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Utilisation of Internet of Things to Design a Gas Detector Device for Monitoring Gas Leakages in Underground Mines

Nuhu Ndaka AGORO[1*], Kayode Augustine IDOWU[1], Adeola ADEGBUYIRO[2]

[1]*Department of Mining Engineering, University of Jos, Nigeria*
[3]*Nigerian Institute of Mining and Geosciences, Jos, Nigeria*

agoronuhu88@gmail.com, idkayus@gmail.com, ademolaadebuyiro@gmail.com

*Correspondence: agoronuhu88@gmail.com; Tel.: +2349054112063

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Abstract: *The primary goal of the research was to design, evaluate, and fabricate a gas detection device using the Internet of Things (IoT). This subject matter was appropriate as it addressed a fundamental and significant facet of contemporary living in the mine. The objectives of the project were to design a gas detector device using an Arduino microcontroller, construct a gas detector device that rings a buzzer and sends an alert to an Android device on detection of harmful gas in the mine, and implement a gas detector device using the internet of things. Background data on gas detection technologies, pertinent standards and guidelines, field research, and durability factors related to the mines were gathered in order to define a test method. Arduino Uno was used as the control unit with other necessary components. Upon completion of the project, the gas detector device using the Arduino Uno was tested and found to work optimally.*

Keywords: Internet of Things, gas detector, Arduino Uno, Arduino IDE, Bluetooth HC-05.

1. INTRODUCTION

There have been significant gains when it comes to safety, both in surface mines and underground mines, as a result of the frequent implementation of safety measures, worker education and training, and health and safety regulations in modern mines [1]. Accident harmful gas leaks are one of the primary causes of mine workers fatalities. By implementing Internet of Things, gas leakages can be quickly identified and addressed [2]. The risk of exposure to hazardous gases that may be present in significant quantities and have the potential to have fatal physiological effects on humans makes working conditions in underground mines perilous. Timely detection of these hazardous gases is an essential challenge that must be overcome for the miners' safety inside the mine.

Riruwai (a mining town) is a headquarters of Doguwa local government area (LGA) that was established in 1996 from Tudun Wada LGA. It is a tropical continental climate with rainfall above the average that is obtainable in the state due to the effect of relief. The highest point in the study area reaches up to 1230 m above sea level. The relief exercises control on temperature, rainfall and other climatic elements such as wind and pressure. The LGA composes of Hausa, Fulani, and other minor tribes as shown in Figure 1. The area is within the ring complex of past volcanic eruptions and hence characterize by rough terrain. Rich and fertile soils are found around the valleys and foot of slopes which support vegetation and cultivation of rice, maize and sugar cane. Steep slopes and rocky surfaces are devoid of significant vegetation and even constructions are barely absence. Riruwai shares a border with Bauchi by East and Tudun Wada at North. It has a distance of over 150 km from Kano city and hence has more interaction with Kaduna and Plateau states due to their proximity. Mining tunnels of different dimensions are still conspicuous in the study area. It occupies an area of 129 square kilometers and is located between latitudes of 10°43"97"N and 10°45'01'N and longitudes of 8°43"3E and 8°47'39E. Figure 1 shows the map of the study area.

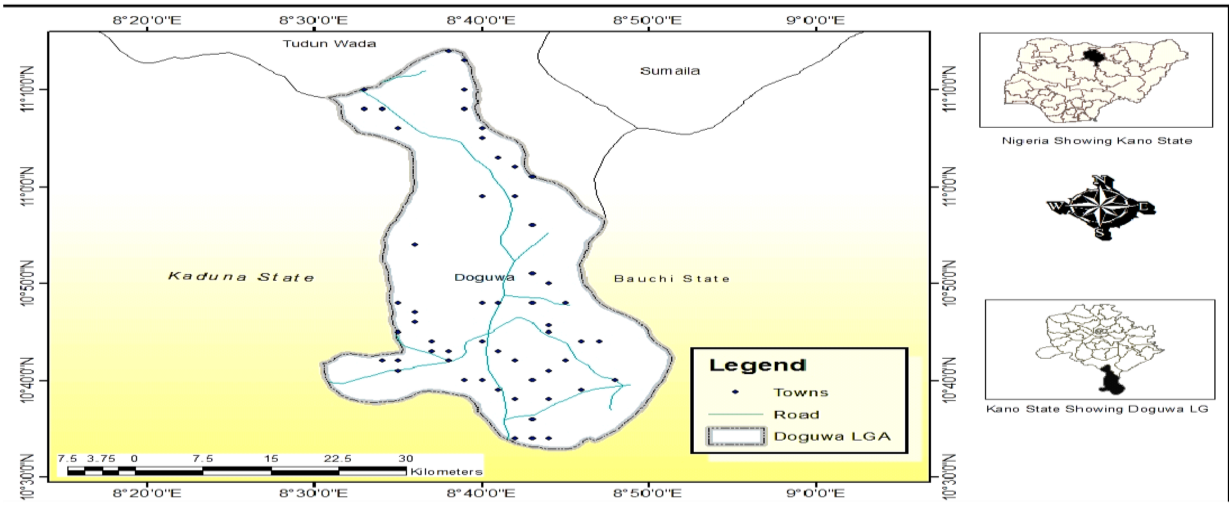

Figure 1: Map of the study area

2. LITERATURE REVIEW

2.1 Internet of Things (IoT)

The term "Internet of Things" (IoT) refers to the expansion of Internet connectivity into real, everyday objects. The Fourth Industrial Revolution, or Internet of Things (IoT), is a new revolution in the possibilities of the internet-connected world [3]. Due to these devices having sensors, internet connectivity, and other technological features, they can interact and communicate with one another via the Internet. These devices are remotely controlled and observable. IoT is used in the mining industry to improve safety procedures and maximize productivity and cost. The Internet of Things (IoT) enables remote object sensing and control via an existing network infrastructure [2]. It could also be used as a means for developing artificial intelligence needs in mining (where implied).

It is a given that mining is the most labour-intensive and risk-prone activity. There is a need for the industry to deploy advanced technologies to aid ease of critical work taking place in lead mines. That is where the Internet of Things (or IoT) can make all the difference.

2.1.1 Benefits of internet of things in mining

i. Enhances efficiency

The ability of the Internet of Things to collect a mass of real-time data on all aspects of operations in mines means this data can then be analysed using Artificial Intelligence and machine learning, which it then uses to make recommendations for miners, such as reserves for exploration. This makes exploration and other parts of the mining process more streamlined, saving time and improving results.

ii. Improves health and safety in mines

Internet of Things plays a key part in mining safety. It has a lot of possible uses that can help protect the health and safety of employees working in mines, especially underground mines which are known for being risky environments to work in. Enabling real-time tracking of air ventilation and levels of hazardous gases is just one example. IoT can also help miners to monitor the mines for vibrations that give a warning a tunnel is about to cave-in and indication of structural weaknesses. Also, in some cases, it provides the use automated vehicles for operations in place of sending humans into underground tunnels in such vehicles.

iii. Enables the tracking of workers' health

This is an extension of health and safety in mining but on an individual physical level. IoT allows employers to monitor personal protective equipment (PPE) on workers that collect data on their physical states such as their body temperature, heart rate, and perspiration levels. PPE devices send alerts when something looks wrong with one of these, giving early warnings to indicate the employee may be in danger or at risk of being in danger, such as that they are overexerted. This is a useful preventative measure to protect employees' health on the job [4].

2.2 Methane Gas

Methane is a colourless, odourless gas that burns very easily. It is also lighter than air. It is present in quantities ranging from 60% to 80% and constitutes the majority of natural gas. [5]. As the miners approach the deeper sections of the mine, methane is released into the atmosphere. In certain situations (when there is a 5% to 15% concentration of methane in the air), this methane may ignite and cause a string of explosions in addition to suffocating the miners to death. In the mine, it is crucial to identify methane in the air as soon as possible. The discovery of methane gas too late has resulted in numerous mine explosions and many fatalities among mine workers. With the help of the MQ-4 sensor, this gas can be detected.

2.3 Carbon Monoxide Gas

With the chemical formula CO, carbon monoxide is a poisonous, flammable gas that lacks colour, taste, odour, and density, being slightly less than that of air [6]. In general, this gas is the main toxic gas in underground mines. It exhibits a strong affinity for haemoglobin. When carbon monoxide and haemoglobin combine to produce carboxyhaemoglobin, it impairs breathing and increases the risk of asphyxiation. This gas may be produced during mining operations by the burning of carbon-containing materials, such as gasoline, wood, diesel fuel, paper, explosives, or welding gases. The range of 1-70 ppm is the globally recognized limit for carbon monoxide in an underground mine. The MQ-7 sensor has the ability to identify carbon monoxide.

2.4 Gas Sensors

Gas sensors are frequently used in safety systems to identify the various gases that are present in a particular place. The electrical response of sensors varies proportionally with the required gas concentration. Thus, the instrument holding it will alert adjacent personnel if the concentration rises above the threshold concentration level, and it may also trigger other corrective actions like increasing ventilation or turning off the power [7]. A relatively new invention, smoke or gas detectors gained widespread use in the 1970s and 1980s. These consist of air sampling detectors, catalytic diffusion detectors, ionization detectors, optical or photoelectric detectors etc. These detectors can be of many forms and operate according to various principles. Each of these categories has particular uses in particular situations [8].

3. METHODOLOGY

3.1 Materials

Materials used include:

i. Bluetooth HC-05
ii. MQ-4 sensor
iii. MQ-7 sensor
iv. Arduino Uno
v. Jumper wires
vi. Solderless breadboard
vii. LCD screen
viii. LED bulbs
ix. Buzzer
x. Arduino IDE
xi. Ardu tooth

3.1.1 Bluetooth HC-05

The HC-05 was a popular module that added two-way wireless capability to the research. This module was used to interface with two microcontrollers, like Arduino, and any Bluetooth-capable device, like an Android phone. The HC-05 operates in two modes: AT command mode allows you to modify the default device settings, and Data mode allows you to send and receive data from other Bluetooth devices as shown in Table 1.

Table 1: HC-05 description

Pin Number	Pin Name	Description
1	Enable / Key	This pin is used to switch between AT command mode (set high) and data mode (set low). It is in data mode by default.
2	VCC	Powers the module. Connect to +5 V supply voltage
3	Ground	Ground pin of module, connect to system ground.
4	TX – Transmitter	Transmits serial data. Everything received via Bluetooth will be given out by this pin as serial data.
5	RX – Receiver	Receive serial data. Every serial data given to this pin will be broadcasted via Bluetooth
6	State	The on-board LED that the state pin is attached to can be used as feedback to determine whether Bluetooth is functioning properly.
7	LED	Indicates the status of module
8	Button	Used to control the Key/Enable pin to toggle between data and command mode

It is easy to pair the HC-05 module with microcontrollers since it operates using the Serial Port Protocol (SPP). Figure 2 shows the image of the Bluetooth HC-05.

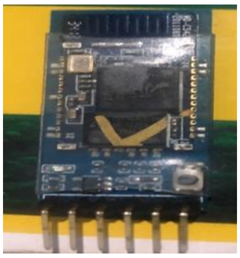

Figure 2: Bluetooth HC-05

3.1.2 MQ-4 sensor

Tin dioxide and ceramic tubes make up the MQ-4 gas sensor. The heater and electrode are affixed to a layer. For sensitive components, the heater produces the optimal working environment. When the gas is present, the sensor's conductivity rises and the gas concentration rises. Table 2 shows the pin configuration of the MQ-4 sensor.

Table 2: Pin configuration of the MQ-4 and MQ-7 sensor

PIN NAME	DESCRIPTION
VCC	Power supply input
GND	Power supply ground

PIN NAME	DESCRIPTION
Analogue input/output	Provide analogue input and output of voltage

It also has the following characteristics:

1. Characteristic of gas: 5000 ppm methane
2. Sensitive resistance: 1 kilo ohm to 20 kilo ohms in 5000 ppm methane
3. Response time is less than or equal to10 s
4. Ambient temperature when working is -20 ℃ ~ + 55 ℃
5. The humidity when working is less than or equal to 95% RH.

The image of the MQ-4 sensor is seen in Figure 3.

Figure 3: MQ-4 sensor

3.1.3 MQ-7 sensor

Carbon monoxide (CO) detection is the primary application for the MQ7 semiconductor sensor. The MQ-7 gas sensor is composed of Tin dioxide (SnO_2) and a small Al_2O_3 ceramic tube. This is demonstrated in Figure 4. The heater and electrode are anchored into the crust. The heater creates the ideal working environment for delicate components. Along with the increase in gas concentration, the sensor's conductivity has increased. Table 2 shows the pin configuration of the MQ-7 sensor.

Figure 4: MQ-7 sensor

3.1.4 Arduino Uno

The Arduino Uno is one microcontroller that the system makes use of. The main component of the system is the Arduino board. Every component has an external interface to the board and is set up to function in tandem with one another. It should be able to withstand an input voltage of at least 8 V and current of 30 mA and also have a port to insert the commands for the device. Table 3 shows the Arduino Uno pin configuration. The Arduino Uno image is shown in Figure 5.

Figure 5: Arduino Uno

Table 3: Arduino Uno pin configuration

Pin Category	Pin Name	Details
Power	Vin, 3.3 V, 5 V, GND	Vin: Input voltage to Arduino when using an external power source. 5 V: Regulated power supply used to power microcontroller and other components on the board. 3.3 V supply generated by on-board voltage regulator. Maximum current draw is 50 mA. GND: ground pins.
Reset	Reset	Resets the microcontroller.
Analog Pins	A0-A5	Used to provide analog input in the range of 0-5 V
Input/output Pins	Digital Pins from 0-13	Can be used as input or output pins.
Serial	RX (0), TX (1)	Used to receive and transmit TTL serial data.
External Interrupts	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.
SPI	10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Inbuilt LED	13	To turn on the inbuilt LED
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide reference voltage for input voltage.

3.1.5 Jumper wires

When necessary, jumpers are often used in conjunction with breadboards and other prototype tools to enable quick circuit adjustments. Three types of jumpers are commonly available: male-to-male, male-to-female, and female-to-female. The two sorts of wires can be distinguished by their ends: male ends feature an extended pin that enables them to be connected into objects, while female ends are used for plugging things into. Male-to-male jumper wires are the most common and often used type; they are required to connect two ports on a breadboard.

3.1.6 Solderless breadboard

A breadboard has several uses. You can construct temporary circuits using a breadboard and change out components as needed before adopting them to a permanent circuit board. This is especially helpful if you are building the circuit from scratch and need to replace components on a regular basis. Figure 6 shows the image of the solderless breadboard.

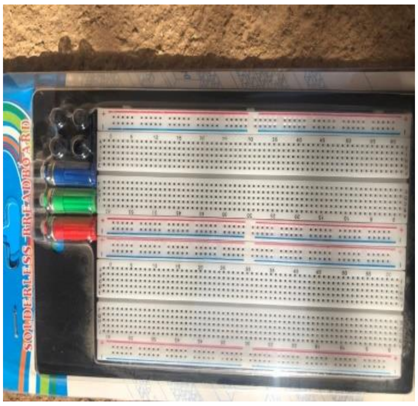

Figure 6: Solderless breadboard

3.1.7 LCD screen

The LCD screen displays the message "Gas detected" when the sensors pick the gas emitted. This information was originally coded in the program to alert the user to the danger. The LCD's registers for the message it is displaying, data and command are all editable using the register option. The pin layout of the LCD is displayed in Table 5. Figure 7 shows the image of the LCD Screen

Figure 7: LCD screen

Table 5: The pin layout of the LCD

PIN NO	PIN NAME	PIN DESCRIPTION
1	VSS	Ground
2	VCC	+5 voltage supply
3	VEE	Contrast control
4	RE	Register selects
5	RW	Read/write
6	E	Enable
7	D0	Data pin 0
8	D1	data pin 1
9	D2	Data pin 2
10	D3	Data pin 3
11	D4	Data pin 4
12	D5	Data pin 5
13	D6	Data pin 6
14	D7	Data pin 7
15	LED+	Led +5 V
16	LED-	Led – ground

It also has the following characteristics;

i. Character Count: 20 characters over 4 lines
ii. DC Input Voltage Scope 4.5 V to 5.5 V
iii. The LCD's operating voltage is 5 V DC.
iv. Forward Current for Backlight: 120 mA
v. 4.1 to 4.3 volts for the forward voltage of the backlight
vi. Module Dimensions:9.8 × 6 × 1.2 cm
vii. The interface comprises the following buttons: VSS: Ground, VDD: DC 5 V power supply, and VL: LCD contrast adjustment.
viii. When high level changes to low level, it becomes active.

3.1.8 LED bulbs

The LED bulbs in the device were used to indicate the detection of the gas. Three different bulbs were used. The amber bulb (for the detection of methane), the red bulb (for the detection of carbon mono oxide) and the blue bulb (for when a gas is detected and when it is cleared).

3.1.9 Buzzer

The output device known as the buzzer emits a buzzing sound when gas is detected. It is an output device that is attached to the microcontroller. The buzzer receives the gas detection signal from the sensor and forwards it to the micro controller. An active buzzer that was linked to the Arduino was utilized in the gadget. When an active buzzer is attached to a battery, it can emit sound directly. When the positive and negative terminals are correctly connected to the power source, the oscillator that is built within it produces sound on its own. The easiest buzzers to operate are active ones.

3.1.10 *Arduino IDE*

The computer code is usually written with the aid of the Arduino IDE (Integrated Development Environment) and uploaded to the actual board. The Arduino IDE is the software that interacts with and gives commands to the hardware components of the circuit.

3.1.11 Ardu tooth

This is the simplest way to view Arduino sensor data in real time right on an Android device. The values of up to 6 sensors can be displayed at once via the App. All that is necessary is to put some code onto your Arduino board, connect a Bluetooth module (such as the HC-05), and pair your Android device with the Bluetooth module via the System Preferences. The app will create a Bluetooth-Serial through wireless connection between the Arduino and the smartphone.

3.2 Design Methodology

The concept behind the gas detector device is that the effects of gas adsorption on the surface of an active material can be transformed into a detectable signal by means of variations in electrical, mechanical, thermal, optical, and magnetic (magnetization and spin) properties. The device has an LCD display, an Arduino Uno, gas sensors, a Bluetooth HC-05, and other parts or components attached to a bread board. The Arduino Uno, Bluetooth HC-05, LEDs, LCD screen, buzzers, and gas sensor are all connected to the board via jumper wires that are placed on it. The Arduino Uno, the main control component of the system, performs the following tasks.

i. The output signal of the sensor, which serves as an input to Arduino and performs signal conditioning.
ii. The detection findings shown on the LCD screen show the gases' exposure levels.
iii. The buzzer activates and emits a beeping sound.
iv. The Ardu Tooth application, which communicates with both the Arduino, Bluetooth HC-05 and the smartphone, will also be used to send an alarm to the mine's chief engineer.

3.2.1 Block diagram

The design and implementation of system is illustrated in the block diagram as shown in Figure 8.

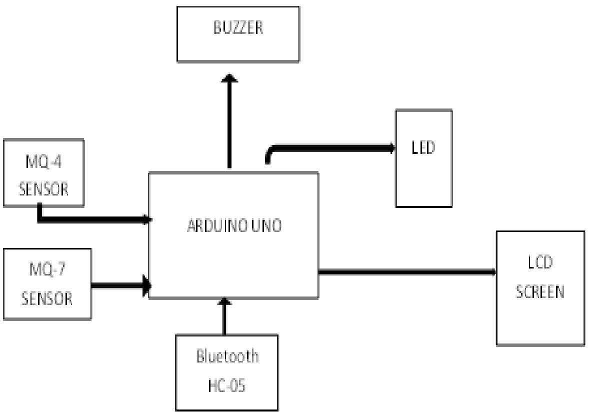

Figure 8: Block diagram of the system

3.2.2 Flow chart

A flow chart in Figure 9 is an algorithm that shows the pattern in which the code implemented in the Arduino microcontroller interfaces with the other components used.

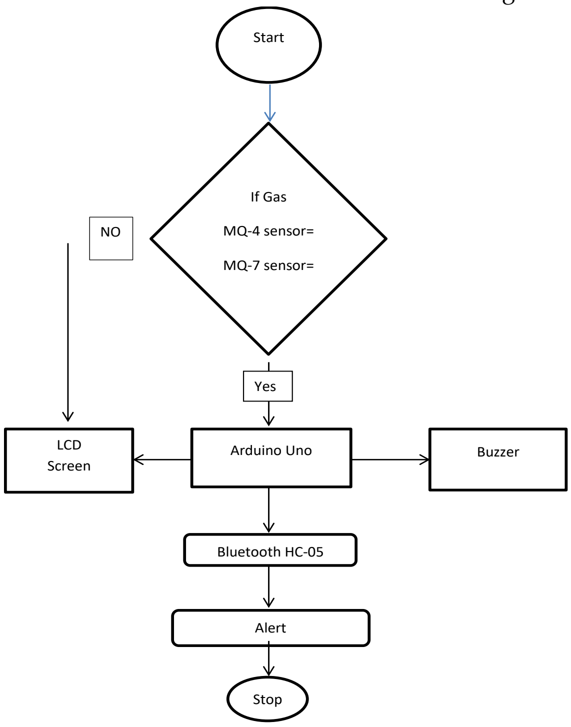

Figure 9: Flowchart of the system

3.3 Connection Methodology

1. Arduino Uno
   a. Connected the breadboard's positive rail to the 5 volts pin.
   b. Connected the breadboard ground rail and the GND pin together.
   c. Joined the A4 pin (SDA), LCD module's SDA pin and the Bluetooth HC-05's SCL pin together.
   d. Attached the A5 pin (SCL) to the LCD module's SCL pin and the Bluetooth HC-05's SCL pin.
   e. Connected the RX pin of the Bluetooth HC-05 to the TX pin of the Arduino Uno.
   f. Connected the Arduino Uno's RX pin to the Bluetooth HC-05's TX pin.
2. Bluetooth HC-05
   a. Use the breadboard's +5V to power the module.
   b. Joined the module's RX pin to the Arduino Uno's TX pin.
   c. Connected the module's TX pin to the Arduino Uno's RX pin
   d. Attached the VCC pin to the breadboard's positive rail.
   e. Connected the GND pin to the breadboard's ground rail.
3. MQ- 7 sensor
   a. Attached the VCC pin to the positive rail of the breadboard
   b. Attached the GND pin to the ground rail of the breadboard
   c. Connected the A0 pin (analog output) to the available analog input pin on the Arduino Uno
4. MQ-4 sensor
   a. Attached the GND pin to the ground rail of the breadboard

b. Attached the VCC pin to the positive rail of the breadboard
c. Attached the A1 pin (analog output) to the available analog input pin on the Arduino Uno

5. Buzzer
   a. Connected the positive leg of the buzzer to a digital output pin on the Arduino Uno
   b. Connected the negative leg of the buzzer to the ground rail of the breadboard
6. LCD screen
   a. Connected the VCC pin to the breadboard's positive rail
   b. Connected the GND pin to the breadboard's ground rail
   c. Attached the SDA pin to the Arduino Uno's A4 pin (SDA).
   d. Attached the SCL pin to the Arduino Uno's A5 pin (SCL).

During the programming phase of the work, the thresholds of the sensors were taken into consideration. The lower the threshold of the sensor, the more sensitive the sensor becomes.

3.3 Circuit Diagram

The circuit diagram is a map designed to outline or show the connection of the various components either in series or parallel. Figure 10 is a pictorial view on how the components are connected to form a circuit.

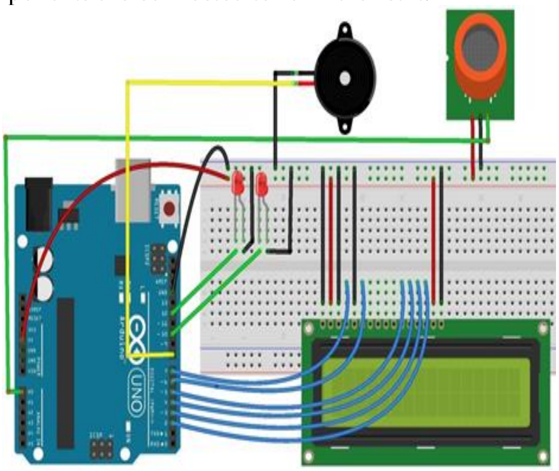

Figure 10: Circuit diagram of the system

4. RESULTS AND DISCUSSION

Before power was applied to the circuit, a continuity test was performed to make sure that the circuit or its components were properly linked together. After power was applied to the circuit, the entire circuit had been troubleshot, and then the various components of the entire system were tested to make sure they were in good operating condition. Figure 11 shows the image of the system before being coupled.

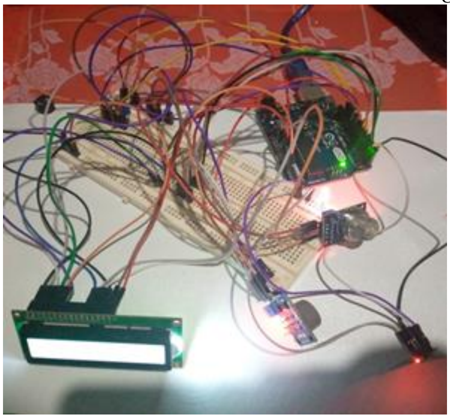

Figure 11: The complete coupled system

4.1 The Complete Coupled System

The apparatus operated satisfactorily, according to the results attained throughout the building stages and following any necessary troubleshooting. As seen in Figures 12 and 13, the Ardu tooth will be reading normally prior to any gas detection. Once a gas is detected, it displays the gas's level and indicates whether it is harmful. It is claimed that the system reacts to its operation.

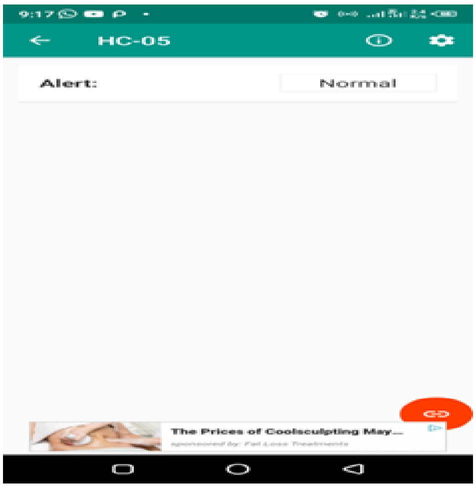

Figure 12: Before gas was detected

Figure 13: After gas was detected

5. CONCLUSION

In order to address the shortcoming of more conventional methods, a novel framework for toxic gas discovery checking and warning has been established in this study employing Bluetooth modules and the internet of things. For the two gases listed in the study's purview, it only used two sensors. Additionally, the MQ-4 sensor for methane gas and the MQ-7 sensor for carbon monoxide were adjusted to 100 ppm, which is the globally accepted threshold for the two gases in the subterranean mines. The main purpose of the gas detection system is to safeguard persons and property by detecting and eliminating gaseous hazards in the mine at all times of day or night. On gas detection, the system sounds a buzzer to signal an emergency. It also features a display screen that shows the levels of various gases. Also, an android app was used to implement the internet of things.

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