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The Design and Construction of a Smart Waste Bin Management System

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ABSTRACT : *As people are getting smarter, so are things. While the thought of Smart cities came up, also requirement for Smart waste management. It is common to witness garbage spilled over in and around dustbins. An improperly maintained dust bins can house disease spreading animals. The environment around such dustbin is also conducive for increasing the pollution level of the city. The aim of this paper is to design a smart dustbin for proper disposal of waste without human intervention by providing a smart technology for waste system monitoring, reducing human time, effort, and intervention. This was achieved through a waste bin integrated with a microcontroller-based Arduino board, interfaced with ultrasonic sensors, servo motors, liquid crystal displays and Global System for Mobile communication (GSM) modem. The Arduino microcontroller is programmed using Arduino C which measures the height of the dust bin using the ultrasonic sensors. The lid of the dustbin automatically opens whenever an object comes near the dustbin and after certain period, the lid will close. Once the waste gets to the pre-set level, the microcontroller activates the GSM modem to send a message to a designated number. The status of the waste in the bin is transferred to the designated line and also displayed on the LCD attached to the bin.The replacement of the traditional waste bin with smart waste bin will help in efficient management of waste by assuring that filled waste bin are emptied when the pre-set value is exceeded. This also helps in reducing the time involved in checking the status of the waste bin and number of trips embarked by the waste collection vehicle; thereby the total expenditure associated with the collection is minimized and eventually helps to maintain cleanliness in the environment. Therefore, the system makes the waste collection more efficient. The combination of intelligent waste monitoring and other technologies in production of smart dustbins are better and shoulders above traditional garbage dustbin.*

KEYWORDS *Arduino Microcontroller, Passive Infrared Sensor, Smart waste bin, waste management, smart city*

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I. INTRODUCTION

Globally, environmental protection faces serious challenges due to escalating trash production. Thereby making people increasingly concerned about trash management, yet inefficiently filled trash cans persist in many places. The harmful impact of garbage on both human life and the environment has turned waste management into global issue. Factors like population growth, urbanization, and industrialization contribute to the rise in global trash production. Shockingly, at least 33% of the 2.01 billion tons of annual municipal solid trash worldwide is not ecologically managed. Predictions indicate that global waste production will reach 3.4 billion tons by 2050. Nigeria, with a population exceeding 200 million, grapples with inadequate solid waste management. Only 20-30% of Nigeria's annual 32 million tons of solid waste is collected, leading to environmental hazards. Technological solutions, such as Radio Frequency Identification (RFID)-enabled waste bin monitoring, aims to

improve waste disposal. However, the development of smart trash cans with infrared sensors could revolutionize waste management by automatically opening and closing lids based on user presence. Ultimately, solid or liquid waste poses serious health risks and requires proper disposal.

The primary objective of the automated waste bin with SMS alert system is to improve waste disposal, this paper presents a novel and inventive method of maintaining cleanliness through a Smart Waste Bin that employs a proximity sensor. When a person walks in front of it, the sensor ensures that the lid automatically opens allowing a disposer to drop trash in the bin and closes itself after a set time. This system also promotes the use of contemporary engineering technology in waste management which enables rubbish collection with minimum human interaction for cleanliness and health safety.

A. Review of Related Works

Several papers that discussed smart waste bins were reviewed. These papers included:

B. Internet of Things (IoT) Based Waste Management, Monitoring and Tracking-Smart Bin

Using IoT, waste management, monitoring, and tracking, [1] constructed a garbage bin using a microcontroller-based on Arduino mega board that is interfaced with a GSM modem and an ultrasonic sensor. A cutting-edge tool that will help keep the environment and communities clean is the Internet of Things-based trash Monitoring system. The administrative department is informed of the amount of rubbish collected in the dustbins by this system, which keeps track of them all across the city. IoT, is a term that refers to technological devices that are connected to the internet and can be viewed online. Throughout this structure, trash cans are positioned in a variety of locations,
[2] proposed an intelligent waste management system that comprises of three phases which included a system with low energy adaptive clustering which extends life of the smart network. The second phase handled the missing values which are retrieved from smart bins by using artificial hummingbird optimization, and the third phase took care of an optimal energy-efficient route process. The three phases achieved energy savings of 34% for the smart waste bin.

C. Garbage Collection and Monitoring System for Smart Cities using IoT

Sahu *et al* in [3] published a novel system that made use of IoT. To ensure that the garbage can be picked up on time and the environment is protected, a system that notifies the municipality when the bin is about to fill up was developed. The work suggests a Smart Waste Bin solution that will warn and tell the designated person when the rubbish bin is about to fill up in order to prevent unwholesome instances. The chosen person will subsequently be informed to collect the rubbish from any specified location. From online application, an authorized individual will send SMS with notification to the garbage collectors. In this setup, dry waste and moist waste are kept apart. Thus, the environment is protected and kept clean by reducing rubbish overflow.

In [4] a proposal was presentedthat provides insight into the potential of smart cities and associated communities coming together in assisting waste management initiatives. The proposal offers dynamic waste collection scheduling and route optimization while achieving quality of service. Their system intended also to improve waste management by making regular environmental sterility and making COVID situations more convenient.

D. Solar Powered Waste Compacting Bin

This solar powered compacting rubbish bin system was created by [5] of REVA University's School of Mechanical Engineering. Waste compaction is the action of compacting rubbish, the multiple waste degrading processes contaminate the water and the air. Waste is now placed for decomposition at a higher level, condensing trash without harming the environment is the aim of the work. With the use of a microprocessor and a compaction mechanism, the size of the garbage is decreased, allowing for the storage of more waste in a given amount of space. The space that was previously used to keep the garbage can be freed up by compacting the waste once again. Additionally, it will assist in preventing illnesses.

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E. Robot Smart Waste Bin

A robotic smart waste bin was proposed by [6]. The suggested system monitored the trash level of the bin. Once the bin got filled, the bin automatically moved to a designated location for garbage disposal and then returning to its initial position via a two-axis robot. Some sensors were also added that included gas sensor to pick up harmful gases and alert nearby occupants, a rain sensor to detect rain and automatically closing the lid of the trash can once rain is about to fall. A microcontroller was also included which was linked to an infrared sensor that kept track of the trash level. A Wi-Fi module was attached to communicate with internet and website page was used to monitor the entire system.

[7] developed a system with two major components of a smart dustbin and the garbage collecting van. Two ultrasonic were mounted; one on the rim of the dustbin container and the other at the base of the robot facing forward. The sensors were for garbage level detection and obstacle detection. If the garbage level reached the threshold, the dustbin went to a direction where the van can empty thecontents. Every dustbin had a unique path since the robot had to be trained by the owner initially and the same path would be followed unless a new path had been inputted in the memory. Once the bin was emptied, the dustbin had to move back to its original position. The other addition was the garbage collecting van can view the locations of all the bins that were to be collected. Dustbins with more than the threshold level of garbage are highlighted and the ones that were partially filled need not to be collected. This improved time management and fuel efficiency.

F. Summary of the Reviewed Literatures

The idea of the smart waste bin had been tried in several aspects which had resulted in areas like the compaction of waste. This way the garbage cans do not get filled easily, thereby creating room for more waste's disposal. The SMS Module is also a very convenient way to pass information across to the waste management authorities. All the literatures also presented the need to save money and energy.

G. Literature Gaps

In as much as the aforementioned contributions had ways to accomplish a healthy and safe way to manage waste in the society, there are a few loopholes. As for instance, in a case where the trash cans are full, the procedure is that it won't open until it is emptied. If an individual happens to dispose any waste within the period when the waste management authorities are yet to empty these cans, best bet is that the waste will be left of at the foot of the trash can.
The proximity sensor used in this paper is at an advantage, this way any human movement around it will prompt it to open once sensed. Another major challenge from previous works and literature is the inadequate provision of garbage bins, leading to the overflow and delayed emptying of bins. In this paper, we proposed two cans, such that one of the two must be free and available at every point in time. This procedure would truly reduce air pollution, keep our environment cleaner and healthier to live in, and even save operational costs in some cases. This system allows for easy user experience, and satisfaction.

II. THEORY/CALCULATION/METHODOLOGY

This section involves the design consideration of the smart waste bin, its physical structure and methodology.

A. Design Consideration

When designing a smart waste bin, several crucial considerations come into play to ensure its effectiveness and seamless integration into waste management systems. These design aspects are:

1. The automated lid system is an essential component. It enables the bin's cover-lid to open and close without requiring physical contact between the user and the bin. By avoiding direct contact with waste, it reduces the chance of exposure to germs, bacteria, and viruses on the bin's surface. The lid opens when incoming trash is within 20 cm (or less) of the bin, providing user convenience and hygiene. Furthermore, the lid remains locked when the garbage bin reaches 95% full capacity to avoid overflow.
2. Communication is the second most important system. It is essential for notifying waste management authorities about the bin's fill level. When the bin reaches 95% capacity, the system sends an alarm to waste management professionals, requiring immediate emptying. This reduces rubbish overflow, keeps the environment cleaner, and helps to prevent global warming.

3. Mobile Technology Integration: Smart garbage bins use SMS notifications to notify waste management professionals. Mobile notifications ensure prompt garbage management, avoiding unsightly overflow and associated health hazards.
4. Smart bins use ultrasonic proximity sensors to detect human presence and waste levels. Data capturing features allow for real-time monitoring and informed decision-making for waste collection routes.

As applied to this work, the hardware requirement of the system design is listed below:

- Arduino Nano; 16x2 Liquid Crystal Display (LCD); GSM Module; Passive Infrared (PIR) Sensor; Light Dependent Resistor (LDR); Light Emitting Diode (LED); LM 358 OP AMP; Servo Motor; Relay; ULN 2003A IC; Resistors; 5V Voltage Regulator

B. Physical Structure

In order to illustrate the functionality of this work, the main body of the device is a rectangular container made of plastic, with a lid that can be opened and closed by a hinge. The lid has two PIR sensor placed on it, the PIR sensor detects motion of objects (or humans). If the distance is less than a certain threshold, the sensor sends a signal to the Arduino board. The Arduino board is a microcontroller that controls the logic and behaviour of the device. It is connected to the ultrasonic sensor, a servo motor, and an LCD screen by wires. The Arduino board can be powered by a battery or an external power source. The servo motor is a small device that can rotate its shaft to a specific angle, attached to the lid by a plastic tube, and acts as a lever to open and close the lid. The Arduino board sends a command to the servo motor to rotate its shaft to a certain degree, depending on the signal from the ultrasonic sensor. The LCD screen is a display device that can show text, numbers, or images. It is mounted on the side of the device, and can be used to show the status of the device, such as the level of waste, or the battery life. The Arduino board sends data to the LCD screen to update the display. This is to ensure easy demonstration of the sensing capabilities of both sensors.

C. Methodology

The steps necessary to develop the system are detailed in this section. The design element and the study of each component that make up this device are the key topics covered in this section. It lays forth the criteria on which the circuit's part are selected to guarantee the system's dependability and correct operation. Additionally, it demonstrates the connections between the circuit's various components. The design of this work is in such that two trash cans are used but attached to each other as one. The aim of this work is to design a double compartment smart waste bin that can automatically switch to the second compartment when the first one is full. The system has two major parts: the automated trash collection system, and the bin communication system. The two systems are connected to the same Arduino Nano board. The automated trash collection system involves an ultrasonic sensor that uses a technique similar to echolocation, which bats use to detect nearby objects, to detect oncoming trash. The ultrasonic sensors measure the distance between the incoming trash and the bin, then promptly feeds the received data (in form of measured distance) to the Arduino Nano. The Arduino Nano then compares the distance measured by the sensor to the set threshold of maybe 20cm that has been programmed into it. If the distance measured is less than or equal to 20cm, the Arduino Nano energizes the servo motor to open the lid but if the distance between the bin and the object is greater than 20cm, the bin stays shut. The system was programmed with such a small threshold distance to prevent the bin from opening unnecessarily when people pass by it. It is expected that the user would walk up to the bin and extend the trash towards it. The smart waste management system involves another ultrasonic sensor present inside the bin that measures the height of the trash in the bin. With this sensor present, the capacity of the bin can be measured and displayed on the liquid crystal display (LCD) in real-time.
The methodology of this work is the process of designing and developing the hardware and software components of a smart waste bin, as well as the interaction and communication mechanisms between the bin, the user, and the waste management system. The common steps involved here includes power specification determination, circuit design etc.:

a. **Power Specification**

A direct current DC-DC converter transformer of 12V/5A rating was used. A DC-DC converter is a device that can step up or step down the voltage level according to the output requirements. The DC-DC converter in this

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case provides a constant output of 5V voltage, which is suitable for this work. The converter having a current rating of 5A means it can deliver up to 5A of current to the other units without overheating or damaging itself. Fig. 1 shows the power circuit of the system

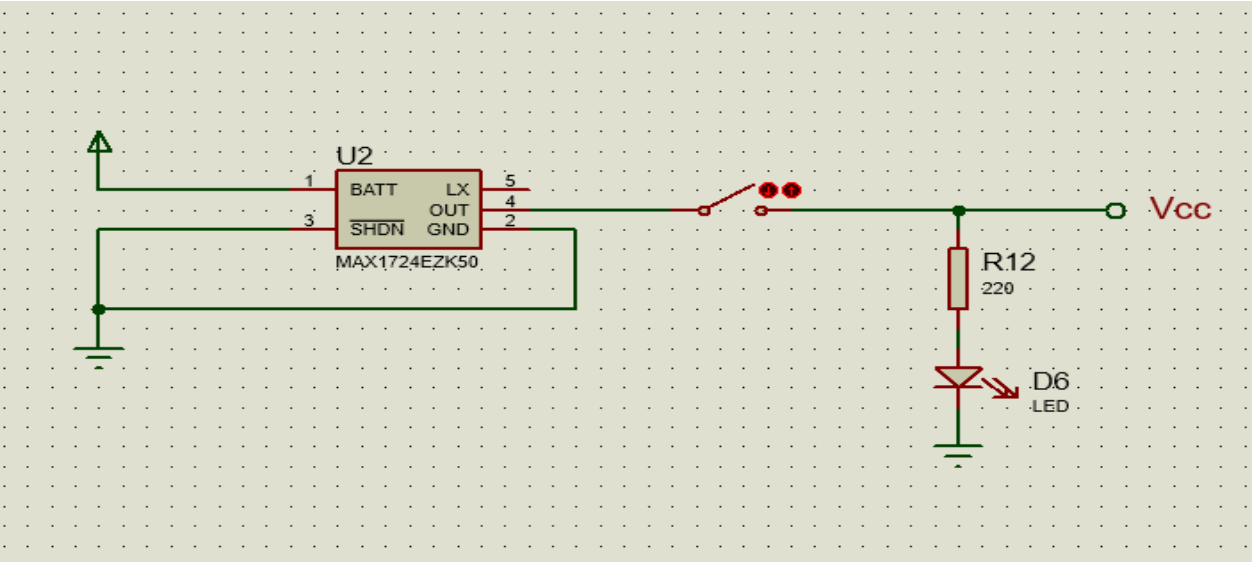

Fig 1: Power Circuit.

A 220Ω resistor is connected to the converter output, LED indicator and the ground. This resistor limits excessive current to reach the LED. The LED indicator has a forward voltage drop of 2V, which means that it needs at least 2V across its terminals to turn on. This LED has maximum current rating of 20mA,

Calculation of the Resistance value
if I =10mA, V = 2V
applying Ohm's law

Then $R = \frac{2V}{0.01A} = 200\Omega \sim 220\Omega$,

However, since the resistor value of 200Ω is not a standard value, a commercially available resistor of 220Ω is used instead. This resistor value is slightly higher than the calculated value, which means that the current through the LED indicator will be slightly lower than the maximum rating. This is acceptable as it will not affect the performance of the LED.

b. **Circuit Design**

This subsection describes the individual electronic components that came together to make up the entire system. This starts with the block diagram of the system, which illustrates how the individual subsystems ties up together to form the entire system. It is shown in the Fig. below:
The block diagram in the Fig. 2 below, shows the interconnection of the units that makes up the smart waste management system.

- Power Unit: This is the source of energy for the entire system, ensuring that all other units and components are powered to function effectively.
- Sensor Unit: All the functions of the different sensors used was captured here. Various sensors such as Passive Infrared Sensor (PIR), ultrasonic and so on could identify the waste and send a signal to the next unit.
- Level Detector Unit: This unit works in tandem with the sensor unit to precisely determine how full each cabin is at any given time. It involves a simple mechanism consisting of LED and LDR sensor placed inside top of the bin. When an object (waste) covers the light, it sends a low signal to the Arduino, indicating that it is full.
- Limit Switch Unit: A limit switch is a type of switch that is activated when an object reaches a specified position or angle. It can be used to control the movement of mechanical parts, such as lids, flaps or levers. In this project, limit switch is used to check when the lid is fully

opened to a particular level or angle.

- Evacuation Button: An evacuation button is a type of emergency button that is pressed when the bin is full and needs to be emptied. It is hidden but known only to the waste management officials to avoid tampering by the public.
- Host Controller: This unit is the central processing unit that receives data from all sensors and switches, and makes decisions on which actions to take, such as activating the second cabin, opening the lid etc. Here, the host controller is Arduino Nano, and it runs the code or the algorithm that controls the smart waste bin.
- GSM Unit: This unit is used for communication purposes, sending alerts or data remotely via GSM networks about the status of the waste bins. It is used to send SMS messages to notify the waste management service about the level of waste in each bin, the need for emptying, or any errors or malfunctioning in the system. Transmission (Tx) pin of the Arduino is connected to the Receiver (Rx) pin of the GSM module. This is because the Arduino transmits the message while the GSM module receives.
- Display Unit: This unit consists of the LCD display, where real-time data and statuses of both cabins are displayed for monitoring purposes. It could show the percentage of waste in each cabin, current cabin in use, or any warnings or messages from the system.
- Reset Unit: It is specifically designed to address system malfunctioning. In the event of a failure or error in the system's operation, activating the reset unit can help in restoring normal functionality. The reset unit consists of a button that can be pressed by the user or the system administrator to reset the system and clear any faults.
- Switching Board (Cabin 1 Control and Cabin 2 Control Units): These units control opening, closing and switching between both cabins based on signals received from other units like level detection and sensor units.

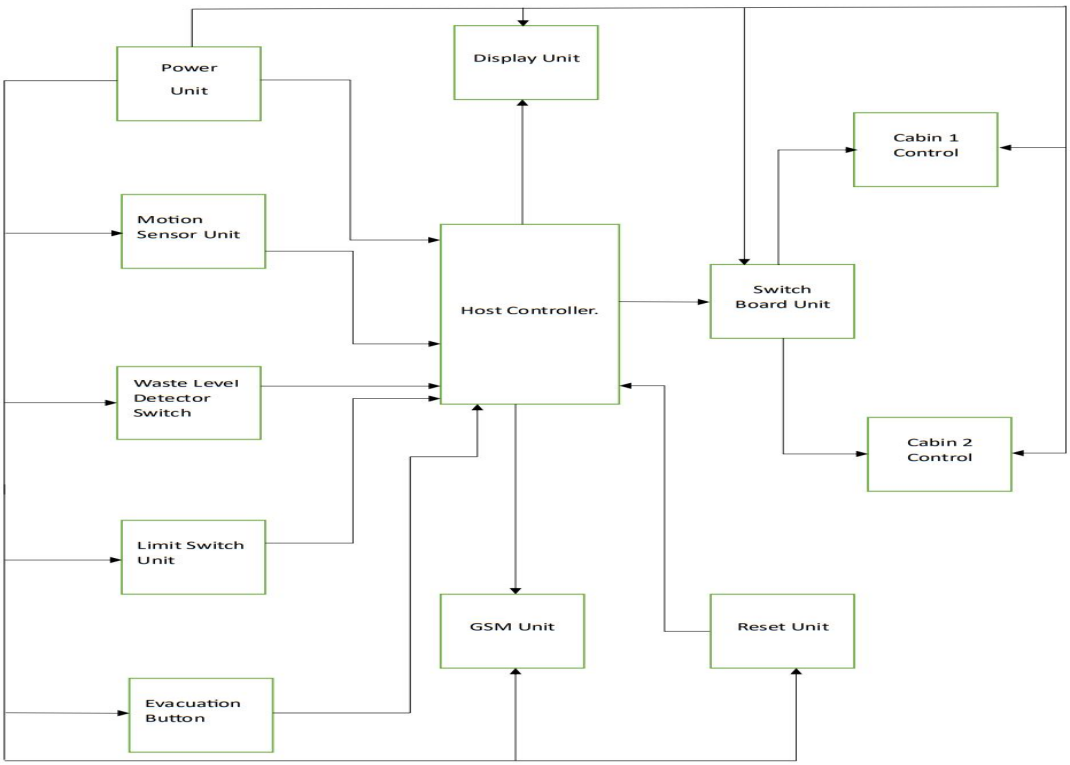

Fig 2: Block Diagram of the System

c. Microcontroller and Proximity Sensor

The proximity sensor used in this work is the PIR sensor. It has a sensing range of about 20cm to 20m. But for this work, it was pre-set to sense up to about 3m, which can be adjusted to 20m through the pre-set nub that is attached to the PIR. The sensor is interfaced to the microcontroller by connecting it directly to pin 8 of the microcontroller. The PIR sensor is mounted on the body of the waste bin so that it can be able to detect when someone is coming towards the waste bin to drop waste. When the presence of a human is detected, the PIR sensor will send a high state signal to the microcontroller. The microcontroller will in turn send a high state to the ULN 2003A driver that will energize the relay to trigger on the DC motor so that the container can be wheeled open.

d. Microcontroller and GSM Module

The GSM Module used in this work is SM900A GSM module type. The GSM module is connected directly to the pin 0 (RX) and pin 1 TX serial port (SPI) of the microcontroller. This GSM module gets a high state signal from the microcontroller anytime the waste bin is filled up. Upon receiving a high state signal from the microcontroller, the GSM module sends an SMS to the waste management authority, to alert them about the current status of the waste bin.

e. Microcontroller and Level Sensor

The level sensor in this work is responsible for monitoring the fill level of the waste bin. This was carried out by interfacing the LDR sensor directly facing the LED in the waste container to the microcontroller through the LM358 Op Amp. The LDR sensor is interfaced to LM358 Op Amp that gives feedback to the microcontroller about the current fill level of the container. The LM358 Op Amp is connected to pin 7 and pin A0 of the microcontroller. When the ray of light from the LED falling on the LDR sensor is being blocked completely by the waste in the waste bin, the LM358 Op Amp will send a high state signal to the microcontroller so as to enable it activate the GSM module. See Fig. 3 for the schematic diagram.

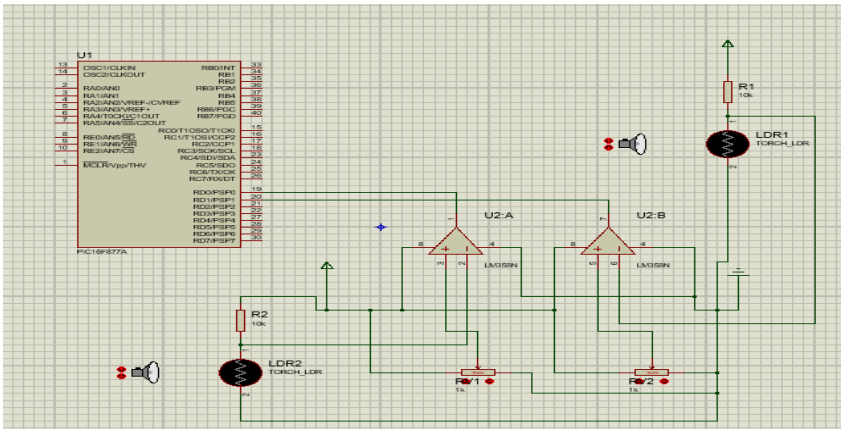

Fig 3: Schematic diagram of the microcontroller interfaced with the two LDR sensors through LM358 OPAMP

f. Microcontroller and LCD

The LCD panel used in this work is a 16x2 alphanumeric display type. This was interfaced directly to the microcontroller by connecting it to pin A4, pin 2, pin 3, pin 4, pin 5 and pin 6 of the microcontroller. The LCD acts as a graphical interface between the smart waste bin and the human intending to dispose a waste in the waste bin. During implementation of this work, we programmed the LCD panel to function at two states which are:

- Empty state and,
- Filled up state

When it is in the empty state, it is programmed to display that the bin is still empty and therefore has room to contain more waste in the trash system. The filled-up state comes up when the LM358 Op Amp which monitors the fill level of the container sends a high state signal to microcontroller indicating that the waste container is

full. See Fig. 4 for the schematic diagram.

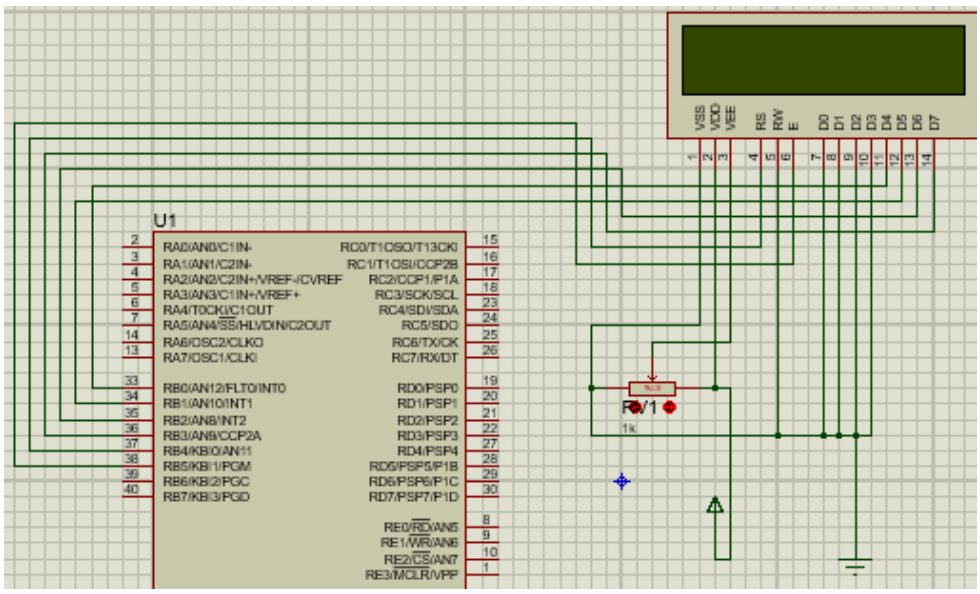

Fig 4: Schematic diagram showing how the LCD was interfaced with the microcontroller.

Fig.5 shows the entire circuit diagram, the diagram illustrates how the individual subsystems ties up together to form the entire system.

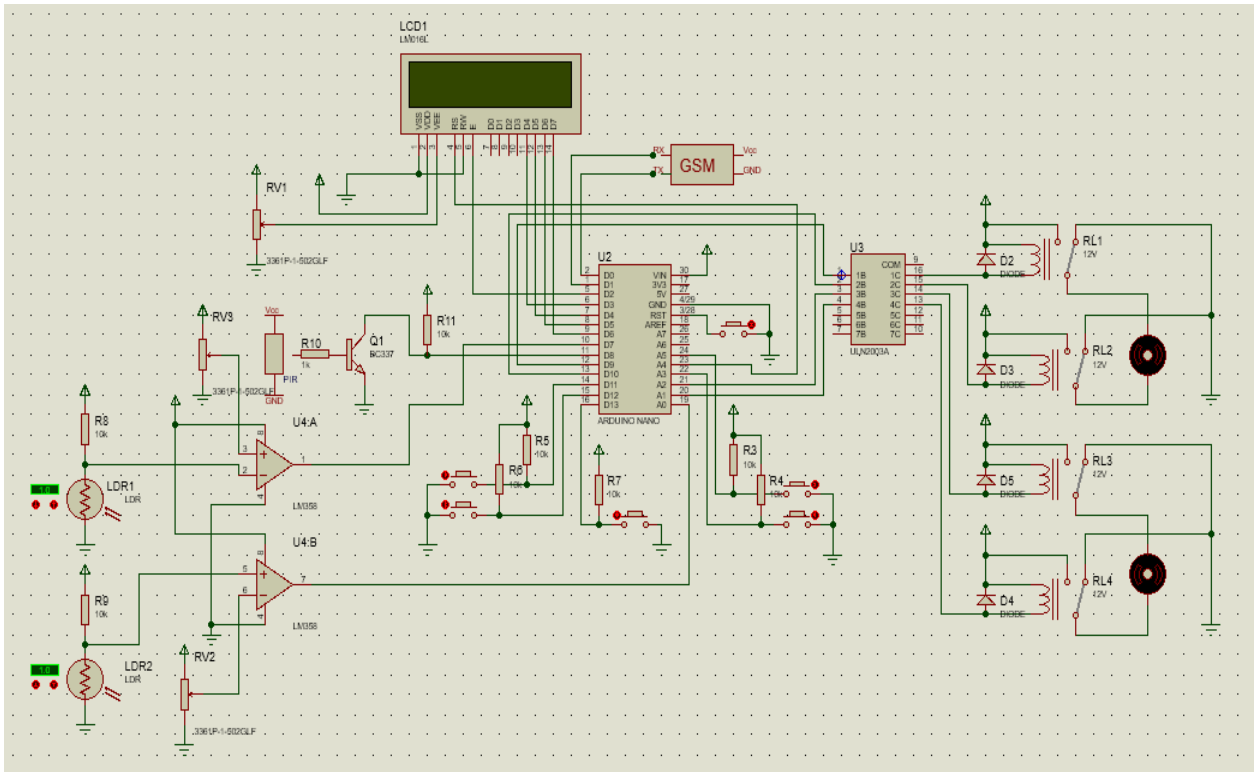

Fig 5: Circuit Diagram of the Entire System

This system operates in such a way that when someone comes closer (predefined sensing distance) to the waste bin to dispose waste, the PIR sensor senses the person and immediately signals the microcontroller. The microcontroller on receiving the signal, activates the DC motor by sending a high state signal to the ULN2003

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driver that drives the relays which eventually activates the DC motor. The DC motor then wheels up the waste bin cover. After disposal, the waste bin closes back through the help of the DC motor as well. After the closure, the microcontroller deactivates the ULN2003 driver by sending a low state signal to it which then de-energizes the relay and in turn deactivates the DC motor. The level sensor monitors the level of the waste in the waste bin. The LDR, LED and LM358 are the three main components that act as the level sensor. The LDR and LED are placed directly opposite each other in the waste container, it is designed in such a way that light rays coming from the LED will constantly fall on the LDR surface, so when the waste disposed in the container reaches a level that it begins to block the light rays from getting to the LDR, this signifies that the waste bin is full, then the LM358 Op Amp will detect a voltage drop at the LDR as a result of reduced light intensity. After this detection, the Op Amp will send a high state to the microcontroller which then activates the GSM module to communicate the waste management authority concerning the fill level of the waste bin. Upon activation of the GSM module, the microcontroller will write to the LCD to display the status fill information on the display panel after which the PIR sensor will receive a low state from the microcontroller disconnecting it from the circuit until the entire system is being reset manually on arrival of the municipal workers. The signal transmitted by the GSM module is received as text message at the local base station. After receiving the signal, the local base station decodes the waste bin location and accordingly sends a dispatch signal to the nearest monitoring vehicular system about the location of the waste bin for immediate pickup of trashes in the waste.

III. IMPLEMENTATION AND RESULS

A. System Implementation

The system was implemented in units, each section of the system was implemented separately and tested so that once all the units have given the desired results, the sections are integrated to form the smart waste management system.

a. Implementing the Output Unit of The System

The output unit of the system in this work is the LCD display, this acts as the user interface between the user and the system as a whole, it displays the current status of the system and tells the user about the next phase of instruction that is being carried out by the controller. Fig. 6 and Fig. 7 is the simulation and real time image of the LCD displaying the current status of the system.

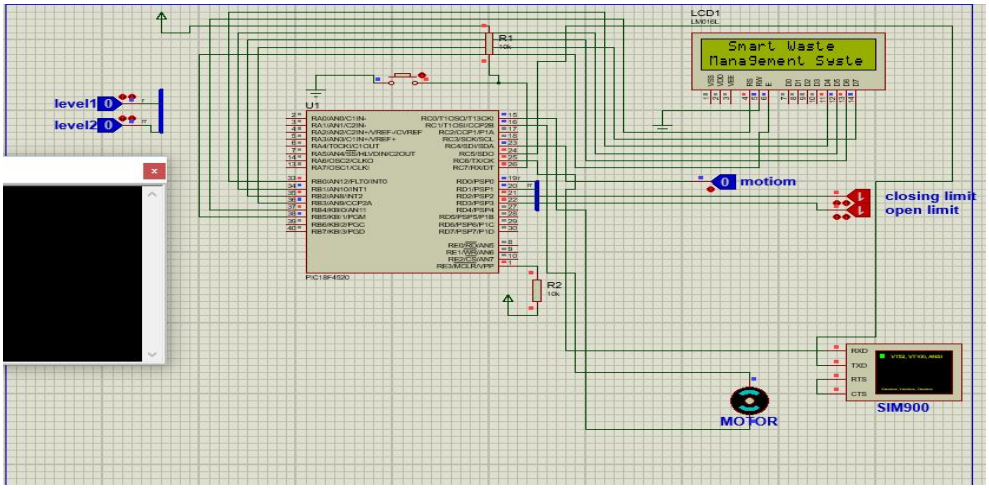

Fig..6: Proteus Simulation of the system showing its initialization mode

Fig. 7: Image view of the output unit displaying the current status of the system

b. Implementing the SMS Sending unit using the GSM Module

The reaction of this unit was as a result of the low state assigned to the level sensor when the waste bin was filled up. The microcontroller sends a high state to activate the GSM module which is connected to its serial port. The GSM module sends a message across to waste authorities notifying them that the waste bin is filled and is ready for evacuation. Fig. 8 is a circuit simulation that shows the serial transmitter displaying the SMS text that is to be sent to the waste authority.

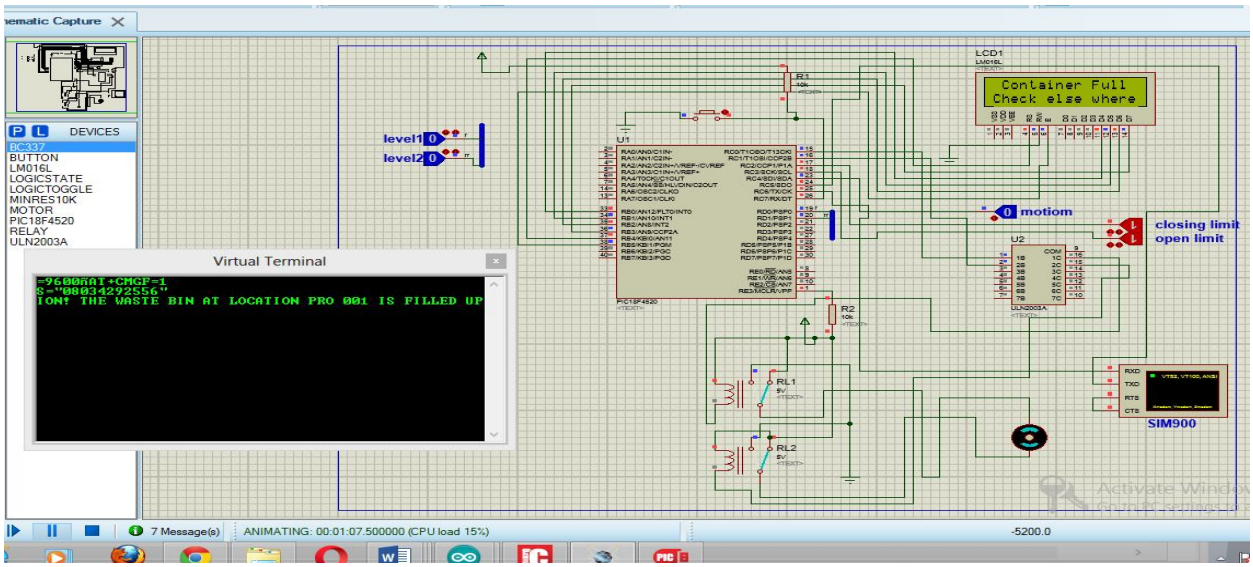

Fig. 8: Circuit simulation of the current status of the system

c. Implementing the Power Unit

This section being the part to power up the entire system to function as it should. This is an essential component of a smart waste bin system, as it provides the energy needed for the sensors, microcontrollers, and communication modules to function. The main item used in this section was the power jack and power pack, see Fig. 9. A power jack is a device that allows a smart waste bin to be plugged into an AC power source, such as a wall outlet or an extension cord. A power jack can be used to implement the power unit of a smart waste bin system, as long as the system has a compatible voltage and current rating, thus can provide a steady and reliable power supply to the smart waste bin. In this design, we did the following: Stepping down the voltage to 12V, Rectifying AC to DC using diodes, Filtering using capacitors. Regulate the output using a regulator of 5v. The

output of our power pack is 12v but we also need 5v so we use a DC-AC converter to step down the 12volts. Finding the resistance going to the LED:
V = IR; V = 2V; I = 10mA, i.e.; 0.01A and R = 200ohms.

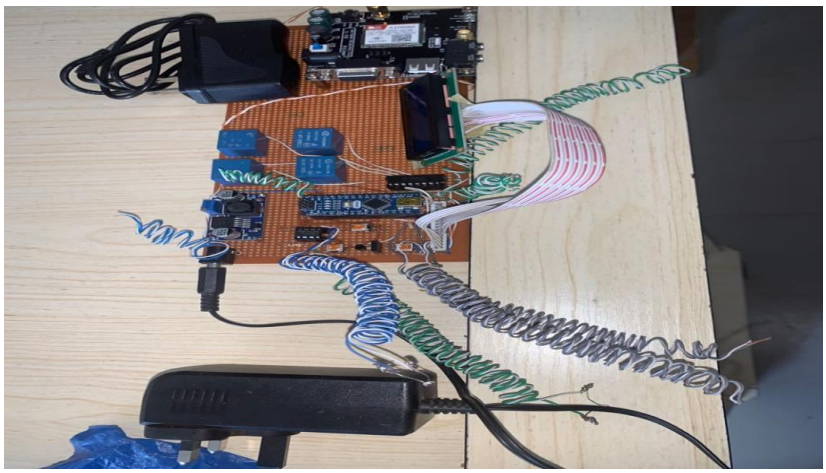

Fig. 9: Power unit connected to the Vero Board

B. Assembling and Testing of the Project

The electronic components were soldered on a Vero board and placed inside an adaptable box after which the box, was fitted to the metallic waste container as shown in Fig 10 and Fig. 11 respectively.

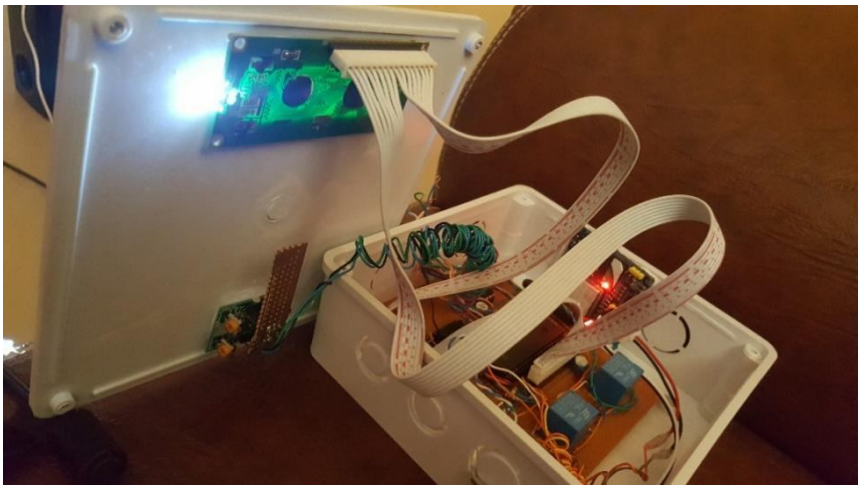

Fig. 10: Image of the system assembled together in an adaptable box

Fig. 11: Adaptable box fitted on the waste container

a. System Testing

After the units were interconnected, an open circuit test was carried out where the individual connections of the system were tested to ensure continuity. Satisfied with the continuity test, the power supply test was carried out to ensure that the power requirements of the various branches were met. The functionality of the individual sensors and components were also tested. The testing of the application was not done at once after it was completed, rather each unit of the application was tested individually. The second unit was not tested until the first unit gave the expected result and until it was working according to the necessity of the application. After all of the units were working correctly, the units were kept together and then the whole system was developed and tested. It was easy to Fig. out the bugs and the problem of the system as the behaviour of each unit was known while testing it. It would be impossible to Fig. out the problems and the bugs in the system if the system was developed and tested after it was completed.

C. Results and Performance of the System

The aim of the work was to implement a smart waste management system and the goal was met. The microcontroller unit responds to the signals sent by the sensors according to the logic states assigned to them i.e. what they sensed from the environment. The microcontroller also triggers the GSM module to send an SMS to the waste authorities anytime the logic states of the level sensors are both high. Table 1 to Table 3 shows the test result of the system.

Table 1: Test result table of the proposed system.

UNIT	LOGIC STATE	MICROCONTROLLER ONGOING OPERATION	WASTE CONTAINER STATUS	OUTPUT OF THE SYSTEM AS DISPLAYED BY THE LCD PANEL
Motion sensing	Low			EWM system in operation
Motion sensing	High	Checking fill level of waste container	Not full	Opening for waste disposal
Motion sensing	High	Checking fill level of waste container	Full	Container full check elsewhere
Level sensing (both LDR)	High	Activating DC motor	Not full	Opening for waste disposal
Level sensing (both LDR)	Low	Activating GSM module	Full	Container full check elsewhere

GSM module	High	SMS sending in progress	Full	Waiting for waste evacuation
Evacuation button	LOW	Activating DC motor	Full	Opening for waste evacuation
Evacuation button	LOW	Activating DC motor	empty	Closing cabin

Table 2 shows the System availability on demand for the electronic waste bin system on ten (10) trials.

Table 2: System availability on demand for the electronic waste bin system

Number of trial (N)	Result
1	successful
2	successful
3	successful
4	successful
5	successful
6	successful
7	successful
8	successful
9	successful
10	successful

Table 3: shows the latency experienced at every successful waste bin opening.

Number of trial (N)	Waste bin latency (sec)
0	0
1	05
2	05
3	07
4	05
5	06
6	07
7	05
8	05
9	06
10	05
Total average	5.6

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D. Discussion on the System Availability on Demand and Latency Experienced at Every Successful waste Bin Opening of the System

The service availability on demand was ascertained by switching ON and accessing the functionalities of the system. This was done ten (10) successive times and each of them was successful as shown in Table 2. The latency (the time delay for the waste bin to be fully opened and ready for use) of the system was also noted as shown in Table 3, it can be seen that its average latency is 5.6 sec, giving that the maximum allowable latency for such a system should be 20 seconds, it means that the latency of the existing system is 28.0% of the maximum allowable latency as shown below;

$$\text{latency} = \frac{\text{Average}}{20} x100\%$$

$$\text{latency} = \frac{5.6}{20} x100\%$$

$$\text{latency} = 28.0\%$$

The Fig.12 shows the graphical representation of the latency experienced at every successful waste bin opening.

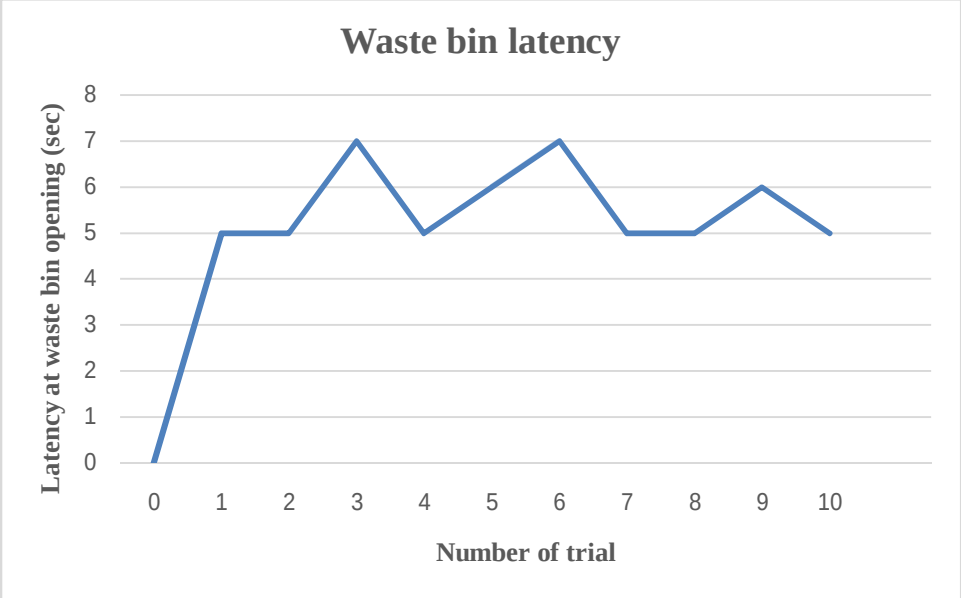

Fig.12: the graphical representation of the latency experienced at every successful waste bin opening.

E. Performance Evaluation of the Electronic Waste Bin System

The developed electronic waste bin system was evaluated by comparing its availability on demand with that of the existing waste bin system. Table 2 shows the availability of the electronic waste bin system. It can be seen that the system success rate which is a function of the system's availability is the same as the existing system, because the existing one is always available. This means that the intelligent features incorporated in this system had zero (0) impact on success rate or system availability.

On the other hand, the Fig. 12 shows the graphical representation of the latency experienced at every successful waste bin opening, it can be seen that the automation introduced an average delay of 5.6 seconds (28.0%) into the electronic waste bin system.

Environmental safety and availability are the key performance indicators for evaluating environmental waste bin system. In this system, the safety of the environment is of great importance, which is provided by this system, while availability which is measured by latency of the system, is not critical as compared to environmental safety.

IV. CONCLUSION

In this paper, a smart waste bin system to address the challenges associated with waste management in smart cities was devised. The system effectively collects waste, and can be used in future waste generation forecast. Connecting bins wirelessly to a central can help in timely waste collection, preventing overflow and environmental preservation. The Smart Waste Management system also allows continuous monitoring of waste bins. It generates standard pickup routes, focusing only on containers that require collection. The advent of smart bin technology contributes to reducing pollution and waste removal costs. It benefits all stakeholders in waste management and promotes cleaner communities. Cities embracing smart waste bins can have a more sustainable future with efficient waste collection. Optimization of the system was achieved by utilizing an Arduino board-based microcontroller integrated with ultrasonic sensors for the optimization of the waste bin. The developed smart waste bin was evaluated with three test cases in order to determine the servo time response. The waste bin was found out to have a better servo time response, and was efficient and effective in monitoring waste.

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