Garbage Disposal System for *Smart Cities*

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Bachelor of Technology
Computer Science and Engineering

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$11^{th} May, 2016$

To our family and well wishers.

Declaration of Originality

I, Ashish Kumar, Roll Number 112CS0155 and Chinmaya Dehury , Roll Number 112CS0560 hereby declare that this dissertation entitled Garbage Disposal Systems for Smart Cities presents our original work carried out as a B.Tech student of NIT Rourkela and to the best of our knowledge, contains no material previously published or written by another person, nor any material presented by us for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom we have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Bibliography". We have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.
We are fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

Date: $11^{th} May, 2016$
Place: Rourkela

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Certificate

This is to certify that the work presented in the report entitled **Garbage Disposal System for Smart Cities** submitted by **Ashish Kumar**, Roll Number **112CS0155** and **Chinmaya Dehury**, Roll Number **112CS0560**, is a record of original research carried out by him under our supervision and guidance in partial fulfillment of the requirements of the degree of Bachelor of Technology in Computer Science and Engineering. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

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Abstract

Owing to development garbage disposal has become a challenging problem. In this project we use the power of Internet connected (IoT) devices to tackle the problem of waste management. We have developed a product which constitutes the subsystems: hardware and software. The developed product can be deployed into waste bins to collect data based on which we have optimized the garbage collection process. The sensor attached to the bin communicates the characteristic data of the bin that would help avoid spillage. The sensor sends the height of the garbage that it measures inside the bin relative to its position in the bin and using suitable mathematical formulation we estimate the filled percentage of the bin. If the fill percentage crosses the threshold value, then suitable actions are initiated in order to avoid spillage. Additionally, the fuel cost optimization has been done by calculating the optimized pick up route. The capital saved per trip and the number of vehicles to be used in garbage collection routine is also calculated. With the help of this system we are able to monitor the bins in real time and save nearly 20% in fuel capital expenditure with each trip. From our findings we can now design a complete Garbage Disposal System for a smart city.

Keywords: Internet of things (IOT), Waste Management, Sensors, Cost optimization

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Chapter 1

Introduction

1.1 Introduction

The thing we can call an Internet of thing can just be about any thing physical in the real world, in your house or work place, your car or objects worn around your body but it has to be connected to the Internet. By "*connected to the internet*" means it should be capable of receiving input from the surrounding (using sensors) and transform them into data that could be sent on the internet for collection and processing and in some cases required to present results (using actuators). For example, a refrigerator may sense the contents present inside it for example milk, fruits or vegetables and remind everyday while you are leaving work by sending the list of the items in short.

The term Internet of Things was initially coined by Kevin Ashton (1999), former director of Auto-ID Center at MIT [3]. The idea of the Internet of things is simple, rather than having a small number of extremely powerful computing devices in life such as laptop, PC, phone, player, etc. you may have a large number of devices which perhaps may be less powerful such as an umbrella, bracelet, mirror, etc. Together we can summarize these components in the following appealingly simple equation.

The world is developing continuously, be it in medical, industrial or technological front. These rapid changes are affecting our environment. And there is one particular problem, the problem of waste management, which

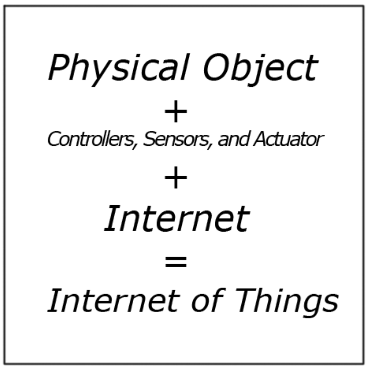


Figure 1.1: A simple equation for the Internet of Things

[1]

will have serious repercussions if its not addressed immediately.The growth in population and the economic power possessed by people has had an impact on our environment, since with more money people tend to consume more. This has led to huge growth in the amount of waste generated. But the garbage generation is not an event that generates exact amount of garbage. Each day the amount of garbage generated varies.This often leads to overflow of garbage bins. Everyday, in our lives we use dustbins, some are managed well, while others are overflowing with waste and this creates a foul environment. In one way or another this gives rise to dreadful diseases like malaria, typhoid, jaundice among many others, it also increases the number of mosquitoes, flies and other insects that act as the carrier of these diseases. This has become a major concern not just in India but around the globe. Todays metropolitan cities are facing a very big challenge of solid waste management. Hence, we are in need of a system that could handle this problem entirely or reduce it to a level where it no longer becomes a threat to our developing society. This project showcases one of the most effective and efficient way to tackle this problem of waste management. In this project we use the power of small Internet connected (IoT) devices to keep this big problem of waste management at its minimum so that we can have a cleaner and greener environment.

1.2 Garbage Disposal System

A Garbage Disposal System(GDS) pertains to all the activities that takes care of garbage from its generation to its disposal. This includes amongst other things, collection, transport and disposal of waste together with monitoring and regulation. It also encompasses the legal and regulatory framework that relates to waste management encompassing guidance on recycling etc. It includes all kinds of waste, whether generated during the mining of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, or other human activities, including municipal (residential, institutional, commercial), agricultural, and special (health care, household hazardous wastes, sewage sludge). Waste management is intended to reduce adverse effects of waste on health, the environment or aesthetics. The waste to be managed can be of any form i.e. gaseous, liquid, solid and radioactive matter. In India the garbage disposal system involves municipality trucks visiting each locality to collect garbage bins. They have the job of visiting a number of locality and collect the garbage bins. These trucks follow a time bound schedule. The truck drivers do not necessarily have the knowledge of the amount of waste generated in a locality. So the same locality may need more than one truck for garbage collection. Following the garbage collection, these trucks go to a landfill located in a vacant area situated usually at the edge of the city and dump the garbage there. Once the landfill is full they use a new landfill.

1.3 Literature Review

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. There are a many application spaces which will be affected by the rising Internet of Things. According to Jayavardhana Gubbi, Rajkumar Buyya the applications can be grouped in view of the sort of system accessibility, scope, scale, heterogeneity, repeatability, client association and effect. They classify the applications into four application spaces: (1) Personal and Home; (2) Enterprize; (3) Utilities; and (4) Mobile. Their vision of IoT can be seen from two perspectivesInternet centric and Thing centric [4]. The Internet centric architecture will involve internet services being the main focus while data is contributed by the objects. In the object centric architecture, the smart objects take the center stage.

A smart city can be described as an urban development vision to integrate multiple information and communication technology (ICT) solutions in a secure fashion to manage a citys assets the citys assets include, but not limited to, local departments information systems, schools, libraries, transportation systems, hospitals, power plants, water supply networks, waste management, law enforcement, and other community services. The goal of building a smart city is to improve quality of life by using technology to improve the efficiency of services and meet residents needs. M Batty and K.W. Axhausen in their paper Smart Cities of the Future define smart city as a city in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies [5]. They begin by defining the state of the art, explaining the science of smart cities. They define six scenarios based on new cities badging themselves as smart, older cities regenerating themselves as smart, the development of science parks, tech cities, and technopoles focused on high technologies, the development of urban services using contemporary ICT, the use of ICT to develop new urban intelligence functions, and the development of online and mobile forms of participation.

Mackinnon Lawrence and Eric Woods point out the trend in growth of waste volume: 97% of waste volume growth is expected to come from Asia Pacific and Africa, primarily in developing economies across these regions [9]. A recent report published in 2012 by World Bank, What a Waste, is among the most widely cited studies. According to this study, the amount of MSW(Municipal Solid Waste) generated is growing faster than the rate of urbanization. World Bank estimates that roughly 3 billion urban residents generated an average 1.2 billion kg per capita per day (1.3 billion tonnes per year or 1.43 billion tons per year) in 2012. By 2025, this is expected to increase to 4.3 billion urban residents generating about 1.42 kg per capita per day of MSW (2.2 billion tonnes per year or 2.4 billion tons per year). This represents a 900 million tonnes (992 million tons) increase in a little over a decade, a near doubling of the total volume of MSW generated globally today. Building on this analysis, it was projected that the total MSW generated globally in 2014 will be 1.5 billion tons, increasing to 2.2 billion tons by 2023. Substantial growth in the volume of waste generated in Asia Pacific and Africa will be one of the defining trends of the next decade in the global waste management market.

Proper waste disposal is an important operation in any city and is more relevant in case of smart cities. Ohri.A and Singh.P.K explain the need for a

Decision Support Systems in managing solid waste. In India, most of the municipalities are currently unable to fulfill their obligation to ensure environmentally sound and sustainable handling of waste generation, collection, transportation, treatment, and disposal of Municipal Solid Waste [7]. Their proposed DSS consisted of Data Base Management, Model Base Management and User Interface System. Yann Glouche and Paul Couderc, they propose a new solution to enhance waste collection efficiency using the RFID technology [8]. Fully relying on digital information attached to waste items, this approach does not require any sensor, nor external information system support, enabling high scalability and availability. The presented system helps the user in correctly sorting and disposing wastes.Their approach involves attaching an RFID tag to each kind of waste to categorize them into various types according to their recyclable nature. The reported information about the content of each bin is also a way to compute statistics of each type of waste in the recycling process. Building on the RFID design Insung Hong, Sunghoi Park proposed their smart garbage disposal system which consisted of bins that could communicate with each other and were battery powered [6]. Their idea was aimed at monitoring the waste generated by households and sending customized reports to minimize wastage.

1.4 Motivation

Todays consumerist society has led to large amount of garbage generation from each household. Inefficient garbage disposal leads to littering, overflow of garbage bins. According to Central Pollution Control Board of India and Centre for Science and Environment nearly 0.14 million ton of garbage is generated daily and this number is only expected to grow in the foreseeable future as India is acing its way to the fastest growing economy. Mackinnon Lawrence and Eric Woods[6] points out the trend in growth of waste volume: " 97% of waste volume growth is expected to come from Asia Pacific and Africa, primarily in developing economies across these regions ".

A recent report published in 2012 by World Bank, What a Waste, is among the most widely cited studies. According to this study, the amount of MSW(***Municipal Solid Waste***) generated is growing faster than the rate of urbanization. ***World Bank*** estimates that roughly 3 billion urban residents generated an average 1.2 billion kg per capita per day (1.3 billion tonnes per year or 1.43 billion tons per year) in 2012. By 2025, this is expected to increase to 4.3 billion urban residents generating about 1.42 kg per capita per day of MSW (2.2 billion tonnes per year or 2.4 billion tons per year). This represents a 900 million tonnes (992 million tons) increase in a little over a decade, a near doubling of the total volume of MSW generated globally today. Building on this analysis, it was projected that the total MSW generated globally in 2014 will be 1.5 billion tons, increasing to 2.2 billion tons by 2023. Substantial growth in the volume of waste generated in Asia Pacific and Africa will be one of the defining trends of the next decade in the global waste management market. Taking these statistics into account we realize that if waste is not handled properly it could lead to devastating change in living conditions. In some incidents the stink and gases released from the uncollected wastes catch fire and compromise the air quality of the surrounding along, damages the biota and not to mention jeopardizes human life.

The garbage disposal system in India which is handled by the Municipal Corporation follows a schedule for the pickup and disposal of wastes in the garbage bins. This schedule is followed without having the knowledge of the levels of waste in bins, the garbage collector sticks to schedule whether or not there is garbage to collect. Because garbage generation is not an event that generates exact amount of garbage. Each day the amount of garbage generated varies. There are certain key points which can be chosen as motivation for this work. They are as follow:

1. For establishing a mechanism to know levels of waste in the garbage bins in real time.
2. For scheduling the garbage collector based on the real time data, so that no pick-up trip is wasted or under utilized.
3. For providing a quality of service, which is this case is keeping the garbage bin from overflowing.
4. For managing the resources at disposal to maximize the profits for the organization.

1.5 Problem Statement

The main goal of this project is to achieve sustainable development by contributing in the solutions of waste management along with minimizing the wastage of resources like fuel consumption and manpower that are usually not closely monitored by the authorities. This will also help save time, since a computer will be behind taking decisions and planning pick up routes seamlessly. Hence, it also minimizes the capital expenditures in the operation. The products immediate goal is to provide services and functionalities which are mentioned below.

1. Fill value measurement - Sensors have to be deployed inside the bin to measure the percentage of the bin filled with waste. This also includes development of deployable sensors, modelling its design and functionality, so that they can function as independent modules in a network.

2. Analysis and modelling - Each container would be connected to a near by access point and it will send its data to the cloud at regular intervals. Based on this acquired data actions are initiated and planned.

3. To minimize spillage of waste bins.

4. Route Planning - Planning the route for picking up the garbage from the bins, the route that would be selected would indeed be such that the vehicle that is on duty will consume minimum energy while carrying out its operation by avoiding longer routes or traversing the same path again.

   The aforementioned goals are interdependent, to minimize the spillage of waste (3) one has to develop a methodology to find the fill value of the waste in the bin at anytime. To make sure the process of collection of waste uses minimal resources to do the job (4) we need to model and analyze the process (2).

1.6 Contribution

In this project we have developed a Smart Garbage Disposal System for efficient garbage disposal in smart cities. The ultimate goal of our system was to minimize the fuel, man power and time consumed in a GDS. For this we designed a smart module that can be attached to garbage bins to provide them with better utility. Our system not only takes care of monitoring of garbage in the garbage cans but also takes care of planning of garbage collection routine based on the amount of garbage level and the location of garbage cans in the locality. The main contribution of our work can be outlined as:

1. Dynamic garbage level monitoring: Our smart module employs an HC SR04 ultrasonic sensor that measures the amount of garbage in a bin. The sensor has been programmed with the help of ESP8266 microcontroller to send periodic data regarding the garbage level to the cloud server. The ESP8266 also monitors the battery health of the smart module. The data collected from the unit include the fill percentage, battery health, bin ID along with a time stamp.

2. Data collection and monitoring system: We employ a MySQL based apache server for maintaining data generated from multiple bins. Each bin has a separate table and each table contains all the collected data. The primary key used to identify bins is the Mac ID contained in the ESP8266 wifi unit which is also used as the bin ID. The collected data is displayed in tabular form and graphical form using bar graphs.

3. Position Based Route Planning: By checking the MAC ID of the bin we can identify the bin and its location. The position of each bin is noted and input into Google Map API to generate the garbage collection route. The API returns a map where the location of each bin is demarcated clearly. The route to be followed is also displayed.

1.7 Thesis Outline

In this project we worked towards developing a system that include hardware and software sub-systems. These can be further divided into smaller sub-systems.In **Chapter 2** the mathematical formulations and metrics are defined with respect to the waste bins. Additionally, the fuel cost optimization has been described by calculating the optimized path and the non-optimized path using the bin parameters. In **Chapter 3** we deal mostly with the hardware sub-system of the system where we describe the details that went through in the sensors model for example, selecting the right power source, firmware and the microcontroller itself. What kind of battery that would be required and how we would interface the mictrocontroller with other hardware parts, this chapter contains answers to the above questions. In the next chapter,**Chapter 4** we discuss various prototypes and hardware components needed in the sub-system. This chapter showcases experiments performed using different approaches. The development of different prototypes has been categorically shown and the shortcoming regarding each prototype has been noted down. In **Chapter 5** we mostly deal with the software sub-system in which the process of integrating the hardware with the software is discussed.

This chapter shows how the data is collected and represented via wireless module and what are the steps needed to do the same. The subtopics covered includes data acquisition, data storage, locating bins via MAC address and efficient route planning. **Chapter 6** finally concludes the thesis and in **Chapter 7** the related future has been mentioned.

Chapter 2

Garbage Disposal System Model

2.1 Introduction

In this chapter the techniques adopted in minimizing the fuel consumption is described along with the parameters used to do the same. Minimizing fuel consumption will ultimately lead to the minimizing the capital and time expenditure in the process of solid waste management. This chapter also describes the parameters and metrics used in the waste bin, which will be source of the data. In this section we have modeled the problem using various mathematical constraints. The parameters like fill height, fill level and usable height have all been specified and shown using diagram. Additionally the fuel cost optimization has been done by calculating the optimized path and the non-optimized path. To calculate the actual fuel cost saved we have used the mileage detail provided by truck company and the current diesel price in state. The capital saved per trip and the number of vehicles to be used for garbage collection routine is also calculated.

Assumptions following the Garbage Disposal Model

1. All the bins considered in this project has the same shape and size.

2. All the pick up trucks are identical in volume.

3. The price of fuel (diesel) is taken to be 55 km/l.

2.2 Waste Bin Parameters

The bin that is used to collect the wastes is equipped with a sensor at the head of the bin, the design of which is mentioned above and it is capable of sending the fill value of the bin by connecting to a nearby access point. In the general diagram of the bin below, the sensor is situated at its head which functions like sonar and gets the height of the garbage relative to its height inside the bin.

1. *th* - It is the total height of the bin.
2. *h* - It is the usable height of the bin.
3. *mh* - This is the height that is detected by the ultrasound sensor from its position.
4. *fh* - This is the height till which the garbage is filled in the bin.
5. *free height* - The height that is available.

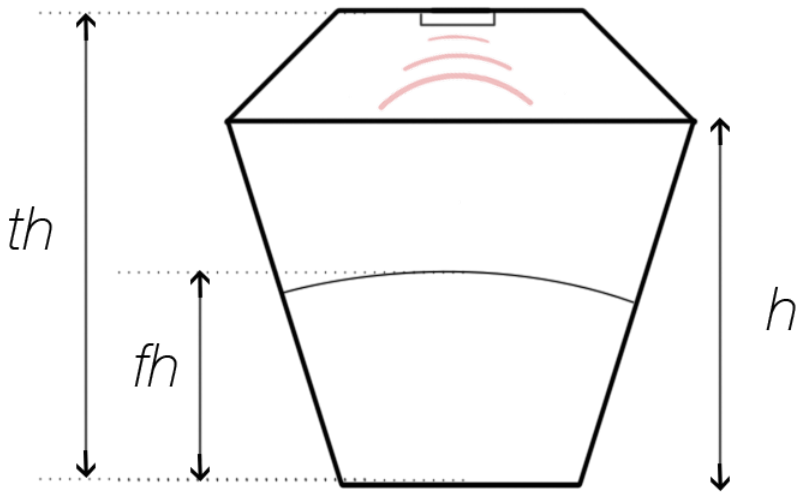


Figure 2.1: Figure: Bin Metrics

Moreover, the fill value (*fh*) is calculated using the below relation:

1. [gap = th - h], *gap* is the buffer distance between the sensor and beginning of the usable height (h) of the bin.

2. [*free height* = *mh* - *gap*], once the value of the gap is obtained then the free height can be easily measured using the height which is measured by the sensor (mh).

3. [*fh* = *h* - *(free height)*], finally subtracting the free height from the usable height of the bin, the fill value (*fh*) is obtained.

The bin is scheduled to pick up if the fill value crosses a certain threshold value (ν) , usually this threshold is set to 75%, to calculate the percentage of bin filled, the following relation is used:

$$Percentagefilled = \frac{fh}{h} * 100\%$$

The experiments conducted in this project were based on bin of total height (*th*) = 90 cm, with the usable height (h) being 70 cm and gap being

20 cm and the threshold (ν) was set to 75% that comes out to roughly 53 cm. Another important need in Solid Waste Management System is to minimize spillage (γ).Bin approaches the spilling condition when $fh \geq \nu$(*threshold value*)

γ is used to represent spillage.

$$\gamma = min(fh) \equiv max(free\ height)$$

Since, $fh = h$ - *(free height)*

The only way to maximize free height is monitor waste bins *fh* value in real time and take necessary actions before they reach the spilling condition. The findings in this section has helped us to initiate the design process of the sensor. The early stage prototype is illustrated in the figure 4.2.

2.3 Fuel Cost Minization

The unstable price of the fuel sometimes makes it difficult to figure out the exact expenditure, but any savings in this section will be advantageous. By optimizing the pickup route and establishing the number of vehicles to be assigned in the pick-up process we can the expenditure on the fuel. The method to get the optimized pick up route is mentioned below in detail. To calculate the savings due to optimization the following methodology is adopted.

First we consider the Optimal Trip Distance (OTD), which we get using the methods mentioned in the later sections via Map APIs, then the second parameter which is involved is a little tricky as Non-Optimized Trip Distance ($NOTD$) can be anything depending on the drivers perception of the route, so to calculate this the average of distances from the start point (A) to the dumping zone (H) connecting arbitrary points in between is taken as Non-Optimized Trip Distance, this is calculation is retrieved from the Map APIs by fixing the start point (A) and end point (B) but varying the other pick up points in between and collectively taking their average.Also the following conclusion is derived $NOTD \geq OTD$.

Then to get the actual estimate we consider the price of the fuel, which is essentially diesel in this project, which is capped at INR 55/litre currently.

The average mileage of the vehicles used in the process is obtained by referring the government standards in Solid Waste Management, which states that the vehicles should least have a mileage of 10.63 km/litre to be used in the Solid Waste Management process. After which the total fuel saved in the process is obtained using the following relation.

$$S = \frac{NOTD}{10.63} * 55 - \frac{OTD}{10.63} * 55$$

To get the percentage of the capital saved in fuel optimization the below realtion is used.

SP is the percentage of capital saved per trip.

$$SP = \frac{S}{\frac{NOTD}{10.63} * 55} * 100\%$$

The second part of the fuel cost optimization involves the determination of the number of trucks to be deployed on the pick up routes. To establish a number, the data obtained from bins have to be used, first we have to find the number of bins that are well above threshold (ν), say we get the information that bin_1 is filled $X_1\%$ and bin_2 is filled with $X_2\%$ and so on bin_N is filled with $X_n\%$. Since it assumed that all the waste bins are of same volume, area and height, let the volume of the each bin be u and each truck be V. Then, the following relation is established.

N.T is the number of trucks required during the trip.

$$N.T = \left\lceil \frac{X_1 u + X_2 + \ + X_n}{V} \right\rceil$$

2.4 Conclusion

In this chapter we defined how our system will look like in mathematical terms. We realized all the problems to tackle, and we got an idea what features we need to emphasize on. So Now that the problem has been clearly outlined and we have the task of designing the system in such a way that it performs all the tasks specified above. We need to design the hardware and the software part of the system based on our model.The findings in this chapter has helped us to initiate the design process of our prototypes which has been discussed in Chapter 3.

Chapter 3

Garbage Disposal System for Smart Cities: Design Process

3.1 Introduction

In the previous chapter we learnt all the different parameters we have to calculate. And in this chapter we look at the different hardware components to be used to help us determine these parameters. For selecting the various components we focus on the functionality of each of the unit. Our smart unit will employ multiple electronic components like sensor, power splitter and battery module and we will need a microcontroller to be able to control them. So the first task we perform is determining the microcontroller to be used. All the sub components have different power requirement so we also examine what kind of power source we need to have. What kind of firmware we need to have on our microcontroller and how do we interface the microcontroller with the sensor are the kind of questions we try to answer in this chapter.

3.2 Design Challenges

The design challenges were integral to the development of the sensor that would be attached to the head of the bin. The process of the design that the sensor went through before being finally deployed is mentioned below in the following sections.

3.2.1 Selecting the right micro-controller unit

In a world dominated by the Arduino microcontroller units, one really needs to have the patience to look for its alternative, more than 56% of the developers use Arduino in their work process. But I was looking for something much smaller and yet with the same level of sophistication and dependability.As per the information collected using the literature survey, 56% of people are Arduino users, 9% are Arduino Nano users, 8% are Arduino Mega users, 6% are Sparkfun users and remaining 22% user other hardware.

The basic and most fundamental requirement for the MCU was to be compact and have a very minimal energy footprint so that it could last longer on batteries or any independent power source. On comparison of various micro-controller units based on their size, power consumption, size and other essential features that I required like encryption, TCP/IP Protocol, I arrived with the following result.

	ESP-01	Arduino	Raspberry Pi
Cost	~ ₹200	₹800 - ₹2000	₹2500
Wifi	Built-in	Shield(₹3000)/ESP	USB Dongle
Sleep Current	<10 uA	<1 mA	<20 mA
Size	21 x 11 mm	66 x 53 mm	50 x 60mm
Wifi Standards	802.11 b/g/n	802.11 b/g	802.11 b/g/n
Storage	Built-in	Built-in	External

Source : *Compiled from various online resources*

Figure 3.1: Figure: Comparison of Micro-controllers

So, the MCU I settled with is ESP8266, because it has the fundamental features that I need and is very economical. It is a SOC with integrated TCP/IP Protocols, supports standard wireless protocols 802.11 b/g/n, has more than two General Purpose Input Output (GPIO) pins and internal memory to store my scripts.

3.2.2 Selecting the right power source

The power source has to be such that it would last longer, reliable and dependent by which it means it should be able to provide consistent power throughout its life with very little variations. Also a method to determine the status of the continuously exhausting power source had to established. By all means, this is a very crucial part in the life cycle of the sensor, its reliability and accuracy. Below are the problems we faced with the ESP8266.

1. ESP8266 needs a perfectly stable input source, any fluctuation in the voltage in the order of 300mV causes it to abruptly restart.
2. Another problem was with the finding of the right voltage and baud rate at which the chip-enable would work without which all I ever got was garbage as output.

The first problem was later solved temporarily but we were yet to find a better and stable source, however the second problem persisted long after the first problem was resolved, more-over we still think the second problem was related to the first one. The explanation follows in the later sections.

Experiment - 1

So, the temporary solution was to use an Arduino as the power-source because it had a 3.3V output pin. This would power up the ESP8266 but this could not be the final solution, because it would take up more space and power and it had to be connected to an USB port for the Arduino itself to be powered. Albeit using Arduino powered on the ESP, but we were getting random non-interpretable output and here began the second problem which persisted a long way. The main reason behind this was that ESP8266 is manufactured by a Chinese company and it doesnt come with an instruction manual and moreover, the company released different versions of same module that ran at various baud rates. Hence due to unreasonable output and quest for the right power source we kept getting bad data as you see in the

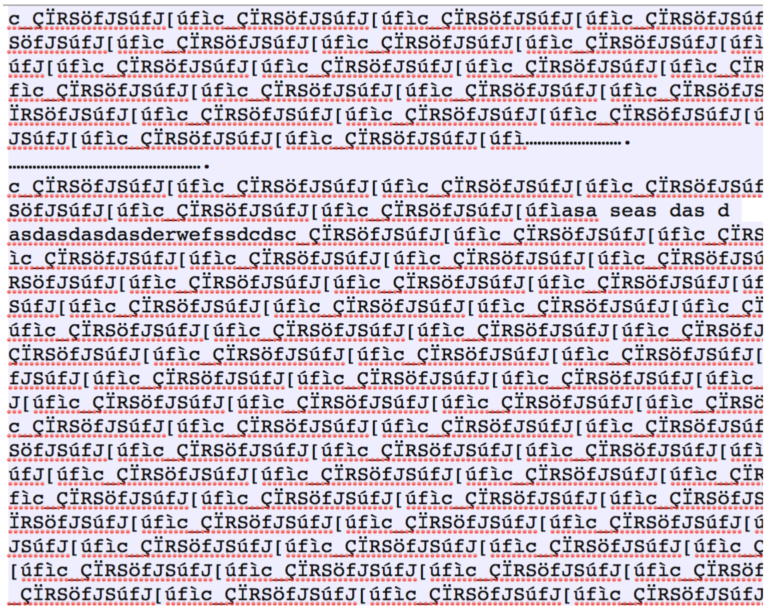
[H] 

Figure 3.2: Figure: Corrupted Output

below picture.

Experiment - 2

Before this we tried to make a voltage-divider but we decided not to pursue since it was not reliable. Finally, we settled on MB102, which is a bread-board power supply module, at that time it looked like the perfect candidate but unfortunately it didnt work out as well because the input that was given was an AC current using an AC to DC adapter, we still had the bad data problem.So, we finally used AA batteries as the power source, we figured that bad data output was due to wrong baud-rate and wrong voltage to CH_PD, so from this we learned that the ESP8266 module that was being used in the project worked at 9600 Bd (baud-rate) and with 1K-ohm resistor pulled between Vcc and the power source.

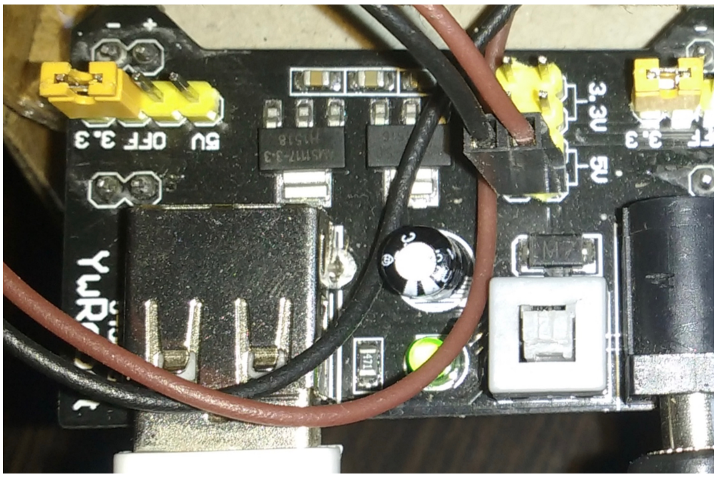


Figure 3.3: Figure: MB102 Bread Power Supply Module

3.2.3 Selecting the right firmware

We were looking for a system that was more compact than an Arduino but with same or more level of sophistication and dependability. ESP8266 comes with an pre-installed firmware called AT. The problem with the existing firmware is as follow:

1. AT is not event driven
2. AT requires Arduino support to run the application on it. ESP8266 is a slave to the Arduino, we was not desirable in the first place.
3. Redundant work had to be done to configure and manipulate hardware features.

Due to above mentioned problems we moved from AT to NodeMCU. NodeMCU is programmable just like an Arduino and completely eliminates the need for it. It supports LUA scripts which is very much similar to widely used the scripting language Python and its open source. Below are some strong reasons why NodeMCU become the ideal choice.

1. It has an advanced API for the hardware input/output.
2. It supports event-driven network API. The advantage of using an event-driven API is to make quick decisions quickly in response to an event.

3. Reduces the redundant work for configuring and manipulating the hardware features.

4. The open source source community provides better support for bugs and fixes.

5. Finally, it completely eliminates the need of an Arduino.

3.2.4 Interfacing with the ultrasonic sensor

Interfacing ESP8266 had brought up two problems which was completely technical. Firstly, the scripting language was comparatively new and hence interfacing HCSR-04 became challenging. The next problem was ESP8266 required an abundant of 5V, any fluctuation of the voltage cause by the ultrasonic sensor in the ECHO pin would cause the system to reboot abruptly as the ECHO pin from the HCSR-04 connects to the RX of the ESP8266.

The solution was rather simple, cause we already learned the techniques to handle voltage fluctuation in the quest to find the stable power source, which is described in the earlier sections. The experience gained there helped us to figure out the solution. We connected the ECHO pin of the HCSR-04 to 1K-ohm resistor in the line connecting to the RX of the ESP8266. And also, the HCSR-04 has no problem receiving a 3.3V signal on the TRIG pin form the ESP8266.

3.3 Conclusion

In this chapter we finalized all the different hardware components to be used in our system as well as the kind of firmware to be used for our components. We determined that the best microcontroller for our model was ESP8266 based both on cost and usability. The ideal choice for the power source was AA batteries; it provided both the stability and the independence required by our module. NodeMCU which runs LUA scripts became the goto firmware for our system. The problem of interfacing the ultrasonic sensor was also handled successfully. Now lies the task of integrating all these components together and to evaluate their performance.

Chapter 4

Product Developed

4.1 Introduction

In the previous chapters various hardware components needed in the module was determined. Now that the theoretical part of our modeling has been completed we come to the actual implementation part. This chapter showcases the experiments performed using different approaches. The development of different prototypes has been categorically shown and the shortcoming regarding each prototype has been noted down.

4.2 Various experimented models

In this section the various prototypes that were developed in the process are described. Initially we began with a wired model and later switched to the wireless models. We experimented with four prototypes and they are shown below:

4.2.1 Prototype -1

In this section the various prototypes that were developed in the process are described. Initially we began with a wired model and later switched to the wireless models. We experimented with four prototypes and they are shown below.The data from the Arduino can be read in several ways. We used python and CGI to read the data as the final application was planned to be monitored or controlled over the web. Using the pySerial library the serial output from the Ardunio was read.

Operating HCSR-04

HCSR-04 is an ultrasonic ranging module with an accuracy of measurement between 2cm 400cm, the ranging can reach 3 meters as specified in the modules spec sheet. This module is used for two reasons. Firstly, it is inexpensive and affordable, on the other hand it can measure distances up to three and a half meters. Hence, it could be used inside the bins. The basic principle of its working is as follow:

1. We use the input/output trigger for at least 10 s on a high signal level.
2. The module automatically sends eight 40kHz waves and waits for a pulse signal to return back.
3. If the signal returns back, its obstacle distance is calculated as follows:

Distance = (high level time * velocity of sound (340 m/s)/2) Because, the time taken by the pulse is twice to reach the obstacle, one one half is required to reach the obstacle and the other half is to return back to the receiver of the HCSR-04

$$distance\_measured = \frac{high\ level\ time\ *\ velovity\ of\ sound\ (340\ m/s)}{2}$$

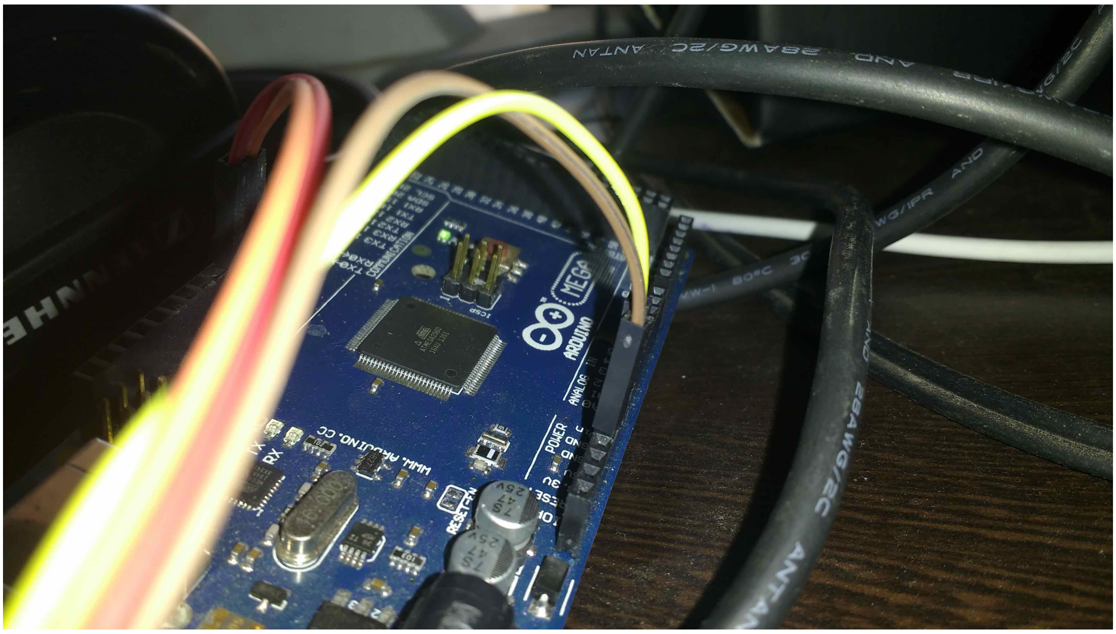


Figure 4.1: Figure: Prototype - 1

Albeit rudimentary, it was fast and reliable but took up more space. This setup was not feasible in the real world. Hence we moved on from here to the next prototype.

4.2.2 Prototype -2

This prototype was more focused on results rather than just the hardware improvements. It was very much similar to the prototype 1 but with a different power source, earlier the power source was an USB cable connected to the 5v USB power supply, but this time the power supply was 9V transistor battery. Its voltage was brought down to 5V using a resistor circuit. The prototype was also based on the wired model. The data that was being sent via a USB cable to the server, which the python CGI-driven application would pick-up and based on its processing would display the result in a neat web interface. The result derived from that is shown below.

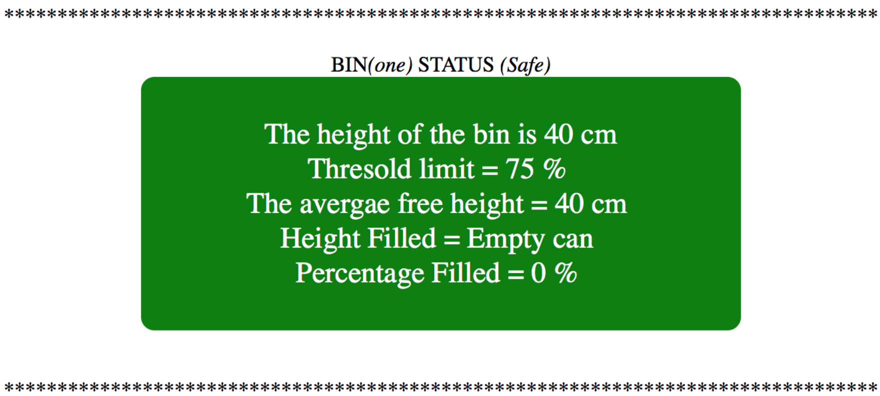


Figure 4.2: Figure: Results derived using prototype - 2

The result that is shown above shows that original usable height of the bin *(ht)* is 40cm, the threshold is set to 75%, *(fh)* is 0 and so it the percentage filled, hence it shows condition for an empty bin. The green color indicates the bin is safe from the spillage and hence no action is required. But if it would have been red i.e. if *(fh)* would have exceeded the threshold then it would require to initiate some action towards the bin.

Figure 4.3: Figure: Prototype - 2

What we learned from this prototype was that in order to make the sensor deploy-able we need to use components that utilize less energy, present prototype was not close to ready to be deployed.Yet after building this prototype it was clear now that wireless prototype would be feasible, but it depended on selecting the right components to full-fill my requirements on its integration.

4.2.3 Prototype -3

Learning from the setbacks of the previous prototype we moved on to the wireless prototype. First problem here was to select the right microcontroller. In a world dominated with Arduino microcontrollers , one has to really have patience to look for its alternative. We were looking for something more compact but with the same level of sophistication and dependability.

The basic and most fundamental requirement for the microcontroller was to be compact and have a very minimal energy footprint so that it could last longer on batteries or any independent power source. On comparison of various micro-controller units based on their size, power consumption, size and other essential features that we required like encryption, TCP/IP Protocol, we decided to go along with the ESP8266 rejecting Arduino and Raspberry Pi. This prototype consisted of the following:

1. 6 AA batteries power source.
2. ESP8266 01 with NodeMCU firmware.
3. MB102 bread board power supple module with 3.3V and 5V output.
4. HCSR-04 ultrasonic ranging module.

The most visible **advantage** of this prototype was that it was **wireless** and needed no dangling wires to send the data. All the components were integrated and set up inside a cardboard box that we designed to hold the components, it was designed so that the parts could be easily replaced or altered. The data and system integration details are mentioned later in Chapter 5. What we learned from this prototype that wireless sensors were feasible but the sensor in the cardboard box took more space and was vulnerable to damage, we needed something compact and strong to hold the components. So we ahead with our next prototype.

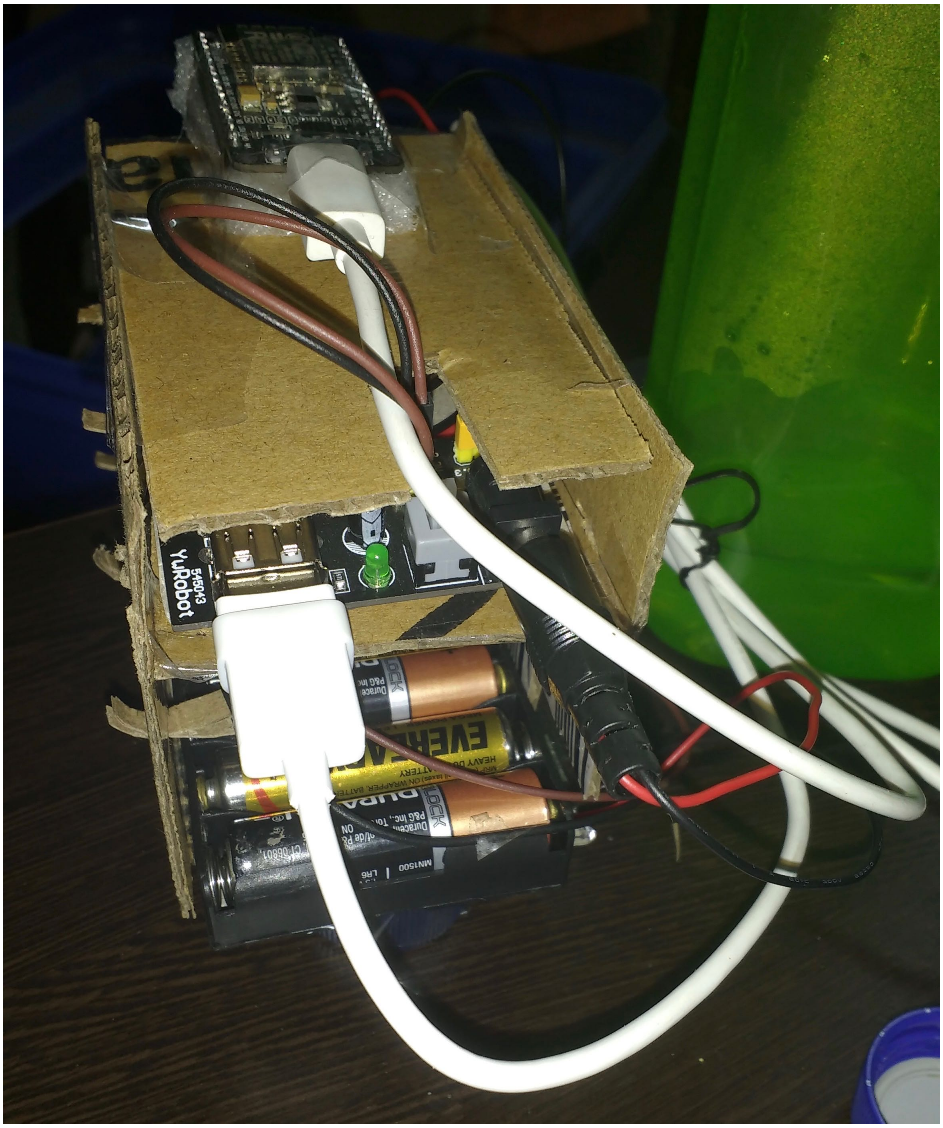


Figure 4.4: Figure: Prototype - 3

4.2.4 Prototype -4

The previous prototype had everything we desired but it was bulky, occupied space, delicate and vulnerable to damage at the slightest misfortune, so we decided to set up the components in PVC box. All the components i.e. (1) 6 AA batteries power source, (2) ESP8266 12 with NodeMCU firmware, (3) MB102 bread board power supple module with 3.3V and 5V output, (4)HCSR-04 ultrasonic ranging module were embedded inside the box and their positions inside the box were made firm, so that they dont move out of place eventually. The HCSR-04 has as receiver and transmitter component which is accommodated outside by making two holes in the box which procures towards outside which can be seen in the picture below.

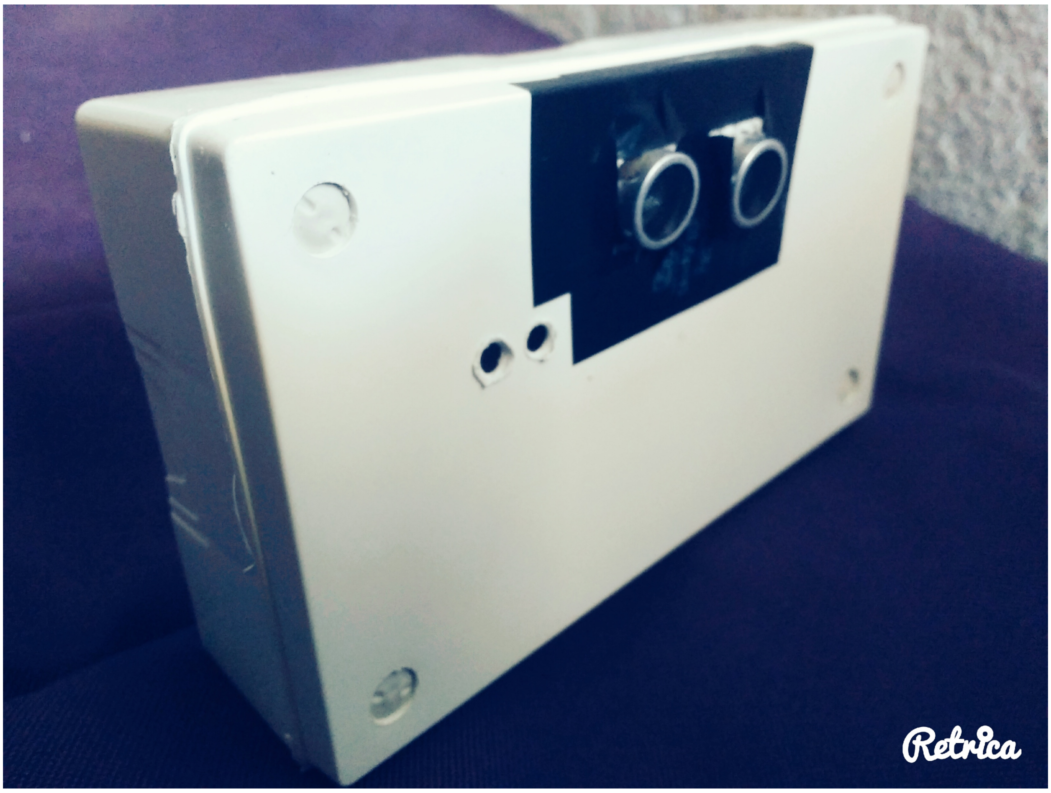


Figure 4.5: Figure: Prototype - 4

4.3 Conclusion

In this chapter we looked into four prototypes developed while implementing the model. The first prototype was a wired one and it used laptop as a power source. The second prototype was a wireless one and it used a 9V battery along with a simple circuit for providing the adequate voltage. The third prototype eliminated the circuitry used for splitting power and used MB102 module instead. The third used a rudimentary cardboard framework as the chassis. The fourth and final prototype used a plastic chassis with only the HCSR04 sensor mounted on the outside and the rest of the components safely fitted inside. Building on the shortcoming of each prototype the final form of the smart module was decided.

Chapter 5

Software System for Data Acquisition

5.1 Introduction

The previous chapter saw the completion of smart garbage bin. So this chapter deals with data generated from the various smart garbage bins situated in different locations and the framework used for handling this data. This chapter also shows how the collected data is represented concisely using tabular and graphical forms. Following collection of data, the execution of collection routine is also shown in this chapter. The subtopics covered in this chapter include data acquisition and transmission, storing of data, location of bin and route planning.

5.2 Assumptions

1. The sensor is well-within the range of a router or an Access-Point (AP).
2. The bins are placed at proper places and with in reach.
3. 3. The capacity of bins is sufficient to last a day or more, unless some unexpected event occurs.
4. The height of the bins deployed is well under three meters.

5. The batteries are always healthy or they are replaced well in advance of their exhaustion.
6. The bins are immobile and are permanently installed.
7. The sensors are not affected by the weather or its changing variables.
8. The routes involved are not subjected to blockage or disruption.
9. The vehicle carrying the trash never runs out of fuel.

5.3 Data Acquisition

Data Acquisition is really important part of the application process. The data that is collected from the bins is very crucial as it all features and functionality of the project depends on the incoming data, this data is responsible for initiating required actions and planning the route efficient pick up route that described in the later sections of this chapter. This sections contains the details of the process that is used to get the data from the ESP8266 in the bin and also how its stored in the server where its received.

5.3.1 Over the air data acquisition

The transmission of the data via wireless protocol is termed as Over the Air (OTA) data transmission. We use this technique to communicate the signals and the data from the sensors to our servers. The way we do it is described below:

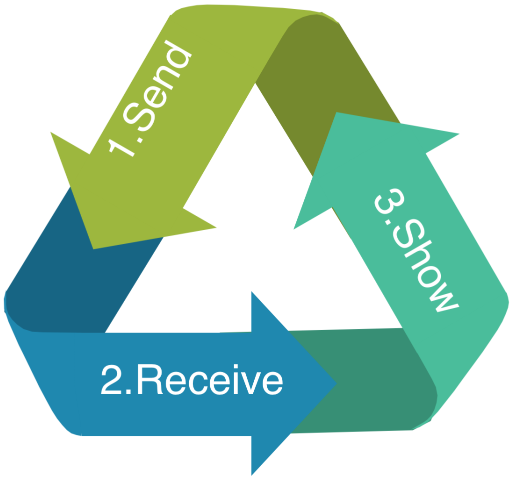


Figure 5.1: Figure: Steps in *Over the Air* data transmission

1. First step is to configure the ESP8266 to connect it to the nearest AP(Access Point), if it fails to connect in the attempt wait and try again. After a successful connection with AP, get the data and post it to the server using its address which could its DNS or its IP via an HTTP request.

2. Then, configure the server that can receive the data sent from from the ESP8266, in our project we used an APACHE server and MARIA DB to collect the data. Data collected is time-stamped, this can be used for analysis and estimate the condition of the sensors battery.

3. Finally, based on the data acquired show the current fill value(fh) and percentage of bin filled, height of the bin and other parameters using the formulations that were described in the Chapter 2.

Given below is the flow chart of the process, which depicts the flow of data in as it moves inside the system. It all starts with the sensor that detects the data in the bin and sends it to the micro-controller (*ESP8266*) which then transmits this data via wireless communication to the nearby AP, AP then transmits this data to the server, where it is processed and stored and based on this data results are derived and the actions are initiated.

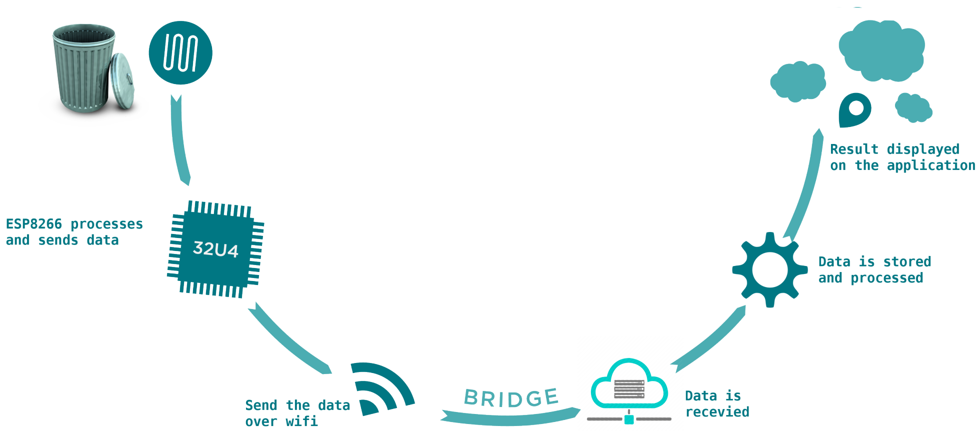


Figure 5.2: Figure: Flow chart of the process

5.3.2 Storing data

The next step is to store the acquired data which we discussed in the earlier sub-section under data acquisition. The data that the sensor reads is communicated to the server using its IP address or its DNS.

At the server end, we run an Apache server that listens to the incoming data from the sensor. It filters out the corrupted or un-related data as the sensor does not always sends an accurate data so its up to the servers logic and justification to decide whether the data is useful or not. Sometime due to bad transmission or packet loss, data is corrupted or sensors working conditions are compromised for example fluctuation in the voltage or the battery discharges then sensors may send erroneous data. Hence, this is filtered out by the server. The incoming data comprises of the measure height /emph(mh describe in Chapter 2), batterys health, sensors id and its MAC address. All the incoming data is initially logged in to the log file to check the working condition of the sensor including the erroneous data, after this logged the filtering process begins. The data which is filtered out is processed and stored in the database.

1. The application is written and handled by the PHP scripts, which is supported by the apache servers. The process of storing the data is further divided into two steps.

2. The incoming data is time stamped including the erroneous data. This time refers to the time when it is received at the server, it not the time at which the sensor had send the data.

3. Then this time-stamped data is filtered in accordance with the height of the bin deployed at the site and its store in the database

The database used in this project is called MariaDB, it is a community developed for to the MySQL relational database management system which is intended to remain free under the GNU General Public License.

Each bin has its own table inside in the database, the schema of the database is shown below, it consists of the columns id(primary key), bin_1 stores the measured height (mh), time_1 stores the time at which the data from the ESP8266 is received at the server, bstat stores the health status of the battery. Here _1 refers to the bin with an id 1.

id 1	bin_1	time_1	bstat
276	10	06-05-2016 15:50:43	2.918
277	10	06-05-2016 15:51:51	2.918
278	10	06-05-2016 15:53:18	2.918
279	10	06-05-2016 15:54:25	2.917
280	10	06-05-2016 15:55:29	2.918
281	10	06-05-2016 15:56:37	2.918
282	10	06-05-2016 15:57:55	2.918
283	10	06-05-2016 15:58:55	2.918
284	10	06-05-2016 16:00:11	2.918
285	10	06-05-2016 16:01:26	2.917

Figure 5.3: Figure: Database Schema

5.4 Locating Bins

The bins are deployed at the site, to decide the shortest pick up route for the waste bins which have *fh* greater than threshold value (ν) we ought to know their locations. Since, we are not using a GPS module, the way we recognize the location of the bin is when the bin is first installed at the site, its location is marked manually in the database against its MAC address, along with the fill value *fh* we send the MAC address of the ESP8266 too, assuming that we already the know the location of the bin and its not changed since its installation, the data received at the server will now be able to tell the location of the bin and this location will be used to route the drivers over an optimized collection path. This is a cheap and efficient way to locate the bins. In the next section we will go through the process of finding the shortest pick up route using the data from this and previous sections.

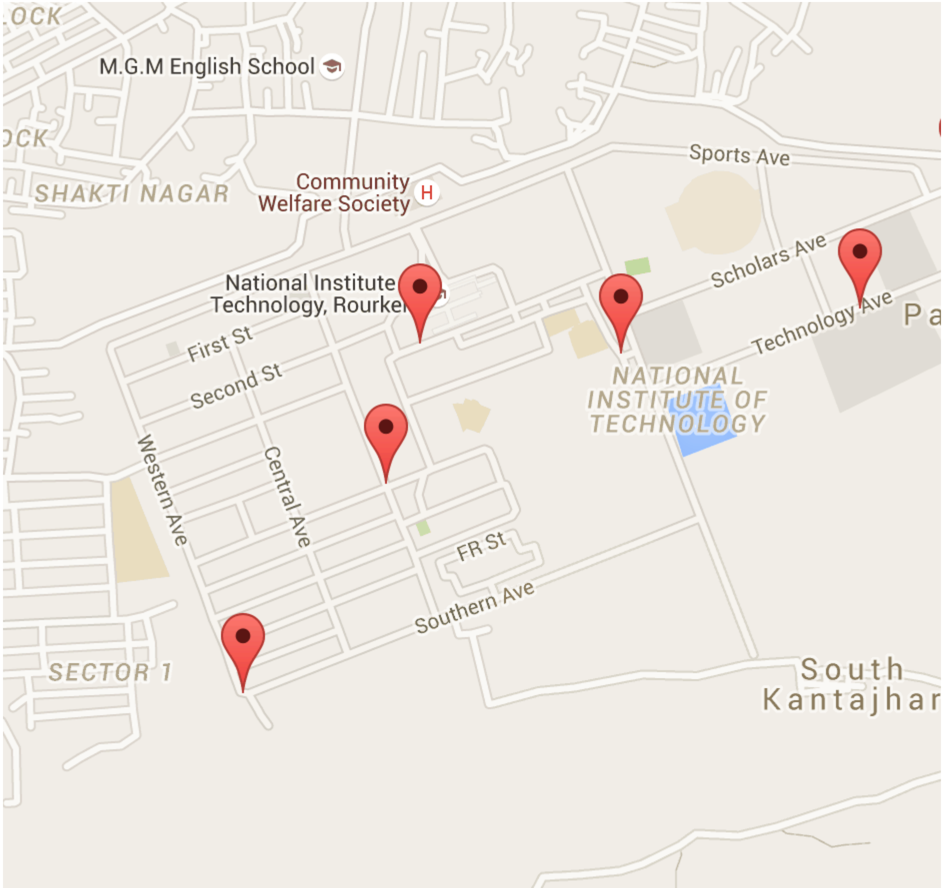


Figure 5.4: Figure: *Mac-Based identification* of the bin location

5.5 Finding and visualizing the shortest path

Bins that are flagged as being above threshold (ν), i.e the fill value (fh) of these bins have crossed the threshold, gets in the queue for pick up and its physical co-ordinates are derived from its MAC address as mentioned in the above section. All the physical co-ordinates of the flagged bins are obtained in this way. Then using all these flagged co-ordinates.

1. First, we mark them on the map, along with start point (A), the pick up point and the dumping zone.

2. Then using the Google Maps APIs for javascript we iteratively find

all distances between every two co-ordinate and tag along the way the shortest path for each successive co-ordinate. c

In our project we selected five locations inside the campus, three close to the boarders residence and two near the staffs residence, along with the initial start point which is located in the Shakti Nagar and the dumping zone which is at the left of the BSNL office in the map. The operation that a pick up truck driver is required to do while on duty is to collect the garbage form the five bins that are of same capacity as assumed, starting from the point A (*start point*) to the dumping zone labelled as H (*end point*). By default the API is not configured to show the optimized route, here un-optimized path refers to the following picture.

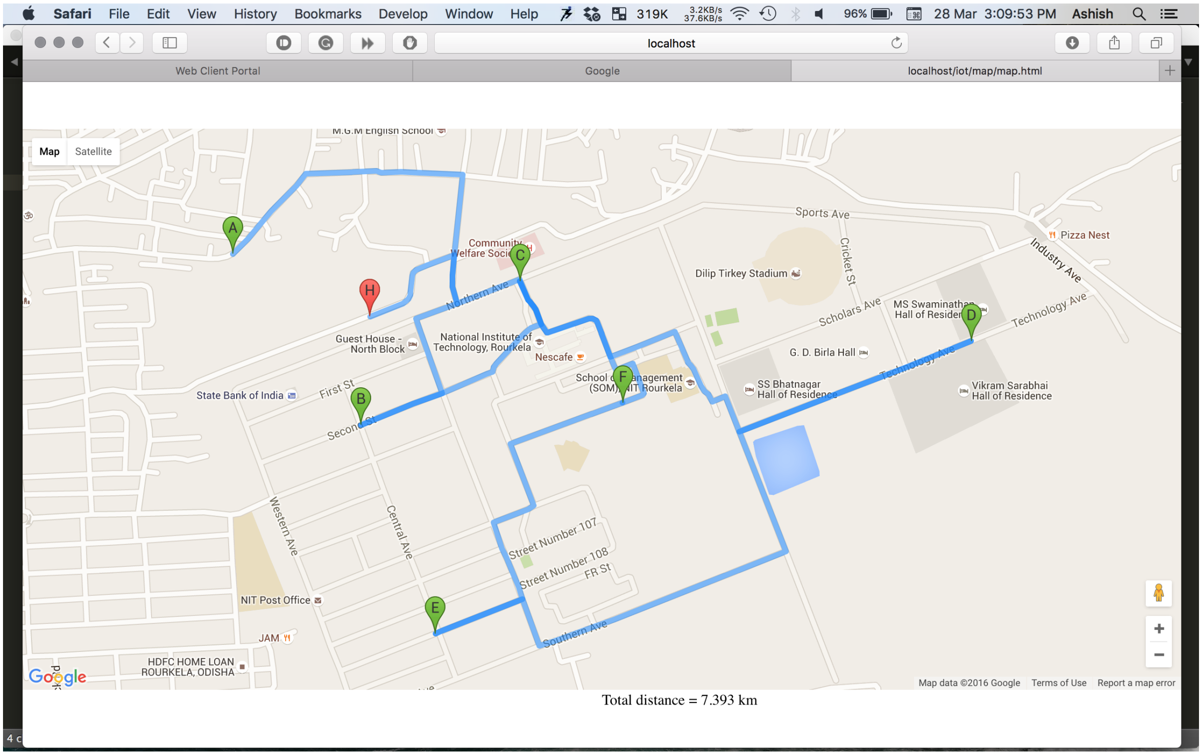


Figure 5.5: Figure: *Non-optimized* Pick-up route

Here each paths are traversed more than once while reaching for the other nodes in the map, hence un-optimized. To optimize the route we define an optimization function and set the (*optimize way-point*). For example, the non-optimized route is around 7.393 Km where as it comes out to 6.006 km in an optimized pick up route. The distance of a kilometer is saved in the long-run this difference can save huge earnings by minimize the expenditure spent on fuel and, number of trucks and time. With the help of this system we were able to monitor the bins in real time, which ultimately reduced the chances of spillage and scheduled optimized pick up routes that led to nearly 20% in savings in fuel capital expenditure in each trip.

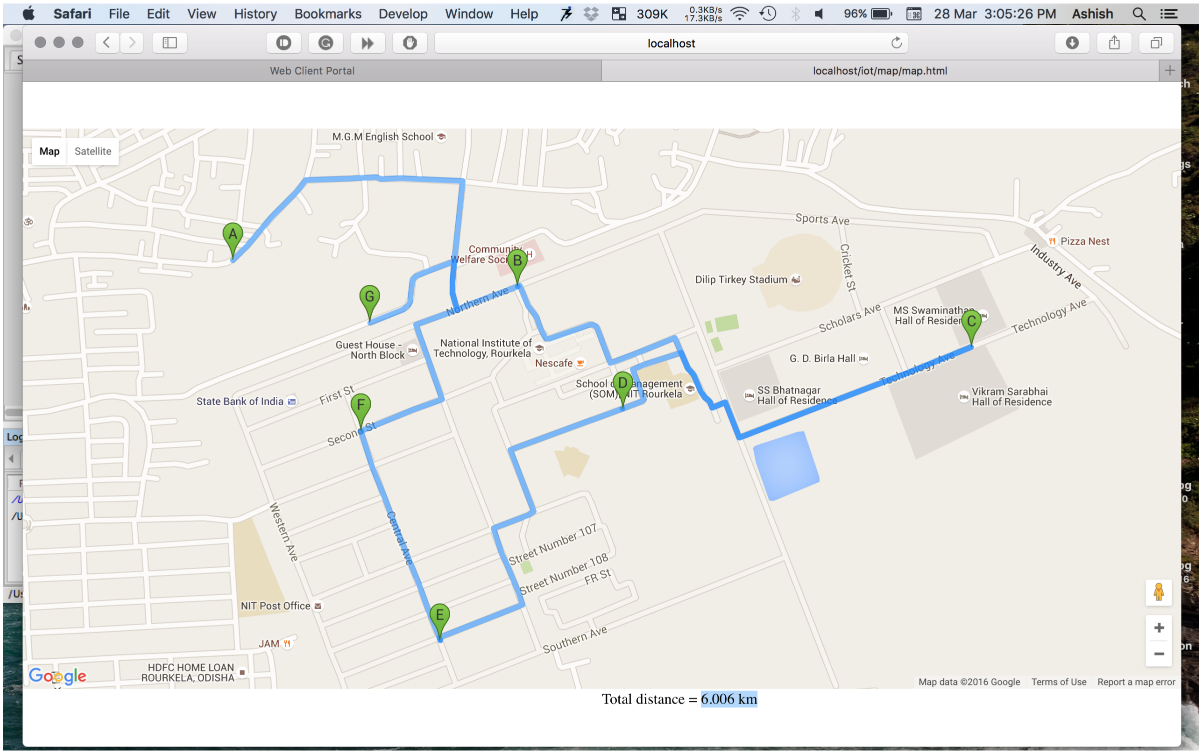


Figure 5.6: Figure: *Optimized* Pick-up route

5.6 Result & Analysis

On integration of the hardware and software subsystems, which involved designing the sensor, reading the characteristic data from the waste bin and transmitting this data to the server via. wireless protocol and then retrieving and storing that data so that it can processed to produce meaningful results. The entire system consists of many smaller sub-systems which can removed, added or modified to accommodate the changes necessary to the Garbage Disposal System.

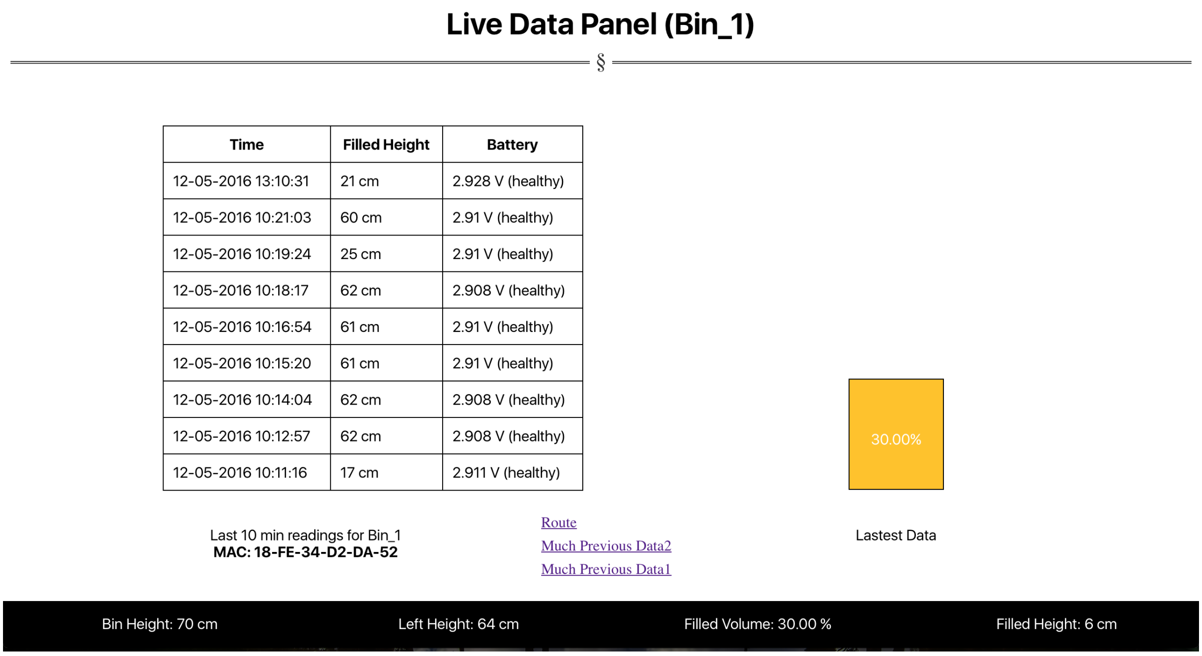


Figure 5.7: Figure: User view of the system

Above is the picture of the user view, this is the result of the hardware and the software integration. In this picture you can view the characteristic data that is collected from the bin with help of the sensors. The characteristic data of the bin includes the time stamp of the data of when it's received, the fill value *(fh)* of the bin and the battery status, towards the right of the page is a illustrative bar graph which shows the percentage filled value of the bin. The bar graph is green when the fill value is below the threshold value and it turns red when the fill value passes the threshold, also the bin id, it's MAC address and the options to see the previous recorded data. It also contains the routing feature which will open a new page with the routing details which has been described in the previous sub-section.

5.7 Conclusion

This chapter elaborated the back-end of the system. The system modeling in chapter 3 using the bin metrics has led us to design the sensor. The final product measures 15x10 cm, it attached to the lid of the waste bins.

Also, post product development we estimate the cost of each unit to be around INR. 600. Using the data that is acquired from the sensor and our cost estimates we can predict the budgetary requirement of Municipal Solid Waste management for the next financial year, so using this data now we are capable to design the Garbage Disposal System for a entire Smart city. With this chapter the description of work done in the project comes to an end. Following this lies the task of identifying the shortcomings still remaining in the system and determining how to eliminate them. There also remains the task of identifying what additional features can be added to our model to increase the functionality of the system.

Chapter 6

Conclusions

Waste administration is an essential necessity for environmentally sustainable development in all nations. Proficient sorting of waste is a noteworthy issue in today's general public. In India, the consumerist society has prompted a steadily expanding generation of waste. In spite of the fact that it is fundamental to general well being and natural security, strong waste administration in many urban communities of developing nations is highly unsatisfactory.

Garbage Disposal System for smart cities is a small but important step forward in automating the garbage collection process. This paper portrays the utilization of our model of Smart Bin in dealing with the waste accumulation arrangement of a whole city. The system of sensors empowered smart bins connected through the IoT system creates a large amount of data, which is further investigated and analyzed at in real time to gather information about the status of waste around the city. This paper additionally goes for empowering further research in the subject of waste administration.

Our proposed system for waste management is efficient and time saving. It is much better than the current method of employing municipal trucks to look for garbage bins across different localities and to check whether they are filled or not. This process is both complex and time consuming. This framework can be implemented at any place effortlessly and inside sensible measure of time. The usage costs for the computerization is likewise reasonable. The general strategy for the identification and administration of waste gets to be productive and clever. We have demonstrated the application and execution of the above framework. This proposed framework would not just have capacity for gathering and upgrading information naturally and opportune, additionally it could investigate and utilize information properly. The proposed framework would tackle a considerable measure of issue identified with strong waste gathering, observing, minimizing cost and quickening the administration.

Additionally, the fuel cost optimization has been done by calculating the optimized path and the non-optimized path. To calculate the actual fuel cost saved we have used the mileage detail provided by truck company and the current diesel price in state. The capital saved per trip and the number of vehicles to be used for garbage collection routine is also calculated. To integrate the above features for the users convenience there is also user interface in the system that allows the user to monitor time to time data from the waste bin. With the help of this system we were able to monitor the bins in real time, which ultimately reduced the chances of spillage and scheduled optimized pick up routes that led to nearly 20% in savings in fuel capital expenditure in each trip.We have effectively tried the model of our smart garbage bin and with support from the side of government we can effectively change this model into an product.

The system modeling in chapter 3 using the bin metrics has led us to design the sensor. The final product measures 15x10 cm, it attached to the lid of the waste bins. Also, post product development we estimate the cost of each unit to be around INR. 600. Using the data that is acquired from the sensor and our cost estimates we can predict the budgetary requirement of Municipal Solid Waste management for the next financial year, so using this data now we are capable to design the Garbage Disposal System for a entire Smart city.

Chapter 7

Future Works

The system developed so far is sophisticated and works on integration of many components which are assembled from various sources. The problem with assembling is often compatibility in the long run. Hence, to ensure better and longer life of the sensors and devices we need to use standard equipment, standards that are set by the industry leaders in IoT such as Intel and IBM . We can use standardized equipment such as Intel Edison chips which much more powerful than ESP8266 and has low energy foot print.

Lot many functions can be added such as our present system is modelled for a single truck, we can scale this model to multiple truck model. For example, say for a locality we need three tucks rather than just one, then we have to plot graphs for the three trucks such that they collect the waste independently in efficient and effective way without having any intersection with the path of the other trucks scheduled in that location.The pick up route scheduling can be made dynamic, this would help to avoid traffic and road blocks and ultimately save time. Also, with being dynamic the end destination may change owing to the availability at the dumping site, this means that trucks can have different dumping zones rather than just one which is scheduled in the beginning as that may change on the go.The sensors can further be modified in the bins to make use of image processing and detect the type of garbage that is put inside the bin and categorize them as recyclable or non-recyclable.This would help in sorting the type of waste and ease the recycling of the waste products. For example, office wastes such as paper, clips, files and cardboard can be distinguished from the food and kitchen waste, this would eventually ease the process of production of bio-gas with respect to the kitchen waste and recycling of paper and plastic with respect to the office wastes. Another functionality that can be added is to predict the data before scheduling the pick up route. For example, if we know that a bin which is currently below the threshold but by the time the truck arrives at the location it will be filled, then such abnormalities cannot be handled without machine learning, if this abnormality pattern is often repeated then we would be able to predict it using time-series forecasting and such bins can scheduled even though at the time of pick up they are below the threshold. Also, on-demand service can be provided along with the on-routine services with a dedicated mobile app for all the platforms.

Another approach to identifying the various garbage type is attaching garbage bags with RFID tags and including an RFID module attached to the bins that can read the tags. This approach would eliminate the use of image processing since the garbage type will be detected as soon as it is brought near the garbage bin. This plan will employ multiple bins each for different types of garbage type. This will help to separate the kitchen waste, recyclable plastic, electronic waste, medical waste and toxic waste into separate categories. Based on the type of garbage different truck will be employed. Since each type garbage needs to be handled differently. Further we can include a LCD display in the smart garbage bin which can display all the essential information regarding the bin. It would display the fill level, the type of garbage it is designed to handle, last time it was emptied, the battery level, etc.

Data collected from the system can used to establish a *Decision Support System*. Such a system will tell us based on the data if we have to add more trucks to the system or to add more bins, by analyzing the data collected over time. It will also help in scaling the Garbage Disposal System to much wider cities. Below are ways the data can be utilised.

1. The data collected over the years can be used by the Municipal Corporation to set a budget for MSW in a year in advance.

2. It can used to determine the place where the bins are to be located to maximize our Quality of Service i.e. to minimize the spillage.

3. Based on the data we can also determine the possible locations of the trucks so that they arrive on time for the pick up to maximize the effectiveness of the system.

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