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CLOUD BASED IoT-ENABLED SOLID WASTE MONITORING SYSTEM FOR SMART AND CONNECTED COMMUNITIES

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ABSTRACT

Indiscriminate disposal of solid waste is a major issue in urban centers and it poses a serious threat to healthy living of the citizens. Timely access to reliable information on the level of solid waste at different locations within the city will help both the local authorities and the citizens to effectively manage this menace. In this paper, an intelligent solid waste monitoring system is developed using Internet of Things (IoT) and cloud computing technologies. Waste containers are strategically situated within the communities and the fill level of solid waste in each of the containers is detected using ultrasonic sensors. The sensor data is transmitted to an IoT cloud platform, ThingSpeak, via a Wireless Fidelity (Wi-Fi) communication link. At different fill levels, the system is designed to send appropriate notification message (in form of tweet) to alert relevant authorities and concerned citizen(s) for necessary action. Also, the fill level is monitored on ThingSpeak in real-time. The system performance shows that the proposed solution may be found useful for efficient waste management in smart and connected communities.

Key words: Cloud Computing, Internet of Things, Smart and Connected Communities, Smart City, Solid Waste.

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1. INTRODUCTION

Population growth and rapid urbanization contribute significantly to the increasing level of solid wastes that are found in most cities today [1]. The volume of solid waste generated globally has continued to increase and a total of 2.2 billion tonnes is expected in the year 2025 [2]. Management of solid waste in urban areas is highly essential because it affects the health of the citizens and the ecosystem in general [3]. The World Bank data [4] showed that the prevalence of this menace is more predominant in developing countries.

Solid waste monitoring is the first phase of solid waste management. It helps to achieve efficient solid waste collection, recycling, and disposal. Specifically, solid waste monitoring will help local authorities and relevant agencies to determine optimal routes, reduce running cost, and minimize carbon footprint [5, 6]. Performing solid waste management operations can be frustrating and unproductive due to lack of empirical information. However, the activities of solid waste management can be efficiently performed and coordinated by exploiting the elastic potentials of Information and Communication Technologies (ICTs). Solid wastes can be monitored remotely and the information can be conveniently stored and displayed in a cost effective manner [7].

Several ICT solutions have been proposed and developed for different phases of solid waste management. Global Information System (GIS), Global Positioning System (GPS), and remote sensing technologies have been extensively deployed to capture, store, analyze, and map solid waste information [8]. Also, identification capabilities have been introduced into solid waste management using barcode and Radio Frequency Identification (RFID) technologies [7]. Sensor and imaging technologies helps in solid waste level detection and measurement [9-11]. Different data communication technologies used in the literature ranges from Global System for Mobile Communications (GSM), ZigBee, Wi-Fi, to Bluetooth technology [12-14].

The adoption of ICTs in solid waste management is still emerging. Most of the available solutions are developed specifically to address a part of the whole system [10]. Access to useful information is a major challenge in currently available systems [15]. The use of GSM/GPRS as communication link increased the overall system costs [16]. Other issues and challenges identified bother on dynamism of scheduling and routing, and environmental effects [17].

In this paper, an intelligent solid waste monitoring system is developed using Internet of Things (IoT) and cloud computing technologies. Waste containers are strategically situated within the communities and the fill level of solid waste in each of the containers is detected using ultrasonic sensors. The sensor data is transmitted to an IoT cloud platform, ThingSpeak, via a Wireless Fidelity (Wi-Fi) communication link. At different fill levels, the system is designed to send appropriate notification message (in form of tweet) to alert relevant authorities and concerned citizen(s) for necessary action. Also, the fill level is monitored on ThingSpeak in real-time.

2. MATERIALS AND METHODS

The developed smart waste monitoring system can be subdivided into the hardware and the software parts. The hardware consists of the controller unit, the sensor unit, the display unit, and the network interface unit. On the other hand, the development of the software includes the program written to automate the processes of the microcontroller in the embedded system, and the IoT cloud platform. The block diagram of the smart waste monitoring system is shown in Figure 1.

Ultrasonic sensors were used to detect the level of solid waste in the bins. These sensors were properly fixed in the inner part of the top lid of each bin. The measured waste level is compared with a pre-set threshold level to determine whether the bin is due for offloading. An Arduino Uno microcontroller serves as the processing unit of the system with all other electronic components connected to it. The output information of the microcontroller is displayed on a Liquid Crystal Display (LCD) unit. A Wi-Fi communication link established a wireless Internet connection to the IoT cloud platform (ThingSpeak). The microcontroller communicates serially with the Wi-Fi module to send both data and commands. The Wi-Fi module is initially connected to the Internet Protocol (IP) address of ThingSpeak, with a write

API key that enables data visualization on the IoT cloud platform. Information about the waste level is received from the microcontroller and preconfigured in station mode. A twitter account was setup for each of the bins to enable the "ThingTweet" feature of ThingSpeak. "ThingTweet" allows embedded device to send tweet notification to other Twitter accounts. The smart waste monitoring system leveraged this feature to alert relevant authorities when a particular bin is due for offloading.

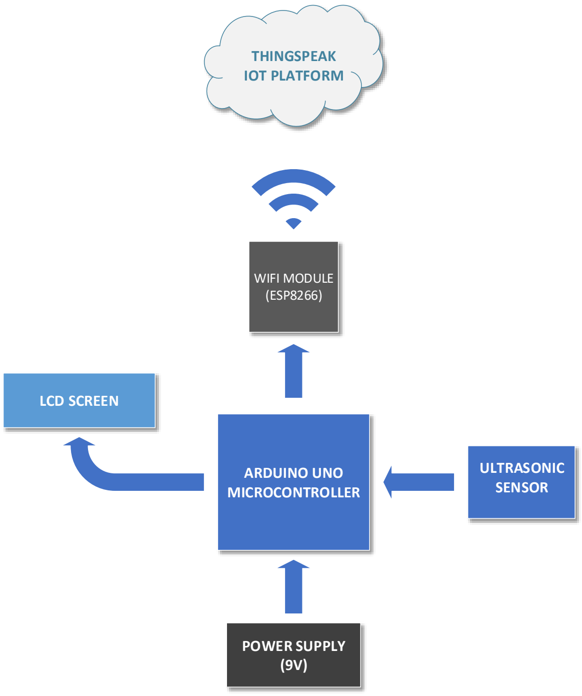

Figure 1. Block Diagram of the Smart Waste Monitoring System

Multiple waste disposal bins were located at different strategic locations at Covenant University, Ota, Nigeria. These bins were enabled with low-cost embedded devices which help in tracking the level of garbage. A unique identification code was generated and assigned to each waste bin in the university community. This helps to identify the waste bin that is due for offloading. It also aids proper routing and reduces fuel consumption. When the pre-set threshold limit is reached, the embedded device transmits the appropriate information about the level of solid waste in the bin along with the unique identification code of the bin. Real time data visualization of the events is displayed on the IoT cloud platform (ThingSpeak).

3. RESULTS AND DISCUSSION

The proposed design concept of the smart waste monitoring system was prototyped and tested. The working operations and testing results of the system are presented in this section. The circuit design of the embedded system is evaluated using an open source simulation software, Fritzing. This simulation tool was chosen because of its robust library of electronic components. The schematic diagram and the system circuit design are shown in Figure 2 and Figure 3 respectively.

Four-pin ultrasonic sensor was utilized. The 'echo' pin and the 'trigger' pin of the sensor was connected to pins 4 and 5 of the microcontroller respectively. The power (VCC) and the ground pins were connected to the source and ground terminals of the microcontroller respectively. The ultrasonic sensor was powered with 3.3-volt obtained from the output pin of the regulator that was connected to the 9 V voltage source as shown in Figure 2.

Communication was established with the Wi-Fi module by serial connection of the transmitter (TX) pin to the receiver (RX) pin. Figure 4 shows the system testing setup.

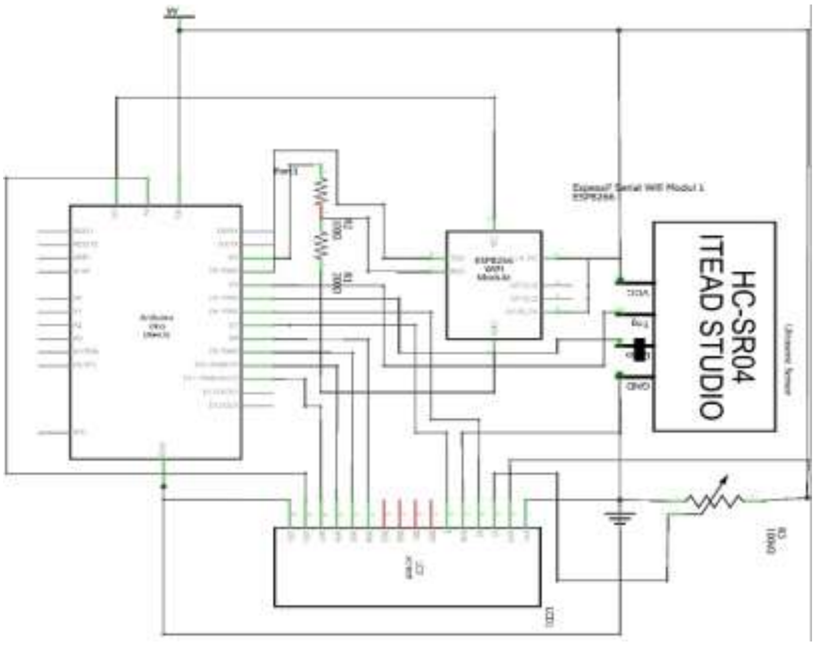

Figure 2. Schematic Diagram of the Smart Waste Monitoring System

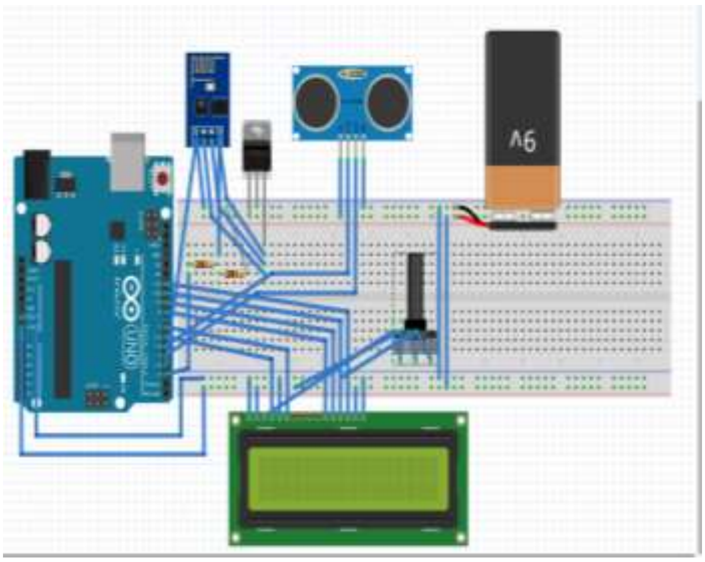

Figure 3. System Design Implementation

Table 1: Results of System Testing

Sent Data	Data Delivery Duration (seconds)
Data 1	18
Data 2	18
Data 3	21
Data 4	18
Data 5	19
Data 5	22
Data 6	18
Data 7	20
Data 8	19.25
Average	18

Data transmission delay test was carried out to ascertain the time taken to send measured bin level to ThingSpeak platform. Table 1 shows the readings of the delay for different data transmission times. The ThingSpeak platform was configured to receive data from the embedded system and visualize the information. The data visualization is presented in form of a bar graph, where the height of each bar corresponds to the waste level in the bin. The ThingSpeak channel receives update every 16 seconds. The IoT cloud platform was properly synchronized with the embedded system. When the pre-set condition of the system is reached or exceeded, ThingSpeak sends a tweet notification using the "Tweet React" of ThingSpeak.

The complete embedded system was housed in a plastic casing and attached to the side of the waste bin as shown in Figure 5. Connecting wires that run out from the side opening of the plastic casing are properly laid on the wall of the bin. The ultrasonic sensor was carefully position to ensure maximum level of sensitivity to the presence of solid waste in the bin. The cover of the casing has an opening where the LCD unit was placed.

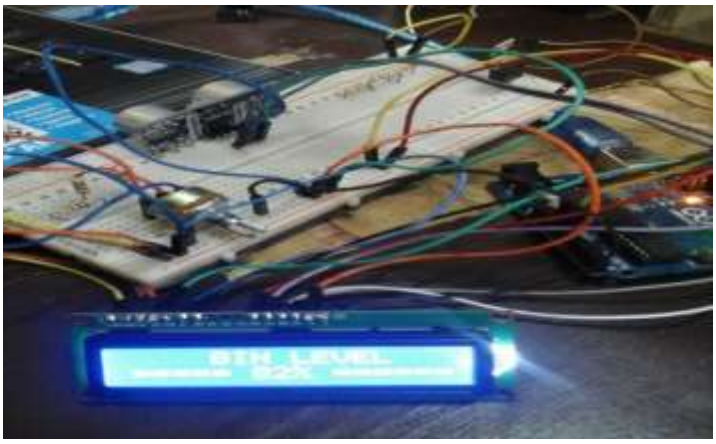

Figure 4. System Testing

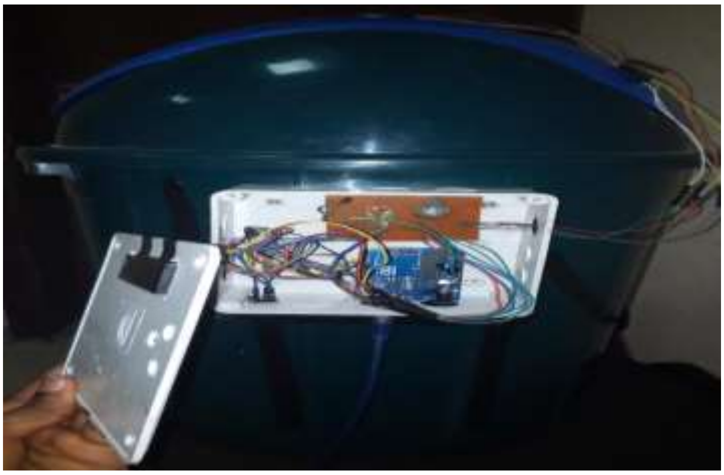

Figure 5. System Prototype

The test results showed that the data visualization of the waste level on ThingSpeak corresponded with the actual measured waste level in the bin. This validated the proper operation of the waste monitoring system. The random nature of the delivery duration may be attributed to traffic congestion in the communication network traffic and the limitation of the Internet speed. The operating performance of the level sensor was verified to be sensitive enough to the actual changes in the waste level in the bin. The remote monitoring capability of the system was also verified. The status update of the bin was accessible at all times as automatic update was performed at defined intervals. The performance of the tweet alert was also validated. The time taken to post a tweet notification varied with Internet connection speed as shown in Figure 6-8.

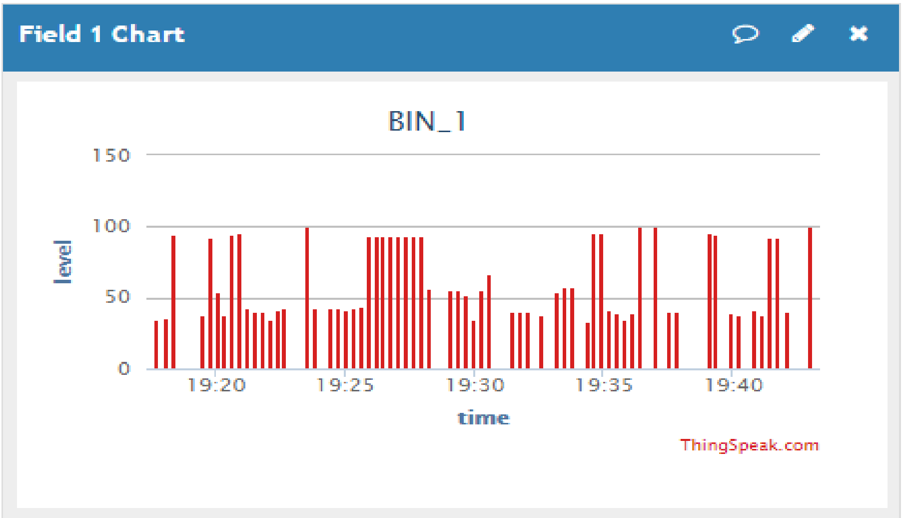

Figure 6. ThingSpeak Data Visualization in Scenario 1

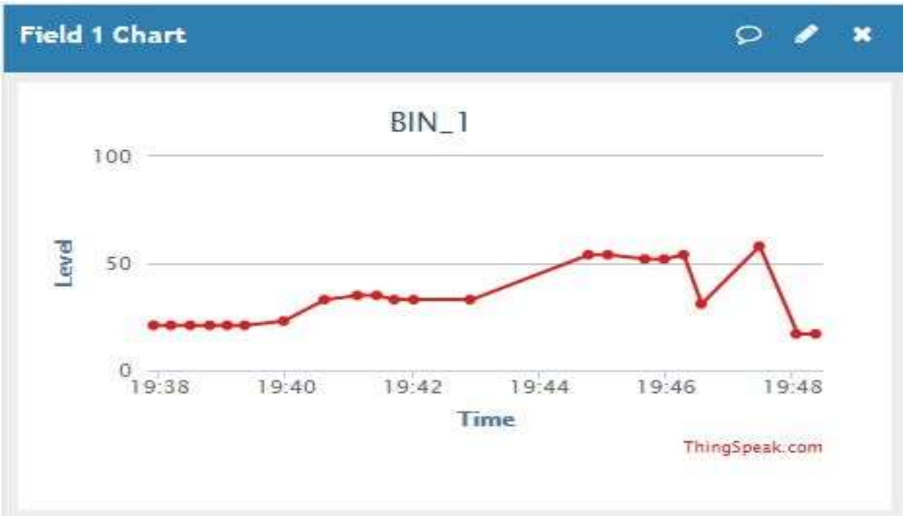

Figure 7. ThingSpeak Data Visualization in Scenario 2

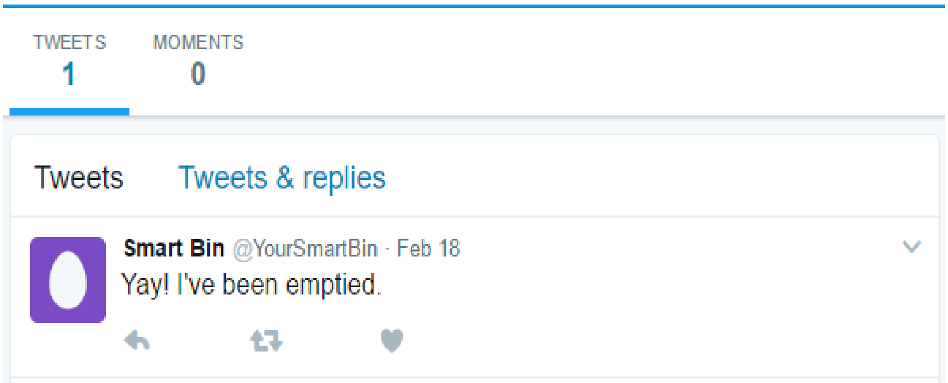

Figure 8. System Tweet Notification

4. CONCLUSIONS

An intelligent solid waste monitoring system was developed to achieve an efficient waste management using Internet of Things (IoT) and cloud computing technologies. Waste containers were strategically situated within the connected communities and the fill level of solid waste in each of the containers was detected using ultrasonic sensors. The sensor data was transmitted to an IoT cloud platform, ThingSpeak, via a Wireless Fidelity (Wi-Fi) communication link. At different fill levels, the system was designed to send appropriate notification message (in form of tweet) to alert relevant authorities and concerned citizen(s) for necessary action. Also, the fill level was monitored on ThingSpeak in real-time. The complete embedded system was housed in a plastic casing and attached to the side of the waste bin. The system performance showed that the proposed solution may be found useful for efficient waste management in smart and connected communities.

In the future, the use of other sensors may be experimented to improve overall system efficiency. Also, a renewable energy source may be considered to ensure system sustainability.

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