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Smart City Waste Management System using Internet of Things and Machine Learning

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Abstract - *Waste management is an arduous process for every locality. Dustbins located at different locations are difficult to monitor leading to overflow and mismanagement. The Standard Methodology used is inefficient due to the static routes followed by the collection trucks and it also leads to time and fuel wastage. An 'IoT' and 'Machine Learning' based Web Application, as implemented in this work, helps in not only monitoring the bins located at different spots easily sitting at one location but also helps in dynamic route generation. The routes when followed, leads to increase in time and fuel efficiency. The data generated by Internet of Things is used for showing the current status of bins on the Web Application as well as for training the forecaster for making later predictions. Machine learning helps to make such predictions possible. A map view helps to view the generated route as well as see the location of bins located across localities. The ability to add, edit and delete bin's data proves to be helpful to keep a record of these bins.The Web Application developed, helped achieve efficiency, scalability, easy monitoring and was easily adaptable.*

Key Words: **IoT, Machine Learning, Smart City, Waste Management, Time Series Analysis**

1.INTRODUCTION

Waste Management is one of the most crucial problems faced by Municipalities. Several bins are located in different parts of the locality and fill at different rates. The monitoring of their filled levels requires frequent visits to the sites that are not feasible, since, a lot of money and fuel is wasted.

The current way of waste collection involves the use of fixed routes and schedules. This introduces issues like even if a bin is not required to be serviced, it is visited and those who require servicing immediately might be overlooked. The fixed routes lead to fuel overuse while fixed schedules lead to overlooking of bins that may require servicing.

The proposed work has its own unique implementation over the previous Research done on this onerous issue of 'Waste Management'. This work makes use of IoT devices along with sensors such as an 'ultrasonic sensor' to monitor the bin fill status which will make it easier to handle.

The data generated is recorded and then be used by a machine learning model to provide the users with future predictions for the bin status, based on this historical data. Use of maps library is done to generate an optimized route for collecting waste over the area which when followed will give more fuel and time efficiency. The Web App in this proposed work provides a user-friendly way to monitor the bins making it easier. Through this web app the user will be able to monitor bin fill status, generate an optimized route, add and remove bins virtually on the map.

2.Existing System

The existing work has made use of IoT modules consisting of Raspberry Pi and HC-SR04 ultrasonic sensor along with data analytics back-end server and web application front-end. The sensors were mounted on the top of the bins, an ultrasonic sensor connected to Raspberry Pi monitored the fill levels of that bin and Raspberry Pi was connected to nearby Wi-Fi router.

Raspberry Pi was programmed to send that collected data to the back-end server on fixed regular intervals. Each bin was uniquely identified with the help of Raspberry Pi's MAC address. C5.0 decision tree algorithm was applied on the collected data to predict future fill levels of the garbage bins. This allowed near real-time live monitoring and also provided with some predictions which were made for next 24 hours on the fill levels of the garbage bins. For the garbage bins the maximum threshold was set to 67.5% and the fuel threshold was set to less than 1% fuel cost of the initial route.

Application development was done with Python and PHP and the Google maps API was used for routing and plotting purposes. The drivers of the garbage collecting trucks were provided with an android application which guided them by providing optimized routes and other required information on garbage-bins which required to be serviced. With the machine learning applied on the data which was regularly collected at intervals from garbage-bins in the municipal area, it provided useful information to the concerned individuals which helped in defining long term policies for their garbage collection operations.

When this system was put in a 10 days trial where 38 bins were fitted with IoT module, they completed eleven service routes within 3.5 hours, The fuel efficiency was calculated at 46% and there was 18% reduction in time required to conduct this operation.

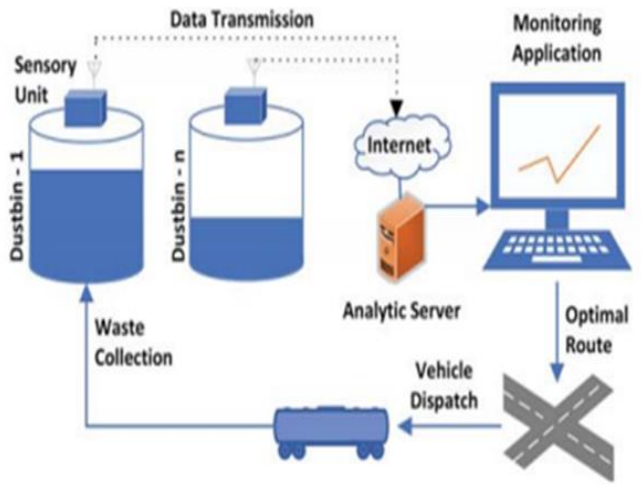

Fig -1: Existing System

3. Basics of Vehicle Routing Problem

In Vehicle Routing Problem, the centre of interest lies in determining optimal routes for a fleet of vehicles given business-specific constraints, such as vehicle limitations, cost controls, time windows, resource limitations related to the loading process at the depot, etc. The complexity in VRP is due to these constraints.

The VRP concerns itself regarding how things are delivered from one or more depots that have a given set of home vehicles and are operated by a set of drivers that can move on the given road network to a set of clients/customers. It helps fleet managers to plan the routes that can increase the efficiency of the fleet.

The first classic Vehicle Routing Problem is the well-known 'Traveling Salesman Problem' (TSP). Traveling Salesman Problem attempts to find the shortest route for the salesman or vehicle to visit all destinations and return to the starting point.

Many other factors contribute to planning the optimized routes. The road network can be described as a graph where the arcs are roads and vertices are junctions between them. Each arc has its own cost which is usually its length or the travel time which might be dependent on vehicle type.

4. Methodology of the System

4.1: Role of IoT in the System

The bin fill level is sensed using HC-SR04 ultrasonic sensor. It operates at a voltage of +5V and can theoretically measure distance between 2cm to 450cm. In order to calculate the distance, it makes use of speed formula.
Distance = Speed * Time

The speed is taken as 0.034 cm/µs and Time is divided by 2 to get the one-way time.

Therefore, the distance formula becomes,
Distance = 0.034 * Time/2

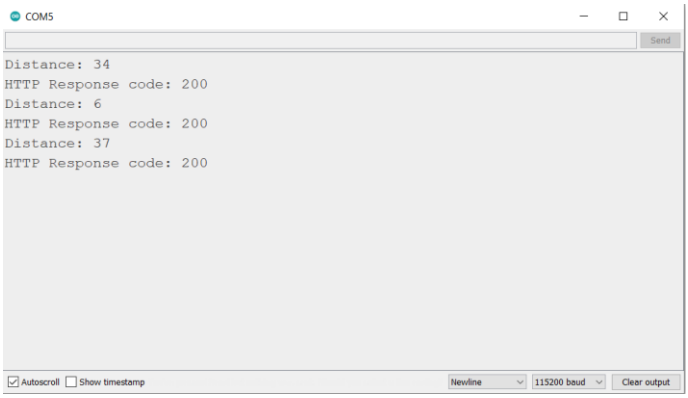

Fig -2: Fill level sensed by HC-SRO4 pushed to MongoDB Atlas database

The Ultrasonic sensor is connected to ESP8266 microcontroller with the help of jumper cables. This microcontroller has an inbuilt ability to connect to Wi-Fi. This ability helps the microcontroller to push the data to NodeJS server which then transfers the data to MongoDB Atlas Database via the MongoDB Realm function. The data is sent in JSON format. The data stored in this database is used to show the fill levels in the Web Application and to train the predictor as well. MongoDB Atlas being a No-SQL database is best suited for Internet of Things Application.

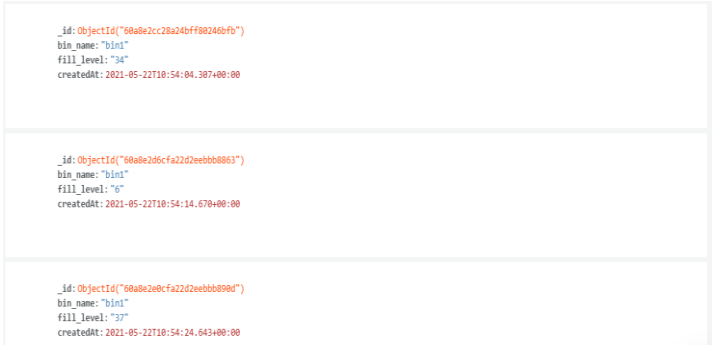

Fig -3: Fill level sensed by HC-SRO4 pushed to MongoDB Atlas database

4.2 Use of Machine Learning

In this work, the data from the IoT devices and sensors which is collected is used by a machine learning model to make predictions or forecast of bin fill level.

We measure the bin status within a decided time interval (5 minutes).

The number of records obtained from the data from IoT device and sensors is higher than the frequency that is being used. The time format is also not suitable for use by the

forecast algorithm used called 'Facebook Prophet'. This data needs pre-processing.

Here we have converted the time field into a standard format and the bin fill values are mapped to the decided frequency of time interval.

The data after pre-processing:

2021-03-15T00:45:00.000Z	24	bin1
2021-03-15T00:50:00.000Z	24	bin1
2021-03-15T00:55:00.000Z	24	bin1
2021-03-15T01:00:00.000Z	24	bin1
2021-03-15T01:05:00.000Z	25	bin1
2021-03-15T01:10:00.000Z	26	bin1
2021-03-15T01:15:00.000Z	26	bin1
2021-03-15T01:20:00.000Z	27	bin1
2021-03-15T01:25:00.000Z	28	bin1
2021-03-15T01:30:00.000Z	29	bin1
2021-03-15T01:35:00.000Z	30	bin1
2021-03-15T01:40:00.000Z	30	bin1
2021-03-15T01:45:00.000Z	31	bin1
2021-03-15T01:50:00.000Z	32	bin1
2021-03-15T01:55:00.000Z	32	bin1
2021-03-15T02:00:00.000Z	33	bin1
2021-03-15T02:05:00.000Z	34	bin1
2021-03-15T02:10:00.000Z	34	bin1
2021-03-15T02:15:00.000Z	36	bin1

Fig -4: Data after Pre-processing

This is done for bin data of some number of days which is then added to a new dataset which will be used by our algorithm used for Forecasting. Facebook Prophet is an open-source library for one variable time series forecasting. It is developed by Facebook.

This newly created dataset is then again cleaned by using only a subset of the fields from the new dataset and converting the date timestamp into a Facebook Prophet friendly timestamp as:

```
df['Timestamp'] = pd.to_datetime(df['Timestamp'])
df['Timestamp'] = df['Timestamp'].dt.tz_convert(None)
```

4.3 Use of ArcGIS

'ArcGIS' is a geographic information system used to work with maps and Geographic information maintained by 'Environmental Systems Research Institute'. ArcGIS is used for creating and using analysing mapped information, maps, sharing and discovering geographic information, compiling geographic data, managing geographic information in a database and using maps and geographic information in a range of applications.

This system provides a base for making maps and geographic information available openly on the Web.

Solve Vehicle Routing Problem (VRP) is a service provided by ArcGIS that is being used in this work. It creates a vehicle routing problem network analysis layer, It also sets the analysis properties and solves the analysis, which is ideal for setting up a Vehicle Routing Problem Web Service. A vehicle routing problem analysis layer finds out the best routes for the fleet of vehicles.

The Work has integrated the ArcGIS API in the Web Application. After clicking on the 'Generate Routes' button, the Web Application provides a checklist with bin fill levels and predicted fill levels for all the bins. The user selects the bins that he wants to provide service for, by checking the checkboxes beside the bins.

After selecting these bins, the user can scroll down to another checklist which is for the waste-collecting vehicles with details such as name, registration number and parking area. Web Application has another column called 'Driver' which provides a drop-down list with driver names, user can assign a driver to the truck. Now the user shall check on the checklist for that truck after assigning a driver.

After deciding on the trucks, the user can move forward with a click on the 'Next' button. This will invoke the ArcGIS API Service Basemaps. A map with the selected bins and vehicles on it will appear along with the routes they will take, providing a visual representation.

A summary of the vehicles will also appear on the same page with details such as running cost, running distance, running time. For routing of these vehicles, the Web Application uses a 'multi-vehicle routing service' from ArcGIS. Multi-vehicle routing gives us the solution for vehicle routing problems. EmailJS is used to send emails using client side technology. No server is required we just need to connect EmailJS to one of the supported email services, create an email template and use JavaScript library to trigger an email.

These Email templates can optionally contain dynamic variables in almost any field which are populated from the Javascript call. EmailJS is a service that allows us to send emails directly from client side JS code.

5. Results

The Web Application, showed the information of all the bins deployed.

Fig -5: Manage Bins Page

The Web Application really made it easy to update the information about the already placed bin.

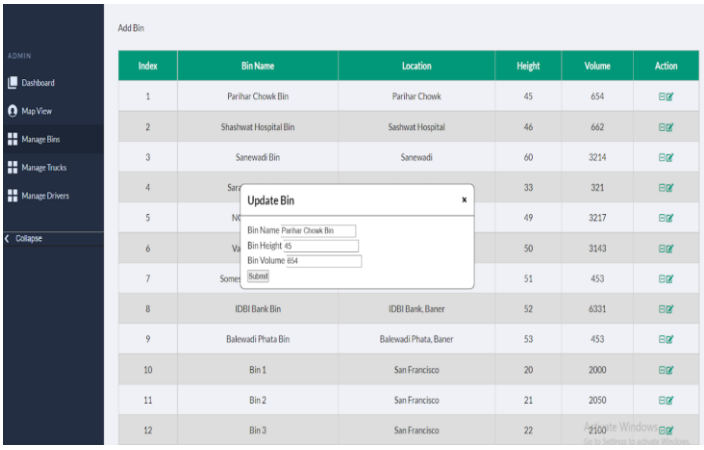

Fig -6: Edit Bin Functionality

In case of further addition of bins, it was found to be easy as well, with the help of 'Add Bin' option.

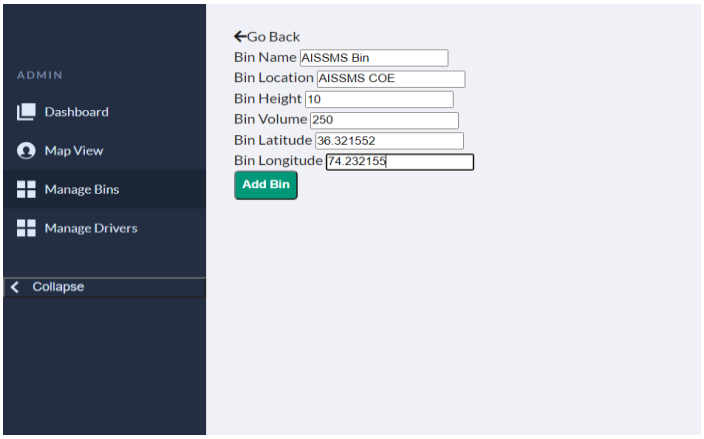

Fig -7: Add Bin Functionality

The map view made it easy to visualize where the bins were placed.

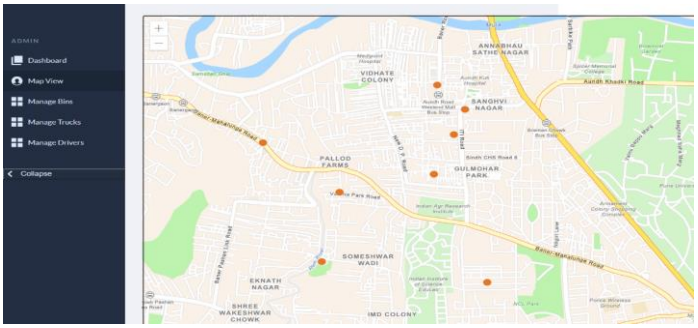

Fig -8: Map View of all the placed Bins

One of the major features of the Web Application being easy monitoring of every bin's current fill level, it was implemented successfully and can be seen below. The data pushed by ESP8266 was readily available on the Web Application.

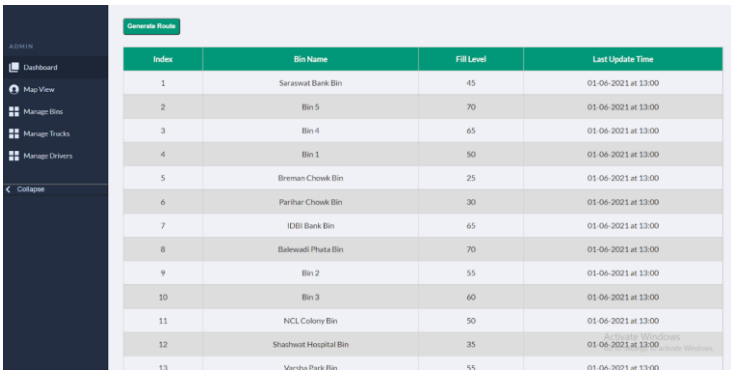

Fig -9: Generate Route Button on the top

As soon as the generate route button was clicked, the Web Application presented current fill levels and predicted fill levels of all the bins available. The predicted fill levels were generated by Facebook Prophet and showcased decent accuracy.

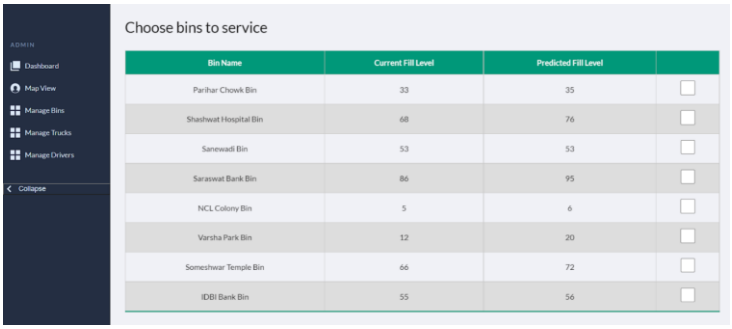

Fig -10: Checkboxes to select the bins to be serviced

After choosing the bins to be serviced, the trucks to be sent to service were selected and the Web Application provided the information about the trucks as well, in order to make a wise choice. The drivers were chosen out of the available ones.

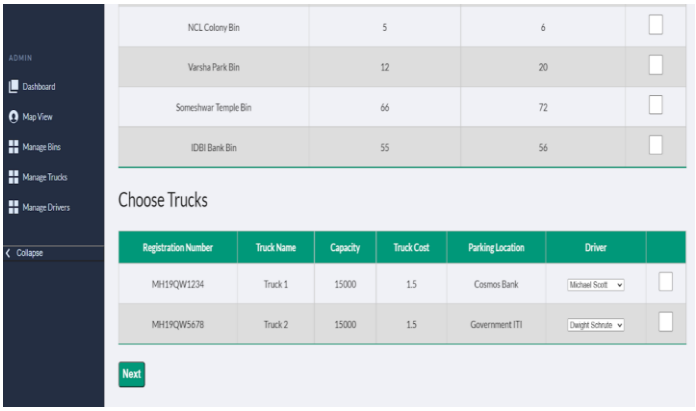

Fig -11: Choosing the trucks and drivers

As soon as the next button was clicked, the Web Application showed the Map View and Routing Summary and was certainly helpful to keep a track of distance, time and efficiency.

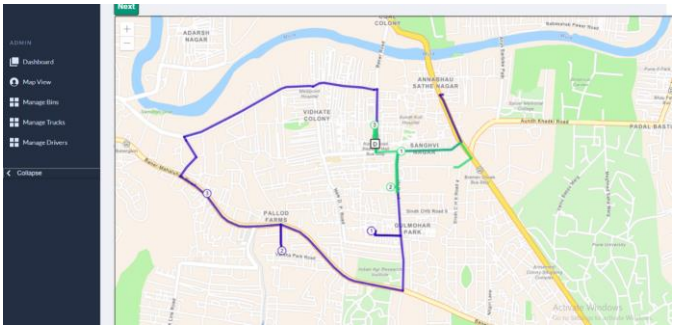

Fig -12: Map View of the Waste Collection route

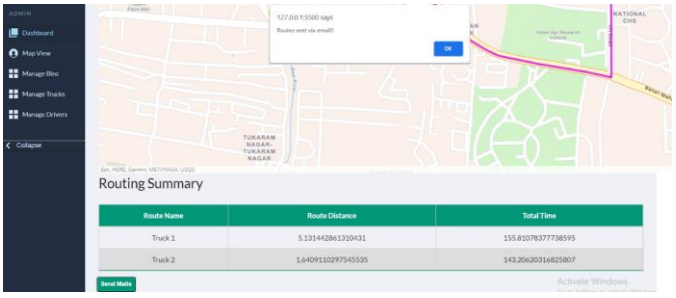

Fig -13: Summary of the Routing and Send Mails Button

The routes to be followed were sent successfully via the Send Mails button to the drivers. To conclude, The Web Application allowed to manage the bins, showed the predicted fill levels and provided dynamic routing as well as per our expectations.

3. CONCLUSIONS

The task of waste collection and Bin management is arduous. Use of Internet of Things and Machine Learning eases up the task. The data generated by the Ultrasonic sensor during the course of this work, helped to keep checking the fill levels and using this data as input to Facebook prophet helped to train a model that predicts the values of fill levels in near future. The Web Application developed is easy to use and alleviates the effort required to keep the record of bins, trucks and drivers. At the same time, it helps to monitor the fill levels of all the bins, sitting at one place and generating dynamic routes which when sent to the drivers makes the process of waste collection dynamic, organised and much more efficient. The future work can be done to include a provision that would allow giving more preference to bins that have high waste decay level.

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