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ORIGINAL RESEARCH

Interdisciplinary Implementation of Supervised Real-Time Waste Management

Praveen Kumar[1] · Rishabh Jain[1] · Deepak Kumar[2] · Seema Rawat[3]

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Abstract

Over time, we are observing a colossal increase in the jillion of waste in the world, waste management is a standout among the most pivotal constituents for the comeliness surroundings and general wellbeing. Significantly influenced by referred components, data were collected from the liable government provincial and state authorities over surveys and consultations, and we saw failure in maintaining a timely collection of waste. To overcome this, a multi-disciplinary model was made, it used a multi-hybrid neural net to segregate the waste into either dry or wet which was previously uncategorized alongside the microcontroller which oversaw the level of garbage in the bins, also sustained restraint by ensuring regular collection of waste with an attendance system. This idea was then supported by an android application to track the full bins in the area. Besides this, it also assisted the managerial team to monitor the movement of liable workers for emptying the bin. This study hereby presents the graphical representations of recently gathered information and an inventive way of dealing with the problems utilizing the wide scope of technology.

Keywords Machine learning · Multi-hybrid · Internet of Things · Android · Waste management · Classification · Interdisciplinary

Introduction

The brisk advancement of cities with world population rising each day has led to the burgeoning of waste production with appreciable increment in some massive cities. The impulse is such that it is expanding day by day and could be a dominant complication in future if one does not look for means to tackle it. During the research, New Delhi, the capital of India was taken into consideration. Delhi has a population [1] of over 29 million inhabitants with an astounding growth rate of 3.5% which gives it significance and an essential position in the world. It is also among the top metropolises' cities of the world. So being such a decisive city, the government of Delhi holds an essential and vital authority of upholding the city that has an area over 1483 km square.

Regulating waste is an indispensable challenge; therefore, it is something for what the government has been following and is in the desire of propositions to advance the current technology. The aspirations of the government are, therefore, targeting "What can be done to enhance the quality of life?" and to assure that the waste is being treated appropriately. Their vision is to have a city that has exceptional urban cleanliness, and that can be a well-managed hygienic city. With the rise of the population, the waste generated is increasing by an average of 1.3% every year, which is quite an immense challenge to handle. The capital is broken down into eight zones, and for dumping the waste of these zones, there are three landfill sites in Delhi, namely, Bhalswa landfill site, Ghazipur landfill site, and Okhla landfill site.

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✉ Deepak Kumar
deepakdeo2003@gmail.com

[1] Department of Computer Science and Engineering (DCSE), Amity School of Engineering and Technology (ASET), Amity University Uttar Pradesh (AUUP), Sector-125, Gautam Buddha Nagar, Noida, Uttar Pradesh 201313, India

[2] Amity Institute of Geoinformatics and Remote Sensing (AIGIRS), Amity University Uttar Pradesh (AUUP), Sector-125, Gautam Buddha Nagar, Noida, Uttar Pradesh 201313, India

[3] Department of Information Technology (DIT), Amity School of Engineering and Technology (ASET), Amity University Uttar Pradesh (AUUP), Sector-125, Gautam Buddha Nagar, Noida, Uttar Pradesh 201313, India

Bhalswa Landfill site commissioned in 1994, whereas Ghazipur in 1984 and Okhla in 1996.

As one can see from the graph that the production of waste is increasing with each passing year, a tremendous growth can be seen, and due to this, the management of waste is considered as one of the complex tasks. It gave rise to many health hazards due to improper waste management. At majority of the places, the waste bins are overflowing, and due to this, bacteria, vermin and insects thrive from the garbage. It increments the rate of unhealthy gases [2, 3] such as sulfur dioxide, nitrogen oxide, carbon monoxide and others in the air due to which the health of the people living is getting affected. It causes countless diseases of the skin and also blood infections resulting from direct contact of the wound with waste, moreover eye and respiratory diseases [4–6], and intestinal infections due to bacterial growth transmitted by flies. In addition, the garbage is contaminating the surface water and affecting all of the surroundings. Different studies prove that few gases have adverse effects resulting in headaches, nausea, eye irritation and dizziness (Figs. 1, 2, 3, 4).

Literature Review

In 2018, Kamal, Chu, Tan, Huang, Xiong and Xie presented their research on "Multilayer Hybrid Deep-Learning Method for Waste Classification and Recycling" [7, 8]. This research focused on the automatic sorting of the disposed waste in public areas. They used high-resolution cameras to have the images of the disposed waste and used CNN-based algorithms to extract the useful information from the captured images, and this derived information was then used to classify the waste into different categories [9]. The model achieved an accuracy of 90% and was successfully able to classify waste items.

In 2010, Arebey, Basri, Hannan, Begum and Abdullah presented research on "Integrated technologies for solid waste bin monitoring systems" [4, 10]. In this research, they used the Geographic Information System (GIS), Radio Frequency Identification (RFID), General Packet Radio System (GPRS), and Global Positions System (GPS) technologies together connected with the video cameras for keeping track of the solid waste bins [11]. The main

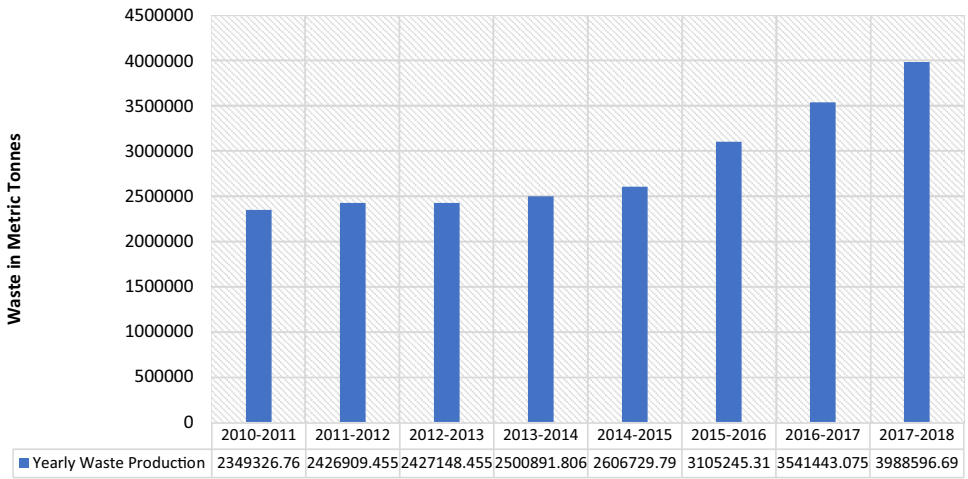

Fig. 1 Annual waste production in Delhi, India. These data are collected by the visits to different landfills present in the Delhi

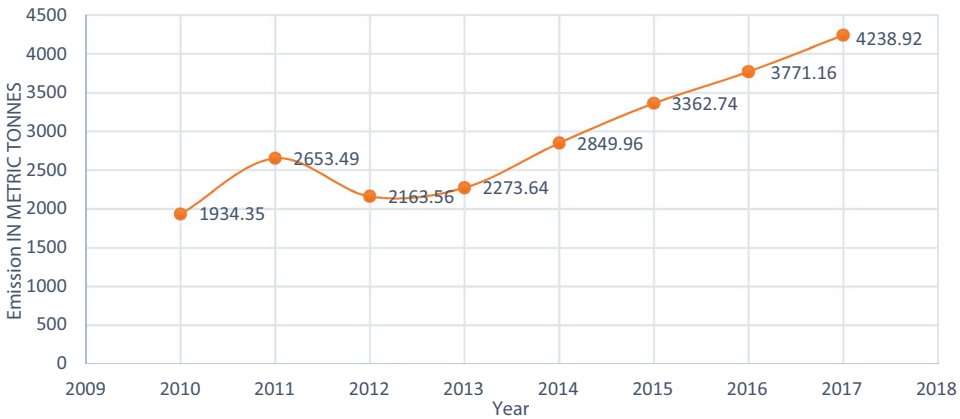

Fig. 2 Annual emission of carbon monoxide in Delhi. The data were collected after the study from various newspapers and websites

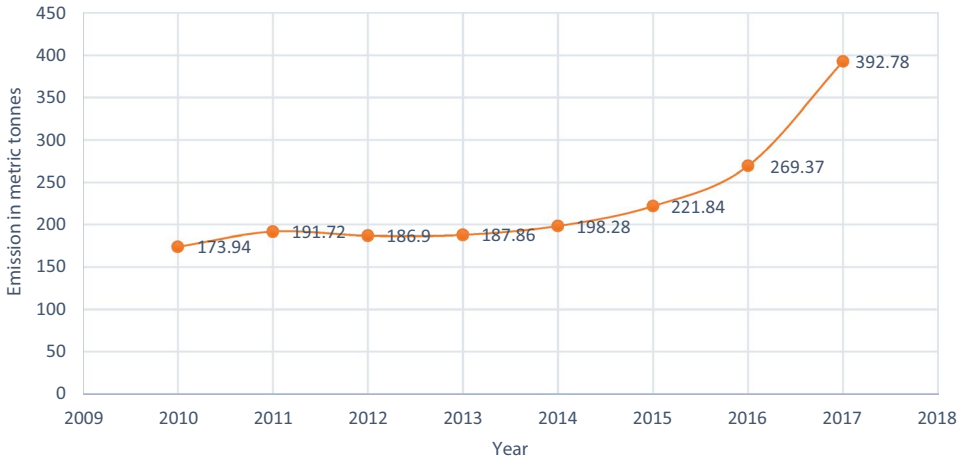

Fig. 3 Annual emission of nitrogen oxide in Delhi. The data were collected after the study from various newspapers and websites

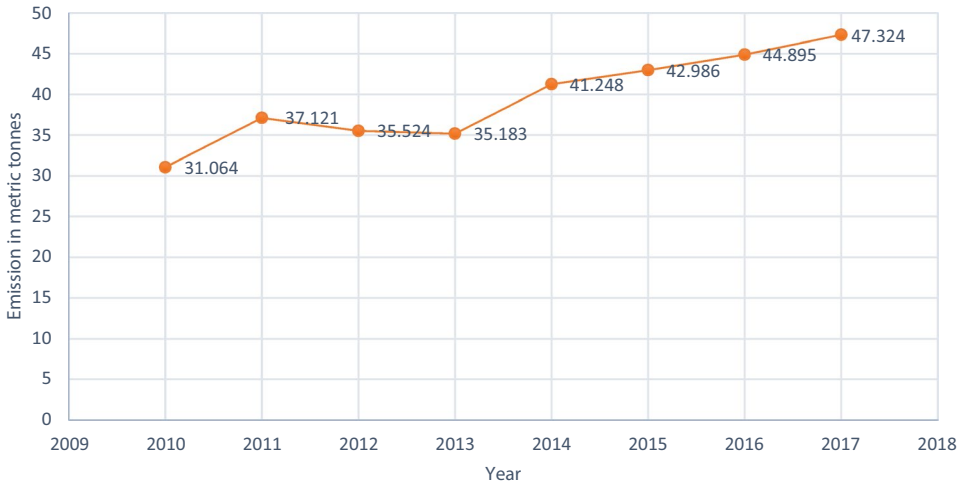

Fig. 4 Annual emission of sulfur dioxide. The data were collected after the study from various newspapers and websites

motive behind this research was to enhance the strategies to reply to the queries asked by the customers and also to evaluate the amount of waste without any participation of garbage truck drivers.

Hannan, Mamun, and Hussain researched "Real-time solid waste bin monitoring system framework using wireless sensor network," [12–14] in 2014 and presented a brand-new model that assisted in the monitoring of solid waste from a remote position. It was made using the General Packet Radio System (GPRS) and the ZigBee-PRO module. This system helps in checking the status of the waste bin. It is wholly based on wireless technology and has three levels of the process. These levels are namely waste bin, a gateway for the system and the station for controlling and analyzing further data. Through this, the current route of the waste collection can be optimized and helps in reducing the operational cost.

Agarwal, Hebbal, Dev, Agarwal Gupta, and Aishwarya, May 2018, published their research on "Automatic Waste Segregation using Image Processing and Machine Learning" [15–17]. It addressed the exponential development of waste products because of fast urbanization which has affected us tremendously. This paper provided an answer that can recognize, distinguish and isolate waste into either biodegradable and non-biodegradable classes without any human help [18]. The waste segregator is a container that gets any waste in its way, the mechanical gets the item and then the AI is utilized to classify that. The proposed framework does not utilize any sensors and the structured isolation of biodegradable and non-biodegradable things achieved an accuracy of 92%.

Ali, Irfan, Alwadie, and Glowacz researched "IoT-Based Smart Waste Bin Monitoring and Municipal Solid Waste Management System for Smart Cities" [13, 19–22]. Together they proposed an IoT-based waste bin model. The model can help in the waste collection, predicting the waste that is to be generated in the future, and also in the checking of fire in waste [10]. This device assisted in checking power by electric bins. These types of equipment are connected wirelessly with the central location where all the information are stored about the filling of bins. This assists in checking on the overflowing bins and saving the environment.

Description of Methods and Their Use During Implementation

In this section, a brief introduction of all the technologies involved in the creation of the model has been discussed. To begin with, the first was the multi-hybrid deep-learning model [3, 23, 24], one of the subsets of machine learning to comprehend between dry and wet waste, then Arduino with the ultrasonic chip was used to measure the level of waste in the bin and theses values were then sent to the android application in which Wi-Fi module of Arduino helped it to connect to the internet and transmit them. These values were then received by the application where it notified the workers if there was a need to empty any bin in that area. The attendance of the workers was also maintained to monitor whether they were actively doing their work or not. Lastly, the application also helped the administration to have vigilance over the workers and the availability of the garbage collection vehicles. The further section of this article discusses about (1) the multi-hybrid deep-learning model, (2) microcontroller integration with ultrasonic sensors being addressed, and (3) the role of the mobile application with various flow charts showcasing the whole process.

Machine Learning

The dilemma of the existence of copious data in the techy world and the complication in the analysis world are surging equally. Humans figured out the solution by compelling the machines to accomplish hard work rather than doing themselves, resulting in what they trained machines to resolve the issues they had. This approach of learning and implementing the given task is what they call Machine Learning [25–27]. Computer programmers identified that any real-world problem could be emulated using mathematics, which comprises the depiction of relations between multiple entities and the machines are liable to find out the relations and patterns by plotting the information on the graphs. One of the famous mathematicians Bayes identified that humans live in the probabilistic world and everything that happens around is uncertain. The perk of associating the probability is that one can accredit it to the rare events as well as the decision making which is framed on the reasoning and relevant features. There are contrasting approaches while taking machine learning into account. Supervised and Unsupervised Learning address the most frequently used, while Reinforcement and Semi-Supervised Learning are newly introduced and considered as the complex ones. In Supervised Learning, the goal of the machine is to grasp the concept of mapping that is to identify the relationship between the inputs and outputs. In this type of learning, the labeled data are provided and this data used for training the model, so the machine will get to know about the features and the labels correlated with it. Using these two basic perceptions, it will be able to predict the output of any new set of data. Another type is the unsupervised one; it does not contain any labeled data. The machine itself analyses the patterns and forms distant clusters of points, using them, it will identify and give the result for new upcoming data. Whereas, in Reinforcement, the machine will take the input and learn from the negative and positive feedback of the output. Lastly, in Semi-Supervised Learning, most of the data are unlabeled, and only a few are labeled or one can say that it is a blend of both supervised and unsupervised. In machine learning, it is believed and observed that if there are more data, the model will have higher accuracy.

The indispensable mathematical concepts used in these techniques are linear algebra, distant algorithms (keeping in mind their complexities), probability theory and statistics, multivariate calculus and some others as well. Deep learning [28, 29], one of the subsets that are considered as the core of machine learning, is an eminent technique for classifying different data into various entities. Here, the precise problem is broken and scattered into different machine-learning algorithms that are steadily standardized into layers. Each layer brings an output, and each layer builds up output from the preceding layer. These layers build up an artificial neural network collectively that imitates the distributed process of solving any problem, just like the neurons in the human brain. The dominant contrast between the machine-learning and deep-learning models is that humans do the featured extraction in the machine learning while in deep learning the model itself does that. The elemental ideas used while composing the deep-learning model are linear regression, logistic reasoning, activation function, weights, base, bias, and neural networks [5]. Linear regression is the analytical method to encapsulate the exchange between two quantitative variables, where one is an independent and another one is the dependent variable. Logistic reasoning is also one of the statistical ways in which multiple independent variables are used to measure the results. The result is determined in which there are two possible outcomes, one is true and the other is false. Activation functions [30] are the group of functions that elect what should be the output of the node at the given set of inputs. The output of every layer is known as the activations as well.

This function is also known as the transfer function. These functions are mainly branched into two categories, one is the linear and the other is the non-linear activation functions. In a linear type of functions, it is not conceivable to define the range of the function. It can be from minus infinity to infinity. Therefore, the functions that are mostly used are of the non-linear types as it will help the model to discern the data and generates the comprehended data that is effortless to evaluate. Nonlinear activation functions

are further branched into distinct categories based on the ranges and curves. The first one is the Sigmoid function and it is adopted to anticipate the output ranging between 0 and 1 that is the probability. Another non-linear function is the Tanh function that varies from −1 to 1 and its curve is s-shaped. The latter one in the category of non-linear functions is the Rectified Linear Unit (ReLU) [31] and it is extensively used in the world for carrying out the models related to deep learning. This function is half rectified and ranges start from zero to infinity. For expanding the range of the function, Leaky ReLu was proposed and it ranged from minus infinity to infinity. The straightforward category of an activation function is the Heaviside step function and it rebounds zero if the linear sequence is insignificant than zero and returns one if its combination is zero or higher than zero. Weights values are drafted when the input gets dispersed into numerous units. The use of weights begins in a random aspect and as the model discovers more about the input with time, the neural network will adjust the weights based on the categorization of errors enclosed in the previous weight, this complete process is recognized as training of the neural network. One can think of weights as the slope for the linear equation and the bias can be treated as another learning feature and can be regarded as the y-intercept. The combination of these disparate notions helps in accomplishing an artificial neural network.

Collection and Cleaning of Data for the Implementation of Multi-hybrid Model

In this research, one of the compelling functions is to segregate the waste, and this is implemented by the deep-learning model. This model concentrates on formulating the trash into two divisions that are broadly the dry waste and wet waste. This element of the design will support the public to diagnose waste items and assist them to select the correct section of the bin. To achieve this, cameras were installed on bins to capture images of the waste and identify its type, after what the sensor will open the correct part of the bin using the digital processing of the image by the microcontroller device (more about which has been discussed under the IoT section). Now for implementing the neural network model, around 6000 images in total were gathered in the JPG format. Each image was grouped and manually labeled as either dry waste or wet waste. For discarding the undesirable noise from the images that were captured by the camera, they undergo the pre-processing under the Keras [32, 33] framework. The refined images were in the 240*240 pixels in the resolution which varied from the initial ones. During the training, six images of a single object were taken after analyzing distant aspects such as shifting of height and width, image resizing, zooming, and rotation to intensify the universality of the model [34]. The training model was assessed thrice to monitor the system's conduct (Fig. 5).

At first, each waste item was reviewed thrice with a preordained position. It comprised 300 test sets that are (100*3) which were produced at the beginning. Then, the same measure was repeated with the same object although in distinct random positions producing another set of 300 test sets. Then, the second step was just repeated but this time with distant objects, so each time a fresh dataset was attained of 300. In total, 900 test datasets were generated and the model was operated to analyze every value of this set, to evaluate in case the provided element falls under the dry or wet category.

Implementation of Multi-hybrid Model Using Machine Learning

The essence of this model is the Convolutional Neural Network (CNN) [18] which retains oversight over the conduct of the system and uses evaluation metrics. CNN is an extensively used procedure for evaluating an image. It accepts an image as its input and then applies a classifier to categorize it among the distinct divisions. The CNN model is a consolidation of various layers, and it comprises fully connected layers, dropout layers and normalization layers. The convolutional layer (Conv Layer) is also considered to be the building block of the neural network and is subjected to about each task that associates with arduous computation.

Fully connected layers as the name indicates are entirely associated with all the activations and also with previous layers. Activation is determined by taking the matrix multiplication followed by a bias offset. The activation function can be expressed as the backward and forward propagation rules. The mathematical equations for representing these propagations are as follows:

$$M_e^{S+1} = \sum_e N_{f,e}^{S+1} M_e^S, \tag{1}$$

$$t_e^S = \sum_e N_{f,e}^{S+1} t_f^{S+1}, \tag{2}$$

where M_e^S and t_e^S demonstrate the activation and gradient of the neurons e at layer S and $N_{(f,e)}^{(S+1)}$ is the weight that is connecting neurons e at layer S to neurons f at the layer $S+1$.

But CNN had its shortcomings like huge computation cost, also several in-field application limitations. Therefore, for overcoming these, AlexNet came into the picture and in September 2012, it competed in the ImageNet Large Scale Visual Recognition Challenge as well. This convolution network is well known for its capable composition and diminishes the top-5 error to 15.3%. It has entirely eight learning layers in which the opening five are the convolutional layers

Fig. 5 The images captured by the camera at the scanning stage in different orientations. So that the model gets assistance in obtaining better and accurate results

and the following three are fully connected. In the rearmost layer, the SoftMax function is used and it takes the input of real numbers and computes the probability distribution of occurrences over different events. The output probabilities scope is from 0 to 1, and the aggregate of all of these is 1. It is used in the multitudinous classification model, it will antiphon the probability of each and the destination class will have an immense probability. The kernels of the second, fourth and fifth layers are associated with those present in the preceding layers and share the same GPU hardware. Kernels of the third layer are connected to the second layer. Response-Normalization layer is coupled with first and second layers and max-pooling layers are implanted after both of these layers and the fifth layer. The rectified linear unit is appended with each learning layer in the model.

The imaging system of the model is connected with and evaluated by CNN. For concatenating and functioning with sensors and cameras and attaining the preferred results, a multi-hybrid model is established in which the multilayer perceptron and CNN are positioned and associated with each other. In a multi-hybrid system, when a waste item received, the snapshot is taken and assessed by the CNN, the sensor connected to the system starts obtaining numerical information from the objects and lastly the binary results are obtained using the MLP and it will help to determine whether an item is dry or wet. The confusion matrix Table 1 shows the accuracy, precision and recall percentage of the classification system in the consecutively three tests. The results obtained from the prediction of the multi-hybrid model are depicted below.

Figure 6 tells the user in which bin he/she has to dispose of a particular item of the waste, this model classifies the waste into two categories using the photos of the item clicked at the scanning stage, these photos are then used by the machine-learning model where it predicts the result using the multi-hybrid neural network and gives the result which gets shown on the Arduino LCD 16 × 2 display as shown in Fig. 7. This instruction is then expected by the user to follow to have a systematic distribution. The model is trained and tested on the dataset of the images extracted using web scraping.

For checking the performance, the evaluation metrics are used shown in Table 2 and the 'truth' is considered when the prediction from the model paired with the manually labeled item.

Table 1 Confusion matrix for MHS model

Confusion matrices	MHS model		
	1st test	2nd test	3rd test
Accuracy (%)	98.6	91.2	92.8
Precision (%)	98.1	96.8	97.2
Recall (%)	98.9	92.5	93.4

Internet of Things

IoT, the term that each person knows in the world whether he/she is a kid or an adult. Everyone is using the IoT-enabled devices ameliorating their life. However, anyone discerns what is it and how it was created and how it can assist in bearing the unhackneyed revolution in the technological field. If no, let us see and also how it is portraying one of the crucial roles in this study.

Description of Internet of Things

The Internet of Things [3, 8, 10, 13, 16] is an original channel of interconnectivity between real-world devices and the digital world, and each device can be connected with any number of tools to form a big network. This smart device came into existence in the year 1999 when one of the British entrepreneurs Kevin Ashton, executive director of the Auto-ID center was working on the presentation for Procter and Gamble. He was working in supply chain optimization and he wanted to tempt the senior management's attention to one of the exciting technologies named radio frequency identification (RFID). The Internet was the hottest trend at that time and for that reason, it somehow made sense that the title of the presentation was given as the "Internet of Things" [8, 10, 16]. At that time, he was successful in winning the interest of some executives at P&G. However, for the next 10 years, the term Internet of Things does not get widespread attention from the public. In summer 2010, it started gaining popularity and information got leaked that Google Street Service had not only made 360° pictures but also stored a large amount of data of people Wi-Fi's network and it shows that they were not only indexing the internet but also the physical world and from now the market of IoT started increasing and some of the popular magazines such as Forbes, Wired, and Fast Company started discussing it and using 'IoT' as their vocabulary to explain the happening. Some of the conferences came into existence as well and the popularity for the IoT outgrown. Nowadays, IoT becomes a giant network with connected devices and they share data about the environment in which they are operating and how they are used. These things are done using sensors that are embedded in the majority of the physical devices around us and all are using them in their day-to-day life. These sensors continuously emit the data about the working state of the devices and IoT helps in providing the standard platform for all these devices to store their data and a common language for all the devices to communicate with each other. Emitted data from various sensors sent to the IoT platform in a secured manner and then IoT combines that data from

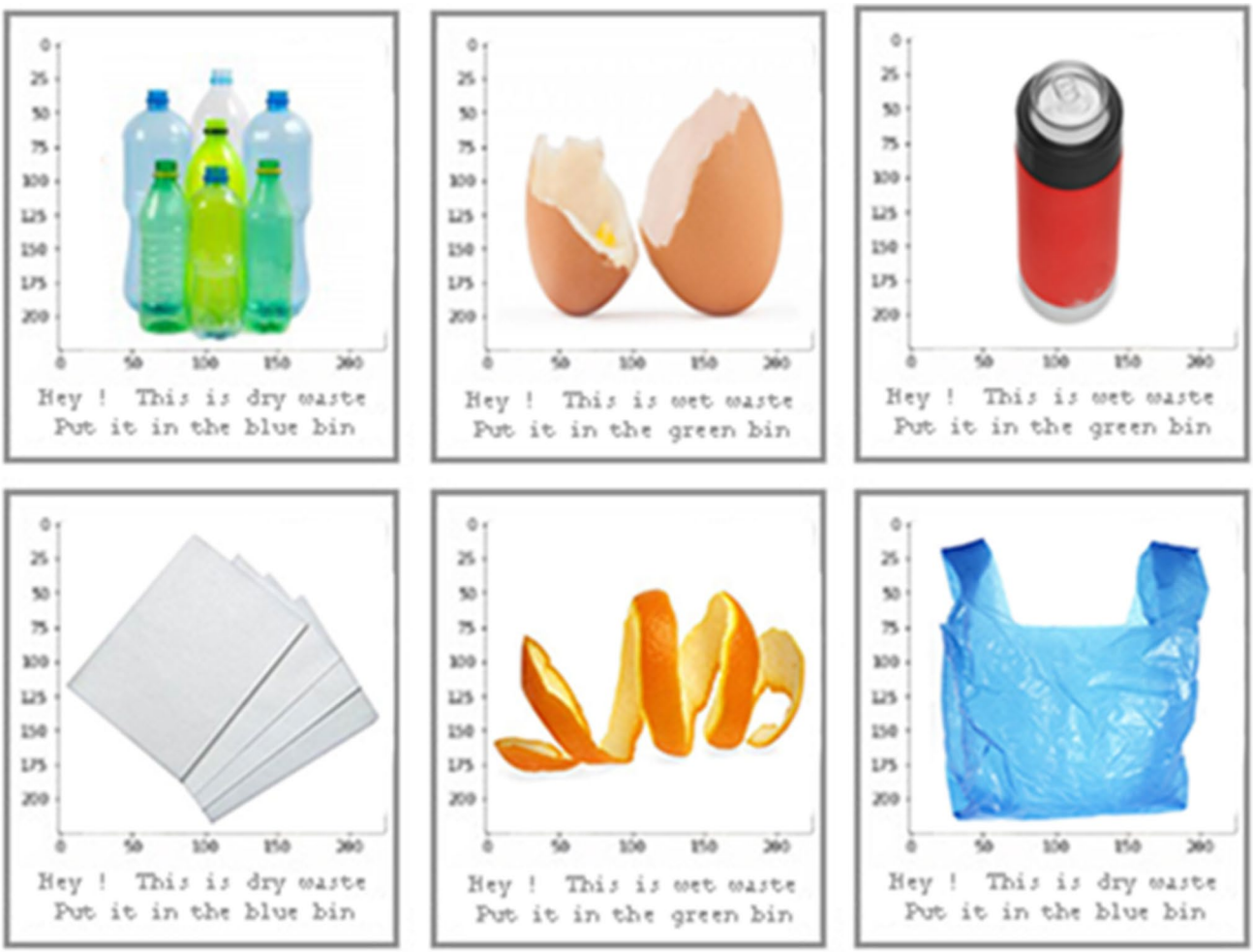

Fig. 6 Prediction of multi-hybrid model

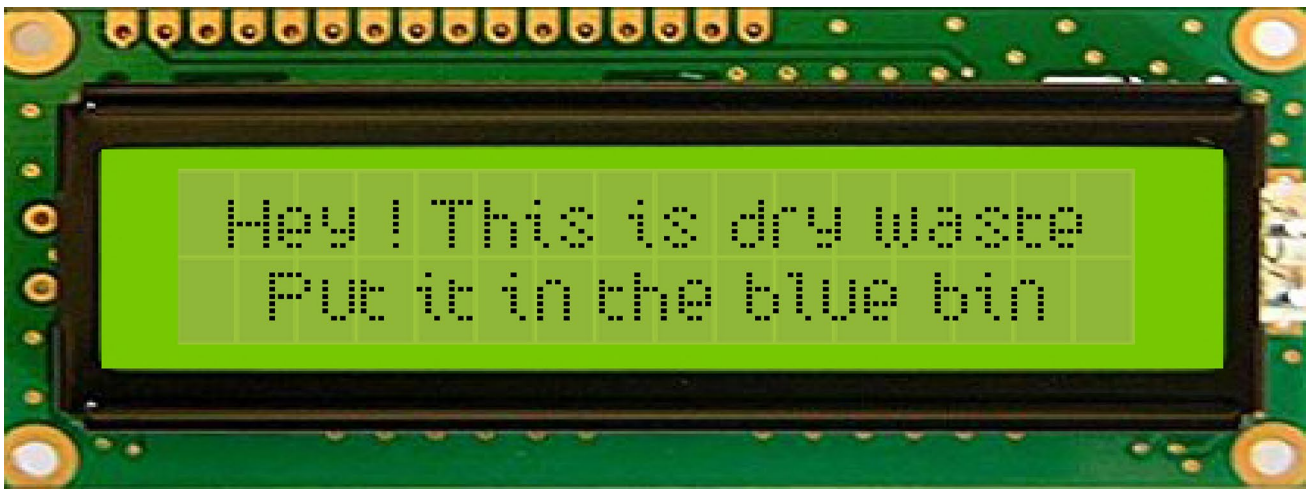

Fig. 7 A 16×2 LCD that was connected with a microcontroller, where it showed the outputs of the multi-hybrid deep-learning model. This clearly showed the user which type of waste was there on the scanning stage and which bin the user had to use

Table 2 Confusion matrix of automated waste classification

	Automatic classification Dry waste	Manual classification Wet waste
Dry waste	True positive	False positive
Wet waste	False negative	True negative

different sources. Further analytics is performed on the data and the valuable information is taken out as per requirement and then the result will get shared with other devices for a better user experience.

Implementation of Microcontroller and Other Hardware Components

The use of the microcontroller in this research was subjected to the detection of the waste level currently present in the waste bins. With each bin, there was an Arduino attached to monitor its level. Each attached Arduino had two more components working with it to ensure that this system as a whole could deliver the desired results and with every microcontroller a Wi-Fi chip and an ultrasonic chip was attached. The Wi-Fi chip or the ESP8266 [5] chip was used with Arduino to have a connection to the local internet of that area so that the bin can be connected to this local internet and the Arduino device can send the instructions to the android application where it acted as a web-server to proceed with the process of sending of the Boolean answers. As mentioned in the previous line, the microcontroller used was also made as a web-server, this was implemented for it to hold the responses from the Arduino ultrasonic sensor, also known as HC-SR04 [13] chip. This chip, as the name suggests, uses the (So)und (N)avigation (A)nd (R)anging System for its functionality, where it replicates the process of having the measure between two points just like the bats do it with accuracy over 400 cm. The HC-SR04 sensor had to keep a check on the rising level of the waste in the bin and when the waste reached a certain level and if it exceeds, it can overflow, the Android app should alert the workers so that they can empty the bin on time.

Figure 8 shows the microcontroller in action where it is continuously measuring the level of waste in the bin. The ultrasonic microcontroller was programmed to send the Boolean values, where if the message contained Boolean "0", the bin still had space to accommodate more trash whereas if the message contained "1" Boolean value, then this was to alert the workers to empty the bin, as it did not have any more space to accommodate more waste. These Boolean values were sent over to the Android app using the web-server services, where the microcontroller first required the internet to connect to the android application, this is when the ESP8266 chip [10] helped out, it established the connection with the local internet and this has the much-needed internet. The user of the application also connected to the internet using either Wi-Fi or the data and now both the devices had a connection between them. After which the Boolean messages were received, the request gets stored in

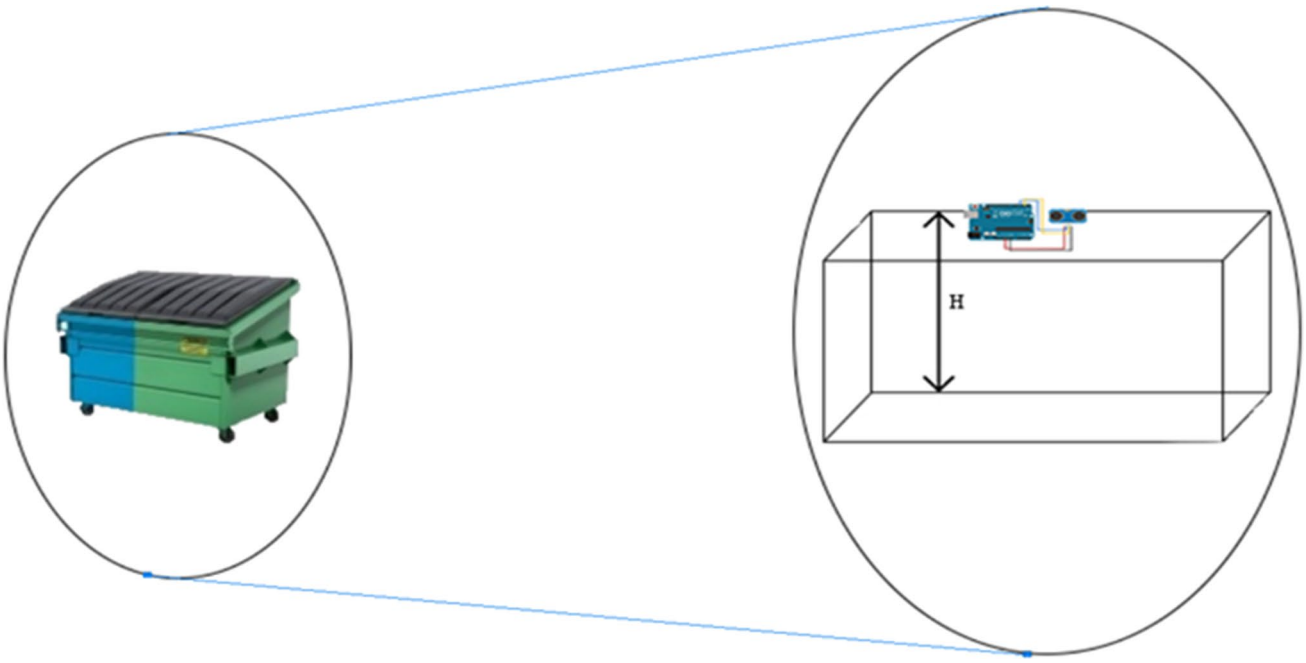

Fig. 8 Representation of microcontroller measuring the level of waste in a bin

the web-server and this stored response could now be used by the android app. For the android app to use these stored messages, it had to be connected with the internet using Wi-Fi/data, after which the responses were received and if they indicated a "full" bin condition, then the application created an alert message which notified the workers automatically the status of that area.

After getting the alert, the workers move to the targeted bin which is shown in the application they have on their mobile devices. To mark their visit, an attendance system was established. The attendance system consisted of a card-punching system. This system not only maintained discipline where workers cannot skip their duty but also helped the municipal to maintain records in the connected database.

Android Application

Cellular telephony is one of the most accepted technologies by people in the world. If one sees around, almost all the people are taking this technology into account and making their life easier with the help of the different applications running on one portable device. These devices are making a high impact on society by providing links to the internet and its resources.

Description of Android Application

Android is one of the software stacks that include the middleware, operating system and key applications. An android operating system is the modified version of Linux Kernel and due to this, it is famous for its open-source nature and one can do bug fixing, make new improvements like adding functionality and installing them into new hardware. On the other hand, the Linux kernel-dependent architecture sums up the use of Linux to the cell phone market, acknowledging taking perks of the knowledge and elements offered by Linux. Android has its virtual machine (VM) and its applications are based on the Java programming language and this feature encompasses the use of a virtual machine environment. This interesting technology was founded in 2003 in Palo Alto, California and acquired by Google in 2005 and from here, the improvements started taking place in this technology. The android architecture consists of four different layers namely the application layer, application framework, next one is divided into two, libraries and Runtime and the following layer is Linux Kernel. Various C and C++ libraries are used by different components. In 2011, around 58 applications were pulled by Google and these malicious applications mainly contained Trojans concealed in the pirated versions and this malware was named as DroidDream. For resolving this issue, various security firms worked on it and some companies such as AVG and Symantec released antivirus software for android devices and after this, the work goes on the security issues and improvements were made in the software. Nowadays, more new changes are taking place in this technology and combining with various revolutionizing technologies such as artificial intelligence, the Internet of Things and many more.

Implementation of the Android Application

The android [8] application was made to have real-time updates from what the Arduino was sensing continuously and to alert the workers if the bin is full on the worker's side of the application. For the implementation part, a map view was required with the positions of bins marked in a particular color, where if the bin gets full, the color of it should change and an alert message should be sent to the workers responsible for emptying it. Therefore, first, the coordinates of all the bins in an area were collected to plot them in a custom implemented map in the application. Then, the second step was to have the google map API key for implementing the map view, after which the SDK Tools such as Google Play Services and Support Repositories were installed in the Android Studio, then the dependency of Google Play Services was implemented in the build. Gradle and the API key were placed in the AndroidManifest.xml under the application heading. The configuration of the permissions (permission to access the location services, the internet, the fine location and the coarse location) in the same XML, these permissions are required by the application to work. Then, the intent helped to switch between the MainActivity.java and the MapActvity.java, which contained the information to bins that were to be displayed. These bins were shown using the onMapReady function where a new marker was added bypassing its coordinates using the map object with the addMarker function, a title to every point was also defined, this was done to avoid confusion. These functions are permitted to alter the icon or thumbnail for the marked point by a simple one-line code where the. icon with the map object was used and then directed to the path of the desired icon. Next up, a function was made for checking the response from Arduino, where the Arduino returned a Boolean value and this value was in charge of deciding the color of the bin on the map view [16], also if it turned to red from the green which was default then, an alert message has to be sent by this function to make the workers aware of the situation. This function accepted a Boolean value and if the value was "1" then it turned the icon to red and if it was "0" then the icon remained to be green. This function is constantly checking the response from the Arduino and processes the request in real-time using the response it received from the microcontroller. The responses from the Arduino were hosted on a web-server where the microcontroller itself was made to act as the web-server handling the interaction with the android application. The android application got the responses in the

form of a JSON file. To parse this file, the JSON parser was made using the doInBackground function and by creating the JSON Object to call the required functions of the org. JSON library in the MainActivity.java file [35]. This function is mainly used when one has some AsyncTask, which means any short operation or transfer of information, which in this case was just the Boolean value. On the municipal side of the application, the application was updated with the worker's current location to keep a check on them, this was done to verify whether the workers are collecting the waste or not, also to monitor their position and availability of the garbage collecting trucks. This bound up the use of the android application in this research (Figs. 9, 10, 11).

Result

For summing up the research, the whole process is explained in the form of flow diagrams given below.

Figure 12 shows the first half of the whole process that is how a waste brought by a person scanned and classified using the multi-hybrid model and then the notification is given in LCD through a microcontroller. The attendance will help in maintaining workers records and they have to punch the card for giving their attendance at the time of collection of waste.

Figure 13 shows the second half of the process that is how the microcontroller sends the notification and how the managerial team and workers can track using the android application.

Conclusion

The health and environmental problems due to the accumulation of waste have been because of shortcomings faced while managing the waste of the bins that leads to an outbreak of diseases and other problems that are required to be minimized. The model proposed in this research is better and an updated version of other models that were studied and mentioned in the "Literature Review". It also focuses on the ways to overcome these shortcomings and make a solution that is feasible and easily available. IoT nowadays is an emerging technology that promises to give affordable and reliable solutions. In the model, an interdisciplinary approach was followed, where IoT alongside auxiliary modules of a multi-hybrid deep-learning network and an Android-based mobile application worked together to address the problem of overflowing waste in the garbage bins successfully. In addition, an in-depth statistical analysis of waste production and the harmful gases produced by the waste content was done to have a better idea of the issue and to check the importance of the proposed method.

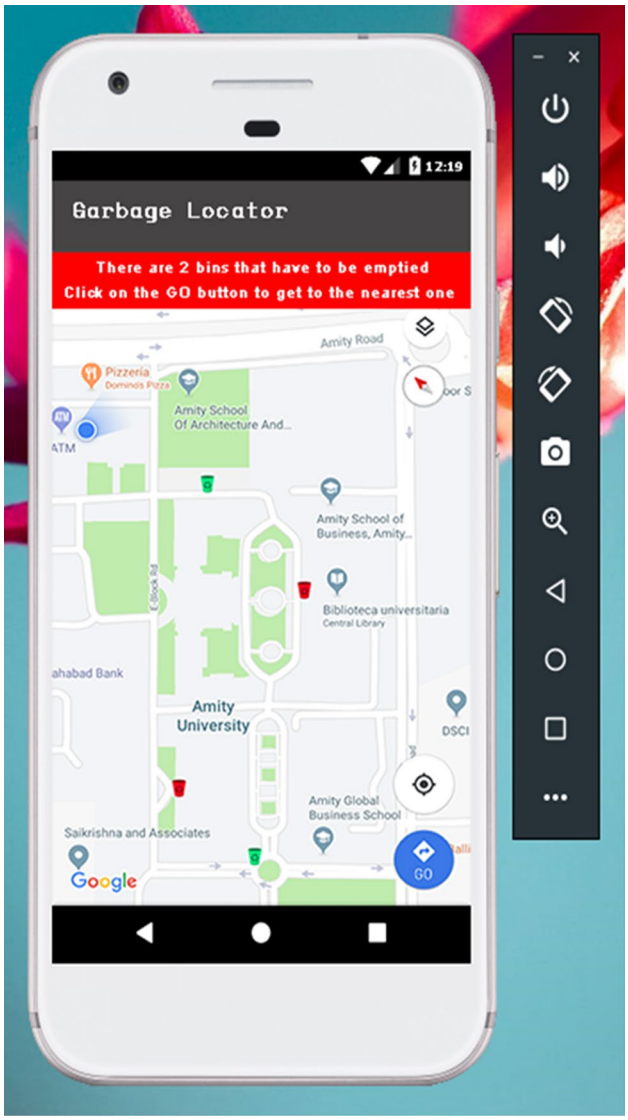

Fig. 9 The Green garbage bins shown by the application represent not filled bins and the Red ones represent filled bins. In addition, the application notifies the workers and calculates the shortest distance from the nearest filled bin

Future Prospects

In future, this research will continue and contribute to the field of waste management by making the classification model more powerful to classify more categories of waste instead of two. For decreasing the budget, the customized microcontroller can be made only for this purpose as the Arduino Uno cost is slightly high. On the other hand, to have good internet connectivity between the deployed model and the local network, the superior version of ESP Wi-Fi modules can be used, although this would increase the budget but will serve its purpose. This research only focused on the android platform but one can work to make

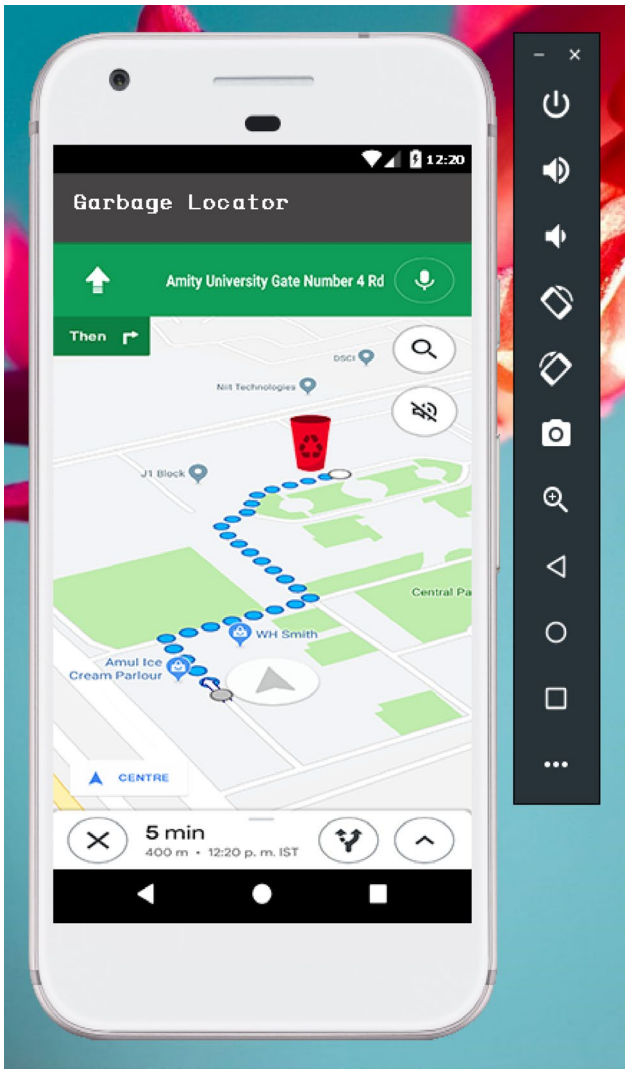

Fig. 10 The worker's view of the application in which it shows the path towards the filled bin from the worker's current location

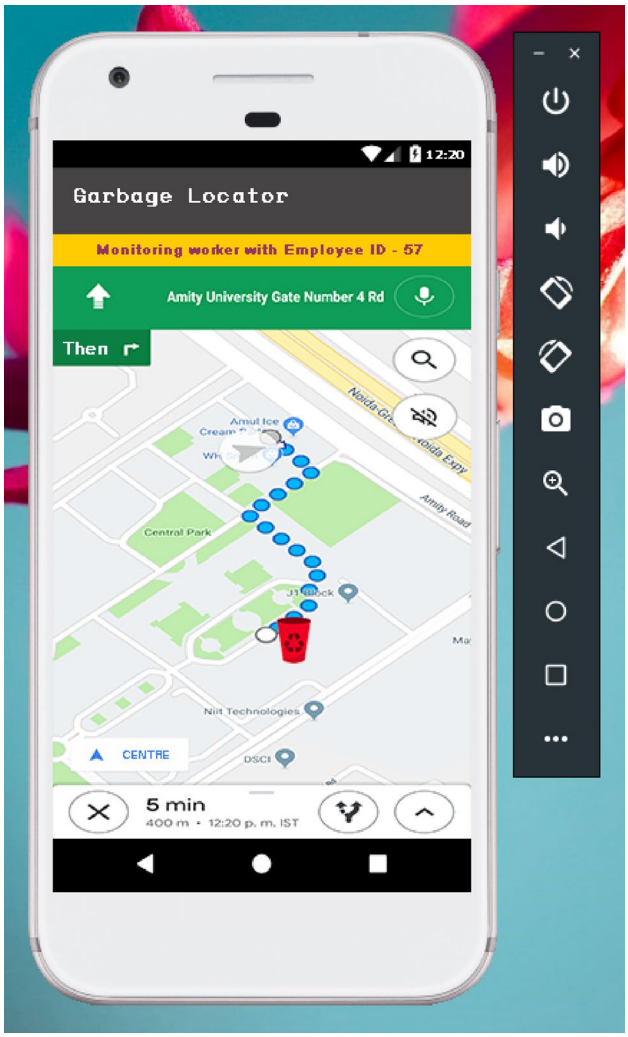

Fig. 11 The view of the management team where it can track the worker from their employee ID as shown above

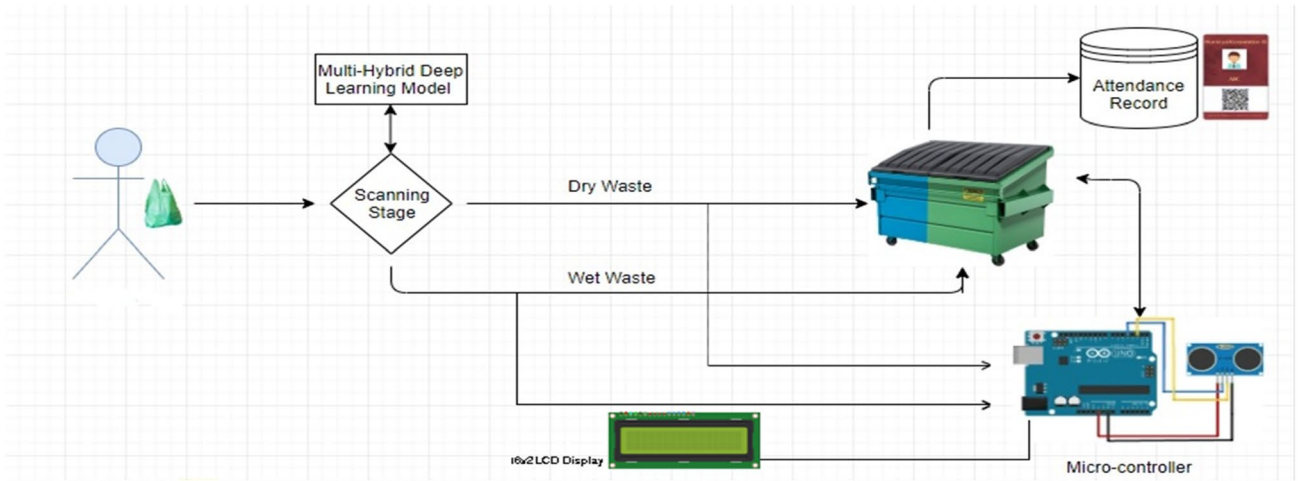

Fig. 12 First half of the process

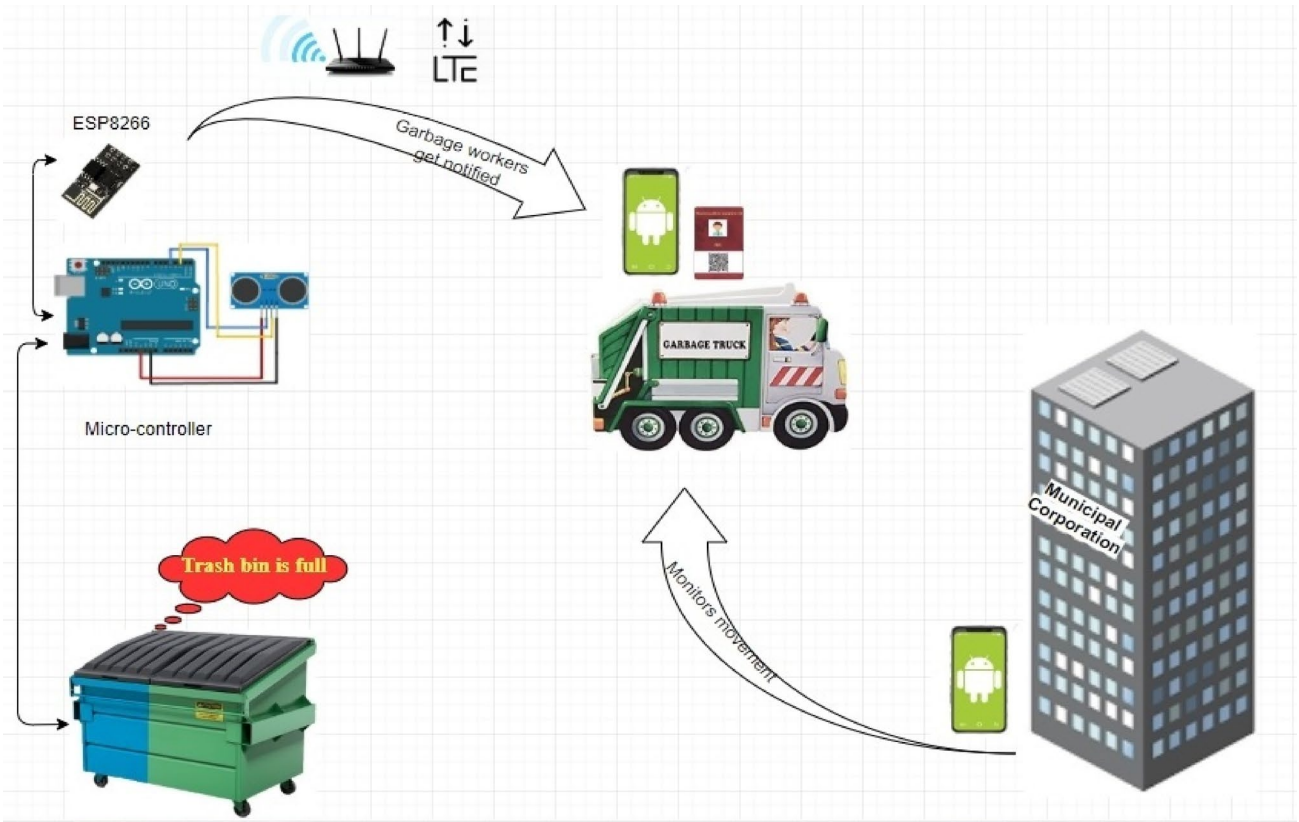

Fig. 13 Second half of the process

this compatible with IOS devices as well. Therefore, that reachability can be increased.

Author Contributions PK and DK conceived and designed the study, and RJ performed the research, analyzed the data, and SR contributed to editorial input.

Declarations

Conflict of Interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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