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

ABSTRACT

n Nigeria, the frequent loss of lives and properties due to LPG usage for cooking necessitates urgent intervention. This paper presents an Internet of Things (IoT) based detection system to monitor LPG leakage in kitchens. Key components include a solenoid valve for gas flow control, an MQ6 sensor for LPG monitoring, and an STM32F411CEU6 microcontroller, programmed in embedded C, as the central processing unit. The system introduces an emergency shutdown mechanism using an MMBT3904 NPN transistor. Upon detecting a leak, the MQ6 sensor informs the microcontroller, which prompts the user with a Short Message Service (SMS) and calls, and then triggers the transistor to close the solenoid valve if the leakage poses an explosion risk, thus preventing potential disasters. Additionally, a custom mobile app allows for remote monitoring and control of LPG leakage. To address Nigeria's unreliable electricity supply, the system includes a 5V power pack, a solar panel, and a battery for continuous power supply to the system. Deploying this system will significantly reduce the risks associated with LPG leaks in kitchens across Nigeria.

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 cooking in 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.Adamu & Suleiman [7] developed a stand-alone system using an MQ2 sensor to detect LPG leaks. This system only alerted the user of leaks but lacked a mechanism to stop them or mitigate associated dangers. Alshammari & Chughtai [8] created an IoT-based gas leakage monitoring system that notified users of leaks, displayed the leak location, triggered an alarm, and used an exhaust fan to remove the leaked gas from the kitchen.In Siddika & Hossain [9], an MQ135 sensor detected gas leakage while leakage information got to the user via the buzzer and a warning display on the Liquid Crystal Display (LCD) screen.In Priya & Kowsalya [10],the system was designed to switch off the solenoid valve using a relay, where leakage occurred while Chandak *et al.*, [11] put forward an IoT LPG monitoring system to detect gas leakage in the kitchen using MQ6 sensor. The leakage information in this device was sent to the user via Short Message Service (SMS).Nguyen & Nguyen [12] presented an IoT-based gas monitoring device using an MQ2 sensor to collect and measure gas leakage information. If the device detected gas leakage beyond the threshold safety limit, the information was displayed on the LCD, and the buzzer was triggered to alert the user. 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. Leakage information was triggered via SMS and the buzzer.Inamdar *et al.*, [14] proposed an LPG leakage monitoring system to detect gas leakages in homes and businesses. Where leakage exceeded the threshold limit, the buzzer was triggered to notify the user and the surrounding of potential danger.Rohan *et al.*, [15]developed a leakage monitoring system to monitor Benzene and LPG using MQ135 and MQ6 sensors, respectively. The data in Parts Per Million (ppm) was displayed on the LCD, uploaded to the ThingSpeak and sent to the user through an email using IFTTT web service.

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. If measured data was above the preset value, after a minute, the microcontroller will prompt the stepper motor to turn off the valve, trigger the buzzer, triggerthe exhaust fan to clear off the leaked gas, and prompt an SMS through the ESP8266 Wi-Fi Module. Rahmalisa*et al*., [17] implemented an LPG gas leakage monitoring system using WeMos D1 microcontroller as the data processor. 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.

Subbarayudu*et al*., [18] designed a system which monitored gas leakage using MQ135 gas sensor, GSM modem, exhaust fan and a buzzer, all interfaced with an Arduino ATmega microcontroller. Where leakage concentration was high enough to trigger explosion, the microcontroller prompted the buzzer to beep, triggered the GSM modem to send an SMS to the user and switched the exhaust fan to blow out the gas through any available ventilation. Kodali *et al*., [19] proposed a gas leakage monitoring system to detect LPG, Methane and Benzene levels using MQ6, MQ4 and MQ135 sensors, respectively. If the measured concentration levels exceed the thresholds, calls/SMS were sent to the factory workers via IFTTT. Simultaneously, the buzzer alerted the workers and Light Emitting Diodes (LEDs) glowed to specify the gas which was leaking.

Soh *et al*., [20] focused gas leakage detection using MQ2 sensor. Leakage level 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 alert notifications sent to the user through SMS/telegram.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 an MQ5 sensor. At a range of 90 cm, the LPG barely detected LPG leakage and failed to account for how gas leaks could be stopped.Khan [22] designed a gas leakage detection system to detect, alert and control gas leakage based on an MQ6 gas sensor connected to an Arduino UNO R3. Where the leakage was high, the microcontroller prompted the buzzer to beep and the LCD to display the leakage information.

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. In this system, gas leakage was alerted in an SMS format via social networking google talk.Fatkiyah*et al*., [24] designed a device to detect LPG leakage using MQ6 sensor. Where the leakage was high, it sent a warming message to the user. Evalina *et al*., [25] developed a system to provide early LPG leakage utilizing MQ6 gas sensor, ATmega2360, buzzer, LCD, and a solenoid valve. The system was designed such that if high concentration of leakage was detected, the LCD was triggered to display and the buzzer prompted to raise an alarm. Hassan *et al*., [26] presented an IoT smart kitchen to automatically monitor the temperature, humidity level,gas pressure and leaks in the kitchen. This system also allowed the user to remotely control appliances such as freezers, ovens, and air conditioners using a mobile phone. 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 leakage. When LPG leakage concentration was high, the buzzer prompted an alarm, the GSM modem triggered anSMS to the user while the exhaust fan sucked out the leaked gas.

Marin [29] proposed a cloud-based IoT leakage detection system. An Arduino Uno microcontroller, a Wi-Fi module, and an MQ2 sensor were the major system's components. Users were notified of leaks via email and SMS. A smart LPG monitoring system based on IoT, utilizing ESP8266 NodeMCU Module was developed by Kapadnis*et al*., [30]. The system used an MQ-6 sensor, IR flame sensor, solenoid valve, buzzer, and the Blynk application to monitor and control gas levels.Tsoukas*et al.*, [31] developed a gas leakage detection system based on TinyML. The proposed solution was programmed 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 utilized two LEDs (green and red) to detect the type of gas, an exhaust fan to remove the leaked gas from the environment while the LCD displayed performance information.

Hussein *et al.*, [33] developed a system for detecting LPG leakages from cooking cylinders which updated the user through GSM network. The system consisted of an MQ2 and MQ9 gas sensors. The system used GSM network to prompt notification to the user, used 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 of leakages. The leakage was detected by an 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 modem, 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] presented an IoT based system for disconnecting electricity if LPG gas above a predetermined level was sensed. If LPG leakage was detected, the GSM modem, LCD and exhaust fan were activated. Sai, *et al.*, [36] proposed a system that detected gas leakages in houses and industries using a cloud-based IoT application. For quick feedback, a buzzer was also attached to the circuit to alert residents of the house in situations of proposed leakages.Devi *et al.*, [37] presented 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. 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 researches, 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.

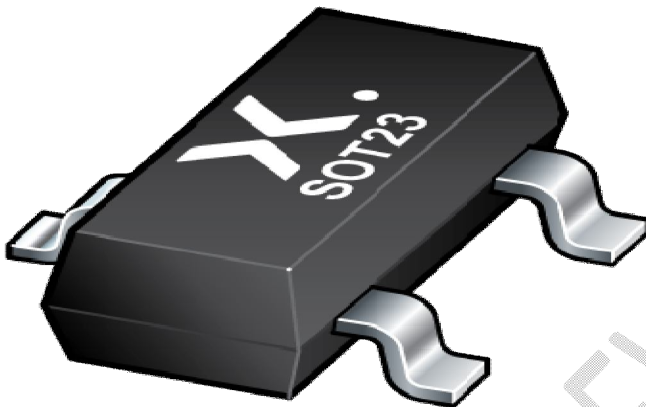

Figure 3: NMBT3904 NPN Transistor

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.

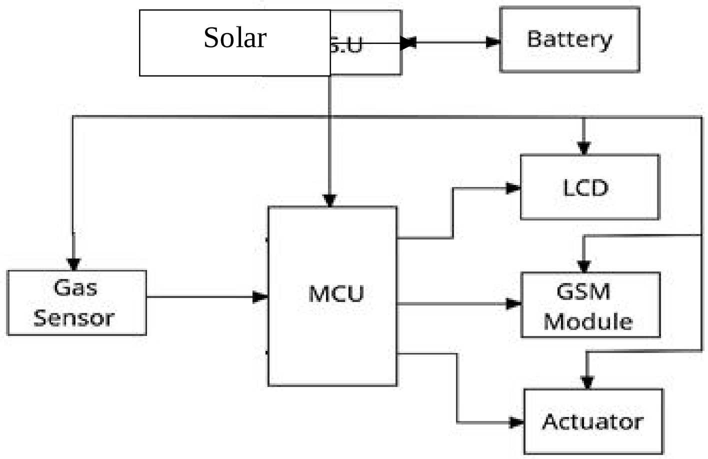

Figure 5: Hardware Block Diagram

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.

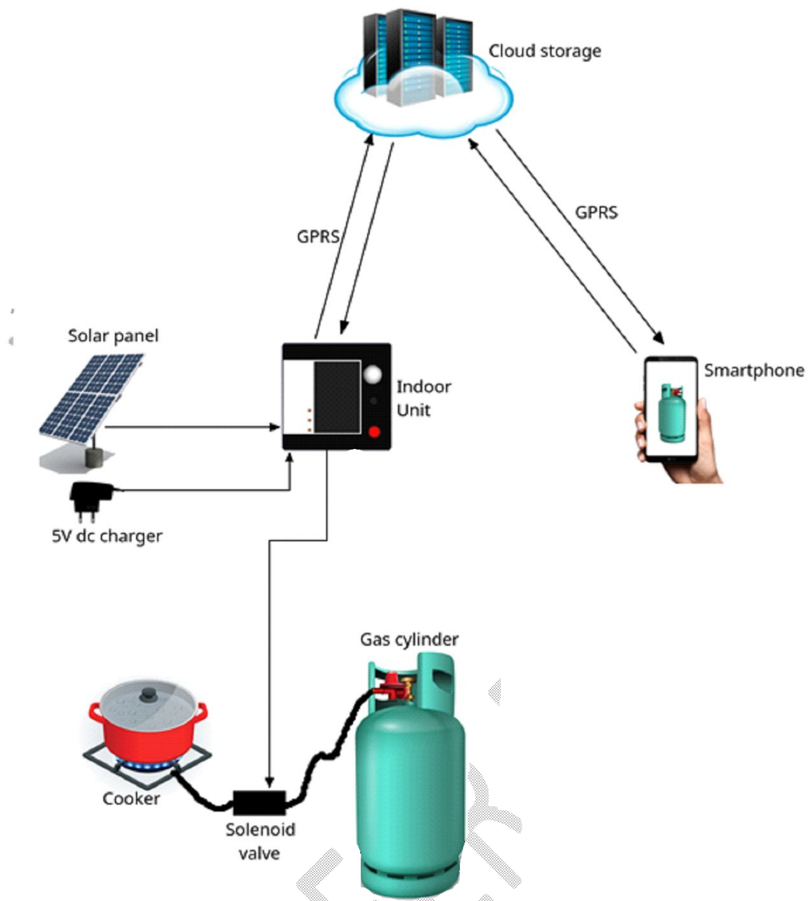

Figure 6: System Overview

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.

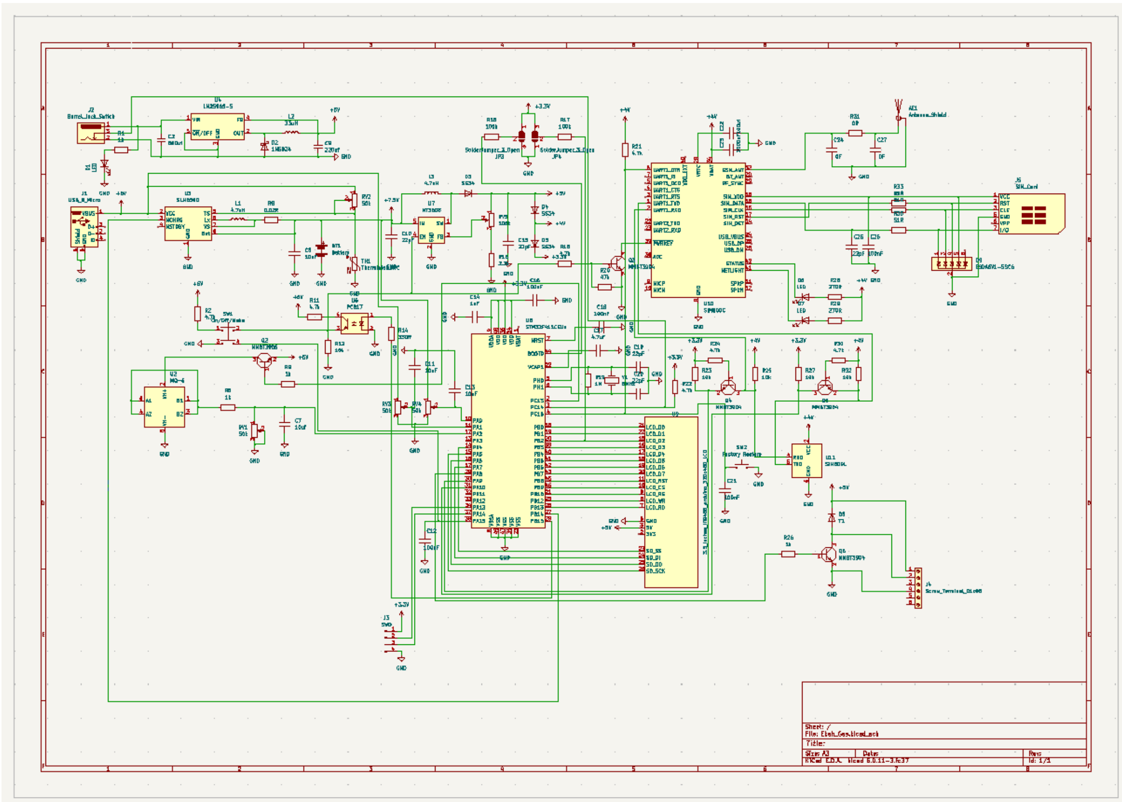

Figure 7: Circuit Diagram of the System

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

$I_C = \beta \text{ x } I_B$ 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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