IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-4, April 2019 E-ISSN: 2347-2693

Internet of Things based Waste Management System for Smart Cities: A real time route optimization for waste collection vehicles

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DOI: https://doi.org/10.26438/ijcse/v7i4.496503 | Available online at: www.ijcseonline.org

Accepted: 20/Apr/2019, Published: 30/Apr/2019

***Abstract*—** Waste management has become an immense concern in the context of today's modern cities. Improper waste management leads to unclean, unhygienic conditions in the city hence spreading lots of diseases and leads to improper management of logistic and human resources. However, Internet of Things (IoT) has brought about a revolution in the traditional system to develop a smart city project in various fields. Our proposed idea is for proper waste management and optimization of waste collection and disposal system to avoid scenarios of waste overflow in the context of technology enabled smart cities. In this research work waste bins are divided into three categories namely (i) biodegradable, (ii) non-biodegradable and (iii) metallic. A real-time monitoring of the garbage level inside the waste bin is periodically sent from each location to a centralized cloud platform. Whenever the garbage level inside waste bin reaches the threshold, the waste collection vehicles are routed according to the decreasing order of percentage of waste filled in the dustbins of different areas. The main objective of the project is to save resources and strict constraint of the overflowing of waste bins. In this project, HCSR04 ultrasonic sensors are used with Arduino UNO for developing the prototypes. ESP8266 is used to send real-time sensor data to cloud.

***Keywords*—**Internet of Things (IoT), Waste Management System, ThingSpeak, Route Optimization, ESP8266, Smart City

I. INTRODUCTION

One of the most challenging problems in Smart city project is solid waste management. About 30% of the total budget of a municipal corporation is consumed for waste management [1]. The municipal corporation has inadequate resources that result in improper waste management. With the implementation of smarter technology resources can be utilized properly with enhanced efficiency.

In today's world Internet of Things (IoT) is an indispensable factor in our life, may it be in healthcare, home automation, industrial automation, smart city or in this case a smart dustbin as well which would have been an unimaginable concept a few years back. However the idea of implementation of IoT in dustbins is not new, rather motivation has been taken from previous research works. The details are presented in chapter II. IoT based Waste management system has made use of various sensing systems to track the dustbin status remotely [2-3] and raise an alert when it is full but those lack in the proper routing of waste collection vehicle and an adequate formula to calculate an accurate percentage of the waste inside the bins. So in this paper, we have proposed a system which tracks the percentage of the waste-filled status of the dustbins remotely with different ID's over the web page and routing the waste collection vehicles accordingly.

Section I contains the brief introduction of Waste Management system for smart city with IoT as a technology enabler. Section II contains the literature survey and related work in the context of the research, Section III deals with the methodology adapted by explaining the proposed system architecture, design and implementation. Section IV deals with results and discussion and finally Section V concludes the research article with future research direction.

II. RELATED WORK

Waste management system has been proposed by various authors in their research works [1-4], these works propose the use of ultrasonic sensor modules to detect filled up waste bins. The authors in [5] propose an Arduino Mega for implementation of intelligent garbage collection using IoT. The authors have given an extensive study in the context for Waste Management for Smart cities [6-7]. IoT as a technology for garbage management is suggested by authors in their research articles [8-12] for Smart cities. The author has commented on IoT as a service enabler for Smart Cities in IEEE IoT Journal [13]. The author in [14] has proposed a waste-bin monitoring using integrated technologies. Iot based smart garbage and waste collection bin has been proposed in the research article [15]. In the research article [16], authors have proposed Wireless M-BUS as a lucrative M2M technology, which can enable various smart city applications and can also be used in the context of waste management system. Universal smart energy communication for various applications is presented in [17]. IoT in the context of healthy Smart city a WHO prospective is presented in [18]. Low power network for IoT is discussed in [19]. Smart garbage management system has been proposed in [20-21]. The author presented a case study of solid waste management in Manipur, India [22].Author shows TCP performance over IoT Network cluster for implementation of RESTful API HTTP POST to centralized cloud like ThingSpeak [23]. Authors have presented a working prototype of online garbage monitoring using Arduino and NI LabView [24].

III. Methodology

A. *Proposed Waste Management System for Smart Cities*

In our proposed system, we have used three ultrasonic sensors to detect the level of waste in the dustbin. The Sensor sends ultrasonic waves and calculates the total time taken to reach the obstacle and to get reflected back. Sensor data is sent periodically to the cloud through the ESP8266 Wi-Fi module and the consecutive dustbin ID its status and its location are stored in the database. The data can be visualized using GUI for monitoring from a remote location. Whenever the status shows filled, an alert is raised and the waste collection vehicle can be dispatched to the destinations in orderly fashion based on the priority.

The above proposed idea of Waste collection vehicle route optimization require a real time waste bin level sensing technique for which a system has been developed using ultrasonic level sensing of waste bin. An ultrasonic sensor would be placed on the top of the waste bins and periodically the garbage level can be sensed. Figure 1 shows the proposed waste management system.

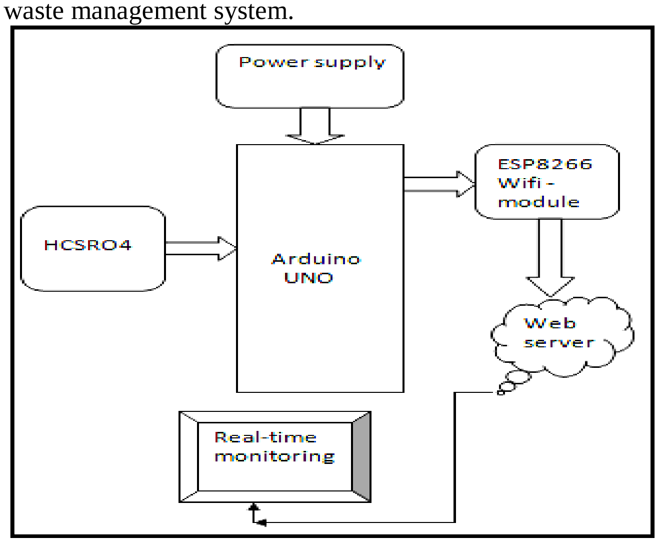


Figure 1. Block diagram of proposed Waste Management System

B. *Garbage level sensing using HCSR04*

The entire framework is accomplished with the help of IoT. In this work we have considered three categories of dustbins- biodegradable, non-biodegradable and metal are placed in different areas of the city which are preferably red, yellow and green in colour respectively. Now, the rate of filling of garbage in the dustbins totally depends on the economy, population, culture and demand so it is unequal at every place, in some place the bins fill faster while in the other place it's too slow. Each of the dustbins are equipped with an ultrasonic sensor, a GPS receiver and a unique RFID. The ultrasonic sensor will give the real time garbage level in the waste bin. The GPS receiver will help Google API to show the location on Map of the Waste collection vehicle. The RFID tag attached to each garbage bin will be scanned while the cleaning staff will empty the garbage bin to set a control flag activated, which will enable the authorities get information on the exact time and status of cleaning from various waste bin sites with the help of the centralized server. The continuous real time filled percentage (%) of every waste bins are sent to the cloud via the ESP8266 Wi-Fi module. These garbage fill levels of each location are stored in the database with its valid RFID and GPS location information.

Let us assume a case study, when at one location the garbage level of the waste bin is 90 %, at the same time some other location it may be 70% and similarly in some other location it may be 20%. Under this case instead of collecting the wastes based on geographical road map of the city, a dynamic optimized route can be calculated based on the status of filled waste bins (% full). This would result in better waste management system in the context of smart city. Dijkstra's Algorithm to find the least cost path in graph theory is given by (1) as follows:

$$D(v) = min\{D(v), D(w) + C(w,v)\} \tag{1}$$

Given; $D(v), D(w)$ are the least cost path from the source $'v'\ node\ to\ destination\ 'w'$ node, provided $v\ and\ w$ nodes are neighbouring nodes. $C(w,v)$ is the direct cost between $v\ and\ w$ nodes. To find the least cost path for Waste Collection Vehicles we have taken motivation from Dijkstra's algorithm. The cost matrices for Waste Collection Vehicles are calculated by considering the real-time garbage level sensor data as the parameter.

The mathematical model given in (2) below is the cost function for a Waste Collection Vehicles to go to a particular garbage bin site.

$$C(x,y) = \left[A.\left(\frac{\Delta\, G}{\tau}\ .G_c\right)\right] \tag{2}$$

$C(x,y)$ is the cost function for Waste Collection Vehicles to go from 'x' location to 'y' location is calculated from two major parameters. First is the, $\frac{\Delta\, G}{\tau}$ gives the slope i.e the rate of fill up the garbage bin at destination 'y' location. Where

'τ' is the total time since the last collection. 'τ' is scaled to hourly scale for getting a optimum denominator for finding the slope for garbage filling rate per hour in a garbage bin location. Second parameter is 'G_c' denotes the current garbage level value as given by the garbage level sensor or in other words the volume of garbage in the bin. In most of the implementation the Garbage sensor will give a percentage (%) of bin filled in real-time to the cloud server. Thus from the total volumetric capacity of the bin it can be easily calculated, what is the current volume of garbage in the bin 'G_c'. 'A' is the scaling factors considering the two parameters. In most of the implementations the scaling factor can be loaded in the algorithm as per the city model.

If we follow the conventional road map then it might be the case, when some partially filled waste bins would be cleaned first whereas fully filled waste bins might get cleaned later. This will create an issue of overflowing of waste bins and hence give rise to an unhygienic condition in the city. The truck driver instead may be guided via an app, which shows the precedence of one dustbin over the other with the help of the data stored in the cloud enabled by IoT. Figure 2 shows the route optimization of waste collection vehicle based on real time monitoring of garbage level in each waste collection site of the city.

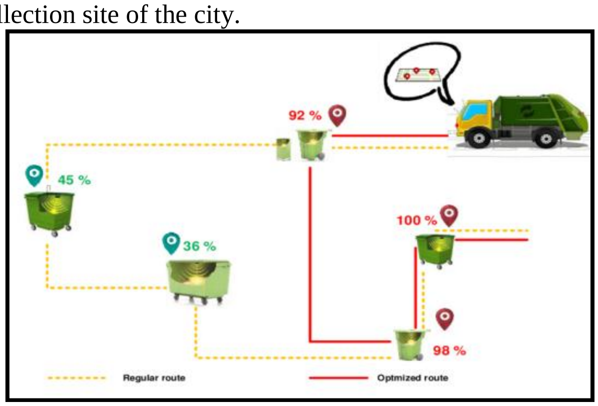


Figure 2. Grabage disposal vehicle routing.

This real time sensor data will help finding the precedence of one waste bin over other bins, which can be synchronized with the Google map API and that will direct the truck driver along the best route from a high precedence location to a lower one. This will avoid overflow of any waste bin and hence help reducing unhygienic condition in the city. Further this strategy would be helpful in optimization of logistic as well as human resources by municipal agencies of cities.

The ultrasonic sensor is used to check the level of waste inside the dustbins. A formula is used on the data collected by the HCSR04 (ultrasonic) sensor, to calculate the percentage fill of the dustbin. 3 cm is distance between sensor and the lid of bin maximum level can be considered as full. All calculations are in centimetre scale. 'G_c' denotes the current garbage percentage (%) filled in respective Garbage bin. The Height of bin is a constant as per the dimension of the bin. The calculation of $G_c(\%)$ can be quantized as per the mathematical model given in (3) below:

$$G_c(\%) = \frac{[Height\ of\ bin - (distance - 3)]}{Height\ of\ bin}\ X\ 100 \quad (3)$$

The calculation of distance between the HCSR04 ultrasonic sensor and the surface level of garbage in the bin can be calculated by the mathematical model given in (4) as below.

$$distantace = \left(\frac{Round\ Trip\ Time}{2}\right) X \left(\frac{1}{Speed\ of\ Ultrasonics\ Wave}\right) \quad (4)$$

The pseudo code for implementation is given as below:

```
Empty=d-3
h-Empty=fill
fill/h*100=Percentage of garbage filled

duration = pulseIn(echoPin_G, HIGH);
  distance = (duration/2) / 29.1;
  fillPercent= ((greenBin_height-distance)/greenBin_height)*100
```

Figure 3 shows the ultrasonic sensor working. The trigger pin sends a very short 10 microsecond high pulse from TX and the RX receives that pulse with some delay after the ultrasonic signal bounce back from the surface of the waste bin. This round trip time (RTT) delay in time can be converted in to travelled distance by ultrasonic wave. This travelled distance when divided by 2 will give the distance between HCSR04 and the surface of garbage in waste bin.

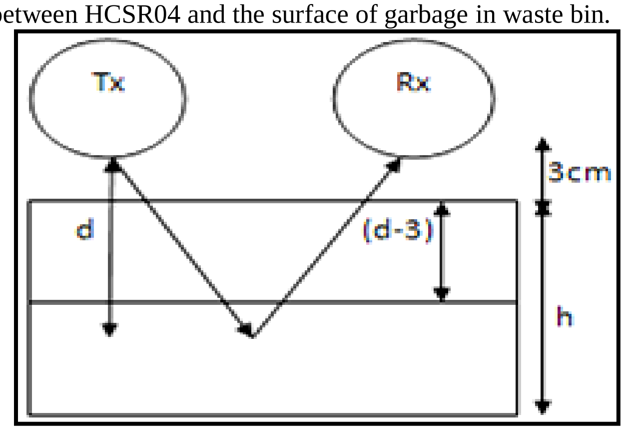


Figure 3. Finding the Garbage level using Trigger and echo signal HCSR04 Ultrasonics Sensor

This calculated percentage is sent to ThingSpeak cloud from where we can monitor the actual variation of data in graphical form graph and actual percentage of waste filled in the dustbin this monitoring helps to track and route the garbage collection trucks accordingly. The data gets updated on the cloud every 30 seconds. Figure 4 shows the data flow of sensor data to cloud and MySQL database integration for storage.

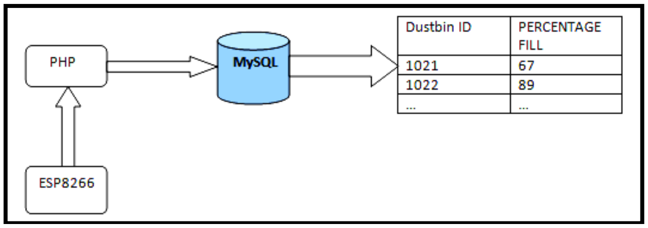


Figure 4. Sending Sensor data to Cloud Server using RESTful API

C. Experimental Setup

We have implemented our idea in a circuit which is simple as well as cost effective. We have made a smart city model with three dustbins (green, red, yellow) of different dimensions respectively 7.2cm, 7cm, 6cm in heights. We have actually made the heights 3cm more than mentioned since the ultrasonic sensor can sense beyond the range of 3cm. Three ultrasonic sensors have been used for three dustbins and its placed at the middle of the bin so that it faces inside the dustbin. The trigger is set high for 10microseconds, so that it sends a pulse and which in turn is received by the echo pin and the total time taken by the signal to go and return is calculated using the formula. The ultrasonic sensor can sense up to 2cm-400cm with almost 3mm accuracy. On the other side, we have used the ESP8266 module with an adapter ESP-01, which directly connects it to the Arduino. Arduino has a voltage of 5V and if ESP8266 is directly connected to it it will burn. So, to prevent the excess voltage divider circuit connection we have directly used the adapter, which has 4 pins namely (TX, RX, VCC, GND). Figure 5 shows the connection diagram of the developed prototype in Fritzing software. Three waste-bin mounted HCSR04 ultrasonic sensors are connected to Arduino UNO using trigger and echo pins as digital I/O and ESP8266 Wi-Fi module is connected through software serial.

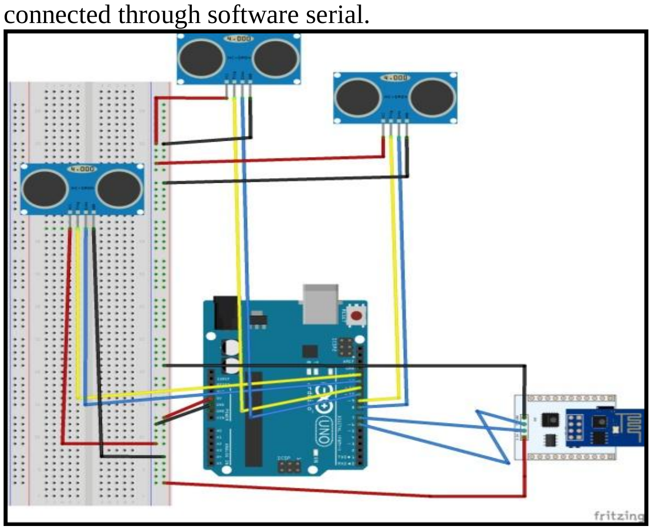


Figure 5. HCSR04 and ESP8266 (IEEE 802.11 Wireless network Adaptor) interfacing with Arduion UNO using Fritzing

We are using ThingSpeak™ cloud platform to monitor the real-time data. This data is sent by the ESP8266 module, which runs on PHP code, which we have developed and here we are using personal mobile hotspot for sending the data. We have integrated the PHP code with the code for the ultrasonic sensor (HCSR04). This simultaneously calculates the percentage fill and sends it to the cloud.

D. System implementation and Algorithm

Figure 6 shows the hardware prototype developed for the proposed waste management system using Arduino, ESP8266 and connected to each waste-bin top mounted HCSR04 ultrasonic sensors for real time level sensing. The figure shows the complete hardware implantation and ThingSpeak cloud data integration.

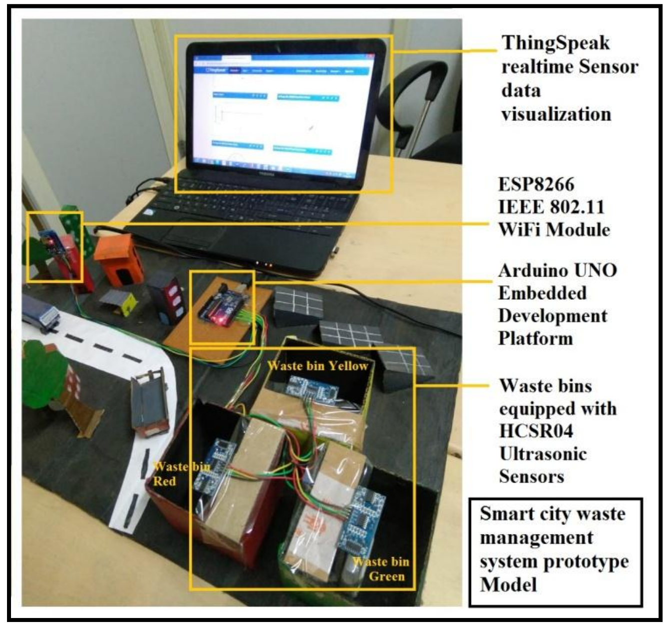


Figure 6. Implementation of Hardware prototype

The proposed system has Arduino UNO as the embedded device for implementation of prototype. The Arduino program developed runs on the proposed algorithm as shown in the figure 7. The program starts with defining all the required parameters for interfacing the HCSR04 ultrasonic sensors with designated digital pins of Arduino UNO. Apart from defining trigger and echo pins for HCSR04 the ESP8266 TX and RX UART Software serial pins are also defined. SSID and PASSWORD for connecting to a IEEE 802.11 WLAN Access point is also defined along with the ThingSpeak API key. Now for initial setup of sensor and cloud connection Pin Mode, Software Serial with required AT commands has to be programmed in void setup (). Further a void loop () function must include the periodic HCSR04 ultrasonic sensor level sensing based on the proposed method. The data acquired from sensor is stored in a variable and sent to cloud using RESTful API HTTP POST method to ThingSpeak Cloud using AT command CIP through ESP8266 every 30 seconds interval. This period data sent to the cloud is programmable and can be changed as per the real world scenario. The loop can be stopped with a control signal=0 when the real time garbage bin level sensing need to be stopped or else with signal=1 it will keep sensing the levels of each garbage bin periodically.

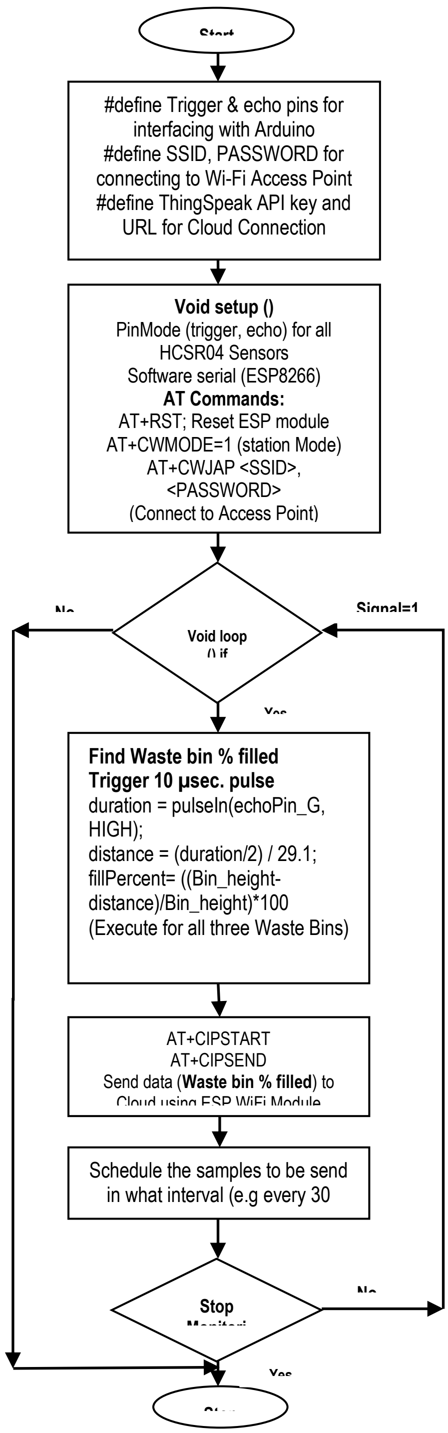
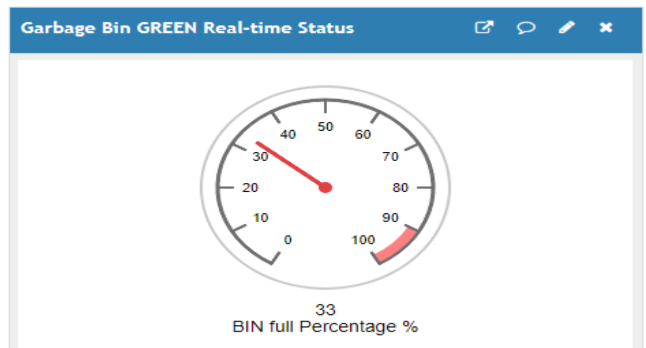


Figure 7. Algorithm for Embedded System implementation

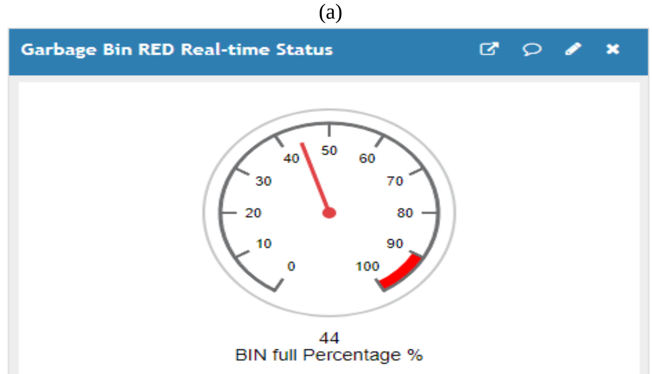
IV. Results and Discussion

A. ThingSpeak™ cloud: Sensor data acquisation and visualization

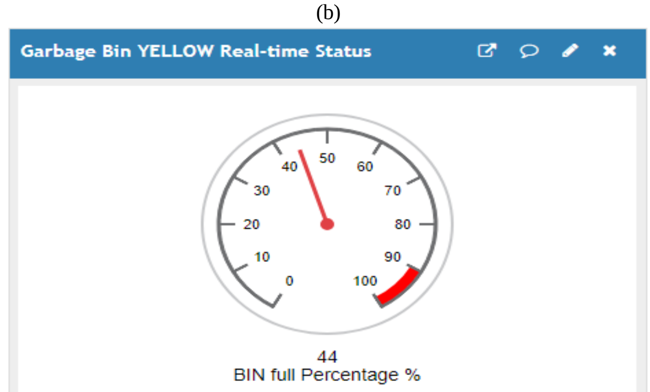
The HCSR04 ultrasonic sensors periodically send the real time waste bin level sensing data to ThingSpeak cloud using RESTful HTTP POST message via AT command CIP+START and CIP+SEND. The data is captured by the ThingSpeak cloud using designated API key which is unique. We have used three channels for three waste bin sensor data. We have observed the results from serial monitor as well as from the cloud. Figure 8 shows the Visualization of sensor data on ThingSpeak™ cloud platform.



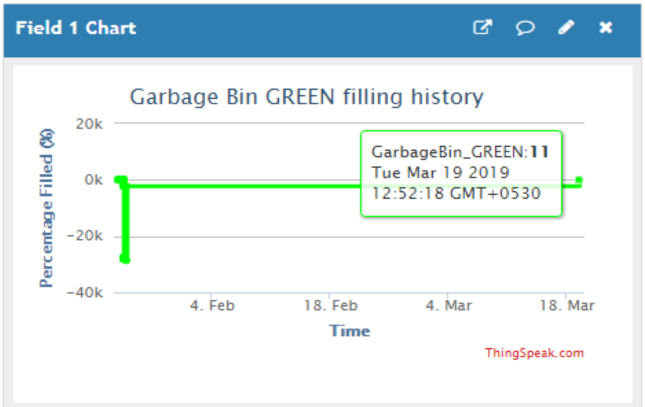
(a)



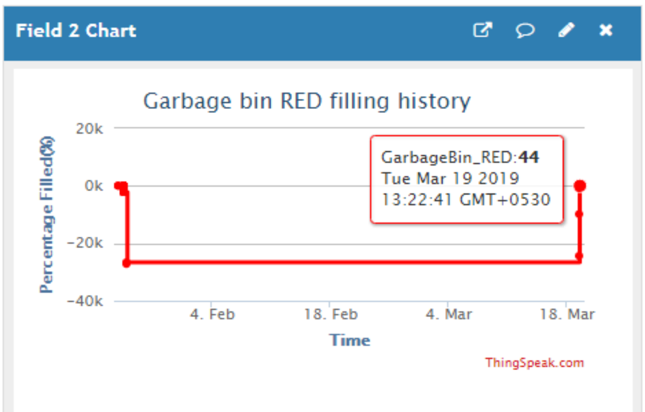
(b)



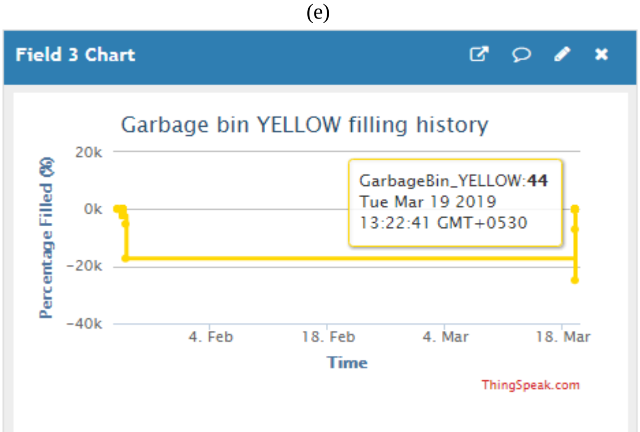
(c)



(d)



(e)



(f)

Figure 8. Visualization of sensor data on ThingSpeak™ cloud platform: BIN full Percentage(%) (a) Green BIN (b) Red BIN (c) Yellow BIN and Garbage bin filling history (d) Green BIN (e) Red BIN (f) Yellow BIN

The percentage of waste-bin filled is calculated by the Arduino code and we can check it in the cloud account, which gets refreshed every 30 seconds. Table 1 shows the sample data collected from the cloud and based on the waste-bin fill real time data the waste collection vehicle route can be optimized as given below.

TABLE I. SAMPLE DATA STORED IN CLOUD DATABASE

Date	**Time Stamp (hh:mm:ss)**	**Real Time HCSR04 Sensor data Waste bin filled %**			**Waste Collection Vehicle Route based on filled %**
		Red bin	***Green bin***	***Yellow bin***	
Feb 10 2019	10:51:45	33	42	63	Yellow → Green → Red
Feb 11 2019	11:55:31	43	21	91	Yellow → Red → Green
Feb 12 2019	12:36:47	67	56	23	Red → Green → Yellow
Feb 13 2019	13:22:56	88	78	93	Yellow → Red → Green
Feb 14 2019	14:46:23	34	96	75	Green → Yellow → Red
Feb 15 2019	15:12:44	23	55	78	Yellow → Green → Red
Feb 16 2019	16:31:11	71	87	59	Green → Red → Yellow
Feb 17 2019	17:51:33	87	78	96	Yellow →Red → Green
Feb 18 2019	18:56:54	78	67	11	Red → Green → Yellow
Feb 19 2019	19:22:32	23	88	45	Green → Yellow → Red
Feb 20 2019	20:23:15	79	69	57	Red → Green → Yellow
Feb 21 2019	21:17:34	34	23	97	Yellow → Red → Green

* Sample data collected from the deployed prototype

B. Result Analysis and discussions

The current garbage levels in Green, Red and Yellow bins are shown in Figure 8 (a), (b) and (c) respectively at the ThingSpeak® cloud visualization tool. The above shown values are calculated in the Arduino system by implementation of mathematical models given in (2) and (3). The cloud stores these *Gc* (%) value on real-time basis with its date and time stamp for finding the best path for garbage collection, which is the first parameter. The all time garbage levels in Green, Red and Yellow bins are shown in Figure 8 (d), (e) and (f) respectively. This Time vs. *Gc* (%) will ensure the calculation of filling rate which is the second parameter given by $\frac{\Delta G}{\tau}$. These two parameter will aid in calculating the best path for waste collection vehicles as proposed in (1) and (2).

As given in Table.1 the real-time ultrasonic sensor data acquisition is done using ThingSpeak® cloud, which is a open platform for IoT applications. The data collected includes date and time with the garbage bin location as Green, Red and Yellow. In real world deployment these garbage bins will be identified by the GPS coordinates all around the city. As shown in the Table.1 a route can be generated by the cloud computing platform to find the best path for waste collection vehicles based on cost function model (2) proposed in section III. The authors of article [25] have suggested a roadmap of cloud computing to IoT can be used as a framework. The last column of the above table depicts the best route based on the real-time garbage bin fill percentage data collected at cloud using IoT system implementation. For an instant if we consider the first sample data collected on February 10, 2019 at 10:51:45 the Red bin sensor shows 33% filled, the Green bin sensor shows 42% filled and the yellow bin shows 63& filled. Hence by calculation proposed by (2) the best route is found as Yellow → Green → Red. From the result obtained and the proposed system implementation, it is needless to say that the logistic recourses as well as manpower can be optimally utilized for a more hygienic smart city with service being enabled by the Internet of Things technology as proposed in Section III.

C. Scope for data analytics and Routing of Waste collection vehicle

As shown in the Table 1, the real time level sensing technique deployed in this proposed work would be helpful in optimizing the system further using various data analytic tools and machine learning algorithms in future scope of this work. Figure 8 shows the data obtained in ThingSpeak cloud that a routing algorithm can be developed in future work for waste collection vehicles based on real time sensor data according to the filled percentage of waste bin (%). Further another parameter like the filling rate can be considered in future work to optimize the route even further. The waste bins which are getting filled in faster rate have more probability of overflow than the waste bins which are getting filled at a slower rate. Hence, further more parameters can be considered to find a more sophisticated algorithm for a holistic Waste Management System for future smart cities.

V. CONCLUSION AND FUTURE SCOPE

On the final note, it can be inferred from previous chapters that, a real time waste monitoring system is the key to achieve a better waste management system. This would optimize logistics and human resources for any modern municipal agency. The above proposed waste management system would solve various scenario specific issues in modern cities when it comes to waste collection and disposal to ensure better community hygiene. As discussed in chapter III, the proposed system would be cost effective solution to achieve a real-time waste bin level sensing by reliable and centralized cloud data integration. The prototypes and proof of concept shown in this paper can be upgraded to industry standard hardware and software for real world deployment. But point to be noted the concept, idea, systematic approach and technique used will remain unchanged. Further as discussed in chapter IV this work has opened new opportunities to work in the domain of data analytics to further optimize the waste collection vehicle route by implementing better algorithms with more relevant and practical parameters, which may come in to picture in a real world scenario.

ACKNOWLEDGMENT

The prototype is developed in Wireless Communication & Networking Lab, School of Electronics Engineering, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University. All the hardware and software vendors are acknowledged and no commercial grade or licensed software is used for this work. This work is for purely academics and research.

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