A REPORT

ON

SMART MONITORING SYSTEM

By

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PROBLEM STATEMENT

Handling the massive amounts of garbage produced in typical Indian cities has always been a tough job for the local administrators. The aim of this project is to make a smart monitoring system which will provide vital logistical support to the civic bodies in solid waste management. This system can be categorized under IOT (Internet Of Things)[A].

Keywords: Smart monitoring systems, smart city, Internet of Things, Ultrasonic sensor, Arduino, Zigbee, Solid waste management, smart garbage bin, radio frequency.

1. INTRODUCTION

Currently waste collection is done using static routes and schedules where containers are collected every day or week regardless of if they are full or not. Also overfull containers with litter and rubbish all around them are a common sight in India. The solution to these problems would be a smart monitoring system which will give real time alerts and timely forecasts of when the garbage bins would get full, thus preventing overflow. This will also eliminate unnecessary trips to collect garbage from bins which are not yet full, thus saving manpower and/or vehicle fuel.

The smart monitoring system will comprise of a sensor network. The sensors would measure the level of garbage in a bin. Ultra sonic sensors[B] would be used for this purpose. The data collected by them will be transmitted over radio frequency or GSM networks[C]. This data will then be used to compute forecasts and optimized routes for garbage collectors to save time and fuel.

All simulations in this report were performed in MATLAB(D)

The section 2 describes the flow of the project. A plan of work was previously made (not included in this report) and the direction of the study was strongly influenced by that. The section 3 of this report explains the building blocks of the smart monitoring system. The section 4 relays the observations of some initial experiments and interprets the results. Section 5 illustrates some of the routing algorithms[G] ideal for our purpose. Sections 6 and 7 are an attempt to reduce the power consumption of the system. In section 8 efforts are made to make the system viable as manufactured product. The potential improvements that can be made in the future are laid out in section 9. Section 10 is a glossary of technical terms used in this report while section 11 is a list of references used for the research done for this study and also compiling this report.

2. FLOW OF THE PROJECT

2.1. STEPS TAKEN PRIOR TO MIDSEM EVALUATION

- The first and foremost step was to explore whether there had been any existing solutions which tackled our problem statement. We came across some companies that provided commercial solutions to this problem. These companies include “Enevo”[1],”Bigbelly Solar”[2] and “Smart bin”[3].
- The second step was to get familiar with the equipment needed to build a prototype. This equipment included microcontroller(Arduinos)[D], Ultra Sonic Sensors, Zigbee module[E]. This was done by first taking simple readings with arduino and ultra sonic sensor. Secondly we tried to set up simple connections with and between zigbee modules.
- The next task was to simulate system architecture using Matlab. (Refer to section 3: system architecture)
- Using the above simulation as a guide a basic module was assembled. This module will be referred to as the alpha version from here on in this report.
- The next step was to generate sample data with the help of this alpha version. Many new problems were encountered during this exercise and it also provided us with vital feedback which set the future direction of this project. All the data thus collected was saved for future use. (Refer to section 4: results).

2.2. STEPS TAKEN SINCE MIDSEM EVALUATION

- High power consumption was among the main problems we faced in the experiment mentioned above. Hence the next step was to optimize power consumption of the module. (Sections 6 and 7)
- Comparisons between different routing algorithms[G] through literature reviews were made in order to select the optimum algorithm for our specific needs. (Section 5)
- This module should work not only in laboratories but also in the real world situations. A few attempts were made to make it more practical.(Section 8)
- These attempts included achieving adaptability to newer containers of hitherto unknown dimensions and to improve remote accessibility of the module. (Section 8)
- After this trials of larger networks having more number of nodes were conducted. (Section 8)

3. SYSTEM ARCHITECTURE

In this section the architecture of simulated model as well as the alpha module is explained.

3.1. COMPUTER SIMULATION

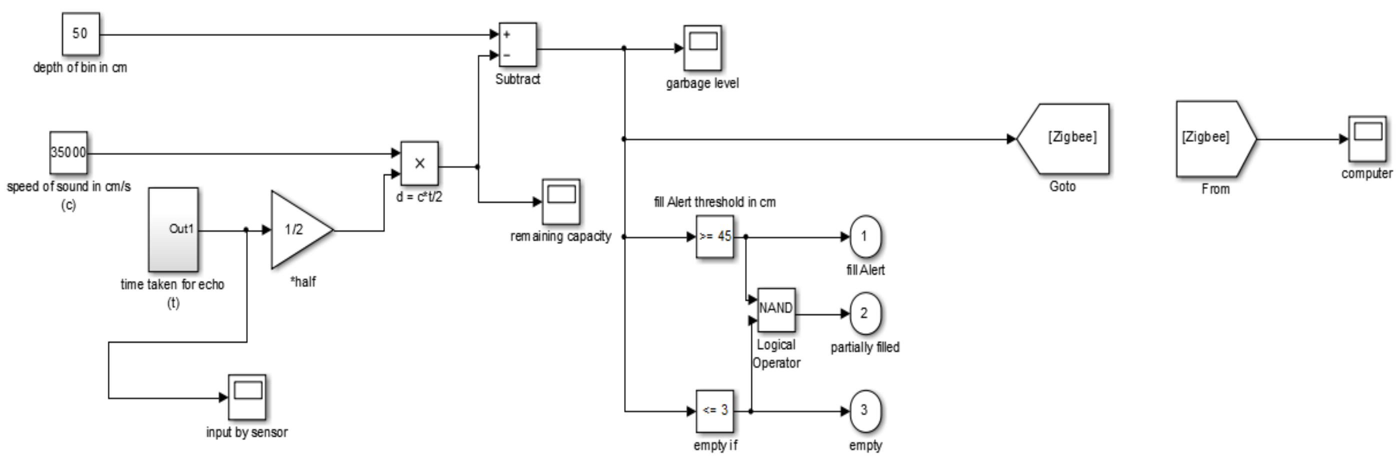


Figure 1- Matlab simulation

The above simulation summarizes the alpha module. The data generated by this simulation is picturised by the following graphs.

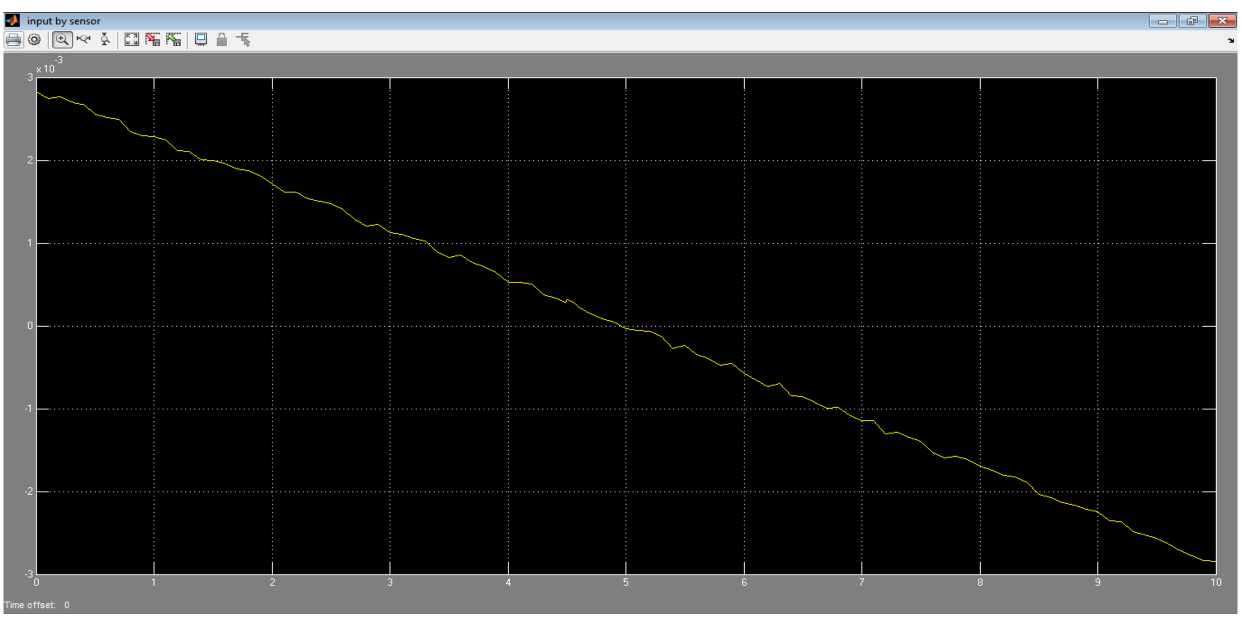


Figure 2 –input from sensor

The above graph shows the input from the ultrasound sensor. As the garbage level increases in the bin, the distance between the surface of garbage and the sensor decreases. It is this distance that we get from the sensor(we need to apply the formula d=ct/2 to get the distance; d-distance, c-speed of sound, t-raw input from sensor).

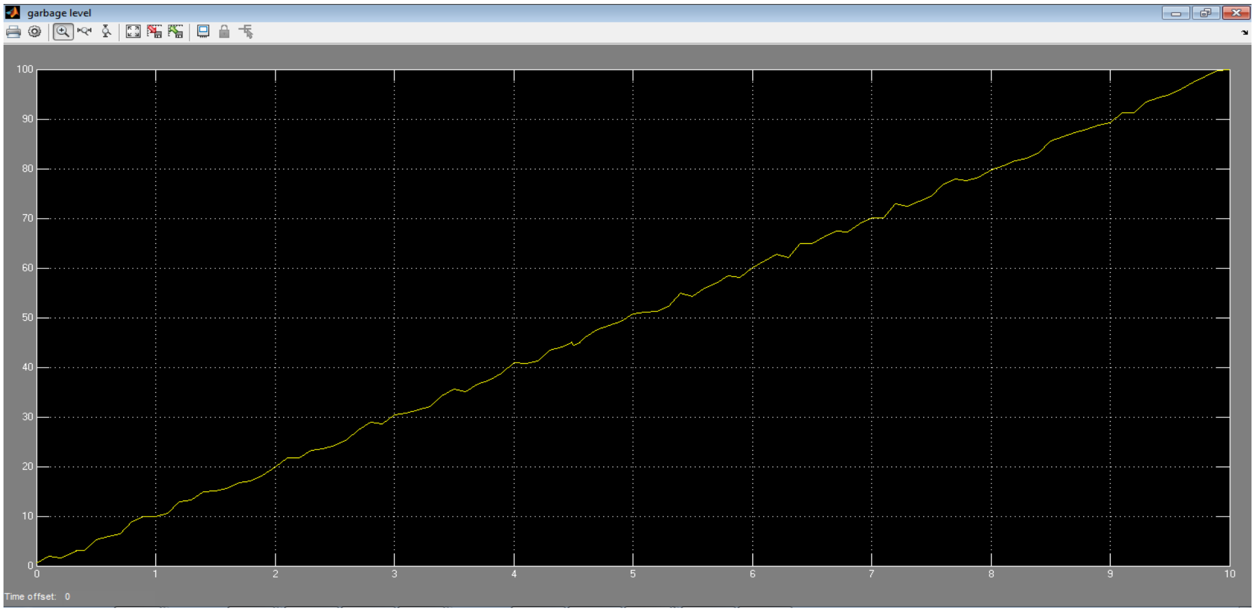
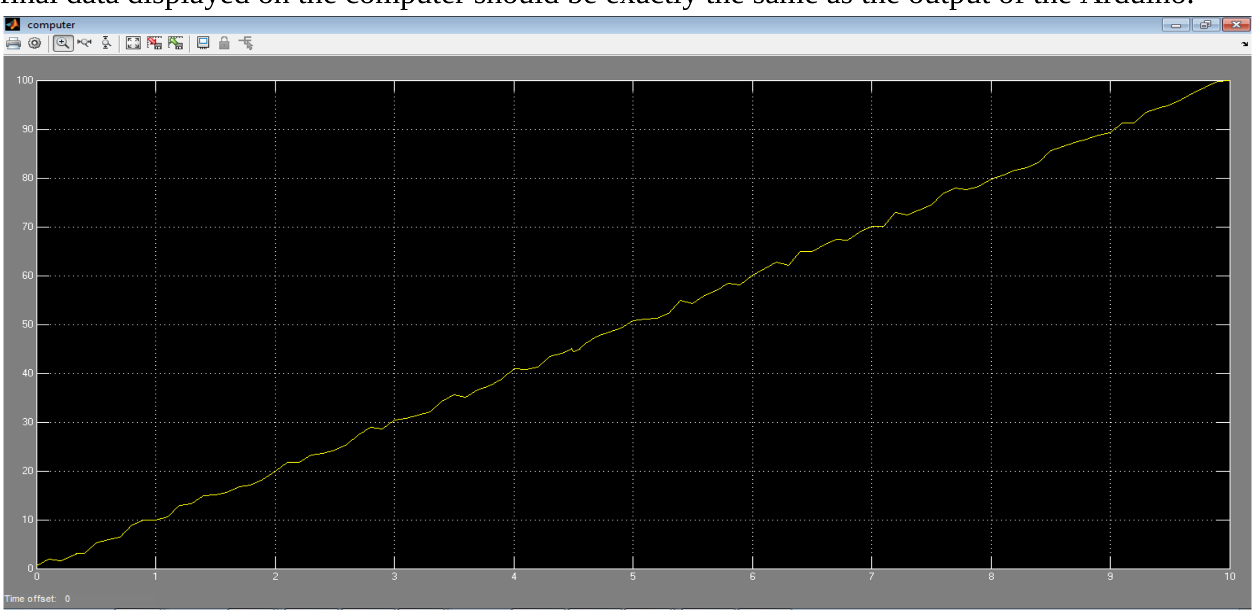


Figure 3 –Garbage level

The microcontroller, which is an Arduino board in this case, calculates the garbage level by subtracting the distance between garbage surface and sensor from the actual depth of the bin. This data is then communicated over RF network with the help of Zigbees. The final data displayed on the computer should be exactly the same as the output of the Arduino.



3.2. BLOCK DIAGRAM

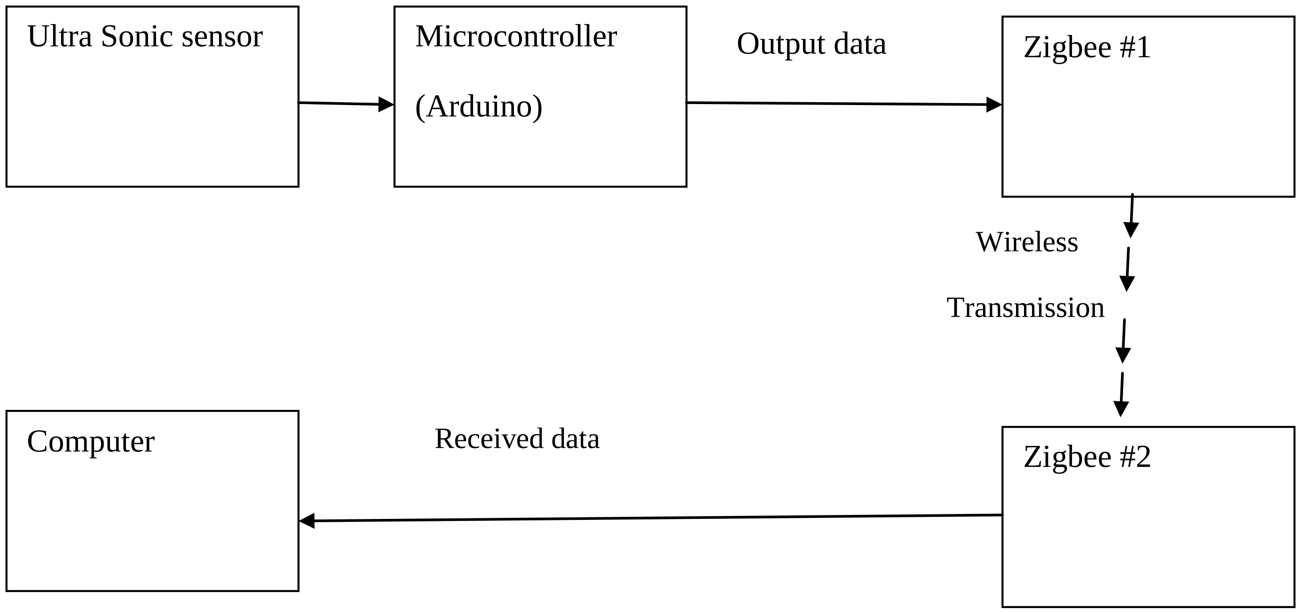


Figure 4 – block diagram

This block diagram is the simplification of the simulation described in the last subsection. It also represents the alpha module. In this subsection explaining the advantages and justification of the equipment/technology used is attempted.

a. Ultrasonic sensors: Ultrasonic sensors were preferred over passive IR sensors because their readings do not vary with the lighting conditions or colour of the garbage unlike the latter[4]. Although the readings can be affected by changes in the ambient temperature and moisture content. Theoretical accuracy thus calculated is +/- 2%[5].
b. Arduino: Arduino boards were the preferred microcontroller because they are the cheapest alternative available and consume the least power. They are also easy to programme and are fairly reliable.
c. Zigbee: Zigbees are programmable and very versatile in their usage. They use RF frequency for communication. Compared to GSM networks, RF is more reliable and consume very little power. RF was preferred over WiFi also because of the same reasons[6].

4. FIELD EXPERIMENT AND RESULTS

An experiment was performed on an actual dustbin to test the alpha module. A certain set of parameters were decided to evaluate its performance. They are:

A. Consistency of measurements taken by the module when compared to visual observations.
B. Power efficiency of the module.
C. Range of the transmissions.

4.1 OBSERVATIONS

A. Consistency of the measurements

The observed accuracy of the module was observed to be +/- 1.5 cm. This created a problem at the threshold limit- the limit used to determine whether the bin is full or not.

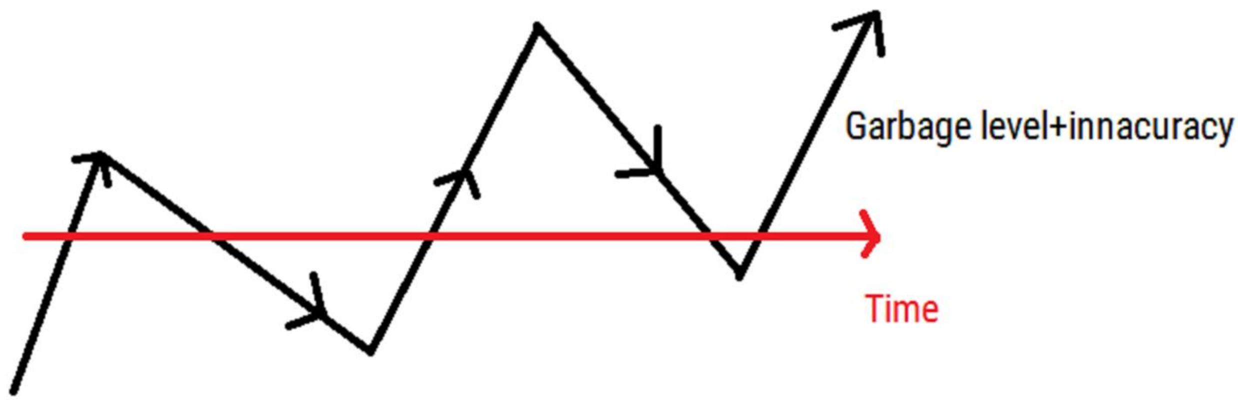


Figure 5 –Need for a buffer

Suppose the time axis represented by the red line is also the threshold. If the garbage level increases above this limit then the module would send an alert that the bin is full. Now assume that due to inaccuracy in the readings, the next entry falls below the threshold. So now the module would say that the bin is not yet full. This fluctuation would go on untill the garbage level rises above the threshold by more than the inaccuracy of the module(1.5cm). This problem was then solved by introducing a buffer of 2cm below the threshold which filtered out the fluctuations in the fill status of the bin. No such fluctuations were noticed thereafter and no appreciable loss of accuracy was reported

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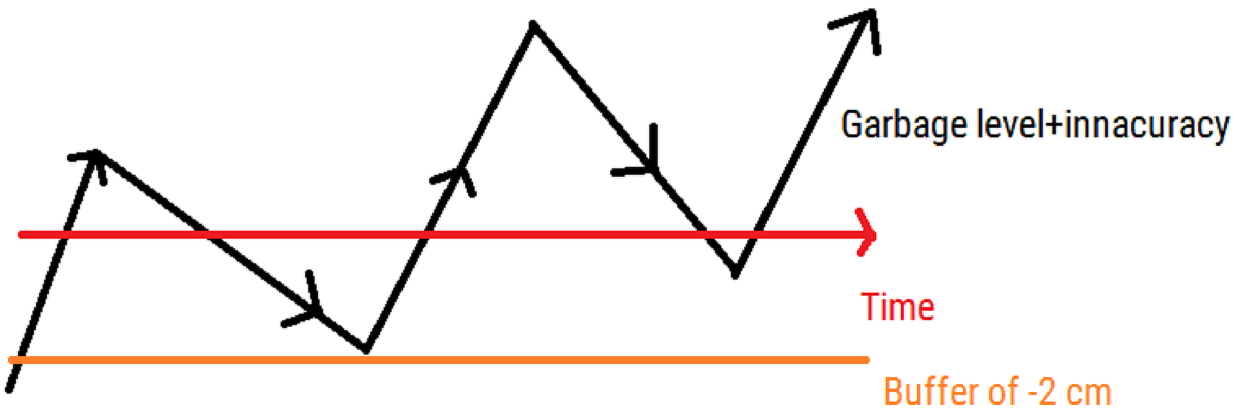


Figure 6 –How a buffer region works

B. Power Consumption

The power consumption of the module was very high and was not sustainable on a 9 V Zinc Carbon Battery for more than 90 minutes. An adaptor had to be used to power the module.

C. Range

The range of the alpha module tested was limited to 18 meters(indoor). Given a line of sight, this range increased to 26 meters. Even still this was a serious limitation on the usability of the module and thus subsequently the scalability of the entire system.

This experiment was vital in providing appropriate direction to this project. It drew attention towards some major drawbacks and exposed other flaws. Efforts were made to address these issues as is explained in the forthcoming sections.

5. ROUTING ALGORITHMS [G]

Today many routing algorithms are available. Some of them focus on optimizing a single parameter while others achieve the best compromise. Here is a short summary of the comparisons made between different algorithms through literature reviews.

5.1. LEACH

LEACH (Low-Energy Adaptive Clustering Heirarchy)[9] is ideal for applications like environmental and health monitoring systems. This algorithm helps improve the performance of networks which have severe range limitations. This algorithm has two phases:

A. Advertisement phase and
B. Clustering phase

A. Advertisement phase

In this phase each node decides whether to become a cluster head[9] or not. This decision is based on a threshold value which is given by the formula[9] in the figure below :

$$T(n) = \frac{P}{1 - P \times (r \bmod P^{-1})} \qquad \forall n \in G$$

$$T(n) = 0 \qquad \forall n \notin G$$

Where n is a random number between 0 and 1
P is the cluster-head probability and
G is the set of nodes that weren’t cluster-heads the previous rounds

Figure 7-Formula for threshold

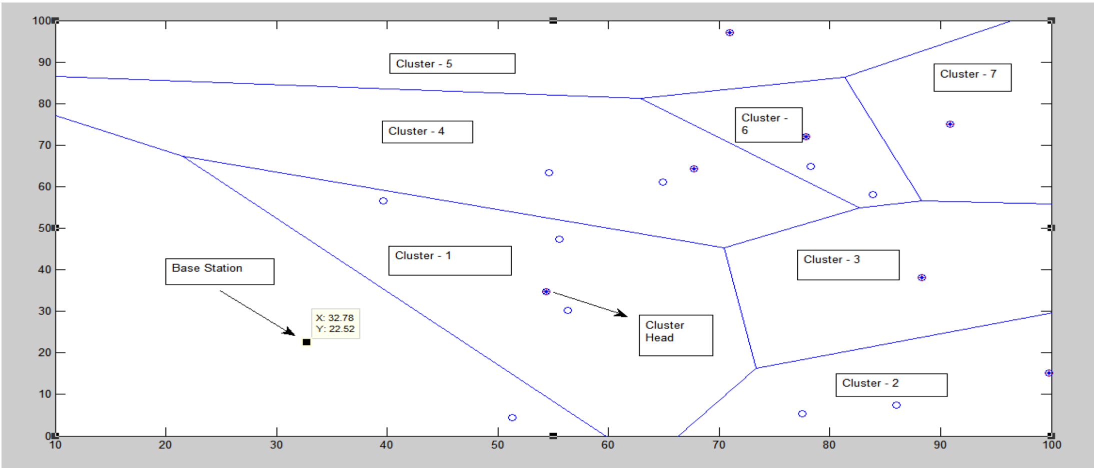


Figure 8-Clusters along with cluster heads

B. Clustering phase

In these phase the cluster heads decide which nodes would be included in their cluster (much like how a team captain selects his teammates). The cluster heads relay the data transmitted from the nodes of their own cluster.

This two phased approach minimizes the energy consumption of the network as a whole, thus maximizing the life of battery operated networks. This also reduces the probability of multiple nodes failing at once.

5.2 DJKSTRA[10]

This is a very simple and easy to implement algorithm. Assume a mesh network of static nodes. What Djkstra does is calculate the shortest path (least number of intermediary nodes) to go from a node A to node B. This, by minimizing the number of transmissions and receptions, minimizes the time and energy required for sending a message from node A to node B.

6. ESTIMATION OF POWER CONSUMPTION

As highlighted in section no. 4, high power was one of the major drawbacks of the alpha module. In order to ascertain the amount of power consumed by each component of the module in various circumstances, a series of experiments were conducted.

6.1. EXPERIMENT 1

In the first experiment we calculated the power consumed by the module minus the zigbee. Later we included the zigbee and repeated the same procedure. Thus we could extract the value of zigbee's power consumption.

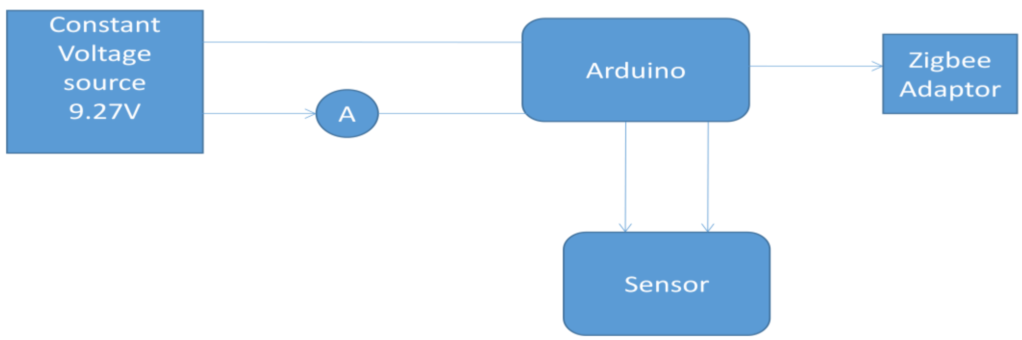


Figure 9 – Experimental setup 1

The average current here was recorded as 45.5 mA as shown below in figure 10.

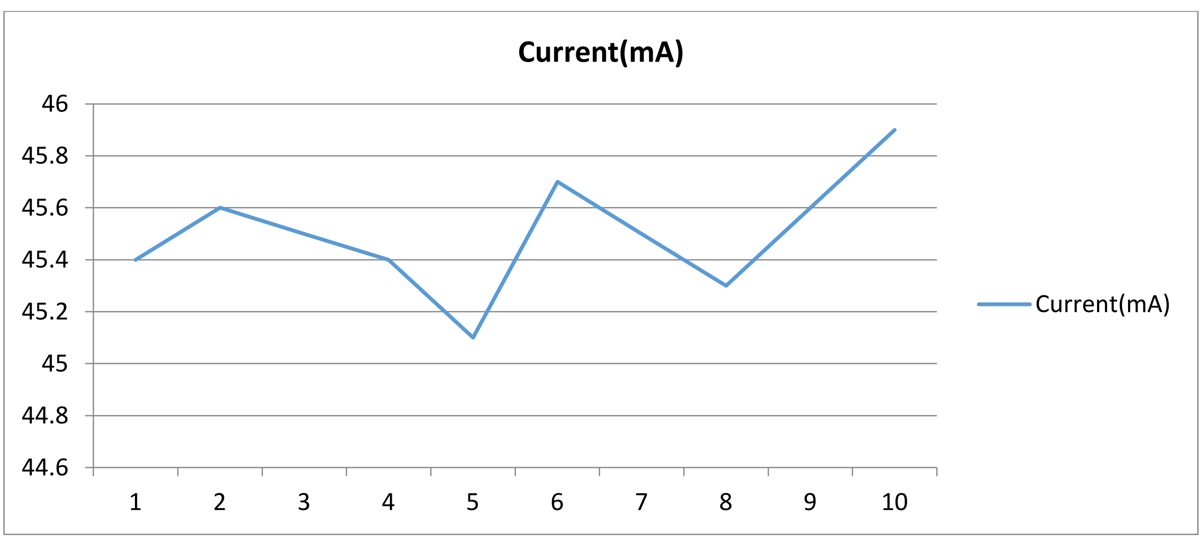


Figure 10 – Current readings in multimeter.

Therefore, Power = (V)*(I) = (9.27)*(45.5) = 421.8 mW. Similarly, the setups and observations of the other experiments are listed below.

6.2. EXPERIMENT 2

The zigbee was in router standby mode; hence it was not transmitting any data.

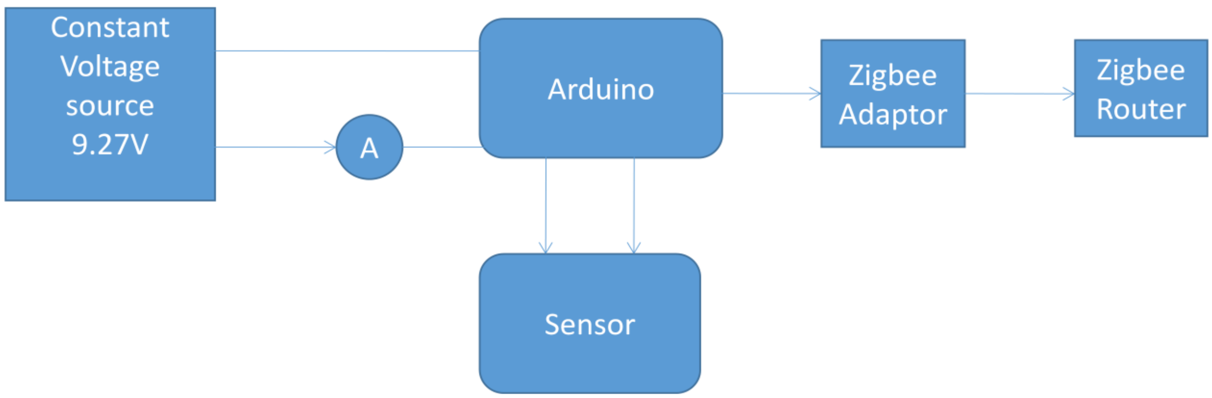


Figure 11 - Experimental setup 2

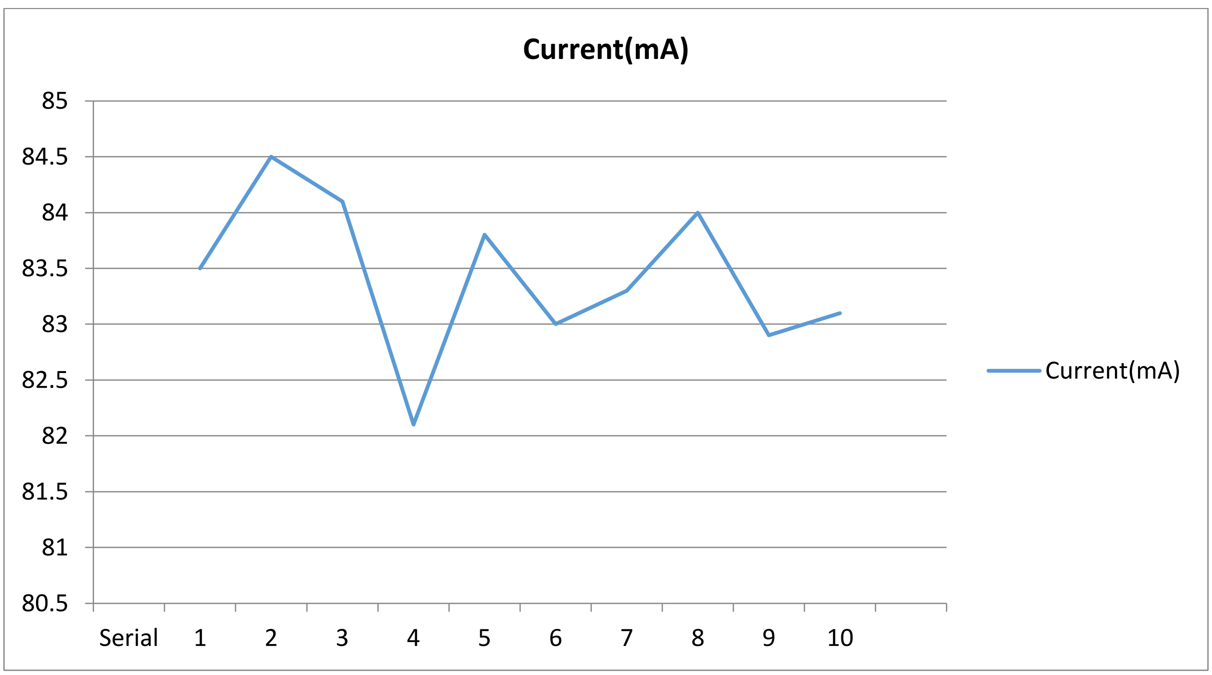


Figure 12 – Observations

Observations :

- Average current(I) = 83.3 mA
- Supply voltage (V) = 9.27 V
- Average power (P) = V*I=772.2 mW

6.3. EXPERIMENT 3

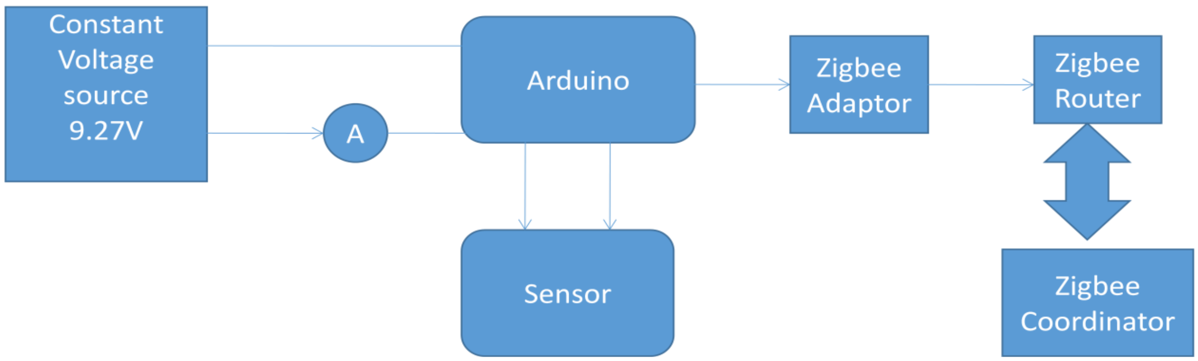


Figure 13 – Experimental setup 3

A few points to note:

- This setup was same as setup-2 except that the zigbee router was transmitting data to the coordinator instead of being on standby.
- Transmitting at 2.8 hexadigits/sec
- Hence bit rate = 4 * 2.8 = 11.2 bits/sec
- Distance between router and coordinator = 526 cm

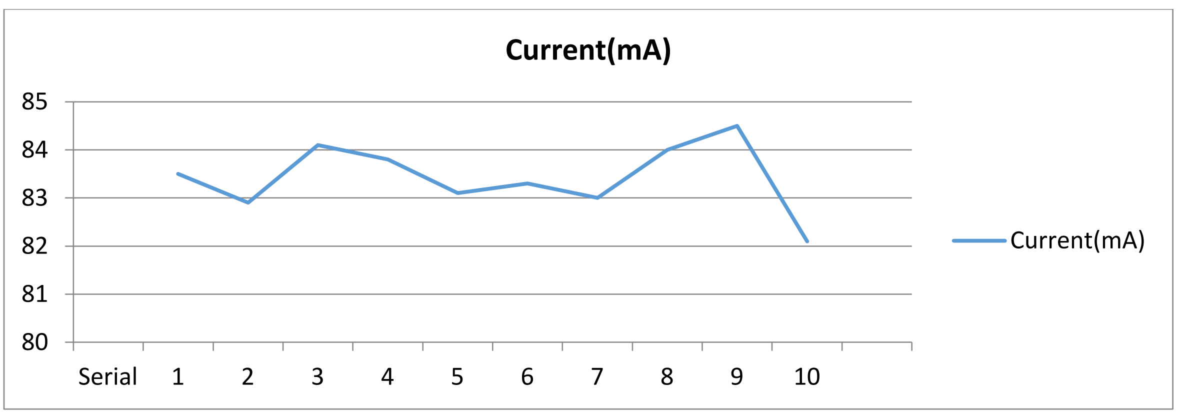


Figure 14 – Observations for experiment 3

Observations :

- Average current(I) = 83.9 mA
- Supply voltage (V) = 9.27 V
- Average power (P) = V*I=777.7 mW

6.4. EXPERIMENT 4

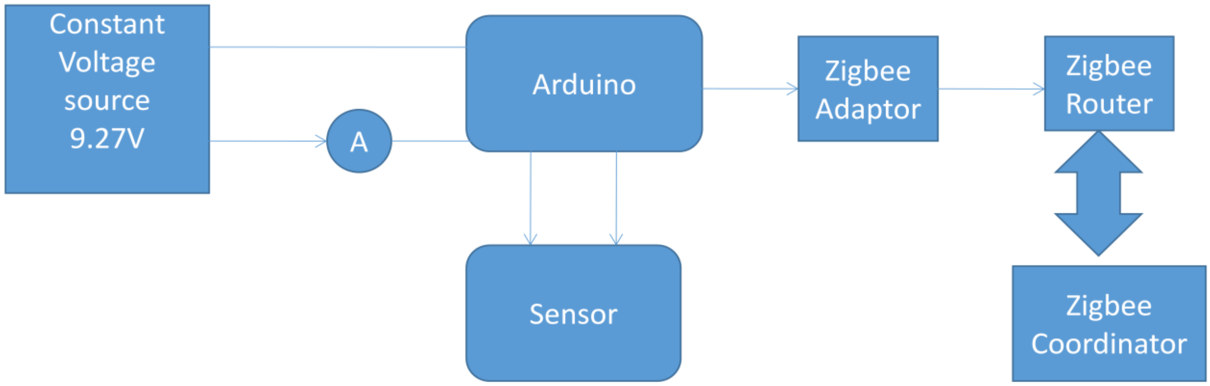


Figure 15 – Experimental setup 4

A point to note :

- This setup was same as that of setup-3. The only difference was the distance between the router and coordinator had been changed to 117cm.

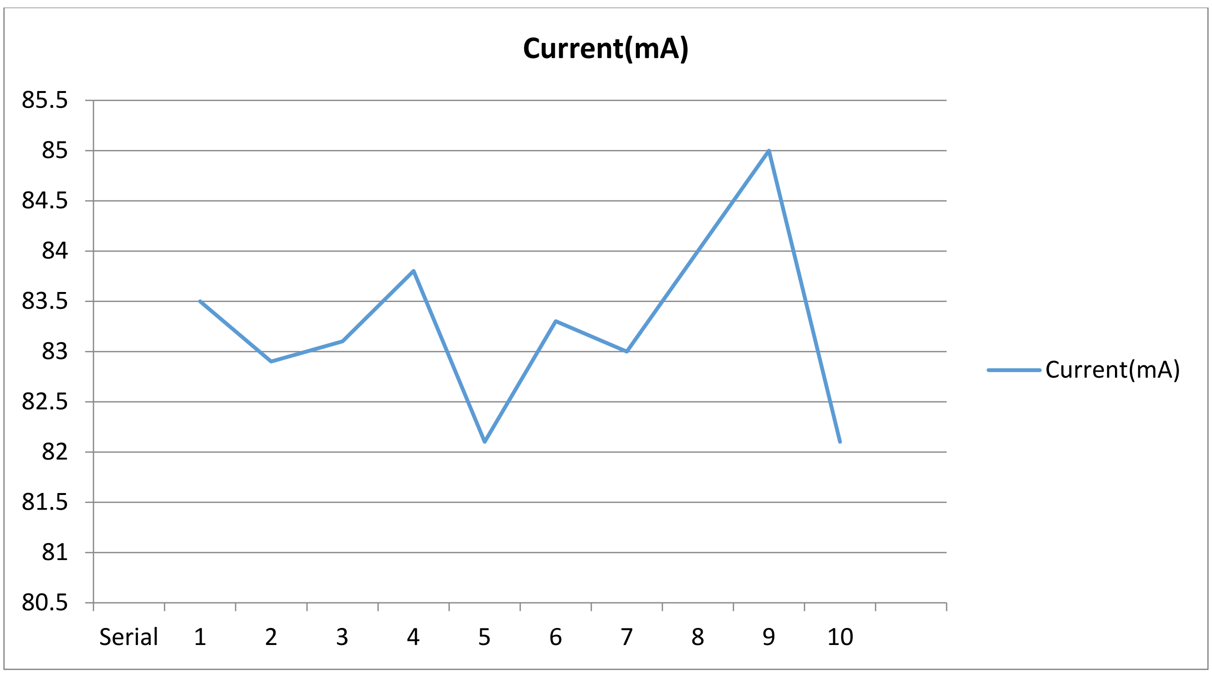


Figure 15 – Observations for experiment 4

Observations :

- Average current(I) = 83.4 mA
- Supply voltage (V) = 9.27 V
- Average power (P) = V*I=773.6 mW

6.5. CONCLUSIONS

In view of the observations made in the above experiments, it can be concluded that the zigbee router consumes almost the same amount of power irrespective of whether it is transmitting or not. Thus, the transmission distance also does not make a significant difference.

7. METHODS OF POWER OPTIMIZATION

In this section we work with the results of the last section and design new methods to achieve minimization of power consumption.

7.1 OPTIMIZATION AT NETWORK LEVEL

In the last section we saw that the energy required per transmission was very small compared to overall power usage. Hence any routing algorithm which optimizes the number of transmissions will not make any significant difference in the power consumption of the entire module.

The above conclusion was cross-checked by the simulation of energy consumption of network of ten nodes using LEACH[9] protocol to send their data to base station. This simulation excludes the stand-by power consumption by each node.

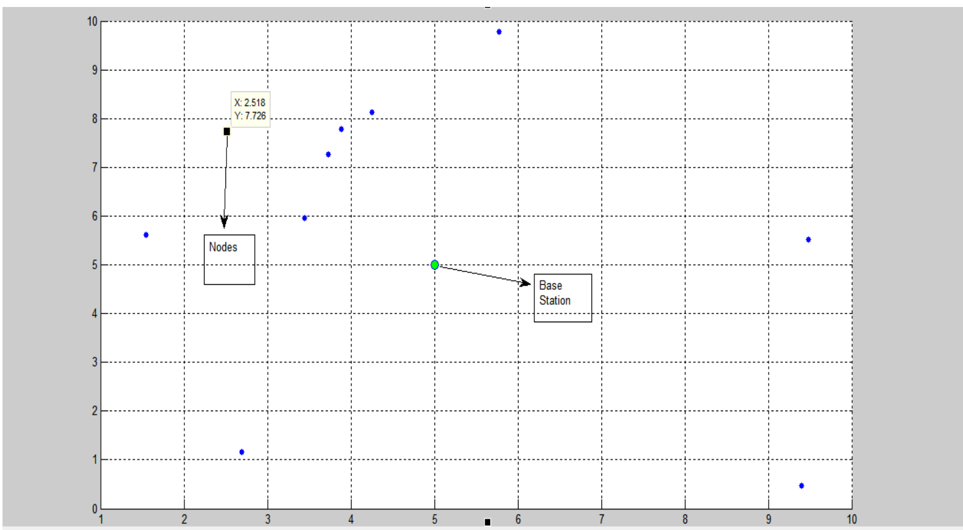


Figure 16 - Network of nodes

Power Calculation:

The network of ten nodes with each node having initial energy of 1 J was for 100 rounds [9] ,with each round lasting for one second.

Observations:

- Total time = 10 s
- Number of nodes = 10
- Total Initial energy of network = 10J
- Energy consumed by network to transmit data = E1= 0.25 J
- Standby power of each node = 772.2 mW

- Standby energy consumption of each node = 0.772 J
- Standby energy consumption of network = E2 = 0.772 * 10 =7.72 J
- Ratio of E2 / E1 = 30.88

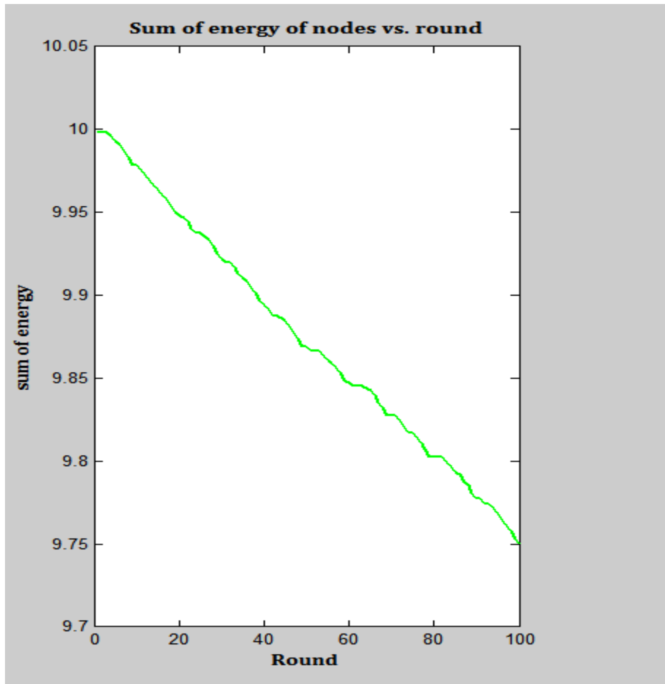


Figure 17- simulation results

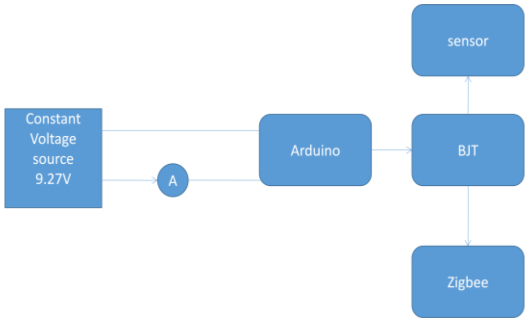
Hence Standby energy consumption is more than 30 times greater than power consumption. So to increase lifetime of network, standby power should be reduced.

As efforts at minimizing the power consumption at the network level did not bear significant results. Hence, more importance was given to the node level optimization.

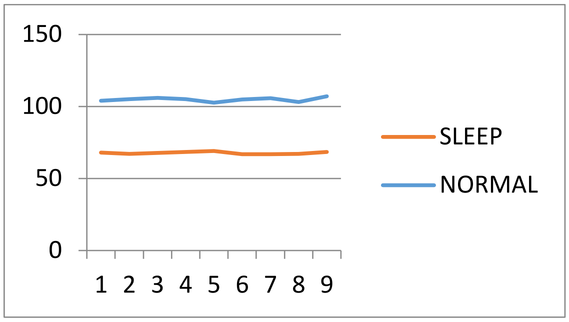
7.2 NODE LEVEL OPTIMIZATION

The best way to reduce power consumption at the node level was found to be reducing the amount of time that the component of the module are kept on; i.e. the zigbee and sensor were kept on for only x% of the time when they were needed to take measurements and send them. Otherwise they were switched off. Let us call this state of the module 'sleep mode'. By controlling the value of the variable x so that the module spends maximum possible amount of time in sleep mode without affecting its performance, it is possible to optimize the power consumption. Transistors were used to achieve this, as illustrated in the following block diagrams. Comparisons between the performance of BJT and MOSFet[F] are also illustrated. This new module with improved power consumption will be referred to as the beta module from hereon.

(A) Using a BJT:



(a) Block diagram



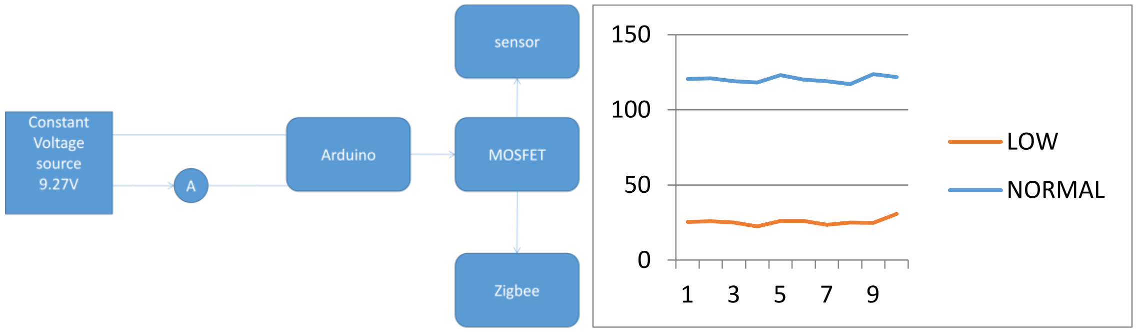
(b) Current vs time

Figure 18 – Using BJT for controlling the zigbee and sensor

Observations:

- Average Current –Arduino+ Zigbee + sensor + BJT = 105 mA
- Average Power Zigbee + sensor + BJT= 105 mA * 9.27 = 973.35 mW
- Average Current -Arduino + BJT = 68 mA
- Average Power - Arduino + BJT = 68 mA*9.27 =630.36mW
- Average Power consumption of Module with duty cycle of 10s = 661.54 mW
- α module power / β module power = 772.2 / 661.54 =1.167

(B) Using a MOSFET:



(a) block diagram (b) current vs time

Figure 19 – Using a MOSFET for controlling the sensor and the zigbee

Observations:

- Average Current - Arduino + MOSFET + Zigbee + Sensor = 120.5 mA
- Average Power - Arduino + MOSFET + Zigbee + Sensor = 120.5 * 9.27 = 1117.03 mW
- Average Current – Arduino + MOSFET = 25.7 mA
- Average Power – Arduino + MOSFET = 25.7 * 9.27=236.38 mW
- Average Power consumption of Module with duty cycle of 10s = 316.43 mw
- α module power / β module power = 772.2 / 316.43=2.44

Thus from the above observations we can conclude that the MOSFET consumes less power and hence it was selected for building the beta module.

8. IMPROVING PRACTICALITY

The alpha and beta modules worked well in the laboratories but in order to make it workable in realistic situations, some improvements were made. We will call this version the gamma module(H).

8.1 ADAPTIBILITY

The aim was to make the sensor module adapt to dustbins of different sizes without having to be reconfigured/coded. Consider the figure 17 below.

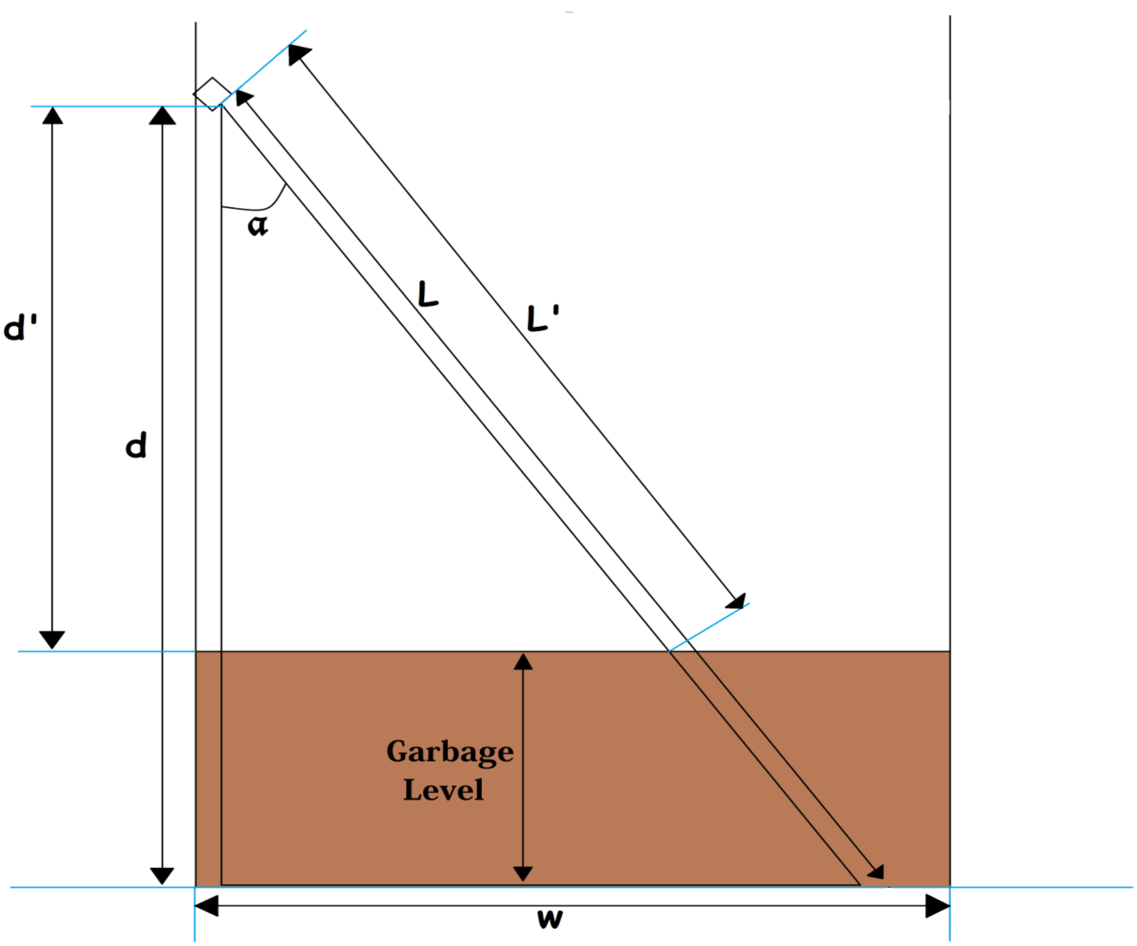


Figure 20- adaptive sensor module

Let us assume a parallelogram/cylindrical dustbin of horizontal width/diameter w. Let the usable depth of the bin be d. The distance between the sensor and surface of the garbage is denoted by d'. Hence the percentage fill level of the bin is given by,

$$f = \{ (d - d') / d \} * 100 \%$$

$$= \{ 1 - (d'/d) \} * 100 \% \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Let the sensor be installed at an arbitrary angle α from the side of the bin. This value need not be fixed. However it does have the following limitation:

$$\tan(\alpha) < (w/d) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

This limitation arises because sound wave from the sensor must reflect from the bottom of the bin and not the sidewall.

The module is fitted into a new bin of unknown depth d. The user must make sure that the bin is empty and then press the reset button on the module. This will trigger the module to take the reading of the bin. We will denote the value of this reading by L. As the bin fills with garbage the module will continue taking readings. Let us consider a reading L' taken at time t. Now according to the midpoint theorem, d'/d = L'/L. Therefore, substituting this in the equation (1),

$$f = \{1 - (L'/L) \} * 100 \% \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Note that this equation does not include the angle α anywhere. Hence this angle can be of any arbitrary value without affecting the final result provided it satisfies the limitation of equation (2). Thus we obtain the percentage fill level of a new bin.

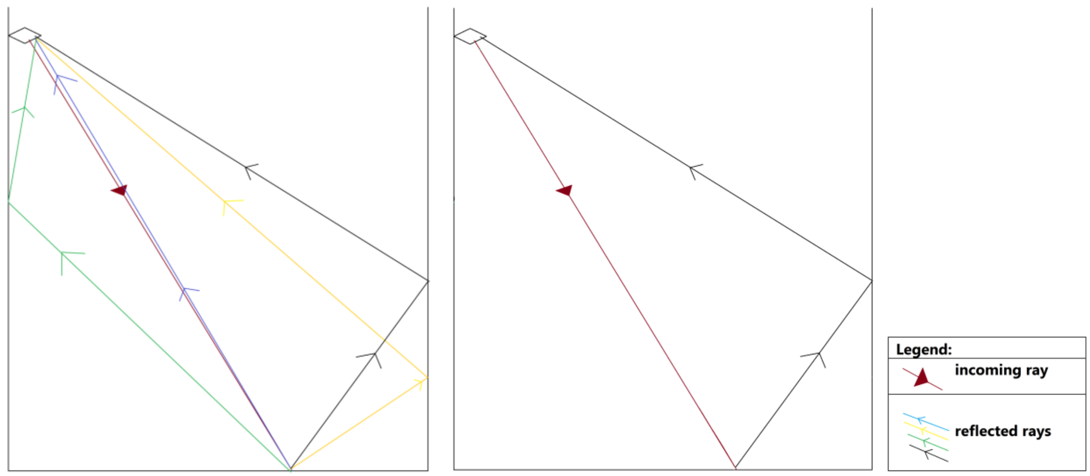
8.2 ISSUES FACED

Let us study the reflection of sound waves from different surfaces. Let us assume a smooth flat surface. When sound waves hit the surface at an angle Φ from the surface, it reflects at an angle 180 – Φ. But, if the surface is coarse it causes any incoming wave to scatter in different directions. This is shown in the figure 18 below.

(a) reflection from smooth surface (b) reflection from coarse surface

figure 21 – reflections from coarse and smooth surfaces.

Let us observe the two cases illustrated below in figure 19. The sensor module is attached to the sidewall of the bin in both the cases. In the first case the floor of the bin is coarse and hence there is sound wave that reflects straight back to the receiver of the sensor. This ray is represented by the blue ray in the figure and this is the wave that reaches the sensor first and hence would be used for calculation of the distance. But in the other case, where the floor is smooth, there is only one wave reflected back from the floor. Assuming it reaches the sensor, this wave would be used for distance calculations; but since it takes a longer route for coming back to the sensor, these calculations would give erratic results. Also if the reflected wave never made its way back to the sensor, it would give some random garbage values as the distance.



(a)floor is coarse (b) floor is perfectly smooth (c) legend

Figure 22 – Comparison between smooth and coarse surfaces.

The same problem would appear if the garbage in the bin contained something made of a material with a smooth surface.

8.3 OTHER MINOR ENHANCEMENTS

In a real world scenarios, it might be necessary to make small adjustments to the configuration of the module. But it would not be possible to physically approach the module to make these adjustments. Hence it is necessary to enable the module to receive and execute real time commands transmitted wirelessly by a coordinator or controller. Using the zigbee communication, this was tried with successful results.

Also the first step to expand the network of modules in order to imitate real networks was taken by connecting three nodes with a single coordinator. Synchronisation between the end nodes and coordinator was achieved by beacon[12] frame mode of the zigbee.

9. FUTURE WORK PLAN

The next objective of the project is to implement a fully functional version of this system in our campus. But a few problems need to be addressed first:

A. The system should be able to transmit data over a distance of atleast 300 meters. Hence, different types of transmission networks like high range RF, GSM network and satellite communication can be explored. One can also try using wifi and connect it to the internet. This will significantly improve the system's usability.
B. The module must be weather, water and corrosion proof.

The module / network must be connected to the internet at some point/ node so that all the real time data can be viewed on a web portal or a smartphone app. Otherwise the feasibility of the implementation of the entire system becomes questionable.

10. GLOSSARY

[A] The Internet of Things (IoT) is an environment in which objects, animals or people are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. IoT has evolved from the convergence of wireless technologies, micro-electromechanical systems (MEMS) and the Internet.[8]

[B] Ultrasonic(or ultrasound or echo) sensors work on the principle of sonar to calculate the proximity of the closest object in its range of detection.

[C] GSM module is an adaptor which enables an arduino to connect with the gsm mobile network.

[D] Arduino is a type of microcontroller based on the ATMEL ATMEGA series of microprocessors.

[E] Zigbee is a protocol for usage of wireless transmission over the radio frequency (RF) Network.

[F]MOSFET and BJT are two types of transistors used widely in today's circuits. Transistors are like electronic switches when used in digital circuits and amplifiers when used in analog circuits.

[G]Routing algorithms determine the path of a data packet in a network of nodes.

[H]The alpha module is described in figure 4 in section 3. The beta module is when the power optimization technique mentioned in section 7 is applied to the alpha through the use of a MOSFET. The gamma module contains improvements over the beta module as described in section 8.

11. REFERENCES

[1] www.enevo.com

[2]www.bigbelly.com

[3]www.smartbin.com

[4] https://www.societyofrobots.com/member_tutorials/node/71

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