Location Based Garbage Management System with IOT for Smart City

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***Abstract* - Smart cities integrate multiple ICT and IOT solutions to build a comfortable human habitation. One of these solutions is to provide an environmentally friendly, efficient and effective garbage management system. The current garbage collection system includes routine garbage trucks doing rounds daily or weekly, which not only doesn't cover every zone of the city, but is a complete inefficient use of government resources.**

This paper proposes a cost-effective IOT based system for the government to utilize available resources to efficiently manage the overwhelming amounts of garbage collected each day, while also providing a better solution for the inconvenience of garbage disposal for the citizens. This is done by a network of smart bins which integrates cloud based techniques to monitor and analyze data collected to provide predictive routes generated through algorithms for garbage trucks. An android app is developed for the workforce and the citizens, which primarily provides the generated routes for the workforce and finds the nearest available smart bin for citizens.

Keywords – IOT; Smart City; Wi-Fi; Predictive Analytics; Data mining

I. Introduction

Proper waste management is a basic requirement in any kind of an environment. Usually cleaning in these environments are done in the morning and the afternoon. If you take an urban city like Colombo usually there are about 1,200,000 to 1,500,000 [1][2] employees heading for their workstations every morning. For all those people, there are just not enough garbage bins available. On the streets of urban cities hundreds of people are passing the same location around one minute. Around 95% [3] of people are carrying food covers, polythene bags and plastic bottles. If they dispose all them at once, the bins will be filled in several minutes. When they fill up people just litter their trash around the garbage bins because there is nowhere else to put them. The obvious solution to this is for the cleaning staff to stay near garbage bins everyday till they fill up to clean them. This is not a real solution. It takes way more cleaning staff and costs a lot of money. So, it is impractical. The same scenario is happening in workstations. For instance, a bank or a government office cafeteria usually has about five to six garbage bins to serve hundreds of employees. This is simply not enough.

There are some notable negative effects when considering the garbage bins always being full. One of the main effects is the surrounding area starting to smell and be very unpleasant. When the garbage bins are full people put their trash on sides of the garbage bins. When this is done for some time, first it starts to smell bad. So, others who come later tend not to go close and throw their trash in the direction of the garbage bins. If there are any leftover food items, throwing it causes them to spill. This attracts animals like cats, dogs and flies. And these animals spill them even more. Another negative effect is the diseases that spread. It's not just the garbage that spread them, but the animals also can be a source.

II. Related Work

In the paper of S. Lokuliyana et al. on "IGOE IoT framework for waste collection optimization" uses a sensor network based on disposal sites setup around the city. The sensor nodes notify relevant authorities about the availability of waste to be collected. A mobile application is built for citizens to alert authorities about an overflow of an authorized disposal site or unauthorized dumping site of waste. The same application is used by the authorities to convey messages to the citizens. An optimization algorithm is used to create the route for which the trucks use to collect the garbage from the disposal sites. Finally, an analysis is done to calculate the delay of waste collection process, effective waste collection rate and the waste collection process efficiency. The whole system is built as a framework and is named the IGOE waste collection framework [4].

The paper by R. Fujdiak et al. on "Using genetic algorithm for advanced municipal waste collection in Smart City" mainly focusses on IoT vision that introduces promising and economical solutions for massive data collection and its analysis which can be applied in many domains and so make them operate more efficiently. To optimize the logistic procedure of waste collection, the paper uses own genetic algorithm implementation. The presented solution provides calculation of more efficient garbage-truck routes. As an output, the paper provides a set of simulations focused on the mentioned area. All the algorithms are implemented within the integrated simulation framework which is developed as an open source solution with respect to future modifications. The algorithms used are as follows: Floyd-Warshal, TSP formulation, crossover algorithm, Mutation algorithm and Dijkstr, TSP formulation Algorithm [5].

Referring to a research paper by T. Anagnostopoulos et al. on “Top-k Query based Dynamic Scheduling for IoT-enabled Smart City Waste Collection” proposes a top-k query based dynamic scheduling model to address the challenges of near real-time scheduling driven by sensor data streams. An Android app along with a user-friendly GUI is developed and presented in order to prove feasibility and evaluate a waste collection scenario using experimental data. In implementation regarding spatial information the Smart City is divided into multiple sectors which cover the entire city area. Each sector contains a number of multiple intermediate waste depots, which are temporary waste storage areas. The proposed system architecture incorporates a heterogeneous fleet of trucks for serving the waste collection infrastructure. Cloud middleware is responsible to collect data from sensors, aggregate and clean them in order to provide them to the engine which is implemented in OpenIoT. Dynamic scheduling algorithm locates the first available truck which can load waste from the filled bins. Then it is performed a top-K query which exploits real time data from the relation. Also, data is stored in a spatial database in which mobile top-k queries specify the number of the full bins in order to initiate dynamic scheduling. An Android app is implemented in order the drivers to have a user-friendly GUI interface with the IOT system [6].

III. PROPOSED SYSTEM ARCHITECTURE

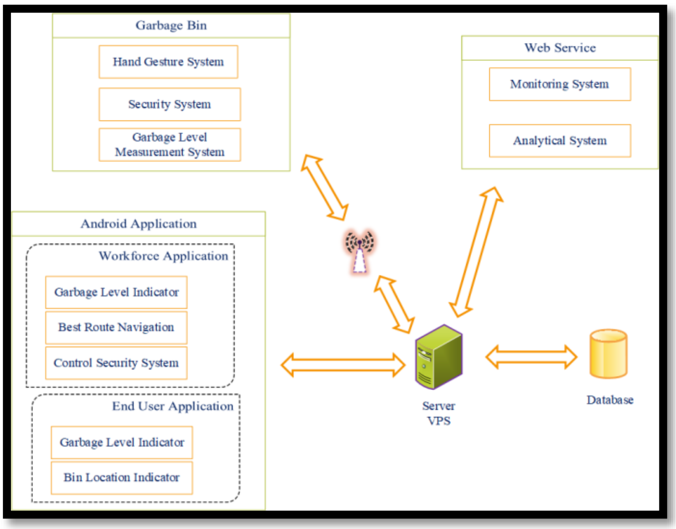

Fig 1. System Overview

Fig. 1 illustrates the proposed system overview for this system. Solid waste management can be broadly categorized as: segregation, collection, and transportation. Segregation of solid waste can be done by the citizens according to the different types of garbage bins provided in a single position. The types of bins are biodegradable, plastic, paper and glass [7]. The bins will be fixed with multiple ultrasonic sensors that will serve 2 purposes, collect garbage level data and detect hand movements to open bin door automatically through a servo motor [8]. All the sensors will be interfaced through a Raspberry Pi Zero W development board the garbage levels will be uploaded to the main server through the onboard Wi-Fi module in the development board [9]. The server will collect the data and store them only a database. This data will be analyzed and displayed on two different dash boards that can be accessed by the workforce and clients. Using data analytics, reports will be generated which can be monitored by the admins though the admin dashboard. Based on the data collected, garbage trucks can be given routes generated through various algorithms and google maps API to efficiently route through all necessary garbage bins and finally reach the dumping site [10]. The routes will be provided though the android workforce application. A client application will be developed which will allow clients to receive routes to the nearest available bin. This application also can be used to provide feedback, complaints, etc.

IV. METHODOLOGY

- The Smart Bin

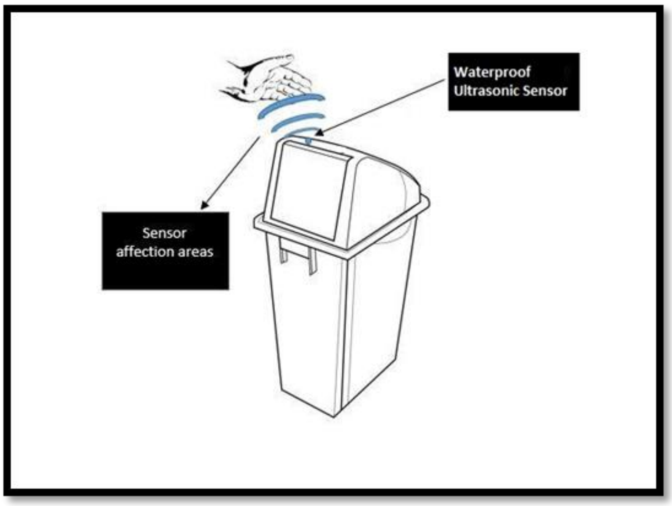

Fig 2. The Smart Bin Architecture

The bin contains four ultrasonic sensors, a servo motor and a Raspberry Pie Zero W development board. Two ultrasonic sensors and the servo motor is dedicated to detect hand movements and open/close the bin door. The bin door will lock if the bin is full. An LED indicator will indicate if the bin is full or not visually. The other two ultrasonic sensors take the garbage level readings each time the bin door is opened and closed, and upload it to the server through the development board. The readings are taken as such: three readings taken from each sensor, average of the three readings are uploaded to the server. The exact level is taken from the average of the two uploaded values. Sensors can be disabled in the time of cleaning. If a bin reaches 80% level, an SMS will be sent to specified numbers. Since four bins are implemented on a single location, one Raspberry Pie board is used to run all four bins.

- The Client and Admin Dashboard

This has a home page which has all the information about the product, contact info and a link to the dashboard. The dashboard has two components, admin dashboard and the client dashboard. The login info provided decides which dashboard is loaded. The admin dashboard has a map which displays Active truck routes and status of all active bins. The admin can add or remove bins and identify sensor faults in bins. The user feedback can be reviewed. The admin has the capability to register new admins and add/ delete numbers from the SMS notification list. There is a feature to view all the different types of reports generated and manage their profile. Before logging in the client has the capability to register a new account to login to the client dashboard. In this, the client can check bin status, give feedback regarding the system, lodge complaints, request bins on specific locations and edit profile.

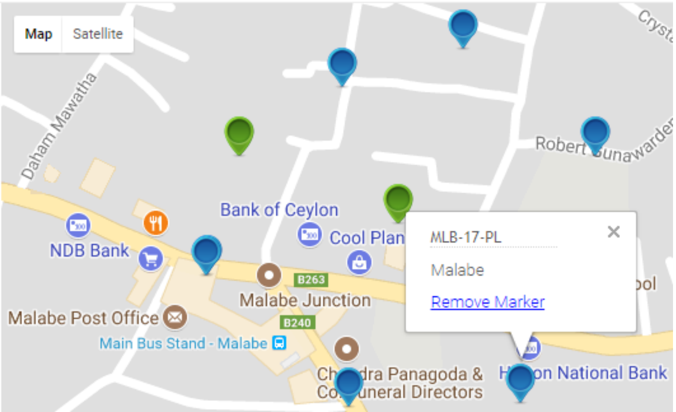

Fig 3. Bin Details Map

- The Workforce Application

The application has a map that shows the current levels of all the bins. This receives the calculated route (mentioned in the route calculation) at the designated time slots and when there is a special bin to be cleaned. The cleaner has to press start when starting the round and press end when the shift ends. The time slots and durations are recorded. The app has the capability to turn off bin sensors when a cleaner is ready to clean.

- The Client Application

This application shows a map with all the available bins. The client can search for the nearest bin and calculate the nearest path to it. The client can lodge complaints and give feedback regarding the system. Client can request bins.

- The Route Calculation

In a one day, three statics times are set for the trucks to do rounds. At each of these times, the server checks for bins that are 80% filled and bins that will be filled to 80% in the next 3 $^1/_2$ hour, these locations are added as waypoints to Google maps API to calculate the quickest route. The interpolation algorithm is used to predict the bin waypoints for the next 3 $^1/_2$ hours [10]. This formula takes the past data of bin levels for the exact times from the database and predicts what level each bin will have at that exact time of day. If the predicted value is above 80%, that bin is added as a waypoint. For all the routes, the end point is set as the disposal site. The map is divided into several regions, and workforce are assigned to different regions. If a bin that is not on the route fills to 80%, that bin is immediately updated as waypoint on the active truck's route. If two trucks are simultaneously active, the waypoint is added to the first starting truck.

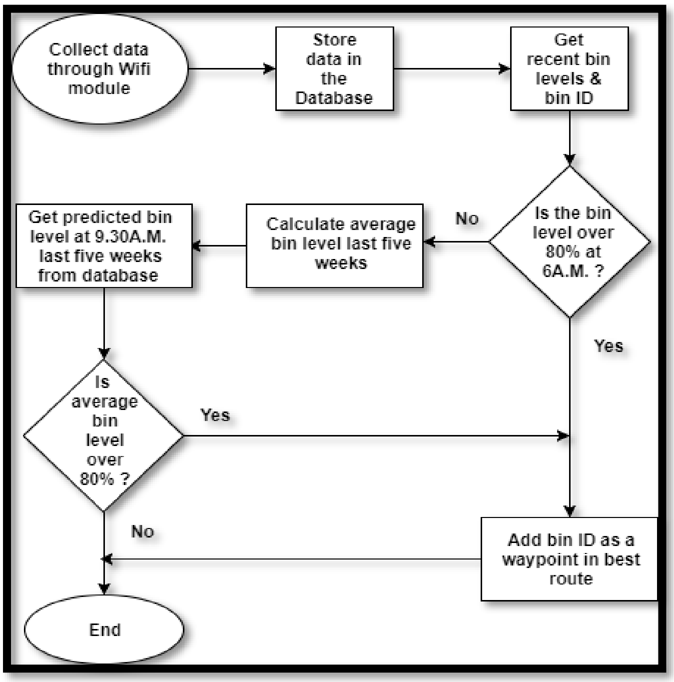

Fig 4. Adding a bin as a waypoint

- The Analysis of Municipal Solid Waste Generation

Four bins for each type (biodegradable, plastic, paper and glass) of garbage will placed on each location. The amount of garbage types used from each region is recorded. With enough data inputs, a calculation is done to find which regions produce the most amount of garbage from each type. Then predictions are made as to the levels of garbage produced in the future months and years [11]. Reports of these statistics are provided to the municipal council to take action. If the type of garbage is not eco-friendly, steps can be taken to reduce the use of these types on these regions. These steps may include setting up more recycling stations, introducing alternatives to the non-eco-friendly types used in the regions, business opportunities, etc. Ultimately these readings are used to check the effectiveness of the implemented steps. The weights calculated from each type is used to calculate the profit that can be made from recycling these garbage types. These reports can be an incentive for the municipal council to set up more recycling stations.

- The Statistical Fault Detection of Sensors

This component identifies malfunctions in the ultrasonic sensors which functions as the garbage level sensors. These malfunctions include the sensors sending bogus values and sensors being inoperative. First a base value is determined from collected test records in the database. Every time two levels are sent from each sensor the difference between these levels is checked against the base value to see if it is lower. If the value is lower the sensors are functioning normally. If the value is higher, this value is checked against the database to see if the value is similar to previous records at the exact time.

- The Analysis of Bin Requirements

First scenario is when a user requests an additional bin on a position which bins already exist, the server refers to the previous fill level records of the existing bins, and other bin requests to the same position. Considering this two information the server determines if an additional bin is necessary.

Second scenario is when a user requests a bin on a position that does not contain pre-existing bins, when the server checks for existing bins in a given perimeter. If existing bins are identified, these bins are subject to the same calculation mentioned above to determine if the requested position requires a bin.

This component includes presenting the initial number of bins needed to implement the system on a new city. The server updates number of bins active on each region which the system is implemented, and monthly calculates the number of bins used by the total population in each region. These records are used to calculate the number of bins needed to be initially implemented on a new city with the specific population.

V. Test Resuts and Evaluvation

Mentioned below is the formula used to predict levels of bins at specific times of day. (1)

$$f(x) = f_0 + r\Delta f_0 + \frac{r(r-1)}{2!}\Delta^2 f_0 + \frac{r(r-1)(r-2)}{3!}\Delta^3 f_0 + \frac{r(r-1)(r-2)(r-3)}{4!}\Delta^4 f_0 + \frac{r(r-1)(r-2)(r-3)(r-4)}{5!}\Delta^5 f_0 + \frac{r(r-1)(r-2)(r-3)(r-4)(r-5)}{6!}\Delta^6 f_0 \quad (1)$$

$$h = x_{i+1} - x_i \qquad r = \frac{x - x_0}{h}$$

where,
$i = \{0,1,2,3,4,\ldots\}$;
$x_0 = Initial\ Time$
$x = Time\ at\ which\ the\ prediction\ is\ done$
$h = Time\ differance\ between\ time\ periods$

This formula is used to predict garbage levels of given bins at a given time using data from the bins for the past five weeks of the same day.

The below formula (2) is used to predict garbage level amounts of specific types of specific areas in a given month in the future.

$$y = byx(x - \bar{x}) + \bar{y} \quad (2)$$

$$byx = \frac{n\,.\,\sum fdxdy - \sum fdx\,.\sum fdy}{n.\sum fdx^2 - (\sum fdx)^2}\cdot\frac{h_y}{h_x}$$

$$\bar{x} = A + \frac{\sum fdx}{n}.h_x \qquad \bar{y} = B + \frac{\sum fdy}{n}.h_y$$

Where,
y = Future amount of garbage
x = The month for which the prediction is made
A = mean of x dataset
B = mean of y dataset

The below equation (3) is used to identify if the current month's specific type of garbage has increased or decreased according to the average collection weight from the past months up to now.

$$l = \frac{\sum_{i=0}^{n} k_i}{n} \quad (3)$$

Where,
l = the average weight of specific type from current type.
k = the average weight of garbage of specific type from each month up to last month.
n = the total number of months up to last month
m = the average weight of garbage collected in the current month from a specific type.
So when $l > m$ the average usage of that specific type has increased and vice versa.

The below method is used to identify a string of faulty value sent sensors of a bin in a short period of time.

At $t = t_1 \quad |H_1 - H_2| \le \alpha$

If at $t = t_2\ |H_1 - H_2| > \alpha$

$G_i \pm \beta$; $\{i = 1,2,3,4,5\}$

If $G_i \pm \beta \rightarrow$ is in the range three, four or five previous weeks

Ignore the S1 and S2 deviation. Both sensors are working properly and if,

$G_i \pm \beta \rightarrow$ is not in the range three, four or five previous weeks

Anomaly detected. Notify administrator about the sensor fault through the monitoring dashboard.

Where,
$\alpha =$ Confidence Factor
$\beta =$ Range Factor
H_1 = Ultrasonic sensor1 (S_1) measured distance
H_2 = Ultrasonic sensor2 (S_2) measured distance
time (t) $= t_i$
$G_i =$ Calculated garbage level

The below equation (4) is used to identify the initial number of bins needed to implement the system based on the population of the area.

$$b = \frac{\sum_{i=0}^{n} \frac{n_i}{p_i}}{n} \quad (4)$$

Where,
b = number of bins needed in the new area.
n = total number of areas
p = population of the area

VI. CONCLUSION

This article incorporates IOT solutions to implement a system that provides the municipal council with a system that better equips them to handle the garbage problem in a smart city. Every party is interacting with this system, that is the citizens, the workforce and the admins.

Mainly this system is aimed at a city with a high or growing population. This system is built to adapt to growing populations, i.e. the number of bins are increased until the amount of garbage collected can be satisfied. The route calculation makes sure that bins are never overflowing. The government can use this system to keep an eye on the levels of use of harmful materials generated, and apply techniques to reduce these levels. They can also use this system to confirm that the applied techniques are actually effective. The government can setup recycling stations and the profit to be gained can be calculated.

All these components of the system ultimately lead to a cleaner city, citizens getting a convenient method to dispose of their day to day garbage and the government saving resources and even making a profit from recycling in the long term.

VII. FUTURE WORK

Future work can include many areas. One area that can be improved on, but limited at this time due to trying to making this project low cost, is identifying types of garbage from the bin itself, thus removing human segregation. If this is implemented, on a single location instead of four bins for the four different types of garbage, one large bin can be placed which segments the garbage by itself. Another area which can be improved is instead of each bin connecting to an access point to communicate with the server, bins can communicate with each other and connect to an access point through a main hub. This method may reduce network costs and make the network process more efficient.

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