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Development and Performance Evaluation of a Household Liquefied Petroleum Gas Monitoring and Leakage Detector

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Abstract- The percentage of death and material losses as a result of the explosion of household liquefied petroleum gas (LPG) has risen in recent years, hence the need for a suitable gas leaking detection and alert system. Gas level monitoring and leakage detection device consist essentially of two main units; LPG volume monitoring unit and leakage detection unit. LPG volume monitoring unit consists of load cells, HX711 signal amplification module, and infrared temperature sensor. 50 kg E-shaped load cell was used for this work due to its relatively small size, lightweight and ease of installation. The system is powered with 9 volts' battery. The leakage alert mode is triggered by a signal from the gas sensor when the concentration of LPG in the controlled atmosphere is more than the programmed safe value. On entry into this mode, a warning alert is displayed on the screen and the buzzer emits a continuous beep until the level of the LPG falls below the programmed level. A rectangular platform houses the load cells and signal amplification module. The alert system was programmed to produce three short beeps on the start of the device whenever the cylinder volume is less than 0.5 kg. The standard safe allowable concentration of LPG in the atmosphere was put at 1000 ppm (part per million) and once this is exceeded, the system automatically switches to the alert mode. The developed system performs satisfactorily, is safe to use, and therefore recommended for domestic use.
Keywords: Cooking gas, gas cylinder, load cell, microcontroller, monitoring system

1. INTRODUCTION

One of the most common uses of liquefied petroleum gas (LPG) is essentially as a household cooking fuel due to a variety of reasons ranging from being a relatively clean source of fuel compared to biogas and wood to its low greenhouse gas emission rating. It is also a relatively fast and easy means of cooking, providing instant heating at 8-9 times the efficiency of wood. The level of use of LPG has increased worldwide in recent time because of its convenience. It is more comfortable, efficient and heat quickly than the recent technology of biomass stoves. LPG stoves reduce time spent in cooking, could be regulated, easily transportable, and provide a cleaner kitchen [1], [2].

Despite the aforementioned advantages associated with the use of LPG for household cooking, there exist a variety of downsides with its usage as cooking fuel. LPG exists as a colourless, odourless, and highly flammable liquid which readily evaporates into gaseous state. Hence, the addition of odourant to help detect leaks. When there is a leakage, LPG evaporates quickly to form a thick big cloud of gas. And because butane/propane is heavier than air, it falls to the ground level, and it can transport for relatively long distance at ground level [3]. In the process of this displacement, if the gas meets a source of ignition, it will explode because of its volatility. It has been reported that LPG can cause cold burns to skin. It can lead to loss of consciousness due to the interruption of breathing and subsequent anoxia (as it acts as an asphyxiant) from choking at high concentrations [4], [5]. The issue of explosion or fire hazard resulting from undetected gas leakage from LPG cylinders and pipes has posed to be a very big problem over the years [6]. Different inventions have been made on the way to monitor gas leakage of which gas sensors are introduced to detect any leakage [7], [8]. Sitan and Ghafar [2] worked on detecting gas leakage by using two types of alarm alert, and two sensing unit. This was connected with an online monitoring to alert the user. Apeh et al. [9] also worked on a gas leakage detection device that will alert the subscriber by using alarm system, and automatic gas shut off system. Ramya et al. [10] also implemented a similar design but without the sprinkler. It detected the level of gas concentration in the air, and automatically notified the user when the quantity of gas in the cylinder goes below a set threshold. This will prompt the user it is time to refill [11]. Another researcher carried out some works in the area of detecting gas leakage and monitoring, by introducing cellphone alerts (beep), turning-off of gas supply, and send notification to the user [2]. These developments have broader focus beyond kitchen gas leakages into industrial usage.

This work is aimed at designing and constructing a functional gas level monitoring system for LPG cylinders with an integrated leakage unit for households. This will provide an easy and reliable way for managing and running gas vending business, attain maximum reliability for the effective use of liquefied petroleum gas, and evaluate the performance of the developed device

2. METHODOLOGY

The gas level monitoring and leakage detection device consist essentially of two main units; the LPG volume monitoring unit and the leakage detection unit. The LPG volume monitoring unit consists of load cells, HX711 signal amplification module, and the infrared temperature sensor [12].

2.1 Load Cells

As a transducer, load cell is used to convert compressive force to create an electrical signal with magnitude that can be standardized and be made to be directly proportional to the force being measured. The three main types of load cell are the pneumatic, hydraulic, and strain gauge.

2.1.1 Hydraulic Load Cells

Whenever there is an application of force on a confined space of a liquid medium, the resultant effect is increase in pressure of the liquid medium, which will be directly proportional to the load. This may imply that the applied force is equivalent to the pressure variation of the liquid. Hence, a hydraulic load cells is a force-balance device that measure weight as a change in pressure of the fluid in the confined space. When there is a change in pressure as a result of movement of the piston and the fitted diaphragm, this change in pressure is proportional to the applied force. This increase is measured on a Bourdon pressure gauge connected with the load cells. Figure 1 shows a sketch diagram of a hydraulic load cell.

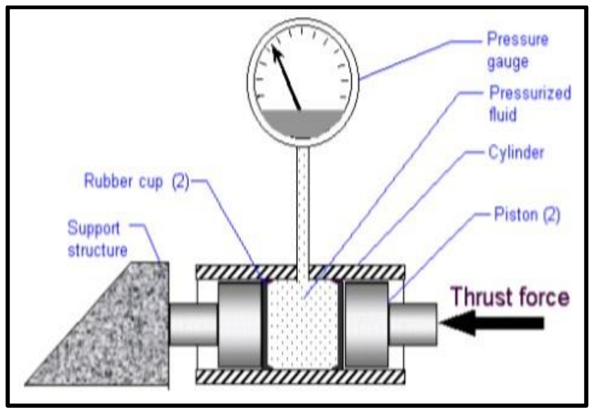

Figure 1: A sketch diagram showing a hydraulic load cell

2.1.2 Pneumatic Load Cells

Air pressure is applied to an elastic diaphragm, and the gas escapes at the bottom of the load cell, which has a pressure gauge inside the cell where the weight will be measured. In other words, the required air to equals the weight will measure the weight of the object applied while (Figure 2).

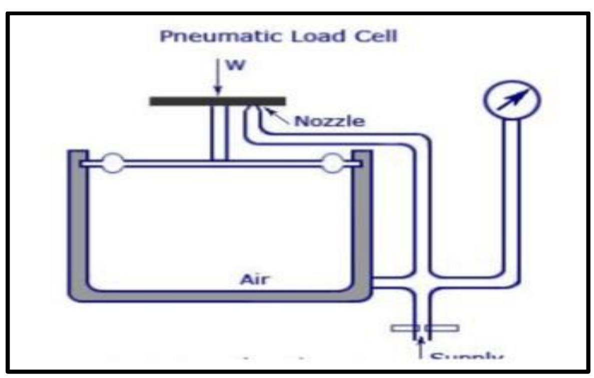

Figure 2: Pneumatic load cell

2.1.3 Strain gauge load cells

Strain gauge load cells resembles the legs of a wheatstone bridge configuration makes use of a mechanical element in which the force is being sensed by the deformation is measured as proportion to the change in the electrical signal of a/or several strain gauge(s) on the element (Figure 3).

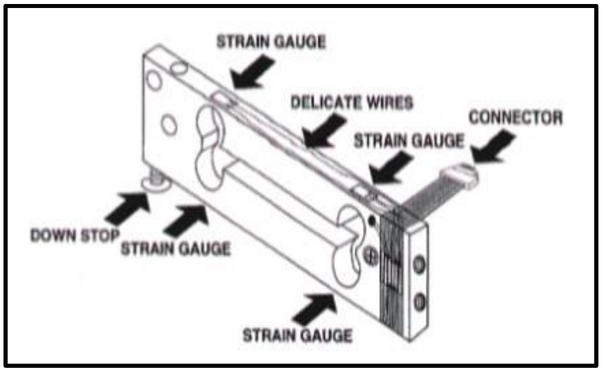

Figure 3: Strain gauge load cells

2.2 Working of the load cell

Today, strain gauge based load cells have become the choice for the applications of industrial weighing. Most load cells use a strain gauge to determine the measurements, the force and the electrical signal it produces. The working of strain gauge load cell is designed as a Wheatstone bridge with two input terminals, it connects four resistors configured in a diamond-like arrangement in a combination to give a null center value [13], [14]. A Wheatstone bridge circuit is shown in Figure 4 below.

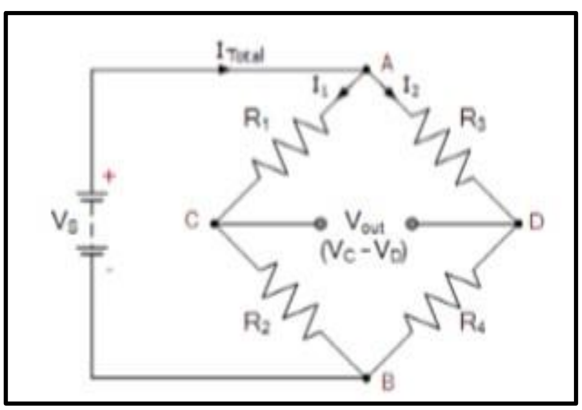

Figure 4: The Wheatstone bridge

The Wheatstone bridge can be determined by connecting the two series strings in parallel and the result of swapping the two resistors is that both sides and arms of the parallel network are different as they produced different voltage drops. At this point, the parallel network is said to be unbalanced as the voltage at point C is at a different value to the voltage at point D (Equation 1);

$$V_{out} = V_C - V_D = (V_C - V_D) = (V_{R2} - V_{R4}) = 0 \quad (1)$$

$$R_C = \frac{R2}{R1+R2} \quad (2)$$

$$R_D = \frac{R4}{R3+R4} \quad (3)$$

$$\frac{R2}{R1+R2} = \frac{R4}{R3+R4} \quad (4)$$

Where, V_c = Voltage of node C
V_D = Voltage of node D
R_C = Equivalent resistance at node C
R_D = Equivalent resistance at node D
At balance, $R_C = R_D$ (Figure 5) thus,

$$R_2 (R_3 + R_4) = R_4 (R_1 + R_2) \quad (5)$$

$$R_4 = \frac{R_2 R_3}{R_1} = R_X \quad (6)$$

Figure 5 shows a diagram of how to find unknown resistance (s) with the Wheatstone bridge as presented below;

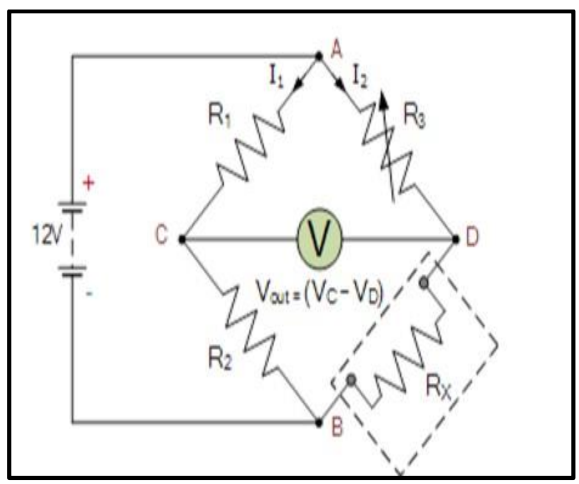

Figure 5: Finding unknown resistance with the Wheatstone bridge

When R_4 is replaced with a resistance of known value at the Wheatstone bridge sensing arm that has correspondence with R_X, R_3 will also be adjusted as the opposing resistor, to a balance point, the resultant network outcome of this will be zero voltage output. This balance occurs when (Equation 7);

$R_1/R_2 – R_3/R_4 = 1$ (7)
And for the calculation of the value of the unknown resistance, R_X at balance can be obtained using Eqn. (2);
$V_{out} = (V_C – V_D) = (V_{R2} – V_{R4}) = 0$
Where, resistors, R_1 and R_2 are known or with preset values. A 50 kg E-shaped load cell is used for this work due to its relatively small size, lightweight and ease of installation. Figure 6 is a flat face load cell for the monitoring of gas cylinder weight. Since most household cylinder are in the range of 5 kg, 6 kg, 25 kg, and 50 kg, A 50 kg E-shape face load cell is used for this work

Figure 6: 50kg flat face load cell

2.3 Hx711 24bit ADC Module

The amplifier module used was based on HX711. It consists of an amplifier and a precision 24-bit analog-to-digital convertor. It was designed for industrial control applications and weigh scale, as it interfaces with the bridge sensor. The input interface of this weight sensor module is used as sensor interface, which is compatible with Arduino input and output ports. The benefits of HX711 24 Bit ADC Module include, fast response, high integration, reliable, economical, and improvement of performance. The output adopts compact terminal that makes weight sensor module easier to connect to the weight sensor [15]. Figure 7 shows the HX711 ADC amplification unit.

2.4 Infrared Temperature Sensing Unit

This unit was incorporated in this design in order to measure the temperature of the cylinder that have been developed as a result of the collision of gas molecules inside the cylinder due to high pressure.

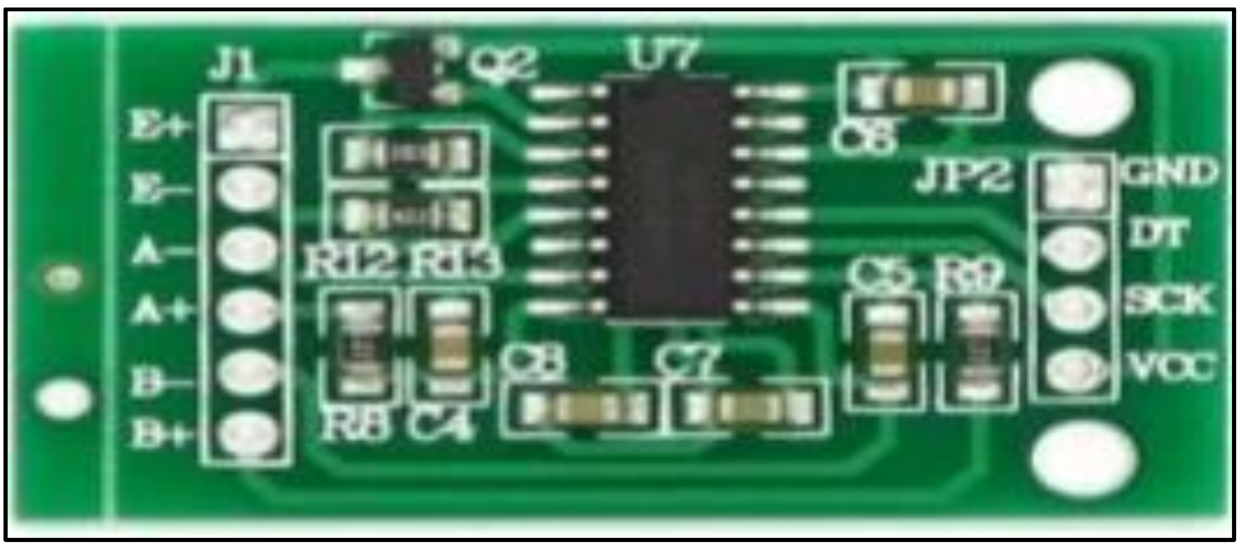

Figure 11: HX711 ADC amplification unit.

An Infrared thermometer sensor. The MLX90614 infrared thermometer used in this work is a non-contact temperature sensing device. Heat is generated inside the gas cylinder due to collision of gas molecules. This temperature changes in the gas are sensed from the body of the cylinder by the infrared thermometer sensor. The MLX90614 is factory-calibrated in a wide range of temperature capacity; between -40 ^{0}C to 85 ^{0}C for ambient temperature, and -70 ^{0}C to 382 ^{0}C for the object temperature [15]. Figure 8 shows the MLX90614 Thermometer sensor.

Figure 8: MLX90614 Thermometer sensor

2.5 Sensor Sections

The sensor comprises of the thermopile detector and signal conditioning section. While the thermopile detector converts thermal energy to electrical energy, the signal conditioning section process signal from thermopile detector and make it readable signal to the external peripherals. The sensor contains a strong Digital Signal Processing (DSP) and a 17-bit ADC which have contributed to its high accuracy and resolution., The 17-bit ADC block convert detected signal by the thermopile and calibrate DSP block quantizes the signal after output signal has travelled through I/O Pulse Width Modulation (PWM) and FC/TWI terminals. 10-bit PWM output provides a resolution of 0.14 ºC, and the I²C method gives resolution of 0.02 ºC [15]. Figure 9 shows a MLX90614 Thermometer with an attached integrated circuit as presented below;

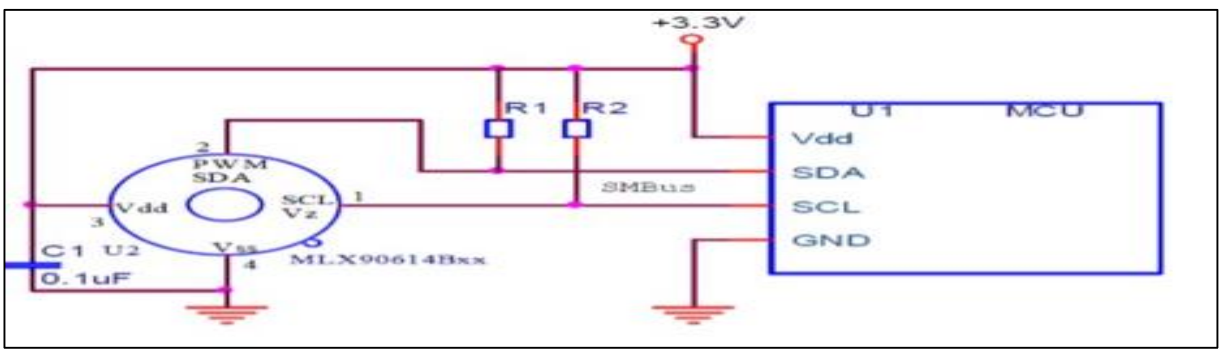

Figure 9: MLX90614 Thermometer with an attached IC.

The MLX 90614 thermometer sensor can be directly connected with an alert device, and can be easily made because it is a plug and play device. Figure 10 shows the Infrared-thermal-alarm-circuit.

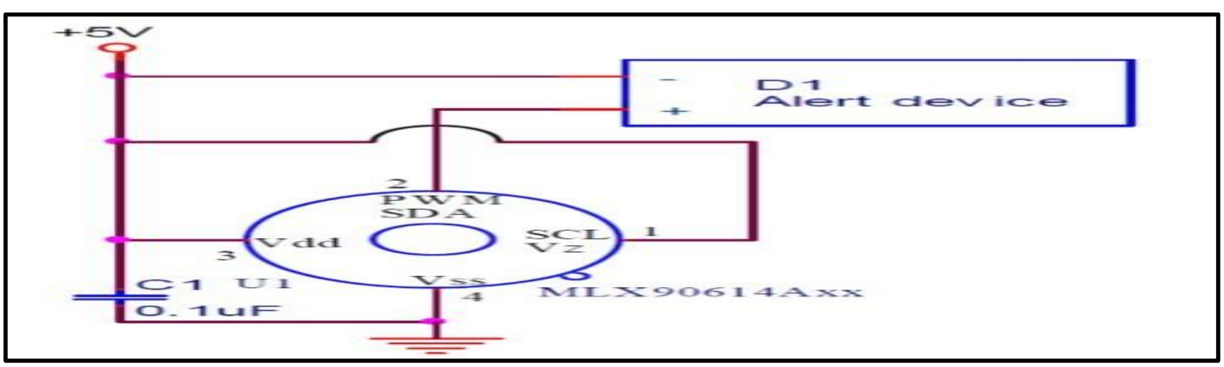

Figure 10: Infrared-thermal-alarm-circuit

2.6 Interfacing MLX 90614:
The MLX 90614 thermometer also has I2C communication lines so that we can interface this sensor with microcontroller without any additional circuits. In the same vein, the microcontrollers have I2C communication way to get interfaced with external peripherals.
The sensor operates with 3.3V DC supply. Beetner et al. [16] reported that, if the microcontroller operates with 5V DC, then there is the need pull up resistors between SDA and SCL lines to +3.3V DC line. The amplifier module is based on HX711, which comprises of an amplifier and a precision 24-bit analog-to-digital convertor designed for weigh scale and industrial control applications, to interface directly with a bridge sensor. Figure 10 shows the interfacing of the MLX 90614 Thermometer with Arduino Nano.

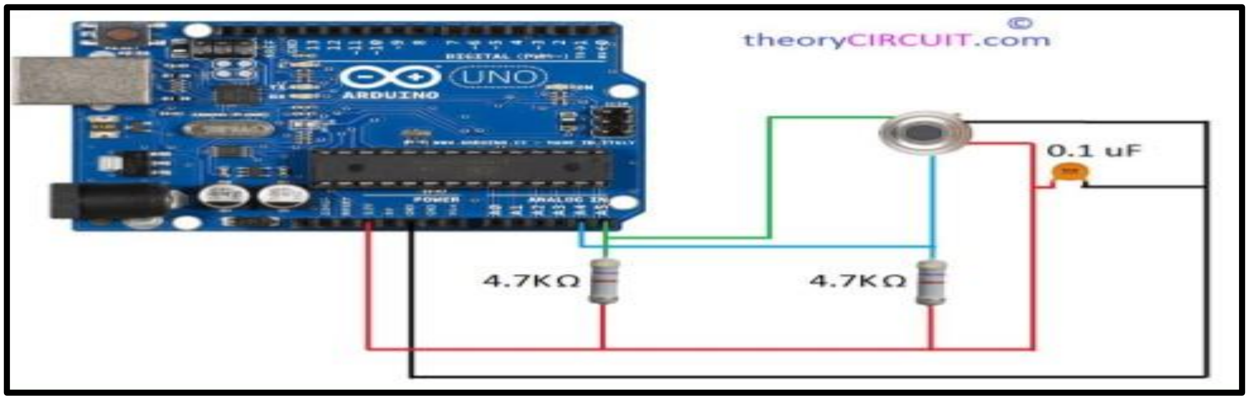

Figure 11: MLX 90614 Thermometer with Arduino

2.7 Leakage Detection Unit
The Leakage Detection Unit consists of the Arduino Nano microcontroller, gas sensor module, and interfaced with control circuits system. This will enable a process to be shutdown automatically. The gas sensor detects the concentration (in ppm) of leaked gas in the surrounding area, this output value is converted to a digital signal through the inbuilt analog to the Arduino Nano microcontroller's digital convertor. The MQ-5 device gas module controls the reading the LPG Gas device module, output, sending message to the LCD and activating of the buzzer. While the function of the circuit once it is in 'ON' position, it initiates the microcontroller and the show of LCD digital display alphanumeric display, and also begins the reading of the analog voltage rom the MQ-5 device. has four pins [17]. Figure 12 shows a MQ-5 LPG Gas Sensor.

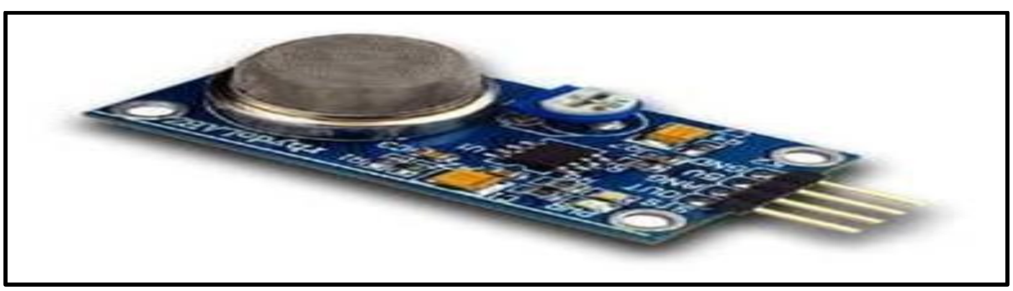

Figure 12: MQ-5 LPG Gas Sensor

2.8 Arduino Nano Microcontroller
The Arduino Nano is a compacted friendly microcontroller board (Figure 13). The Nano board weighs around 7 grams with dimensions of 4.5 cm to 1.8 cm (L to B) [18]. The choice of Arduino Nano over Arduino Duemilanove and Arduino UNO was because of its specifications and special features (Table 1).

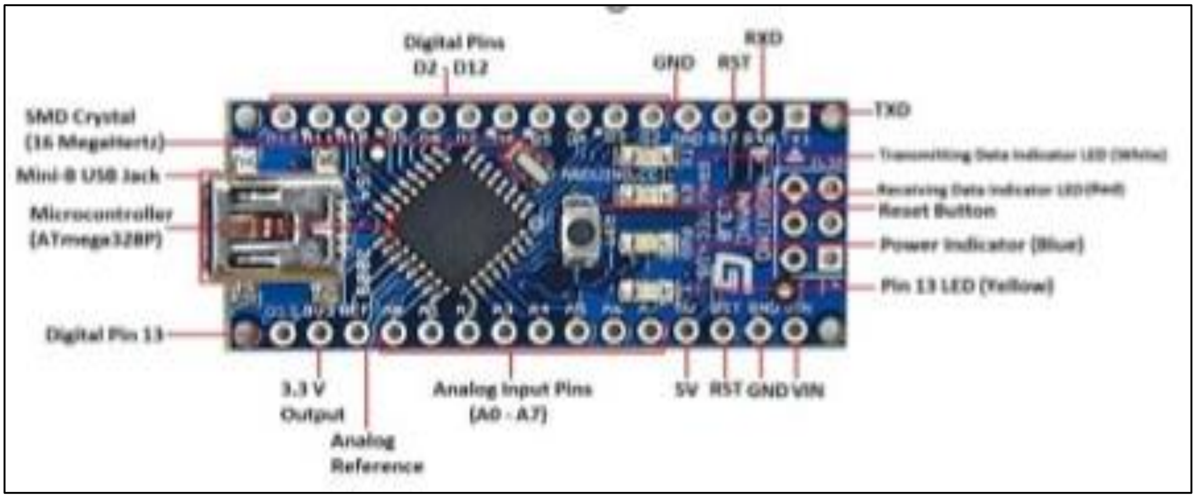

Figure 13: Arduino Nano Microcontrollers

Table 1: The Specifications and Features of Arduino Nano

S/No	Description	Specification
1.	Microcontroller	ATmega328P
2.	Architecture	AVR
3.	Operating Voltage	5 Volts
4.	Flash Memory	32 KB of which 2 KB used by bootloader
5.	SRAM	2 KB
6.	Clock Speed	16 MHz
7.	Analog I/O Pins	8
8.	EEPROM	1 KB
9.	DC Current per I/O Pins	40 milli/Amps
10.	Input Voltage	7-12 Volts

2.9 Liquid Crystal Display (LCD)

LCD is an electronic visual display with flat panel display, that uses the light modulating properties of liquid crystals (Figure 14). Liquid crystals do not emit light directly. According to Rajitha & Swapna (19) reported that LCDs are used in several areas of applications including aircraft cockpit displays, and signage, computer monitors, televisions, and instrument panel.

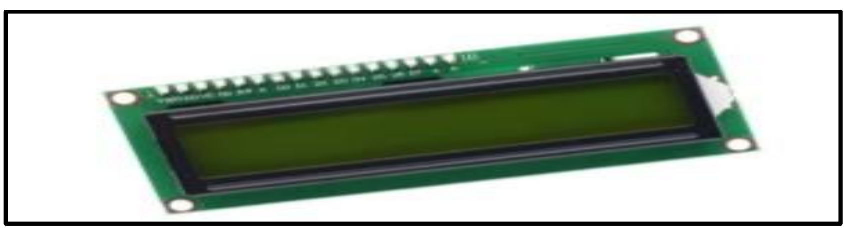

Figure 14 LCD screen 1602

2.10 Modes of Operation

This mode is used to set the initial weight of a refilled LPG or users gas cylinder;

- This mode can be accessed by pressing and releasing the calibration button for at least 5 seconds after switching on;
- The user is prompted to calibrate the new cylinder;
- The device reads the total weight of the gas cylinder and saves the weight in the EEPROM. The

saved weight subsequently forms the reference weights for computing 'low level'.
The leakage alert mode is triggered by a signal from the gas sensor when the concentration of LPG in the atmosphere is greater than the programmed safe value. On entry into this mode, a warning alert is displayed on the screen and the buzzer emits a continuous beep until the level of LPG falls below the programmed level. For the low volume alert mode, this mode is activated whenever the device is switched on. The volume of gas in the cylinder measured at that point is compared with calibrated value a "LOW LEVEL" alert accompanied by 3 short beeps from the buzzer is produced whenever the difference in the calibrated value and current values is beneath the programmed value after which the system enters the monitoring mode. While the normal mode (Monitoring mode) is the default mode of the device in which the system continually checks for LPG leakage as well as measure and show the current weight of the gas cylinder in real time as shown in Figure 15.

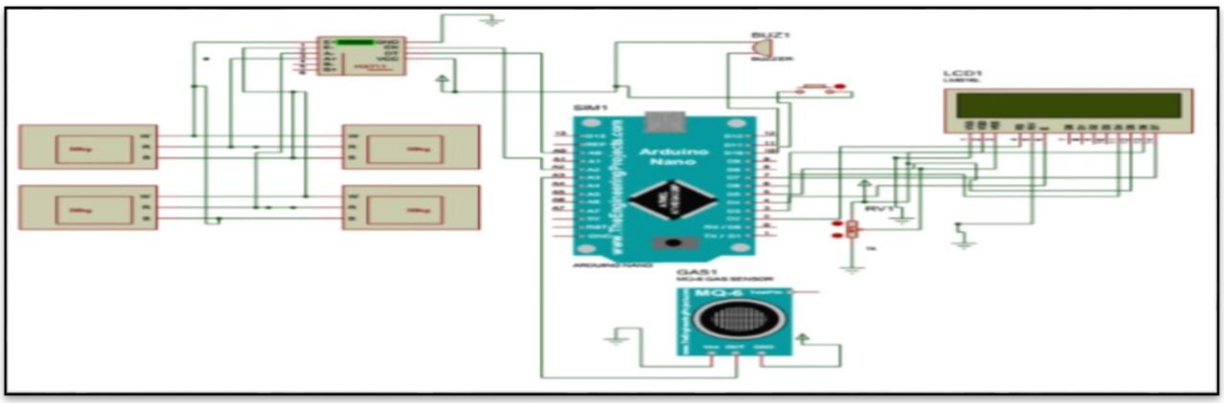

Figure 15: The circuit diagram of auto gas monitoring and leakage detection system.

3. CONSTRUCTION PROCEDURE

The base (rectangular platform) houses the load cells and signal amplification module and essentially provides the platform for the cylinder to be placed while in use. Its dimension was (27 x 27 x 7) cm^3 and made of plywood for bottom and top halves, and particle board for the sides (Figure 16).

Figure 16: Base (cylinder) platform.

The loads cell was arranged in full bridge (4 load cells) and glued to the top half of the plywood and a suitable elevation made of wood for the base of the load cell is provided for the bottom half of the frame as shown in Figure 17. The individual pieces are fastened together via glue and screws to assemble the structure. The control unit consists of the LCD screen (Figures 18-20) an Arduino Nano microcontroller, the control panel, gas sensorand other passive electronic components that made up the control circuit. The casing for the control panel is made from plastic and houses the control circuit. The individual components are soldered to Vero board and the system is powered via a pair of 9v battery [20].

Figure 17: Load cells arranged in full bridge

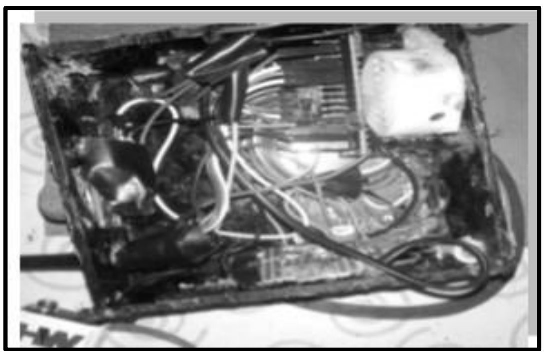

Figure 18: control unit

Figure 19: LCD display

4. RESULT AND DISCUSSION

To test for real time measurement weight and low level alert system:

- The device was installed and with the control panel and sensor unit mounted on suitable location from the base,
- An LPG cylinder containing cooking gas was then placed on the platform,
- The calibration button was then pressed down and released to save the initial weight of the cylinder,
- The cylinder was mounted and placed under usage over a period of time and the changes in volume were observed real time.

The alert system was programmed to produce 3 short beeps on start of the device whenever the cylinder volume is less than 0.5 kg. This value is obtained by subtracting the current gas volume reading from the saved weight or calibrated weight reading. The device was observed to conform to the desired objectives as shown in Figure 21 while Figure 22 shows Performance test of the developed gas monitoring device.

Figure 20: The auto gas monitoring device

Figure 21: Low LPG level mode

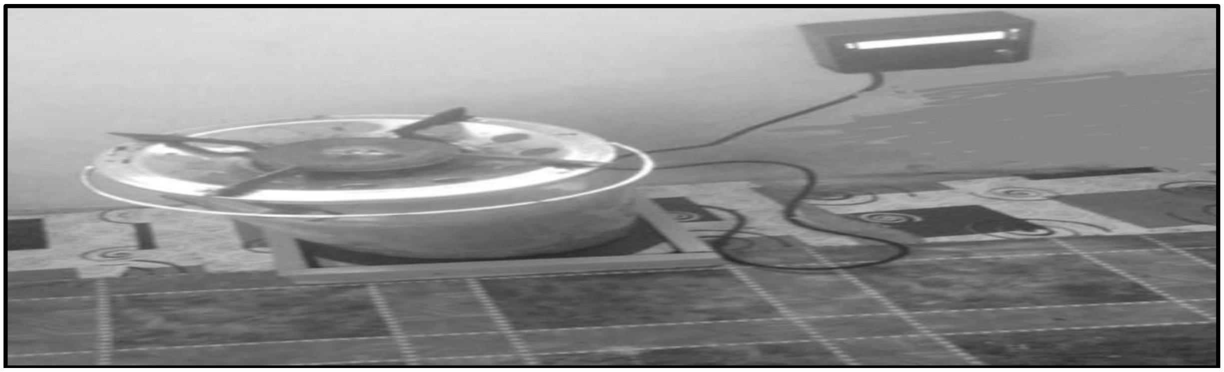

Figure 22: Performance test of the developed gas monitoring device

Figure 23 is the graph showing the Relationship between LPG concentration in air and distance covered. Figure 24 indicated the LPG concentration in air against elapsed time while Figure 25 shows temperature variations with cylinder weight.

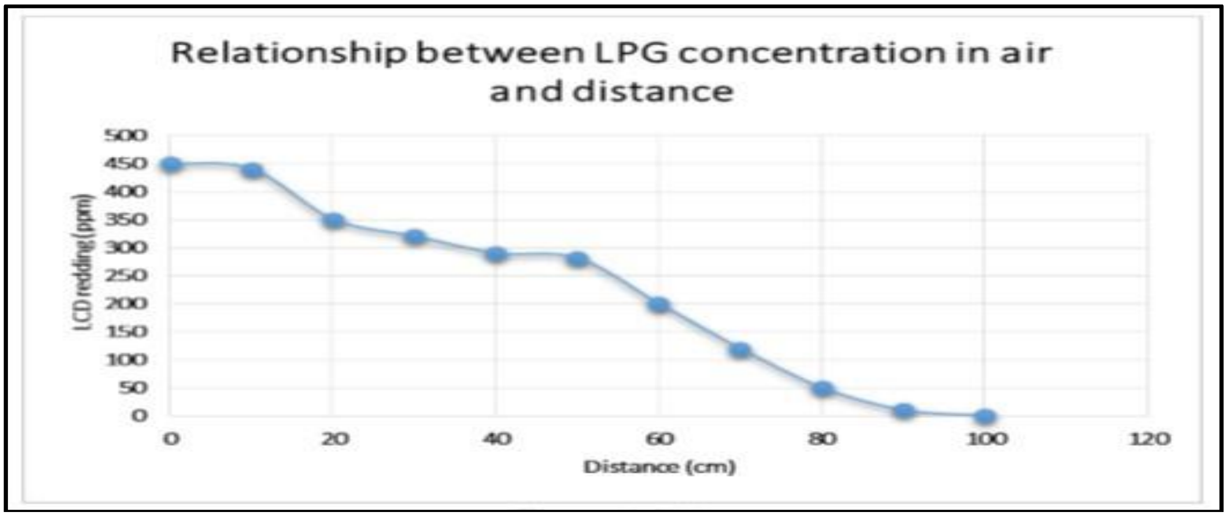

Figure 23: Relationship between LPG concentration in air and distance

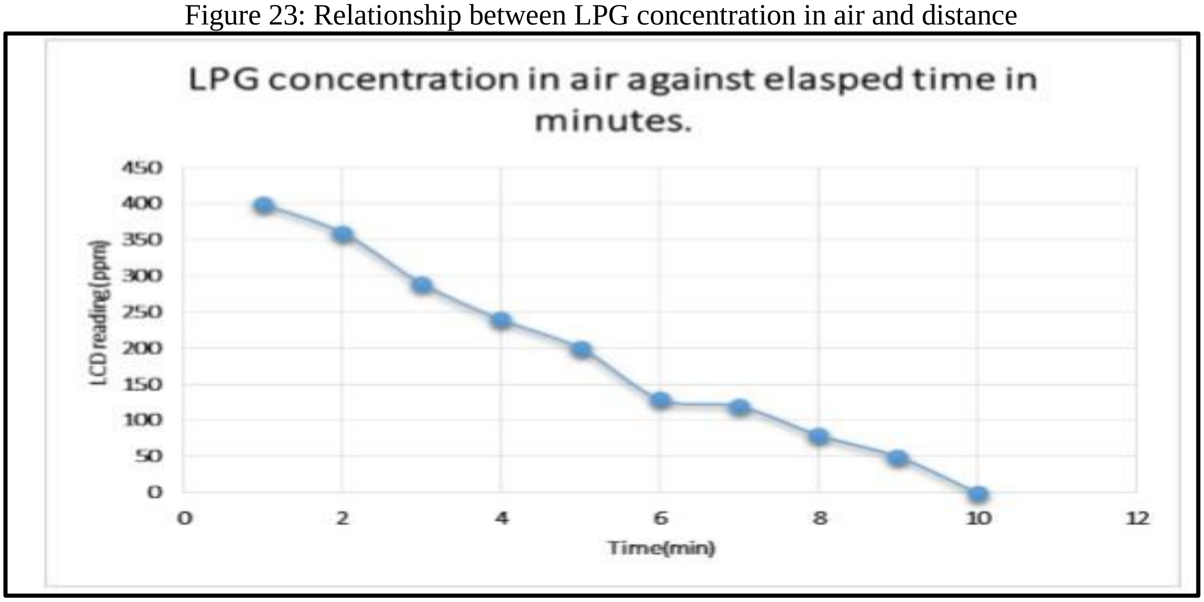

Figure 24: LPG Concentration in air against elapsed time (min)

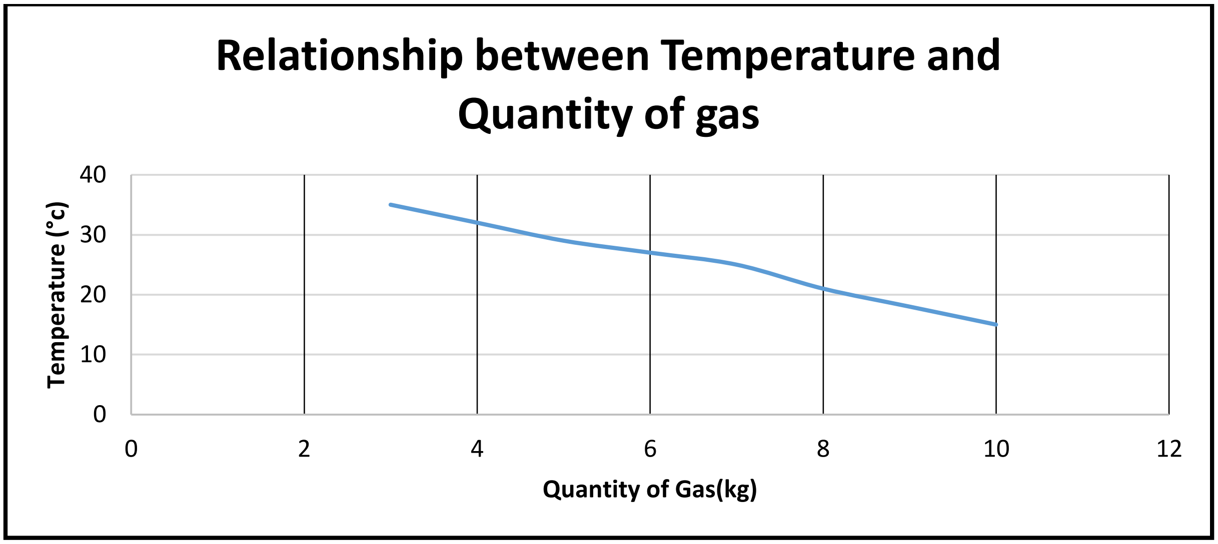

Figure 25: Temperature variations with cylinder mass

From Figures 23 and 24 above, it is noted that concentration of LPG in air is inversely proportional to distance moved away from leakage source and time elapse from staring of leakage. It can be seen that the more distant the device is from the leakage, the more time it will take for the device to detect leakage, therefore thee device must be close enough to the cylinder to detect leakage faster. Figure 25 shows the response of the temperature sensor with constant reduction in gas level. They both

slope downward towards the right. This implies that a reduction in gas level causes a decrease in temperature reading on the LCD, which is also a good way to define the quantity of gas in the cylinder Gupta [21].

5. CONCLUSION

The gas monitoring system here constructed not only measures the weight of an LPG cylinder in real time but also provides a suitable audio-visual alert system for both detections of leakages and low content of LPG cylinders. Results showed that, at 0 cm, LCD reading was 450 ppm, at 50 cm distance, LCD was 281 ppm, while at 100 cm, LCD reading was 0 ppm. The concentration of LPG was 400 ppm in 1min, and 0 ppm in 10 min. While temperature variations with cylinder mass recorded 37 ^{0}C at 3.0 kg, and 15 ^{0}C at 1.9 kg respectively.

CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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