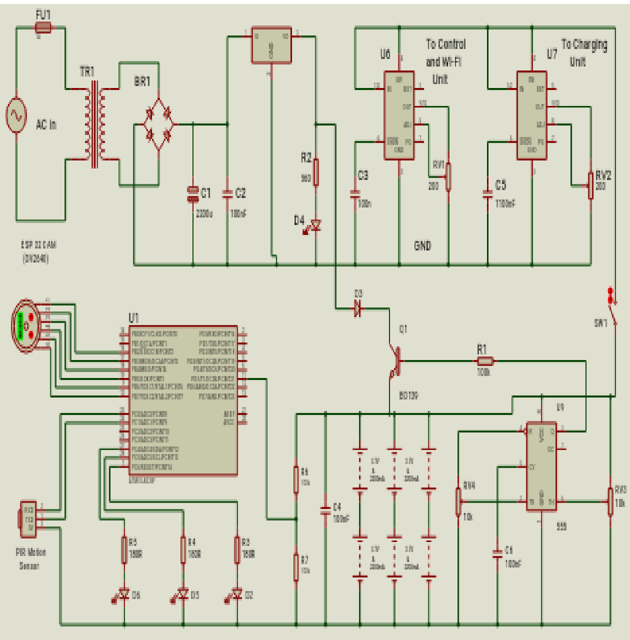

Fig.5. Circuit diagram of the waste bin

3.5. System Algorithm and Flowchart.

The sequence of instructions used by the microcontroller to control the system behaviour is as follows:

Step 1: Initialize all variables.
Step 2: Initialize sensor and camera.
Step 3: Check if there is waste object on the system base. If yes, capture an image and go to step 4. If no, go to step 3
Step 4: invoke the model for waste image detection and classification.
Step 5: Check if the object classified as organic or inorganic.
-If the object is organic, activate the green LED and place the object in waste bin A and go to step 6.
- If the object is not organic, activate the blue LED and place the object in waste bin B and go to step 6
Step 6: Go back to step 3 and continue
Step 7: Stop.
The flowchart of the algorithms is show in fig.6.

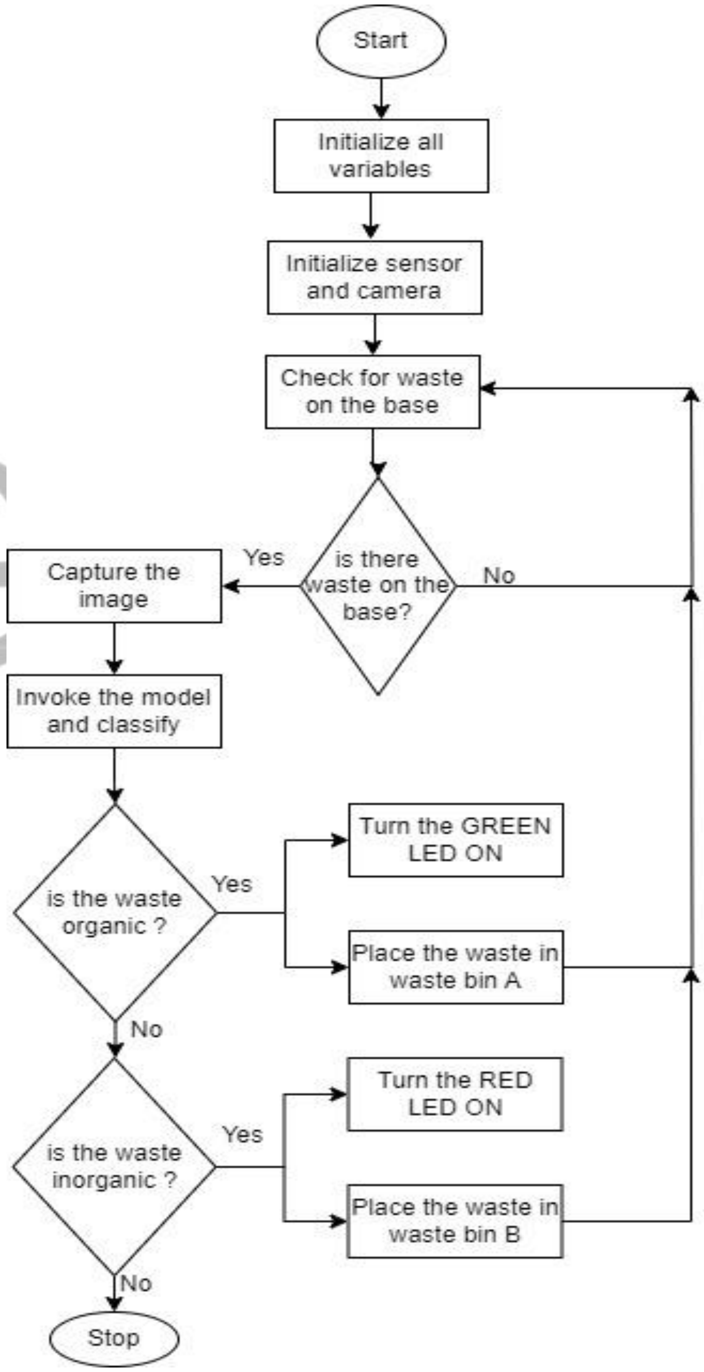

Fig.6: The flowchart of the system

3.6. Waste System Prototype.

The system was designed, simulated and constructed. The packaging of the system was built and neatly arranged in a square wooden base measuring 14 in x 8 in x 1in while the raspberry pi 3B, internal battery and power supply along with the sensor and pi camera were placed in a small black plastic box with a hole for the camera lens. Attached to the plastic case were the three indicator LEDs, camera, sensor and control switch SW1. Fig.7 shows the system prototype, both the internal and external views.

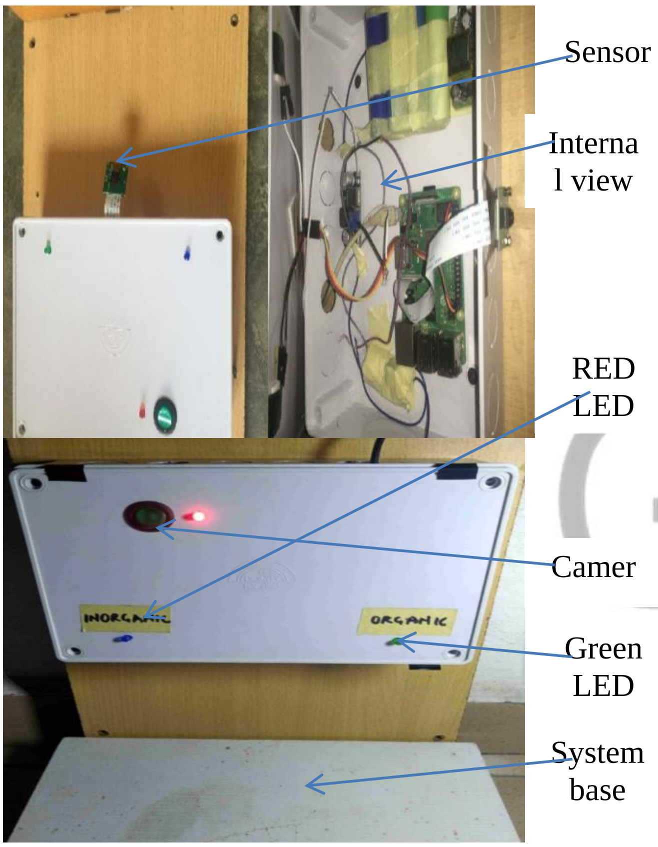

Fig.7: The internal view and complete system

3.7. Artificial Intelligence Model (AI).

The artificial intelligence model for waste detection and classification process has four phases. The phases are waste detection and capture, phase normalization, feature extraction, and waste classification as shown in fig.8. All these steps adopt similar techniques and depend on one another.

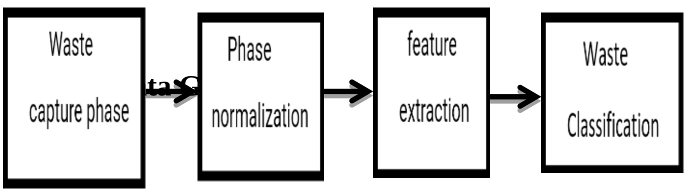

Fig.8. Step-by-step process of the model development

The data for organic and inorganic materials were gathered by taking various pictures of the items and store them in a folder. Fig.9. and fig.10 show dataset samples for organic and inorganic.

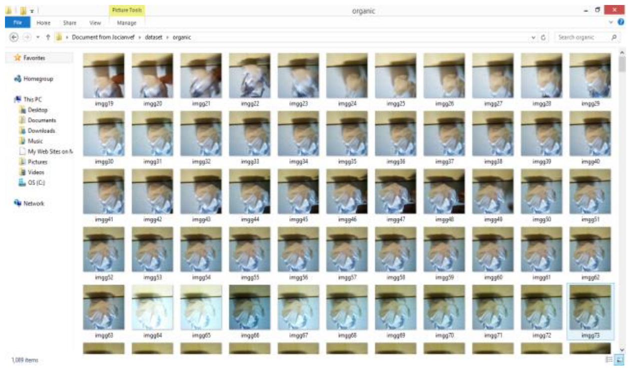

Fig.9 Organic material used in the algorithm training

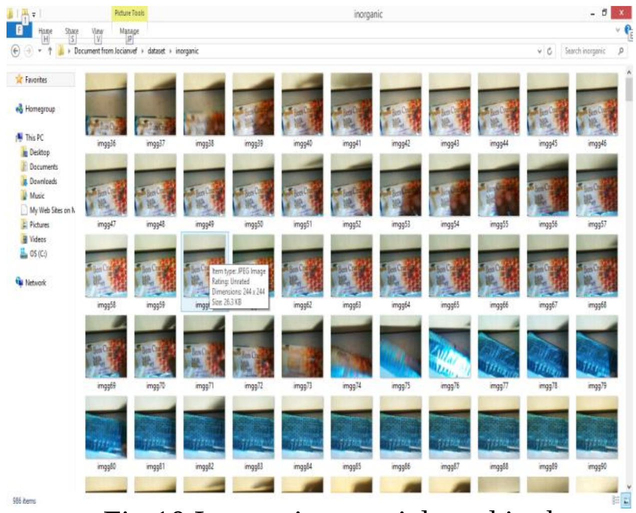

Fig.10 Inorganic material used in the algorithm training

3.7.2 Model Training

The teachable machine Google platform was used to train the Convolutional Neural Network (CNN) algorithm for the proposed model that would classify the waste to be either organic or inorganic as shown in fig.11.

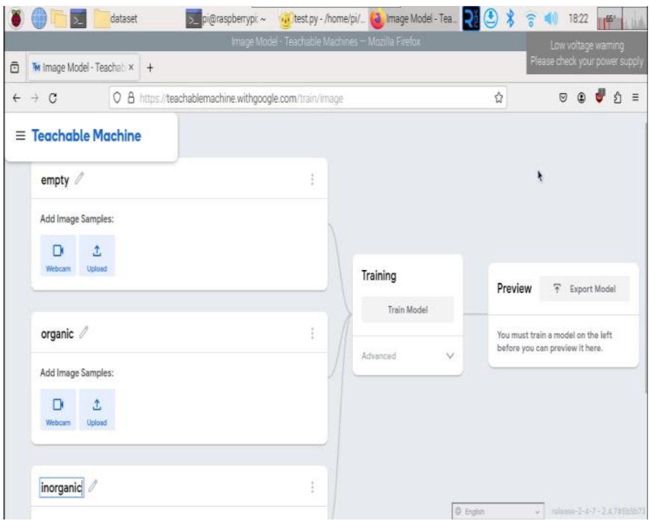

Fig.11. Teachable Machine platform used for the model's training

the training. Each of these classes was uploaded by clicking on the upload button one after the other. 80/20 training rule was adopted. The algorithm training was configured for 50 epochs in 16 batches with learning rate of 0.001. After the training, 98 percent accuracy was achieved.

3.7.3 Training Results

After training the algorithm with several adjustments on the learning rate, the system result is as shown in figure 12.

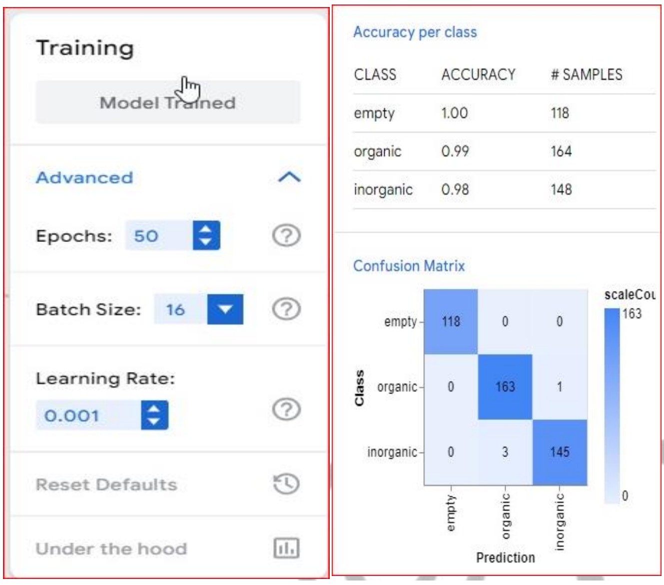

Fig.12. Accuracy result per class with confusion matrix

The graph plot of test loss against epoch shows clearly that the loss started at 0.002 for all the epochs and the system did not learn. After some adjustments made and retrained, the accuracy increased indicating the system has learned. A graph plot of accuracy against epoch shows in fig. 13, the accuracy achieved. 20 percent remaining of the dataset was used to test and validate the model.

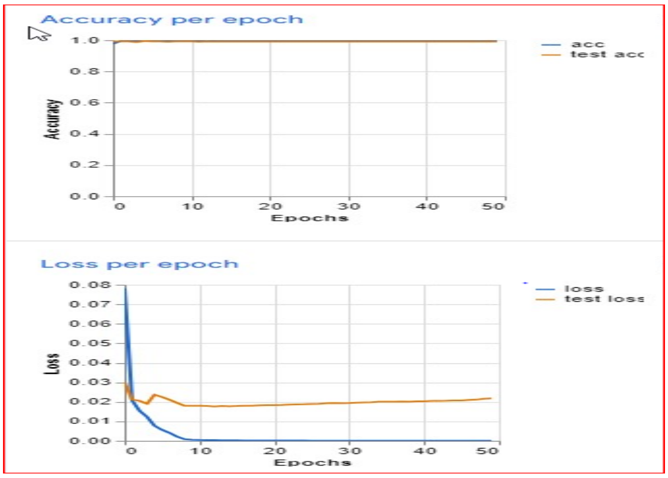

Fig.13. Accuracy and loss performance plot against epoch

The system is switched ON and organic material dropped on the base of the system for detection and classifications as shown in fig.12.

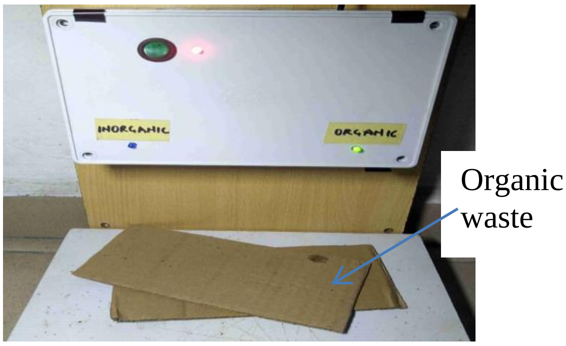

Fig.12: organic waste sample on the base for detection

The system sensed the material on the base with its motion sensor and sent signal to the microcontroller that triggered the camera to take the picture of the material. The image was passed to the developed CNN model for classification. After classification, the microcontroller activates the green LED indicating the material is organic and opened the waste bin for organic to be dropped into. In the same vein, inorganic material was drooped as shown in fig.13; the sensor sensed it and microcontroller triggered camera to take the image and activates blue LED, then opened the waste bin for it to be dropped. The process is repeated until the waste finished.

Fig.13. Inorganic waste sample on the base

5 Conclusion

The implementation of automated waste bin for categorizing waste (organic and inorganic materials) was successfully achieved. The hardware section of the system was equipped with the necessary sensors and components. The model part of the system was developed in teachable machine platform. The developed model is stored in the raspberry pi memory and called when classification is required. The system has been tested with good percentage accuracy in predictions. For further enhancement of the work, researchers can integrate robotic arm to serve as the picking and dropping of the waste material.

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