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Waste Segregation using CNN & IoT

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Abstract:

Due to rapid urbanization and ever-increasing population, India requires a sophisticated waste management system. Only one-fifth of the generated waste is treated and the rest is dumped in landfill sites. Segregation of household waste reduces a lot of complexity in waste treatment plants. Usually, segregation of household waste into dry and wet categories is done manually by the workers collecting the waste. This paper describes a waste management system to segregate waste into dry waste and wet waste through automation. The automation process saves a lot of time and effort and makes it easier for waste treatment plants. The system includes a camera module, which captures the image of the waste based on input from a sensor. The image, that is stored on Raspberry Pi, is then classified used the deep learning classification model. The proposed model is a miniaturized waste management system uses IoT and Deep Learning which can be implemented in the waste treatment plants or large sized community garbage containers on a large scale. The project consists of sensors, Raspberry Pi board, Deep Learning model, model training tool—Lobe, IoT dashboard, camera module, deep learning libraries which include lobe, TensorFlow Lite and open CV and servo motor. The CNN learning model uses ResNet and MobileNet algorithms for speed, accuracy and compatibility. The model, trained using a total of 12000 image samples, is efficient in segregating waste into dry waste and wet waste.

Keywords: CNN, Deep Learning, IoT, Lobe, MobileNet, Raspberry Pi, ResNet, TensorFlow Lite

I. Introduction

According to Down to Earth magazine, around 380 million people live in 7935 towns and cities in India. And, they generate around 62 million tons of waste. Of which, only 43 million tons is collected and 11.9 million tons is treated. Remaining 31 million tons of untreated waste is dumped into landfills. Indian government came up with an initiative towards a Clean India called Swachh Bharat. Now Swachh Bharat 2.0 which focuses on collection of waste to 100% with an investment of 1.41L crores. With the huge population producing household garbage every day, there's a strong need for segregation of waste into dry and wet categories. The segregation is essential because proper waste management not only reduces waste but also reduces the emission of greenhouse gases like methane, carbon dioxide from the landfill sites.

Fig 1.1 - Wet waste and Dry waste categories

The wet waste category includes vegetable peels, leftover curries, chicken bones, fish bones, fruits, flowers, and fallen dry leaves, and etc. While plastic, rubber, glass, metal, cardboard, paper, cloth come under the category of dry waste. Wet waste is packed together bundled using paper for proper composting. Dry waste will be sent for separation of material into recyclable and reusable categories. In this project, we have used around 12000 image samples of dry and wet wastes to build an efficient model for classification. Raspberry

Pi 3 and IoT devices are used to automate the process of segregation at waste treatment plants and municipal garbage bins. Raspberry Pi 3 is the most widely used variant by the student and research community, since the introduction of Raspberry Pi boards. Raspberry Pi is a low cost, SoC computer designed to easily interface with IoT and embedded devices. It plugs into computer monitor, TV or Laptop for its display. Usage of Deep learning along with IoT results in a smart and fully automated waste management system. We have used convolutional neural networks to create an efficient model for image classification. This model which is in TensorFlow lite format is better suited to run in embedded devices like Raspberry Pi 3, with it being a light weight learning model along with better computing power.

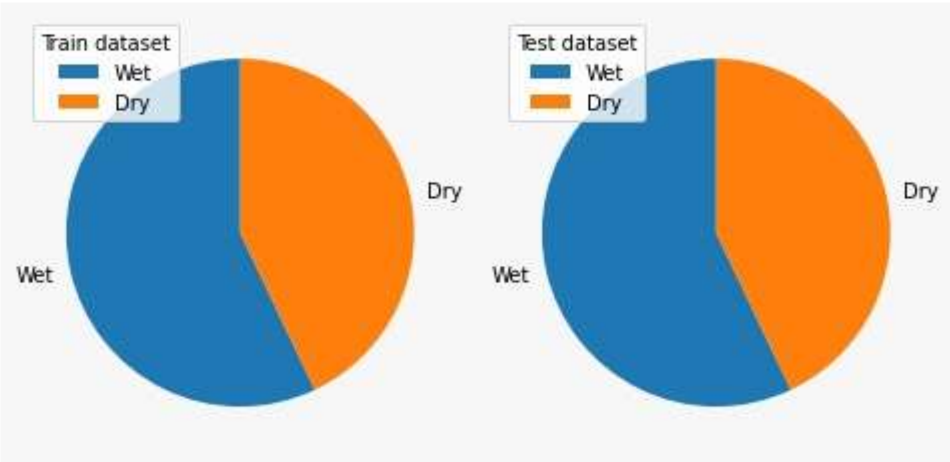

Fig 1.2 – Train dataset composition **Fig 1.3 – Test dataset composition**

II. Literature Review:

The waste management system involves various types of waste like household, medical, electronic waste, and others. Earlier research works proposed the methods that are done by using IoT devices and sensors. Some papers proposed the segregation of waste into biodegradable and non-biodegradable categories, but the paper, which is a recyclable material, will be thrown into landfills along with other biodegradable waste. The intervals of the garbage collection and "distance between the treatment plant also plays a major role" [1]. Conventional methods, where human workforce is involved in the manual segregation of the waste can cause diseases and also such a method is time consuming and requires a lot of effort [15]. There were some models proposed that trash containers will be screened and the waste is classified and stores the data on webserver for future analysis [7]. Although some papers presented a faster algorithm like R-CNN , Raspberry Pi cannot efficiently process these algorithms which require high computational power, which raspberry pi cannot provide[5]. So, we propose to use new generation tool like Microsoft Lobe, which can automate the training of the learning model and builds a model in accordance with our dataset. It also features the option to export the learning model in many formats and can be used like any other pre-trained model. TensorFlow lite format available in this application allows the usage of faster and simpler model to be used in mobile & small devices like Raspberry Pi.

III. Methodology:

The proposed waste management system is designed using model training tool – Lobe and a microcomputer to interface the deep learning model with IoT sensors and devices – Raspberry Pi 3. The IoT sensors used in this project are IR sensor, Ultrasonic sensor along with devices like Pi Camera and Servo motors. The prerequisites are

1. Build an efficient learning model
2. Install the necessary python libraries

The learning model is built using an application called Lobe, which is designed to train a model from a given data set.

Lobe:

Lobe is a deep learning tool designed by Microsoft. It automates model training by extracting the features from the image or video samples from input data. This app is specially designed to train models that involve image analysis, image processing and video analysis. The model is trained from the given data and can be exported from the application. This exported model can be used as any other pre-trained model. Lobe uses ResNet (residual neural networks) and MobileNet (mobile neural networks) to train a model. Lobe simplifies the method of training a model. It requires simply three steps: Import the collected data set, Train the model and Understand the results and improve the model through feedback. Finally, export the model into any desired format that is suits with the device, compatibility and computing power.

Installation of python libraries is done by few simple Linux commands through the terminal of Raspberry Pi. These python libraries allow the python code to interact with IoT devices and sensors connected to raspberry pi. The libraries are used by camera to capture the images and store them in the target folder, to import the code and input image from the source folder, and to use and interact with the learning model. The libraries used are Lobe, TensorFlow Lite, Pillow and Open CV.

Additionally. Python programming language is used to write a code to interface with IoT devices and deep learning model with Raspberry Pi board. The design broadly comprises of three modules. The modules process the input to either send output to the next module or to perform its own functions. The modules are:

1. Camera module: The camera module comprises of a Pi camera and IR sensor to detect the presence of an object. The camera captures image of the object when the output of the IR sensor is positive. The camera uses open CV library to capture the image and store it using a pre-determined name on the local storage. Open CV is an open source library. It contains programming functions and computer vision tools, which are designed to solve computer vision problems.
2. Deep learning model: The deep learning model uses CNN algorithm, which classifies the image sample stored on Raspberry Pi board. The model is exported from the Lobe application in the format of TensorFlow Lite. The python code uses the Lobe, Pillow and TensorFlow lite libraries to get the input image and analyse it by using the learning model to classify the image. The output is predicted by the model after analysing its features and parameters. TensorFlow lite is a set of tools, more compatible with Android, embedded and IoT devices. It performs with higher speed than TensorFlow and can be exported as smaller and simpler model. This library is used to interface with TensorFlow-lite files
3. IoT module: This module composes of IoT devices and sensors. Ultrasonic sensor is used to measure the depth and analyse if there is space available in the bin to dispose the waste into it. Servo motor is used to dispose the waste into appropriate bin.

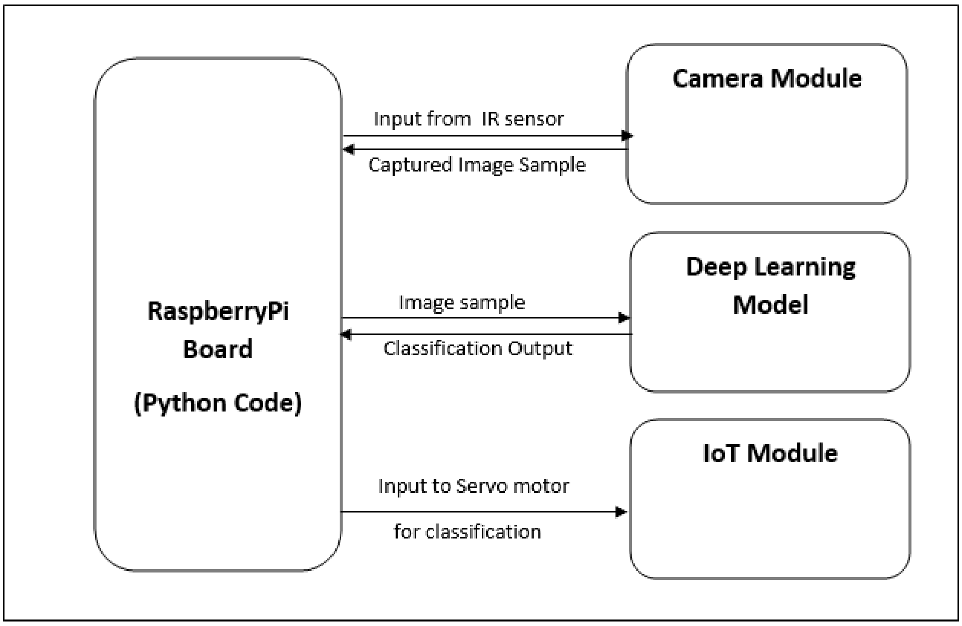

Fig 3.1 – Design

CNN algorithm:

The learning model used ResNet and MobileNet algorithms, which are a type of convolutional neural networks. Convolutional Neural Networks (CNNs) are deep neural networks that are most commonly used for Image classification and analysis and also for Videos samples. CNN casts multiple layers on the image to extract features and parameters and uses these features to analyse the input image. CNN is more suitable for image classification, as it can reduce the parameters, dimensions and features while retaining the important and necessary features. This increases the speed and reduces the complexity. The layers used by CNN to understand the patterns and features are math layers, rectified linear unit layer, and fully connected layer.

1. Residual Networks: Also known as ResNets are a type of deep convolutional neural networks. The architecture of residual network is in Figure 1. ResNet50 is popular convolutional neural network and a variant of ResNet model, that is 50 layers deep.

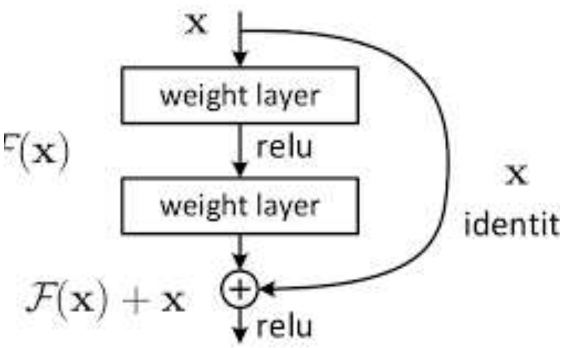

Fig 3.1 - ResNet

2. Mobile Networks: Mobile Networks are streamlined and are of convolutional neural networks architecture that uses depth-separable convolutions, designed to perform well on mobile devices with low computational power like embedded devices, IoT devices, Android devices, and etc. to build light weight deep neural networks. Its structure is similar to the Inverted residual block. MobileNetV2 is the model used in this project, initially contains fully convoluted layers with 32 filters, followed by 19 residual bottleneck layers.

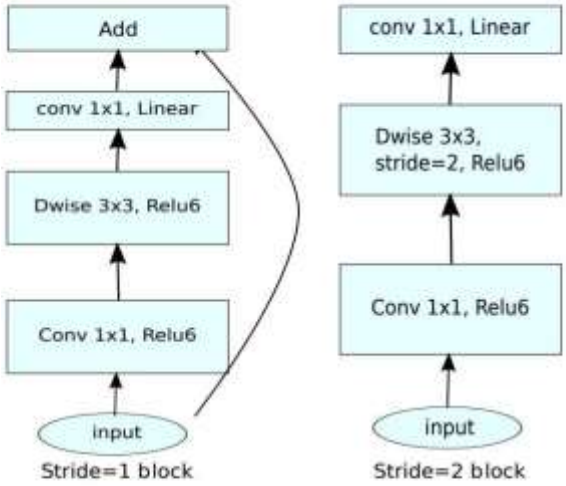

Figure 3.2 – MobileNetV2

IV. Experimental Setup:

The proposed waste management system can be broadly divided into three modules. Prerequisites are Raspberry Pi board, Pi-camera, Lobe application, Ultrasonic sensor, IR sensor, Servo motor. Before implementation of the model, there are libraries that need to be installed and requirements that need to be fulfilled. This includes training deep learning models and preparing Python code to implement our project.

- **Preparing the Deep Learning Model:**
  The model is trained using Lobe software application, which was created by Microsoft Corp. to make it easier for training a model by automating the training part based on the input samples or dataset. Lobe trains the model using CNN algorithm which uses ResNet50 and MobileNet for Accuracy and Speed, respectively. This application was created to easily train models which involve image analysis, image classification, video analysis, and video surveillance.
  This application can be used by importing the folder which contains the input samples with their classes being used as labels. The labels used are 'DRY' and 'WET' for our project. The model is then trained by the application. And then after training, the model can be tested by giving live inputs and providing feedback to improve its accuracy.
  The model is then exported from the application as a TensorFlow Lite file, which is more suitable for Android, embedded and IoT devices.

- **Installation of Python Libraries:**

  The code is written in Python programming language, which easily compliments the usage of functions and libraries of Deep Learning. The libraries required are:

- Open CV:
  The open CV library is used to work with the camera module and store the image in the allotted folder. The captured image is named with a name as provided in the python code.
- TensorFlow Lite:
  This library allows Python code to apply the model, Tflite file, to the input image sample. And a Json file supports this model file.
- Lobe :
  This library is used to implement the DL model which is exported from Lobe application. This library is used to import the model and input image from the raspberry pi folder which consists of the input image sample.

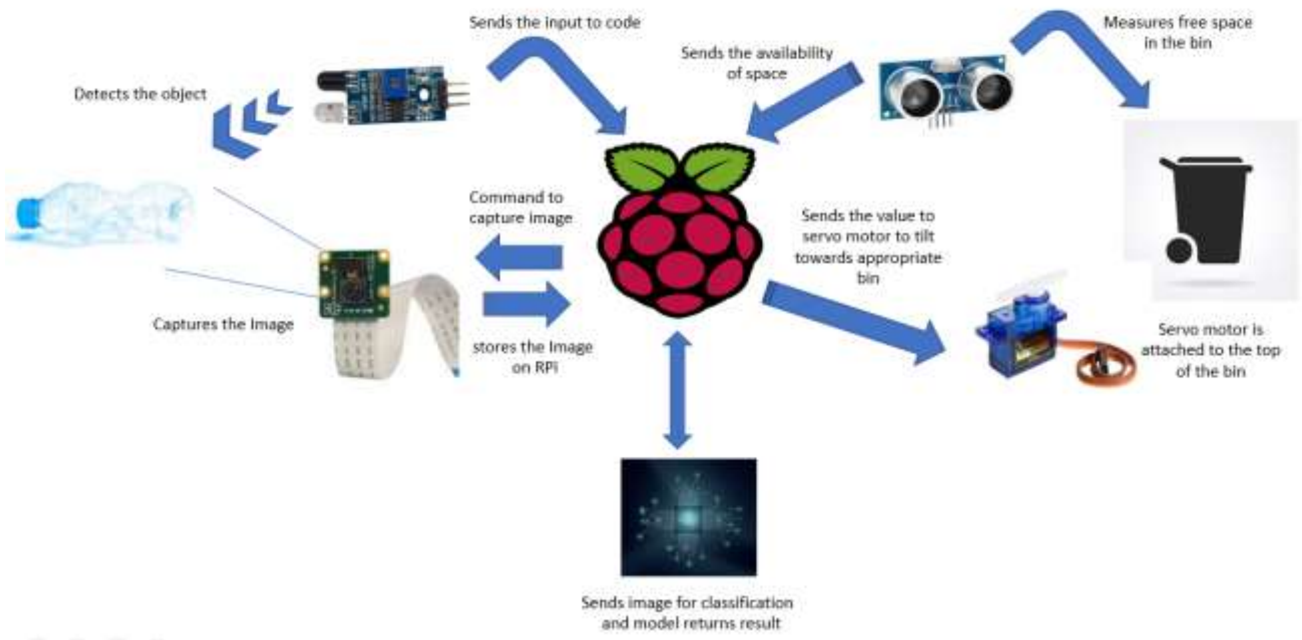

Fig 4.1 - Model Architecture

The components used are IR sensor, Pi Camera, Raspberry Pi 3 board, Ultrasonic sensor and Servo motor and software includes Lobe Application, Raspberry Pi OS, Python and its libraries. The model exported from the Lobe application is placed in a folder on Raspberry Pi and the path is mentioned in the python code. Working of the proposed model starts with the detection of the object thrown into the bin by an IR sensor. The IR sensor, then sends a value, '1' for presence of object and '0' for absence, to the python code. When the object is detected, the camera captures the image and names it 'img' as mentioned in the code, with an extension of '.png'.

The image, after pre-processing and dimensionality reduction, is stored in the local folder of the Raspberry Pi as specified in the Python code. After the image is captured, the deep learning pre-trained model is imported and used to classify the image and decide the category of the object.

The result is obtained from the classification model, which is either 'Dry' or 'Wet'. The ultrasonic sensor attached to the top of the bin, calculates the free space available in the bin. This sensor works by sensing out high frequency sound wave beyond the range of human hearing. The transducer sends and receives the ultrasonic sound and then it calculates the distance using the time taken by the ultrasonic sound to return back and its speed. If the bin is vacant enough, the output from the deep learning model is used as input to the servo motor.

The servo motor is set in such a way that, when the object is classified as wet waste, the top tilts 45 degrees towards the 'Wet waste' bin. Otherwise, it tilts 90 degrees towards the 'Dry waste' bin to dispose the waste into the appropriate bin. If the bin is already full, it sends a message to the user or administration to clear the bin. The administrator is notified by the text message sent through Bluetooth or Internet connection.

V. Results:

The time interval to empty the bins is set to 8 hours and the bins can also be emptied whenever the depth or vacant space calculated by ultrasonic sensor reaches the threshold level. The data is plotted with time vs depth of the bin to analyze and understand the frequency and interval at which the collection of data is ideal.

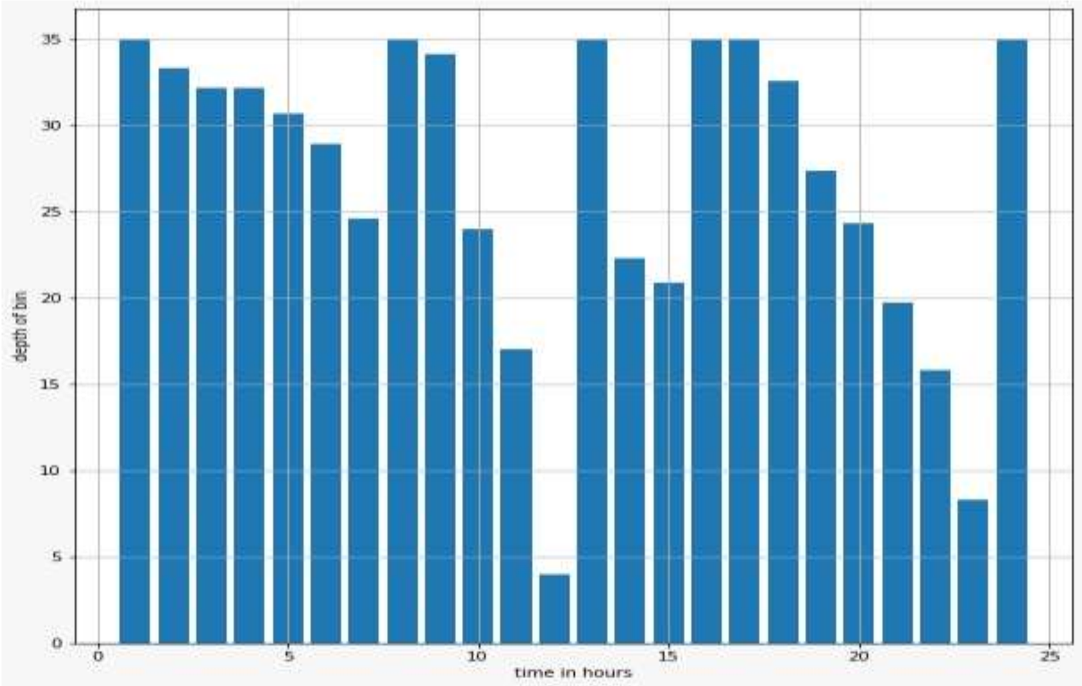

Fig 5.1 – Time vs Depth of the bin

As observed from the Fig 5.1, the default depth of bin is 35cm. Whenever the bin is emptied, the ultrasonic sensor reads a value of 35. Each bar in this graph represents the vacant space available in that hour. Whenever the value is less than our threshold value of 5, the user is alerted to clear the bin. So, the depth in next hour is a value of 35.

The following are input images along with their outputs. The object in the input image is waste object that is classified by our classification model and result can be observed in the output terminal of the python IDE. The output is either 'Dry' or 'Wet' based on the classification of the input image.

Fig 5.2 – Pickle

Fig 5.3 – Polythene cover

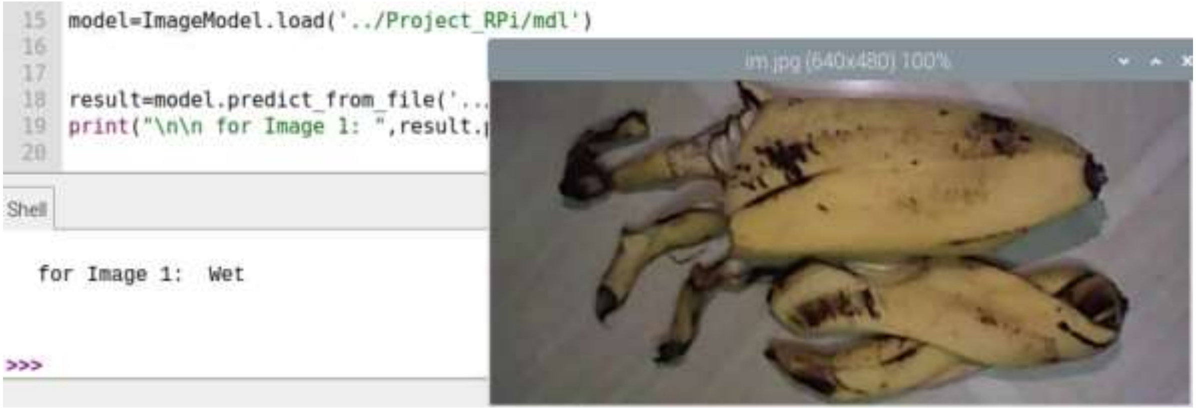

Fig 5.4 – Banana peel

Fig 5.5 – Cardboard

Fig 5.6 – Plastic bottle

The above images are the screenshots of the input images along with the category they are classified into. Objects such as Polythene cover (Fig 5.3), Cardboard (Fig 5.5) and Plastic bottle (Fig 5.6) are classified as 'Dry' waste, whereas Banana peels (Fig 5.2) and Pickle (Fig 5.4) are classified as 'Wet' waste. These results prove that the learning model is working efficiently and classification is accurate.

VI. Conclusion & Future Work:

The use of AI automates the work and processes involved to present an efficient way of doing things. Although people fear that the use of AI is going to affect their jobs, the are some issues that require immediate action and efficient methods to tackle them. Waste management has become a colossal issue, that needs automation of the process along with swift and efficient methods to tackle it. Here, AI can contribute by reducing time and effort through automation. The proposed system can automate the process of segregation and separate waste into Dry and Wet classes.

This system can be efficiently used on a large scale in waste treatment plants and large garbage bins to treat the waste. The automation of model training by lobe application can be further applied in classifying medical waste, Electronic waste, Industrial waste, etc. Through the use of IoT and AI, the segregation and treatment of waste becomes through and efficient, leading us towards a safer, cleaner and greener environment.

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