Design and Implementationof an IoT-based Leakage Detection System for kitchens

ABSTRACT

In a low socioeconomic country like Nigeria, the loss of lives and properties arising from the usage of Liquified Petroleum Gas (LPG) for cooking is worrisome and there arises an urgent need to curb this menace. This paper presents a detection system for LPG, leveraging on the Internet of Things (IoT) technology. The major materials used for the development of this system are the MQ6 sensor for LPG monitoring and an STM32F411CEU6 microcontroller, coded with embedded C-language, which serves as the central processing unit of this device. This research introduces an emergency shut down system using anMMBT3904 NPNtransistor, which serves as a switch. When leakage is noticed, the MQ6 sensor sends the information to the microcontroller for decision making.Where the leakage is enough to trigger explosion, the microcontroller triggers the transistor to shut the solenoid valve automatically, which stops further cooking and averts any potential explosion which may lead to loss of lives and properties. Additionally, a custom mobile app has been developed for the remote monitoring of LPG leakage in the kitchen. Finally, owing to the epileptic supply of electricity in Nigeria, the issue of power supply has been addressed by introducing a solar panel and a battery for uninterrupted supply of electricity. The deployment of this system to users of LPG in Nigeria will put an end to the havoc that arises from LPG leaks in the Kitchen.

Keywords: Liquified Petroleum Gas; Internet of Things; LPG leakage; STM32F411CEU6 microcontroller; MQ6 sensor; MMBT3904 NPNtransistor.

1.0 Introduction

The adoption of Liquified Petroleum Gas (LPG) for domestic cookingin Nigeria is a transformative shift towards clean energy [1-2]. The convenience and environmental benefits of LPG has contributed to its popularity as cooking fuel. LPG, also known as cooking gas or auto gas, depending on its usage, has become a necessity in modern life.However, the lack of public enlightenment on its safe handling procedures has led to inappropriate installation, unsuitable cooking methods or practices, insufficient care, irregular maintenance and poor storage. These has resulted to several cases of gas leakages which leads to fire outbreaks, explosions and suffocation [3-6].

Owing to the intensity of the destruction that occurs during LPG gas explosion,many researchers have designed devices to curb this menace. We shall comprehensively look into these articles, summarize their shortcomings and propose a concept that will put an end to this menace.In Adamu & Suleiman [7], the designed system was a stand-alone embedded system for detecting LPG leakage, making use of an MQ2 sensor and an ATmega328 microcontroller as the central controlling unit. The default threshold of the sensor was set at 390 Parts Per Million (PPM). A buzzer functioned as an alarm and the sensor reported the gas levels to the microcontroller whenever LPG level was detected. Hence, whenever the MQ2 sensor detected gas level below the preset value, the buzzer will not be triggered by the microcontroller but the Liquid Crystal Display (LCD) will be triggered to display "NO GAS LEAKAGE." However, when the gas sensor detected gas leakage above the preset value, the microcontroller triggered the buzzer and "GAS IS LEAKING" was displayed on the LCD. This system only notified the user of gas leaks but lacked the mechanism to stop the leak and the havoc associated with the gas leakage.

Alshammari & Chughtai [8] designed a gas leakage monitoring system using IoT. The major components of the system were MQ5 sensor, buzzer and LCD display, all controlled by an Arduino (UNO-1) that was the central processing unit of the system. The gas sensor detected data was processed by the microcontroller and transmitted through Wi-Fi to the server. Immediately gas leakage was detected, the buzzer triggered an alarm and the leakage location was displayed to alert the user. Finally, the microcontroller triggered the exhaust fan to suck out the leaked gas from the enclosed space, preventing potential ignition and fire hazards. This system notified the user of gas leaks but lacked the mechanism to stop the leak and the havoc associated with the gas leakage.Siddika & Hossain [9]presented a LPG leakage monitoring system based on an Arduino MCU that was powered by a 5 V power supply. Other components used in the system were LCD, MQ135 sensor, GSM module, and buzzer system. In this system the MQ135 sensor was deployed to detect and transmit information on gas leakage to the microcontroller. Based on the transmitted information, the microcontroller took decisions. Where there was leakage, the microcontroller triggered the LCD to display a warning message, triggered the buzzer to alert the user through a beep and triggered the GSM module to notify the user. Where there was no leakage, the microcontroller triggered the LCD to display, "Normal Condition Air Cleaning." This system informs the user of the gas leak but has the disadvantage of not being able to stop gas the leakage.

Priya & Kowsalya [10] presented a method of detecting LPG leakage and switching off of the valves where there was leakage. An Arduino UNO was used to carry out the desired task. The Arduino was connected to the MQ2 gas, LM35 temperature sensor, a relay, a Passive Infrared (PIR) sensor and a buzzer. To detect gas leakage, the MQ2 sensor was used while it was possible to monitor temperature constantly using LM35 temperature sensor. In an event where there is leakage, the gas sensor detected such leakage, forwards the signal to the microcontroller which triggers the valve to be locked. At every instant, the temperature sensor gave an output voltage proportional to the temperature. Also in the system is an exhaust fan which is linked to the microcontroller and in an event where there is leakage, it was turned on to evacuate gases inside the kitchen. In addition, human presence near the cooking gas was monitored by the PIR sensor. If the user was not detected near the cooking gas over a period of time, an alarm was triggered and the valve was automatically switched off. This system lacks the mechanism of monitoring gas level in the cooking cylinder and cannot be remotely monitored. Also, switch used in the cooking valve is an electromechanical device, which is subject to wear and tear.Chandak *et al.*, [11] put forward an IoT LPG monitoring system to detect gas leakage in the kitchen. The system comprised of an MQ6 sensor, Node Microcontroller Unit (MCU) ESP8266, LCD display, a buzzer and cloud service that used a ThingSpeak. Whenever there was any gas leakage, the MQ6 sensor detected it, the microcontroller triggered the buzzer to beep and the GSM modem to send an SMS to the user, respectively. This system also monitored the quantity of LPG in the cylinder, helping the user to request for a refill. Data collected and measured by the sensors were uploaded to the cloud with the help of Node-MCU. This system notifies the user of potential leaks but fails to stop the leakage which may lead to explosion.

Nguyen & Nguyen [12] presented the development of an IoT-based gas monitoring device. The components assembled for the development of this system were an Arduino Mega 2560 microcontroller, an MQ2 sensor, a GSM module, module ESP8266 NodeMCU, module LM2596, LCD and a buzzer. The MQ2 sensor was used to collect and measure gas leakage information. If the device detected that there was gas leakage beyond the threshold limit for leakage safety, the data was displayed on the LCD, and the buzzer triggered to alert the user. Simultaneously, the device automatically texted and called to notify the user of an impending danger. The data measured was also posted on the ThingSpeak web server in every 15 seconds. This device updates the user on gas leaks but is unable to stop the leakage. More so, the system failed to update the user on the status of gas level in the cylinder.Shiyana & Deepa [13] deployed an Arduino ATmega microcontroller, MQ9 sensor, a buzzer and a GSM/GPRS to develop a gas leakage detection device for industrial and home uses. The microcontroller was programmed using Embedded C. To continuously monitor gas leakage, the MQ9 gas sensor was used and when the gas sensor detected leakage, it transferred the signal through its analogue input port to the microcontroller for processing. From the processed signal, if leakage was detected, the microcontroller triggered the GSM/GPRS module to notify the user via SMS and triggered the buzzer to beep. This device updated the user on gas leaks but was unable to stop the leakage. More so, the system failed to update the user on the quantity of gas level in the cylinder.

Inamdar *et al.*, [14] proposed an LPG leakage monitoring system to detect gas leakages in homes and businesses. An MQ5 sensor connected to Node MCU was used to monitor the gas leakage. As the sensor detects gas, it outputs the signal in an analogue which is converted to a digital value using analogue to digital converter of Node MCU. The data collected was displayed on the LCD and could be monitored in the mobile app and the blynk server. Where leakage exceeded the threshold limit, the buzzer was triggered to beep, notifying the user and the surrounding of potential danger. The NodeMCU used in this study was linked with the ThingSpeak. Again, this device updated the user on gas leaks but was unable to stop the leakage. More so, the system failed to update the user on the level of gas in the cooking cylinder.Rohan *et al*., [15] developed a gas leakage monitoring system to monitor Benzene and LPG using MQ135 and MQ6 sensors, respectively. An Arduino ATmega microcontroller, interfaced with the gas sensors along with a GSM/GPRS modem, ESP8266 WIFI module, a buzzer and LCD were the major components used in this system. Real-time collected and measured data of LPG and Benzene were fed to the microcontroller analogue pins, where it was converted to concentrations in ppm. The data in ppm was displayed on the LCD, uploaded to the ThingSpeak cloud in a graphical form and sent to the user through an email using IFTTT web service. This system updated the user on gas leaks but was unable to stop the leakage. In addition, the system failed to update the user on the status of gas level in the cylinder.

With an MQ6 gas sensor, buzzer, exhaust fan, ESP8266 WiFi module, all interfaced with an Arduino UNO, Shah *et al*., [16] developed an LPG leakage monitoring system for homes, hotels and industrial uses. Data collected and measured by the gas sensor was forwarded to the microcontroller for decision making. If measured data was above the preset value, after a minute, the microcontroller triggers the stepper motor to turn off the valve of the cooking cylinder, triggers the buzzer to beep, triggers the exhaust fan to clear off the leaked gas, triggers an SMS through the ESP8266 Wi-Fi Module. This system failed to address the issue of updating the level of LPG in the cooking cylinder. In addition, the stepper motor used in this device is subject to wear and tear due to environmental factors, hence, the system can malfunction at any time. This system had a response time of one minute which was enough to fire outbreak to occur.Rahmalisa*et al.*, [17] implemented an LPG gas leakage monitoring system using WeMos D1 microcontroller as the data processor. Interfaced with the microcontroller was an MQ6 sensor, ESP8266-01S module and buzzer. The MQ6 sensor served the purpose of collecting and measuring leakage of LPG and transferring the information which will be processed by the microcontroller. Whenever the sensor detected LPG value above 80, the microcontroller triggered the buzzer to raise an alarm and triggered the ESP8266-01S module to prompt a notification via Instagram to the user. This system only informed the user of the leak but failed to stop the leak. In addition, the system could not monitor the kitchen remotely and was not designed to check the level of LPG in the cooking cylinder.

Subbarayudu*et al.*, [18] designed a system which monitored and averted gas leakage using MQ135 gas sensor, GSM modem, exhaust fan and a buzzer, all interfaced with an Arduino ATmega microcontroller. The gas sensor monitored and sent collected and measured data to the microcontroller for decision making. Where the leakage concentration was high enough and about to trigger explosion, the microcontroller triggered the buzzer to beep, triggered the GSM modem to send an SMS to the user for caution and triggered the exhaust fan to blow out the gas through any available ventilation. This system informed the user of LPG leakage but failed to stop the leakage. Again, this system was not designed to measure the level of LPG in the cooking cylinder.Kodali *et al.*, [19] proposed a gas leakage monitoring system. The developed device detected LPG, Methane and Benzene levels using MQ6, MQ4 and MQ135 sensors, respectively and uses ESP32 as a Wi-Fi module. The sensors output were analogue resistances whose changes were converted to voltage values through a signal conditioning circuit. These voltages were read by the microcontroller. An in-built 12-bit ADC converted these analogue voltages into digital forms. The microcontroller measured these data and compared it with the threshold values. If the measured concentration levels exceed the threshold values, calls/SMS were sent to the factory workers via IFTTT. Simultaneously, the buzzer alerted the workers about the leakage and LEDs glowed to specify the gas which was leaking. Though the system was not designed for domestic use, it also failed in stopping further leakage of LPG.

Soh *et al*., [20] focused on the detection of gas leakage using MQ2 sensor and whose level of leakage was updated to the Ubidots cloud platform via Intel Edison based sensor node which was connected to the internet through Wi-Fi connection. The gas level was analyzed by Ubidots and an alert notification was sent to the user, even remotely, through SMS/telegram, if there is gas leakage above the threshold limit. This system informed the user of gas leaks but failed to stop the leak.Amuthan &Zin [21] proposed a low-cost system that enabled users to detect LPG leakage through the Arduino Blynk program. Materials used in developing the hardware of this system were Arduino Uno Rev3, ESP8266 Wi-Fi module, and MQ5 sensor. The Wi-Fi module integrated with a smartphone, created a simple user interface. At a range of 90 cm, the LPG barely detected LPG leakage. The sensor could not measure LPG leakage at a range above 0.9m and failed to account for how gas leaks could be stopped.Khan [22] designed a gas leakage detection system that can automatically detect, alert and control gas leakage based on an MQ6 gas sensor connected to an Arduino UNO R3. All data collected and measured were analyzed by the microcontroller for decision making. When the gas sensor detected low or no leakage, it gave a low output signal to the Arduino and since the leakage was not sufficient to cause explosion, the microcontroller did not trigger the system but the LCD displayed that there was no gas leakage. Where the leakage was high, the microcontroller prompted the buzzer and LCD to take actions. The buzzer alerted the user through a beep while the LCD displayed that gas leakage has been detected. This device alerted the user of gas leaks but did not have the mechanism to stop the leak.

Medilla*et al.*, [23] developed a device for the swift monitoring and detection of gas leakage, utilizing MQ4 gas sensor and AVR microcontroller family as control devices. The system was also equipped with XBee PRO S2B datasheet which connected the wireless networking system that was used to transmit sensor data from the detection point to the monitoring center equipped with a personal computer (PC) and software integrated visual basic. In this system, gas leakage is alerted in SMS format via social networking Google talk. This system failed to address how gas leaks could be stopped.Fatkiyah*et al.*, [24] designed a device that can detect if there was LPG leakage, using MQ6 sensor. The prototype worked in such a way that, if there was gas leakage, the MQ6 sensor will detect it and then send the data to the microcontroller in the form of analog data. Where the leakage was high, it sent a warming message to the user. Again, this system notified the user of leakage but did not have the mechanism to stop the leak.

Evalina *et al.*, [25] developed a system to provide early LPG detecting and alerting utilizing MQ6 gas sensor, ATmega2360, buzzer, LCD, and a solenoid gas valve. The system was designed such that if the gas sensor detected high concentration of leakage, it sent the signal to the microcontroller which triggered the LCD to display and the buzzer to raise an alarm. The authors also observed that the sensor must be kept at most 18cm from the gas cylinder, for effective detection of gas leakage. This system offered no mechanism to detect the level of LPG in the cooking cylinder.Hassan *et al.*, [26] presented an IoT smart kitchen project that includes automation and monitoring. In this project, a system was developed that automatically detects the kitchen temperature. It also monitors the humidity level in the kitchen. This system includes built-in gas detection sensors that detect any gas leaks in the kitchen and notify the user if the gas pressure in the kitchen exceeds a certain level. This system also allows the user to remotely control appliances such as freezers, ovens, and air conditioners using a mobile phone. The user can control gas levels using their phone with this system. In this paper, the ESP32, DHT11 Sensor, 5 V Relay X 8, and MQ-135 gas sensors create a smart kitchen by controlling the temperature, managing humidity, and detecting gas leakage. The system was built on an Arduino board that is connected to the Internet. The hardware was integrated and programmed using an Arduino, and a user Android application was developed.

Damodhar& Swathi [27] proposed a Raspberry Pi based real-time kitchen monitoring system, to measure and control parameters such as light intensity, room temperature, fire, LPG leakage and groceries. The system monitored these parameters and informed the user of defaults at certain preset levels. The monitored status of the kitchen was transmitted to the user by email and SMS through the GSM modem.Johare*et al.*, [28] proposed a system that can detect LPG gas leakage. The system was developed for swift LPG leakage detection and alerting utilizing GSM modem, buzzer, and exhaust fan, all connected to ATmega328p microcontrollerthat served as the processing unit of the system. In a scenario where LPG leakage concentration is high, the buzzer raises an alarm, the GSM modem prompts a message to the user while the exhaust fan sucks out the leaked gas.

Marin [29] proposed a cloud-based IoT gas leakage detection system. An Arduino Uno microcontroller, a Wi-Fi module, and a MQ2 sensor make up the system. The sensor notifies the microcontroller when gas is detected, and the microcontroller analyses the information before sending it to the cloud through the IoT module. The cloud platform offers a user-friendly interface for managing and visualising data on gas leaks, and it also notifies customers through email and SMS. The system comes with a GPS module and a smoke detector for real-time position tracking and fire detection. The smoke detector detects smoke and sounds an alert, while the GPS module monitors the system's location. A smart LPG monitoring system based on IoT, utilizing ESP8266 NodeMCU Module was developed by Kapadnis*et al.*, [30]. The system uses an MQ-6 sensor, IR flame sensor, solenoid valve, buzzer, and the Blynk application to monitor and control gas levels. Experimental methods were used to test the sensor response of the system at different distances. The maximum detected distance was found to be 7 cm. The LPG gas sensor value was tested at distances ranging from 1 cm to 10 cm and the average gas values were found to be 5467 PPM, 1052.6 PPM, 798 PPM, 557.4 PPM, 489 PPM, 387.2 PPM, 231.4 PPM, 152.4 PPM, 141.8 PPM, and 121.6 PPM at 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 6 cm, 7 cm, 8 cm, 9 cm, and 10 cm distances, respectively. The results showed that the system is able to control and monitor gas levels effectively.

Tsoukas*et al.*, [31] described gas leakage detection system based on TinyML. TinyML is a technology presented by the research world for building fully independent and safe devices that can gather, analyze, and produce data, without transferring it to distant organizations. The proposed solution was programmed in this project to identify anomalies and warn occupants via the utilization of the BLE technology, in addition to an incorporated LCD screen.Gupta *et al.*, [32] presented a system to detect, control and alert LPG users automatically. It utilizes two LEDs (green and red) to detect the type of gas, an exhaust fan to remove the gas from the environment where there is leakage occurrence while the LCD is used to display performance information. The system is controlled by an Arduino UNO and uses a buzzer for notifications.

Hussein *et al*., [33] developed a system for detecting LPG leakages from cooking cylinders which updates the user through GSM network. The system consists of an MQ2 and MQ9 gas sensors which sends signals to Arduino Uno microcontroller. The system uses GSM network to prompt notification to the user, uses LCD to display warning messages and a buzzer to sound an alarm.In Adabara*et al.,* [4] the authors used GSM technology to send messages and calls to alert users. The leakage was detected by MQ2 sensor and the leaked gas was controlled by an exhaust fan that blows it out through any available ventilation.Ahmed *et al*.,

[34] proposed a microcontroller-based system, using MQ6 sensor, GSM, a display and a buzzer. The system also used an Arduino UNO, a NODEMCU module, a solenoid valve and an exhaust fan. The system was designed to prevent excessive leakage and remove the leaked LPG gas from the surrounding where the leakage occurred.

Ravisankar *et al.*, [35] in a research, presented an IoT based system for disconnecting electricity if LPG gas above a predetermined level is sensed. If the LPG gas leakage is detected, the GSM modem, LCD and exhaust fan are activated. The user will be intimated about gas leakage and electricity is cut off through SMS using GSM modem. Sai, *et al.*, [36] proposed a system that detects gas leakages in houses and industries and attempts to minimize gas leakage. The system is a cloud-based IoT application that receives sensor information and reacts accordingly. The gas leak from the cylinder is detected using MQ2 gas sensor. It is linked to the ESP8266 module, which trigger messages through the cloud to the user's smartphone. For quick feedback, a buzzer is also attached to the circuit to alert residents of the house in situations of proposed leakages.

Devi *et al.*, [37] presented a microcontroller-based model, for toxic gas detection and alarm systems. The developed system has an IoT-based gas and temperature monitoring system. The collected and measured gas were analyzed by the Blynk IoT server. An alarm was triggered when leakage exceeded the preset limit.In Naveen *et al.*, [38], a gas leakage monitoring system was proposed. The system is made up of several components, including a buzzer, an exhaust fan, a servo motor, a LCD display, MQ6 sensor and a GSM module, all interfaced with an ATmega 328 microcontroller. In this work, the MQ6 sensor monitors leakage concentration, sends the information to the microcontroller for processing and where leakage is high, the controller triggers the motor to shut, prompts an alert to the user through SMS, activates the LED and prompts the buzzer to signal gas leakages.

From the available literatures, existing products have shortcomings. Some systems only inform the users of LPG leakage and fire outbreak, either through alarm, SMS, email or Instagram but cannot stop the fire outbreak and the havocs that will arise from the fire outbreak. Researchers who made attempts to stop gas leakages, made use of relays or motors for switching. These relays or motors, overtime, are subject to wear and tear. To curb the menace that arises due to LPG leaks in the kitchen, this research introduces the concept of IoT to address these flaws and to develop a suitable and sustainable gas leakage monitoring system for an average Nigerian kitchen.

2.0 Methodology

2.1 Materials

In this section, we commence by describing the components used in the development of the hardware of the system. A detail description of each component is described below.

2.1.1 STM32F411CEU6 Microcontroller

Thisis a high-performance microcontroller, running at a frequency of up to 100 MHz.In order to improve application security, it incorporates a Memory Protection Unit (MPU) and a complete set of Digital Signal Processing (DSP) instructions.The STM32F411CEU6 belongs to the STM32 dynamic efficiency product line (with products combining power efficiency, performance and integration) while adding a new innovative feature called batch acquisition mode (BAM), allowing it to save more power during data batching. It incorporates high-speed embedded memories (up to 512 Kilobytes of Flash memory, 128 Kilobytes of SRAM), and an extensive range of enhanced I/Os and peripherals connected to two advanced peripheral buses (APB), two advanced high performance buses (AHB) and a 32-bit multi-AHB matrix. All devices offer one 12-bit ADC, a low-power real-time clocks (RTC), six general-purpose 16-bit timers including one pulse width modulation (PWM) timer for motor control, two general-purpose 32-bit timers. They also feature standard and advanced communication interfaces.The STM32F411CEU6 operates in the - 40 to + 125 ℃ temperature range from a 1.7 (PDR OFF) to 3.6 V power supply. A comprehensive set of power-saving mode allows the design of low-power applications.

Figure 1: STM32F411CEU6 Microcontroller

2.1.2 MQ6 sensor

This is a semiconductor device with high sensitivity for LPG, iso-butane, propane. Tin dioxide is used in the making of the gas sensitive layer of MQ6 sensor [39]. MQ6 sensor requires at least 20 seconds to initialize and operates on the principle of detecting changes in electrical resistance when exposed to these gases. This sensor detects LPG at a concentration of 200-10000ppm [11,40]. When it detects LPG, it compares the value with the comparator present in the sensor and produces a digital logic data output to the microcontroller [16,41].MQ6 sensor has 6 pins, 2 of which are used in providing heating current while the rest are used to fetch signals. The four output pins used for fetching signals are A_0, D_0, ground (GND) and V_{CC}. A_0 is the analogue signal output that gives out varying voltages which corresponds to the level of LPG in the air. D_0 is the transistor-transistor logic (TTL) switching signal output which goes high when a certain threshold is reached, otherwise, it stays low.

Figure 2: MQ6 sensor

2.1.3 NMBT3904 NPN Transistor

MMBT3904 is an NPN bipolar junction transistor (BJT) used in a wide range of electronic applications.The transistor is designed to handle a maximum collector-emitter voltage of 40V and maximum collector current of 200mA. Its high current gain and low noise figure makes it suitable for use in switching applications, small signal amplifiers and audio amplifiers.It is housed in a SOT-23 package, which is a small, surface-mount package that allows for easy mounting on printed circuit boards. This package is widely used and can be found in many electronic devices.Its ability to operate at high frequencies coupled with its fast switching speed, makes it well-suited for use in RF and microwave circuits. Its low base-emitter voltage makes it easily driven by low-level signals.

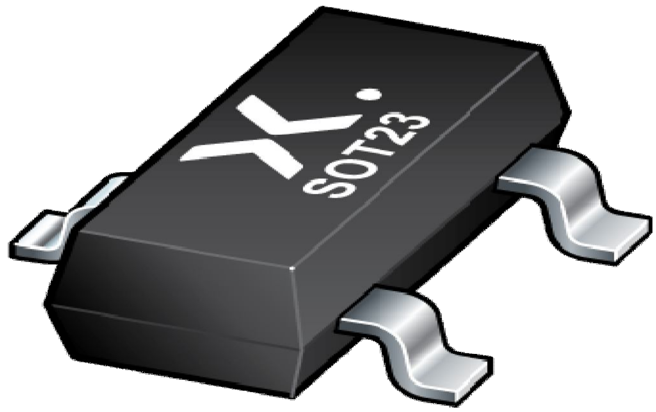

Figure 3: NMBT3904 NPN Transistor

2.1.4 Solenoid Valve: A solenoid valve is an electromechanically operated valve used to control the flow of liquids or gases. It uses an electric current to generate a magnetic field, which operates a mechanism that opens or closes the valve. It consists of a solenoid that generates a magnetic field when an electric current passes through it, an armature, a spring and the valve body that houses the solenoid, plunger, spring, along with the inlet and outlet ports for the fluid. The solenoid valve works in two states; energized and de-energized state.The energized state occurs when an electric current is applied to the solenoid, creating a magnetic field that pulls the plunger against the spring's force, which opens the flow path and allows fluid to pass through. At the de-energized state, no electric current is applied to the solenoid, the spring pushes the plunger to block the fluid flow path, keeping the valve closed.

Figure 4: Solenoid Valve

2.2 System Block Diagram

As seen in the block diagram in Figure 5, the central processing component of the system is the MCU. It controls the reading from the MQ6 sensor, processes the read data, and outputs the result. On the left of the MCU is the gas sensor used to detect the amount of cooking gas in the kitchen environment and comparing it against a fixed set threshold in the program.On the right of the MCU is the output section which consist of the actuator, multicolour 3.5" Liquid Crystal Display (LCD), and the communication module. The actuator section, divided further, is made up of a solenoid valve and driver. The driver has the function of boosting the power required to drive the solenoid valve. The LCD screen gives the graphical output of the system’s status, thus helping the user to understand the system operation. The communication module connects the hardware to the internet, thus making the device an IoT device. All components used in the hardware require certain voltage levels as specified in their respective datasheets. The process involved in converting a single voltage supplied to the system to multiple voltages is taken care of by the Power Supply Unit (PSU). The input voltage to the PSU comes from a 5V power pack or an 18V solar panel.

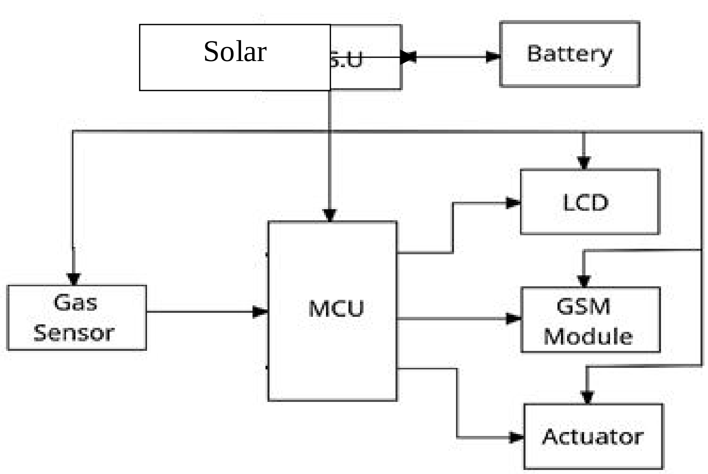

Figure 5: Hardware Block Diagram

2.3System Overview

The system overview is presented in Figure 6. This section describes how each part of the system interacts. The control unit gathers data from the gas sensor, controls the charging/discharging of the battery, switching off/on the solenoid valve and transmits/receives data to and from the ThingsWeb IoT service. At the user end, an android smartphone running a custom app is used to monitor, control and manage the system operations remotely.

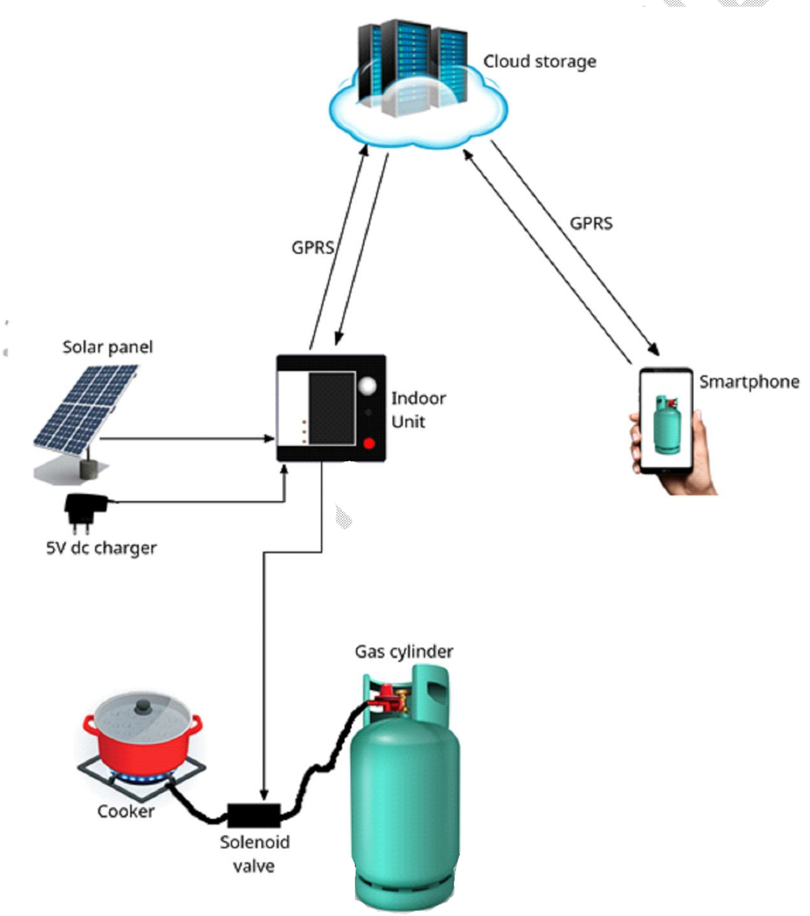

Figure 6: System Overview

2.4Circuit Description of the System

Figure 7 is the circuit diagram of the gas leakage detection system.The gas leakage sensor, MQ-6 sensor, seen as U2 in the schematic, is used to sense the amount of cooking gas in the air around the kitchen. The sensor gives out an inversely varying output voltage level as the gas amount in the air increases. This varying voltage level is sensed at the MCU pin already configured for sensing varying voltage (analog) signals.Since U1 and U8 (the MCU) operates on 5V and 3.3 volts' average, respectively (including the Vref of ADC of U8), the output of 5V from U1 is divided using R10 and R13, so that its possible maximum voltage will not exceed 3.3V whenever it appears on the pin of the MCU.

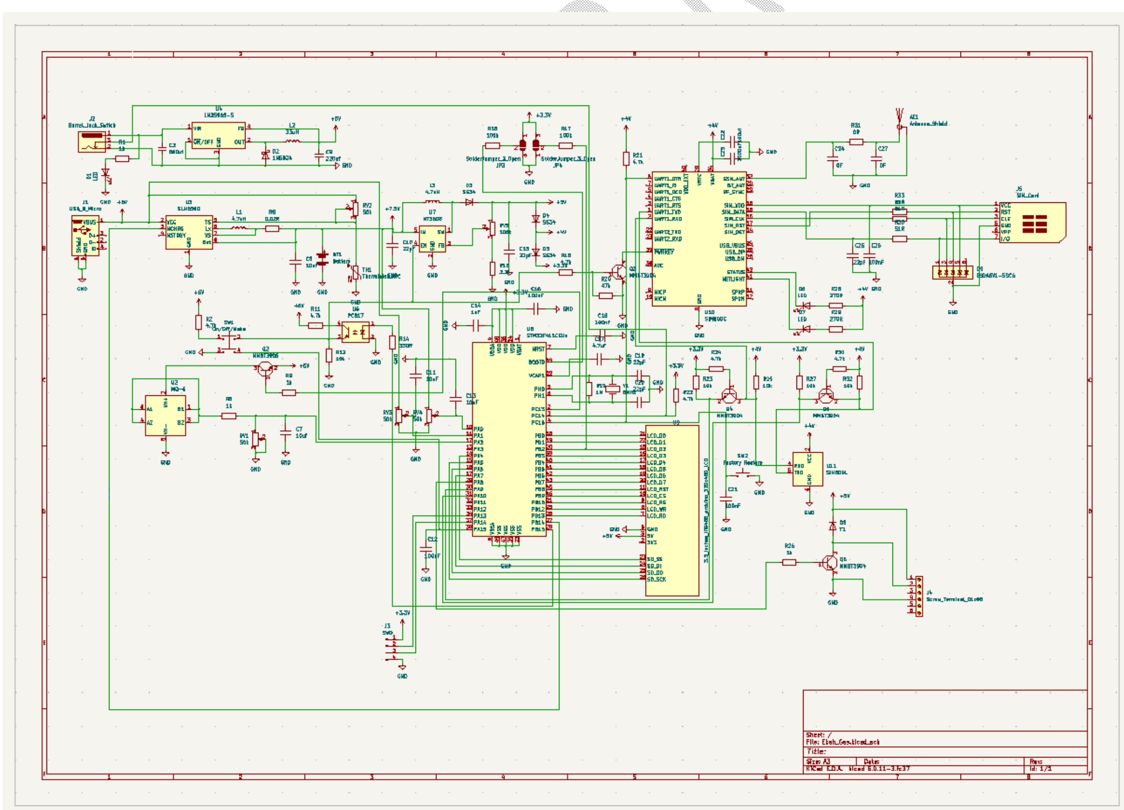

Figure 7: Circuit Diagram of the System

2.5Circuit Analysis of the System

Major components in the circuits are the MQ6 sensor, MCU (U8), resistor (R5), MMBT3906 transistor (Q2),diode (D5), resistor (R26) and MMBT3904 transistor (Q5).

i. Base Current of Q2

The base current is determined by the resistor R5 (1KΩ) and the voltage across it.

$$I_B = \frac{V_B - V_{BE}}{R_5}$$ Equation

1

V_{BE} = 0.7V

B_V = 5V

$$\therefore I_B = \frac{5-0.7}{1000} = \frac{4.3}{1000} = 4.3mA$$

ii. Collector Current of Q2

$I_C = \beta \times I_B$ Equation

2

But β = Current gain= 10

I_C = 10x4.3*m*A = 43*m*A.

iii. Power Dissipation in R5

$$P_{R5} = 1_B^2 \text{x} R5$$ Equation

3

$\Rightarrow 4.3^2$ x 1000 = 18.49*m*W.

iv. Analogue to Digital Conversion for MQ6 sensor: The ADC in the MCU converts analogue voltage from the MQ6 sensor into digital value. The conversion is based on the ADC's resolution which is determined by the number of bits.

$$D = \frac{V_i}{V_r}(2^N - 1)$$ Equation

4

Where D = Digital Value

Vi = Analogue input voltage

Vr = Reference Voltage for STM 32 = 3.3V

N = Resolution of ADC in Sits for SYM 32 = 12

This formula shows that the maximum digital value the ADC can output is $(2^N – 1)$. This value is used to scale the input voltage relative to the reference voltage, converting it into a corresponding digital value in the range of 0 to $(2^N – 1)$.

v. Voltage at the base of Q5

$V_B = V_{GPIO} – V_{BE}$Equation 5

V_{BE} for Q5 = 0.7V, V_{GPIO} = 3.3V

$V_B = V_{GPIO} – V_{BE} = 3.3 – 0.7 = 2.6V$

vi. Current through R26

Current through R26 (I_B) = $\frac{V_B}{R26}$ Equation 6

V_B = 2.6V and R26 = 1kΩ

$$\therefore I_B = \frac{2.6}{1000} = 2.6mA$$

vii. Collector Current (I_C) for Q5

$I_C = \beta \times I_B$ Equation 7

Where β = 40

I_C = 40 x 2.6mA = 10.4mA

iv. Voltage across D5

$V_{D5} = V_S – V_C$ Equation 8

$V_C = 0.7V$

V_s = Supply voltage = 5V

$V_{D5} = 5 – 0.7 = 4.3V$

v. Power dissipation in R26

$P_{R26} = V_B \times I_B$ Equation 9

2.6 x 2.6mA = 6.76mW

vi. Power dissipated in Q5

$P_{Q5} = V_{CE} \times I_C$ Equation 10

At saturation $V_{CE} = 0.2V$

$I_C = 10.4mA$

$P_{QS} = 0.2 \times 10.4mA = 20.8mW$

vii. Power dissipated in D5

$P_{D5} = V_D \times I_C$ Equation 11

$P_{D5} = 0.7 \times 20.8mA = 14.56mW$

2.6Firmware Development

Since the hardware has an LCD intended to display graphically appealing information, there was need to come up with a suitable and easily understandable design. Next, a program plan was developed in flowchart form, to guide in the process of development, which was followed by testing the gas sensor to find out which code worked best with it. This code snippet was used in the final code development. With the sectional experimental code test working satisfactorily, the actual coding of the specific firmware for the project started. Here, the concern was how to arrange the process flow in such a way that MCU resources are managed effectively without any issue and all parts running concurrently.The code was run to check for errors before generating the writable file. When the hardware was ready, the first version of the software was run on the MCU and observed for any possible runtime error.

2.7Mobile App Development and Testing

Mobile development assumed with designing the UI. This involved creating a visually appealing and user-friendly layout for the app. To map out the logical sequence of actions within the app, a flow chart was used. A sectional code test was then conducted before implementing the entire app. After the sectional code test, the actual source code for the mobile app was written in C language. We then proceeded to identifying and fixing errors in the code. This iterative process ensured a stable and reliable application.

After developing the mobile app, it was uploaded and tested on a real device to evaluate its functionality, performance, and usability. This was done to ensure that the app behaved as expected, and to rectify any issues that may have been overlooked during the app development.

2.8Testing of the Gas Leakage Monitoring System

For accurate detection of LPG leakage, the gas sensor was calibrated according to the manufacturer's specification in the datasheet. The sensitivity of the gas sensor was tested to detect various concentrations of LPG leakage. These involved testing for both minor leaks and major leaks to ensure the sensor can detect all levels of leakages. Once these was done, the software handled the job from there, notifying and displaying the gas leakage data.

3.0 Results and Discussion

An IoT-based leakage detection system has been developed. The system's hardware presented in figure 8consists of the MCU, and the MQ6 sensor in the control box. The developed system was then subjected to various test scenarios to evaluate the performance of the system under various cooking conditions.

Figure 8: Hardware of the System

Figure 9: Incoming calldrawing user's attention to gas leakage

Figure 10: SMS prompt showing gas leakage

Figure 11: Gas leakage notification via mobile app

Figure 12: Gas leakage notification via LCD

Figures 9, 10, 11 and 12 are results from various gas leakage scenarios. To check for the system’s ability to detected leakage, the gas was allowed to leak in the kitchen. Once the leakage was enough to trigger explosion, gas leakage notification, triggered by the MCU was displayed on the LCD screen as seen in figure 12. This was also observed on the mobile app in figure 11. In figure 12, there is an “x” symbol by the gas valve. This indicates that the solenoid valve has been switched off. This is done to stop further gas leakage and avert gas explosion. During this leakage scenario, it was observed that an SMS was triggered to notifying the user of the leakage as seen in figure 10, accompanied by a call as seen in figure 9.

The system's high sensitivity in detecting even minor gas leaks, ensured early detection and prevention of potential hazards. The system promptly notifies users upon detecting any gas leakage and automatically shuts off the gas supply. This addresses the issue before it escalates. This approach diminishes the risk of gas-related accidents and enhances the overall safety in the kitchen.

Conclusion

An IoT-based gas leakage detection system has been developed. Developing the system involved design analysis, circuit construction, firmware development, mobile app development, cloud server setup and integration. The system consists of a control unit. The control unit consist of the MQ-6 sensor, the microcontroller and the battery. The control unit gathers data from the gas sensor, controls the charging/discharging of the battery, switching of the solenoid valve and transmits/receives data to and from the ThingsWeb IoT service.

The function of the MQ-6 sensor was to detect the leakage of LPG. When the MQ-6 sensor detects LPG leakage, it sends the signal to the microcontroller for decision making. When the leakage level is low, the microcontroller does not trigger the system. However, when the signal is above the preset value, the microcontroller will trigger the transistor to shut the valve, thereby stopping the leakage and averting possible fire outbreak and explosion. In addition, an SMS, followed by a call, will be forwarded to the user, notifying he/she of the leakage.A mobile app has been developed for theremote monitoring of LPG leakage in the kitchen. Through this mobile app, gas leakage notifications will be triggered as beeps to the user. The system will be powered by mains and solar electricity. The solar system is introduced because of the epileptic power supply in Nigeria.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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