Design and implementation of an IoT based smart waste bin for fill level and biodegradability monitoring

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Abstract
Effective and efficient waste management is a critical component of a smart city. Worldwide, waste management has proved to be a daunting task for bodies assigned with the task. Waste overflow and the menace of degradable wastes as they affect communal health and environmental aesthetics are key challenges faced by waste managers. This paper addresses these challenges with the design and implementation of an Internet of Things (IoT) based Smart Waste Bin that tracks in real time the volume and smell (biodegradability) of the waste in it and alerts the waste managers once the set threshold for volume or smell is reached. An Ultrasonic distance sensor HRSO4 and MQ series semiconductor gas sensors MQ4 and MQ135 connected on an Arduino UNO R3 microcontroller board were deployed for fill level and biodegradability sensing respectively. The status of the bin is communicated to a ThingSpeak webserver via an ESP8266 Wi-Fi module interfaced with the microcontroller in real time. Through this, Waste Managers can be alerted to evacuate the waste before it starts overflowing or the smell becomes offensive. The bin was tested with non-biodegradable and biodegradable waste composed of waste mixed with fowl and pig dung. In the experiment, the biodegradability sensor readings remained constant while the ultrasonic distance sensor reading gradually decreased over time as the non-biodegradable waste filled the bin. On the other hand, all sensors responded with varying degrees when waste mixed with either of the dung types filled the bin. The results vindicated the purpose of the design and implementation.

Keywords: Arduino Microcontroller, Internet of Things, Semiconductor gas sensor, ThingSpeak web server, Ultrasonic sensor.

1.0 INTRODUCTION

In most developing countries, waste management constitutes a major problem. Collection of waste often consumes a larger chunk of waste management budget. Inefficiency of waste collection by waste management agencies results in waste bins overflowing which in turn affects the aesthetics of the environment with severe health consequences. According to the World Health Organization (WHO), more than 3 million persons died of Chronic Obstruction Pulmonary Disease (COPD) in 2005 (Mathers and Loncar, 2006). Almost 90% of COPD occur in the developing countries. This situation is traceable to quality of air inhaled by the people. The decay of biodegradable waste leads to emission of certain gases such as carbon dioxide (CO_2), Ammonia(NH_3), Methane (CH_4) and Hydrogen Sulphide (H_2S) (Raut and Sen, 2017) The smell of these gases is not only offensive but can also impact negatively on human health hence the need to monitor the biodegradability level, which depends on the degree of gas emitted, from decomposing waste and the fill level of the waste bin.

The recent surge of development of internet of things (IoT) led to emergence of smart cities. A smart city is an urban area that integrates different types of internet of things (IoT) sensors to collect data and use the data to manage assets and resources such as schools, libraries, transportation system, hospital, power plants, traffic system and waste management efficiently (Su*et et al*., 2011; Zanella *et al*., 2014). This concept is effected with real time systems and array of sensors by gathering data from human, objects and processing the data for decision making in real time (Karadimas *et al.*, 2016). The schematic diagram of this is shown in the figure below:

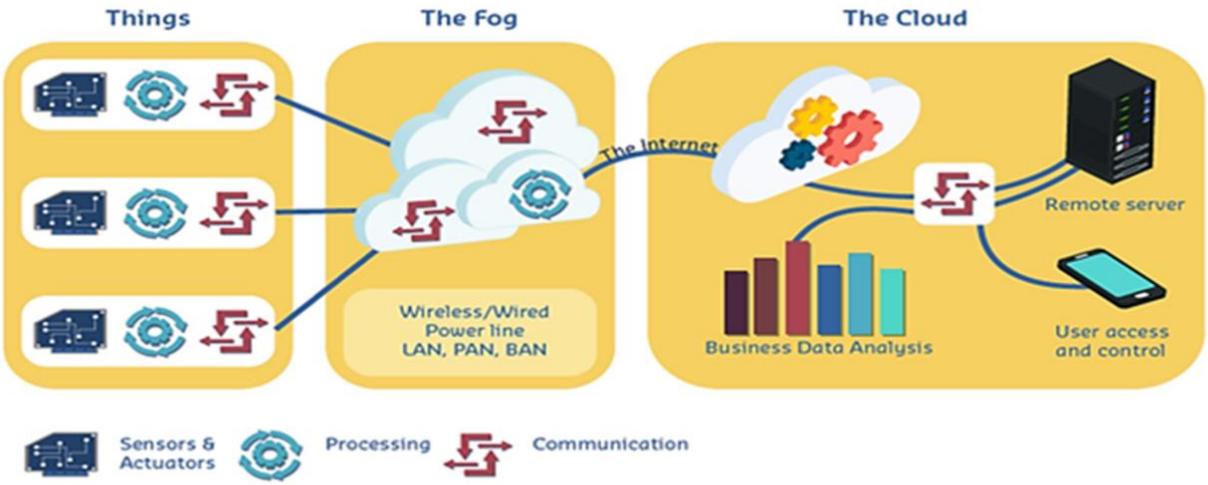


Figure 1: Communications in IoT systems

Various research works have shown that waste fill and pollution levels can be monitored in real time using sensors, microprocessors and communication technologies such as GSM/GPRS, RFI, Wi-Fi and Bluetooth. In one of such works, a smart waste-bin was presented that can manage the waste in a smart city project. The system consists of sensors to measure the weight of waste and the level of waste inside the bin. The system also adapts with network environment, to manage all information from waste management (Wijaya *et al.* 2017). In their study, Sharma *et al.* (2015) presented a " Smart Bin " in managing the waste collection system of an entire city. The collection of sensors allows smart bins connected to the cellular network produce a vast range of data, which when analyzed and displayed show the status of waste in the city. In order to create optimal improvements to the traditional method for collecting waste with the broad range of data generated by the smart bin networks, this work combines analytics and electronics. Waste movement throughout the city can be tracked efficiently and effectively by a single system. Also, Navghane *et al.,* (2016) suggested a microcontroller-based dust bins using the Infrared Wireless Systems and central device that displays up-to-date garbage status on the Wi-Fi mobile web client with HTML page. The workings of the Wi-Fi module, necessary for its implementation, are a major component of the prototype. The project's main aim was to reduce human resources and efforts and enhance the dream of a smart city. A Similar works by Folianto et al., (2015) proposed a smart bin system for data collection and data supply by a network of wireless mesh. In order to reduce power consumption and optimize operating time it uses duty cycle approach. The test bed gathers the data on the uses of the litterbins and offers everyday information on the seasonality of the litterbin. With that detail, better choice by litterbin providers and cleaning contractors is enhanced to increase productivity.

Glouche and Couderc (2013) suggested an insightful waste management of self-describing objects. Each waste object was connected with a smart bin application based on information found in their tags. The waste is monitored with intelligent bins utilizing an RFID-based program without external support. This technique can be used to enhance two key features of the selective sorting mechanism. Firstly, the user is supported in selective sorting operation. Secondly, the intelligent bin understands its material and can report to the remaining chain of recycling. In order to measure waste level in the waste bin, Yusof *et al.,* (2017) presented the implementation of an intelligent waste monitoring system in real-time, and in particular to notify municipalities via SMS. The device suggested consists of a waste level ultrasound sensor, a GSM module to deliver the SMS, and an Arduino UNO to monitor the operation of the device. The municipality gets the alert signals via SMS when the bin is filled or

nearly full so that the waste is promptly collected. A 'Smart Garbage Bin' suggested by Thakker and Narayanamoorthi (2015) was able to sort out and segregate the waste, warn and alert the designated individual about the filling up of the garbage bin. The suggested process for distinguishing the 5 forms of plastic resin (that are not biodegradable) was applied instead of dumping waste into the garbage field using NIR spectroscopy and using the majority of biodegradable waste to create biogas. In another paper, smart recycling bin was suggested by Wahab *et al*., (2014) using a program based on information in the smart card to measure the weight of the waste automatically and to turn the weight into a value, then store it in the card. The waste is monitored by smart bins using an RFID-based system that incorporates the host server's web-based information system. First, using this method it is possible to improve two critical aspects of the selective sorting mechanism. Second, the consumer is supported in implementing the definition of the material waste. Third, the smart bin is conscious of its material and can communicate to the rest of the recycling chain.

Chaudhari and Bhole (2018) in their paper presented an Integrated Platform for Waste Management where smart bins are equipped with a network of sensors and they transmit real time data indicating the fill percentage of the bin. Depending on the status of the bin, route optimization can be performed which increases efficiency of fuel and time used in collection. The large amount of data collected can also be used to gain insights about the waste generated across cities. Atayero *et al.*, (2019) proposed a fill level based smart bin. Waste bins are strategically located within the cities, and the fill level of solid waste is measured using ultrasonic sensors in each bin. The sensor data is transmitted over a Wireless Fidelity (Wi-Fi) connectivity channel to an IoT cloud platform, ThingSpeak. The program is configured to deliver correct warning message (in the form of a tweet) at various filling rates to warn local authorities and interested people to the required action.

The intelligent waste bin proposed here is predicated on an ultrasonic sensor and different gas sensors that detect dangerous gases automatically as well as permissible waste fill limit. This unique approach uses cloud-based predictive monitoring. It does not only regulate the highest possible level of waste in the bin, it also detects various foul-smelling gases using an array of sensors; summing up two essential elements of the work. The management supporting part is to provide the appropriate authorities with relevant data. This approach takes advantage of the cloud system for sensor data analytics. For immediate action, details can be added to the city's web server. Unlike works like Atayero *et al*., (2019), this work incorporates gas sensing from waste.

2.0 MATERIALS AND METHODS

2.1 Materials Requirements

The materials required for the design and implementation of the IoT based smart waste bin are as follows:

a. Ultrasonic sensors (HRSO4 sensor)
b. Semiconductor gas sensor (MQ4 and MQ135 sensors)
c. ESP8266 Wi-Fi module
d. ThingSpeak web server
e. SG 90 servo motor
f. Arduino UNO R3 microcontroller.

2.1.1 Ultrasonic sensors (HRSO4 sensor)

HC-SR04 Ultrasonic sensor is a 4-pin module. This sensor is a very popular sensor used in many applications where measuring distance or sensing objects are required. The module has two eyes: transmitter and receiver. The transmitter transmits ultrasonic waves, which travel in the air and are reflected when they hit any object. This reflection is measured by the receiver module as the distance travelled (Scott, 2012).

2.1.2 Semiconductor gas sensors (MQ4 and MQ135 sensors)

MQ4 has high sensitivity to methane in a wide range while MQ135 gas sensor has high sensitivity to ammonia gas, sulfide, benzene series steam, and can also monitor smoke and other toxic gases well (Barthwal and Acharya, 2018).

2.1.3 ESP8266 Wi-Fi module

The ESP8266 Wi-Fi Module is a self-contained system on chip (SoC) module with integrated TCP/IP protocol stack that allows any microcontroller access to a Wi-Fi network. The ESP8266 can both serve as a web server and act as an access point for other IoT devices. Each ESP8266 module usually comes pre-programmed with a set of attention commands (AT) in its firmware. This means the device can be simply connected to an Arduino microcontroller or can act as a standalone MCU but with limited GPIO pins (GPIO0 and GPIO2) (Mehta, 2015; ESP12-E Datasheet, 2015)

2.1.4 ThingSpeak web server

This is a cloud-based data platform for sending and retrieving data. Other cloud-based platforms include Exosite, Xively, Carriot, Nimbits and Microsoft Azure (Gómez *et al.* 2014). ThingSpeak web server was chosen for this work because it offers great functionality and is quite simple and easy to use (Tiwari *et al.*, 2018). The schematic diagram of the setup is as shown in Figure 2.

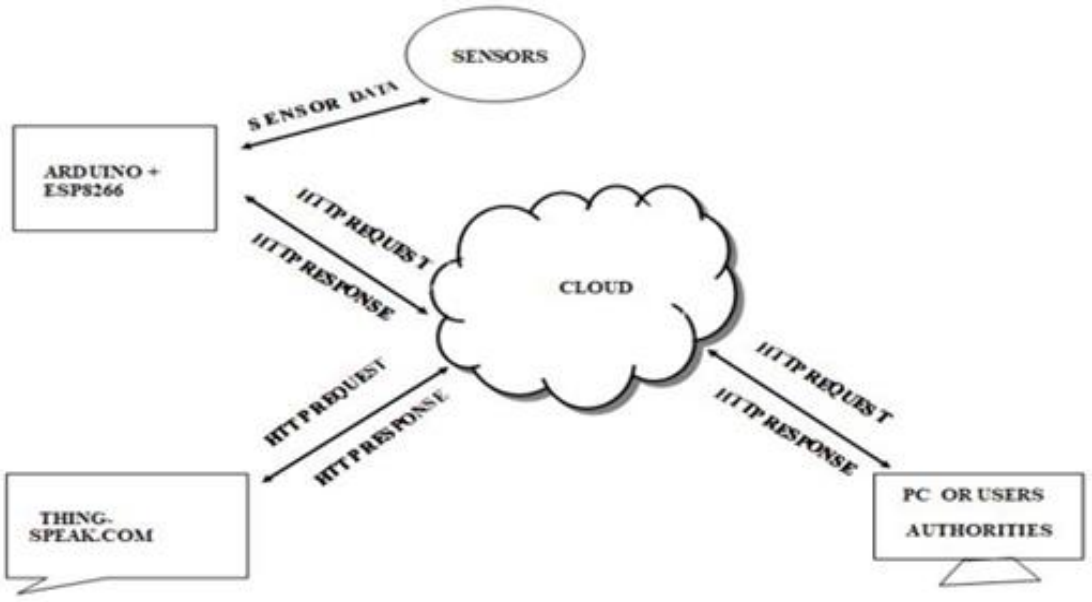


Figure 2: Schematic Diagram of Setup

2.1.5 SG 90 servo motor

This is a tiny and lightweight servomotor with high output power. The servo can rotate approximately 180 degrees (90 in each direction). The servo has three wires: the red wire which is positive voltage (V_{cc}), the brown wire is ground, and the orange wire is for pulse width

modulated signal. The servo motor opens and closes the lid of the proposed smart bin automatically when a user intercepts the signal from one of the ultrasonic sensors.(Cheung, 2018)

2.1.6 Arduino UNO R3 microcontroller

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. The choice for an Arduino in this work is because of its low power requirement (around 99.5mW), ability to interface with low-power devices (Sensors, servo motors, Wi-Fi modules, etc.) (Arduino, 2018). The diagram of the Arduino development board showing the various pin configurations is as shown in Figure 3.

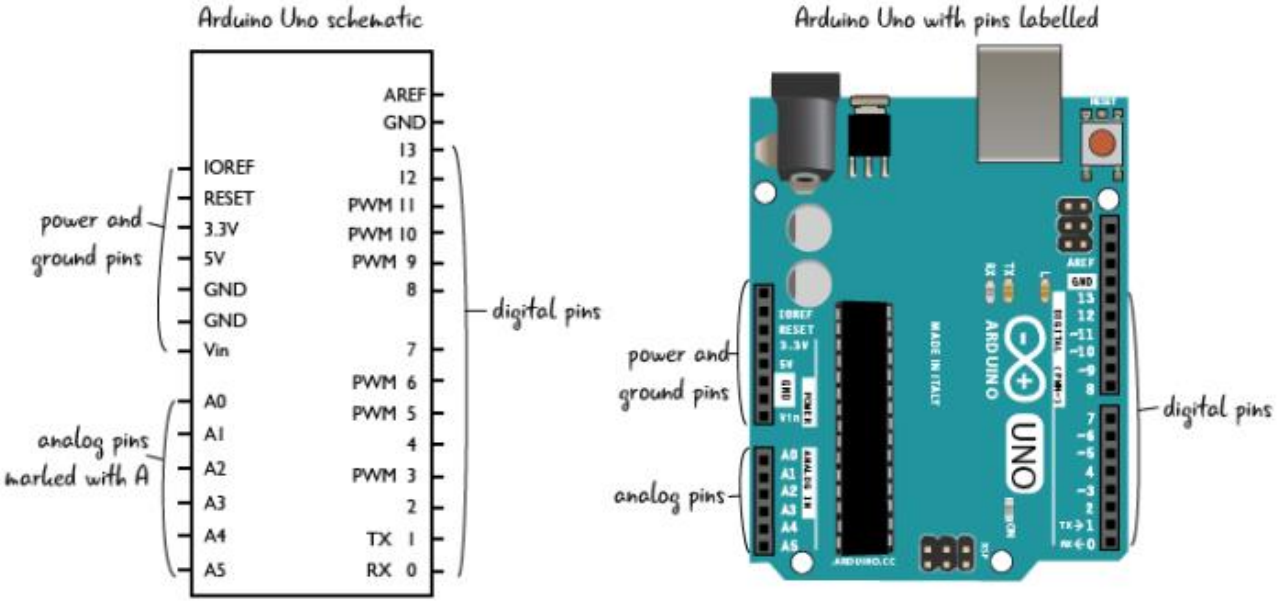


Figure 3: Arduino UNO Schematic (Arduino2go, 2016)

2.2 Design Methodology

Table 1 gives the various pin configurations of sensors, actuator, and Wi-Fi module (IoT devices) on the Arduino UNO R3 microcontroller board used for implementing the smart waste bin.

Table 1: Hardware Pin Configuration

IoT devices	Device type	Pin(s) used
Ultrasonic Sensor 1	Sensor	Digital Pins 2 and 4
Ultrasonic Sensor 2	Sensor	Digital Pins 7 and 8
SG 90 Servo Motor	Actuator	Digital Pin 9
MQ 4	Sensor	Analog Pin 0
MQ 135	Sensor	Analog Pin 1
ESP8266	Wi-Fi Module	Digital Pins 10 and 11 (TX/RX)

IoT devices such as the ultrasonic sensors, MQ series sensors and Servo motor are connected to the 5V and ground (GND) on the Arduino MCU board. The ESP8266 module require 3.3V from the Arduino board or an LM 317 voltage regulator connected to a 5V power supply or even a lithium polymer battery of 3.3V (Mehta, 2015). Other connections include the echo and trig pins of ultrasonic sensor which are connected to pins 2 and 4 on the board, the echo and trig pins of the second ultrasonic sensor connected to pins 7 and 8 on the board, the servo signal

pin connected to pin 9 on the board and the MQ series sensors connected to analog pins 0 and 1.

The RX and TX pins on the ESP8266 Wi-Fi module connect to pins 10 and 11 software serial pins on the Arduino board. For effective communication between the Wi-Fi module and Arduino, the module had to be programmed separately and used as slave for sending data to web server while the Arduino only read data from sensors and send them to the Wi-Fi module serially.
The schematic of the circuit design implementing the smart waste bin is as shown in Figure 4:

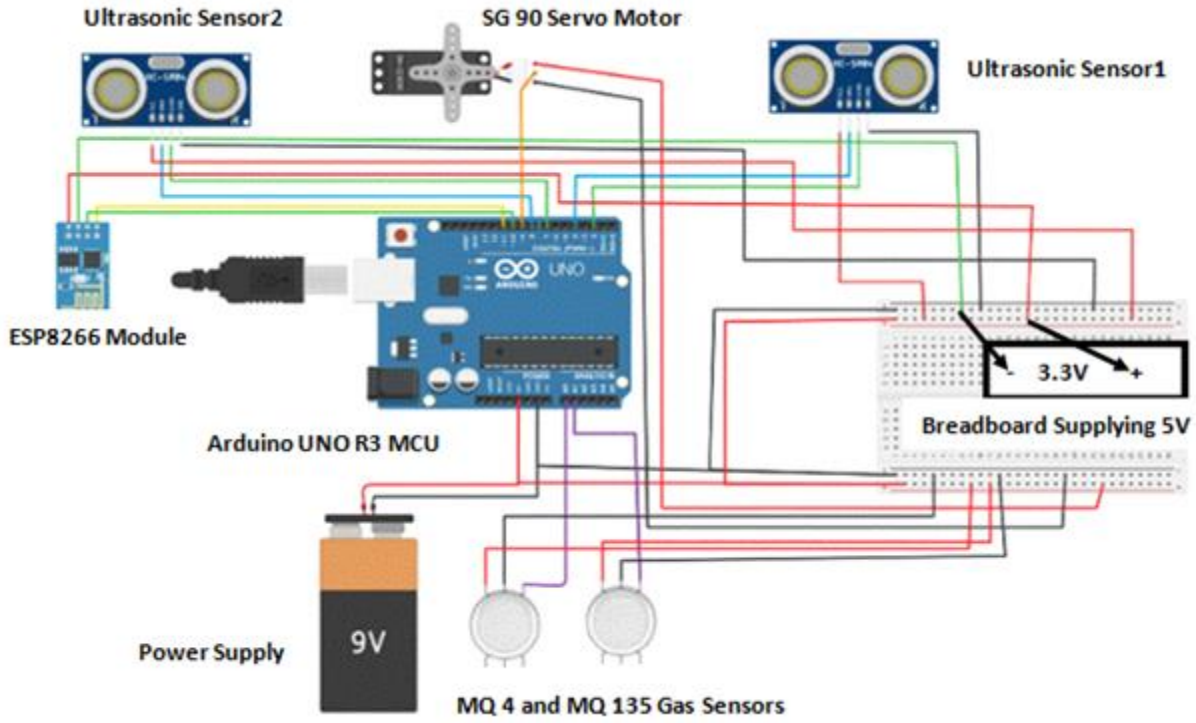


Figure 4: Schematic Diagram of Circuit Implementation

2.3 Principle of operation of the implemented system

The first ultrasonic sensor senses a user close to the bin and directs the servo motor through the Arduino MCU to open the lid for some predetermined time, after which it closes the lid. The MQ series sensors sense the presence of methane, ammonia and Sulphide gases (which are functions of level of biodegradability of waste in the bin) emerging from the bin. These data are read by the microcontroller in real time and displayed on the serial monitor. The second ultrasonic sensor also measure the fill levels of the waste in real time and sends the result to the microcontroller unit, which is also displayed on the serial monitor. The data from the sensors are sent to a ThingSpeak web server in real time by the microcontroller unit via wireless technology using ESP8266 Wi-Fi module. The concerned authorities manage the web server with login access to the webpage. The flowchart describing the working principle of the system and the diagram of the implemented system are as shown in Figures 5 and 6 respectively.

2.4 Tests

The waste bin built was tested with different composition of wastes loaded over time. The waste conditions are:

- When the waste was non-biodegradable
- When the waste was mixed with biodegradable substances.

- Waste mixed with fowl dung
- Waste mixed with pig dung

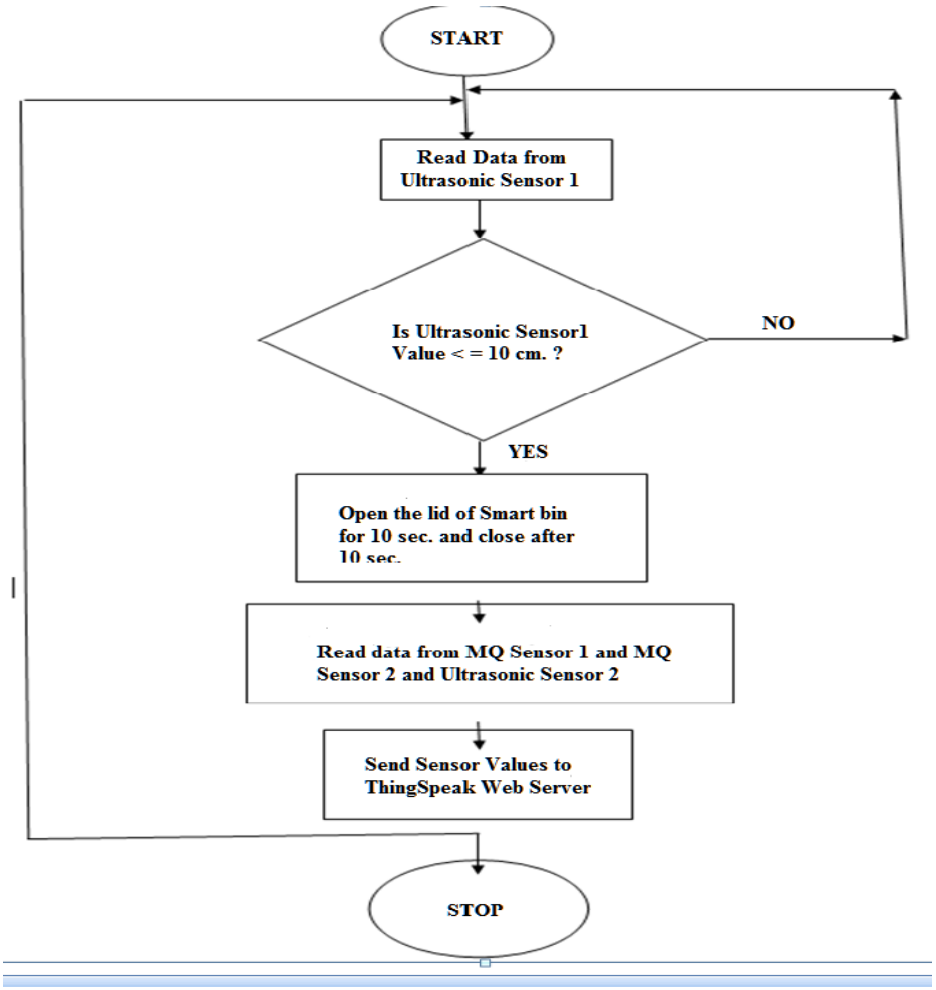


Figure 5: Flowchart of System



Figure 6: The Implemented System

3.0 RESULTS AND DISCUSSION

For all the test cases, the Arduino serial monitor displayed an output of the regularly updated system in real time during experimentation. For example, the typical output from the computer

serial monitor in Figure 7 shows the various sensor data read by the microcontroller in real time. These data include: A user approaching the bin (read by ultrasonic sensor 1), the level of the waste inside the bin (read by ultrasonic sensor 2), and the biodegradability or smell level of the bin (read by MQ4 and MQ135 sensors). After few sensor readings by the Arduino MCU (master), the ESP8266 Wi-Fi module (slave) took turn to send the serial data it received from the Arduino to the web server. For example, the value "*2000#" displayed on the serial monitor means that the Wi-Fi module was sending the string values: waste level=20cm, methane level=0cm and Ammonia-Sulphide level=0cm. Communication to the web server was done using TCP/IP via port 80. Once the system was powered on, and there was internet access, sensor data were sent to the web server.



Figure 7: Output of the Computer serial monitor

On the ThingSpeak's server side, the data were displayed on three fields or channels for both biodegradable and non-biodegradable wastes. The concerned authorities through a valid login would gain access to these fields.

Graphical illustrations of the outputs for non-biodegradable and biodegradable cases over time are as in Figures 8 to 19.

3.1 Non-Biodegradable Waste

Figures 9 to 11 show graphical illustrations of results obtained for the case when the waste loaded was non-degradable. From these figures, it can be seen that only the waste fill level changed from its empty state (when fill level was about 0cm) to a state when the waste fill level was about 20cm. The level reading of the ultrasonic sensor when the bin was empty was about 23cm (this was the distance from ultrasonic sensor 2 to the base of the bin). This value decreased as shown on the graph to about 5cm (Figure 9). The methane and Ammonia-Sulphide values remained at 0cm regardless of the level of waste (Figures 10 and 11) because no biodegradable substance was detected in the bin.



Figure 8: Non-biodegradable waste



Figure 9: Waste Fill level for non-biodegradable waste

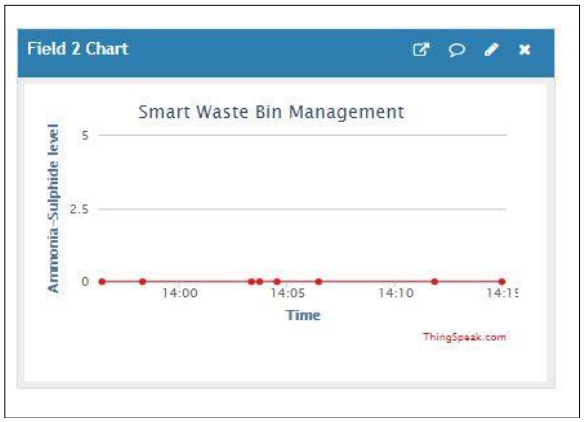


Figure 10: Ammonia Sulphide Value for non-biodegradable waste



Figure 11: Methane Value for non-degradable waste

3.2 Biodegradable waste conditions

3.2.1 Waste Mixed with Fowl Dung

Figures 13 to 15 show graphical illustrations of results obtained for the case when the waste loaded was mixed with degradable fowl dung. It can be seen from the figures that both the

waste fill level and the biodegradable state changed from their initial values when the waste was mixed with fowl dung. It can also be noticed from the output that the Ammonia-Sulphide level changed 5 minutes ahead of the methane value from its zero value. This could be as a result of MQ135 sensor being more sensitive than the MQ4 sensor as found in their data sheet and also because it detects a wider range of gases unlike the methane MQ4 sensor.



Figure 2: Waste mixed with Fowl dung



Figure 1: Figure 20: Waste Fill level for biodegradable waste (Fowl dung)



Figure 3: Ammonia– Sulphide values when mixed with biodegradable waste (Fowl dung)



Figure 4: Methane values when mixed with biodegradable waste (Fowl dung)

3.2.2 Waste Mixed with Pig Dung

Figures 17 to 19 show graphical illustrations of results obtained for the case when the waste loaded was mixed with degradable pig dung. From the figures, it can be seen that only the fill level and Ammonia-Sulphide level changed with time when the waste was mixed with pig dung. The methane level was constant throughout the experiment. This could be attributed to the fact that methane was not one of the target gases or it was in very low quantity.



Figure 16: Waste mixed with Pig dung



Figure 17: Waste Fill level for biodegradable waste (Pig dung)

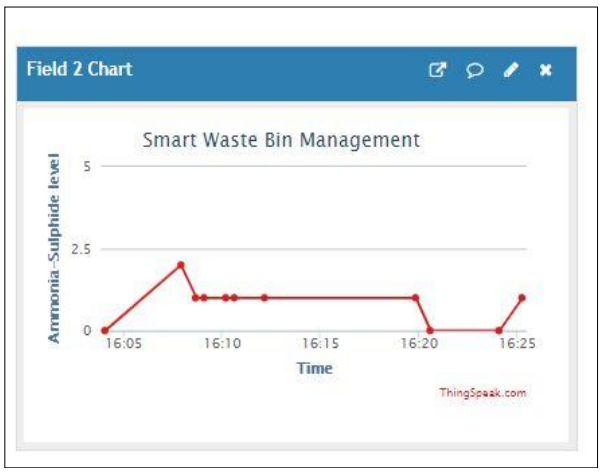


Figure 5: Ammonia – Sulphide values when mixed with biodegradable waste (Pig dung)



Figure 6: Methane values when mixed with biodegradable waste (Pig dung)

4.0 CONCLUSION

It was observed during experimentation that the MQ135 was sensitive to a wide range of gases and as a result could detect other gases other than the target gases (Ammonia and Sulphide). As a result, an ammonia sensor and hydrogen Sulphide sensor can be used in place of MQ135. It was evident from this design and implementation of IoT based waste bin that with the use of distance and smell sensors, the status of a smart waste bin used for a smart city project can be updated in real time to a webserver managed by concerned authorities. This set up will ensure that the attendant consequences of waste littering the streets when they overflow are prevented in real time. Also, the rate of diseases contacted via offensive odour from waste will be greatly reduced with the implementation of this system.

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