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Design and construction of a carbon monoxide and liquefied petroleum gas leakage detection system

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Abstract
Gas leakage is a serious problem in homes and industries. Accidents resulting from gas leakage can cause damage to properties worth millions of dollars and also loss of life. This paper presents the design and construction of a carbon monoxide and liquefied petroleum gas leakage detection and alert system. This system uses two gas sensors to detect leakage of the individual gases and sends the information to the microcontroller. The microcontroller was programmed using Embedded C programming language to collect input data from the different sensors, process them according to set instructions and give necessary outputs to activate an alarm to warn the individuals around of the gas leakage. A short message is also sent through a global system for mobile communications (GSM) module to a predefined number indicating the location for necessary actions to be taken. The system successfully detected carbon monoxide and liquefied petroleum gasses respectively and suitable for use in areas were these dangerous gases are in use. It will also reduce loss of lives resulting generators fumes in residential houses.

Keywords: Natural gas, leakage detection, carbon monoxide, GSM

1. Introduction
Natural gas (NG) is a naturally gaseous hydrocarbon mixture that is formed under the earth's surface. The primary constituent of natural gas is methane. It may also contain higher alkanes with a small percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium according to its origin (Faramawy et al., 2016). Natural gases are energy sources used as cooking gases in homes, restaurant and industries for driving and heating machinery (Makhatab & Poe, 2012; Asche et al., 2006; Hartley, 2008). However, most of these processes and domestic activities are accompanied by the potential use and release of harmful gases. These gases may be a by-product of the processes output, or part of the process input reactants. In some other cases, the gases may be part of the process conditioning components. The oil and gas production plants are example of the cases above. Hydrocarbon vapours are usually released by the process activities as by-product, output product, process condition components and as input feed reactants. Some of these gases can cause death when inhaled or flammable when their concentration in the environment is high. Reports show that several persons have died as a result of inhaling carbon monoxide from generator fumes (ThisDay, 2017). Also, several deaths have occurred as a result of Liquefied Petroleum Gas (LPG) explosion (Femi, 2018).

Harmful gases fall into two categories. These are the flammable class and the toxic class (Subibjo, 2015). The flammable gases are dreaded because of their ability to burst into flame, while the toxic gas causes suffocation. In view of the foregoing, any operational premises in which one or more of the classes of gas is associated with must be closely monitored. Gas tightness policies must be implemented to ensure safety of operators, plants and to avoid economic losses. The premises can be monitored for gas leakages using sensors. The sensors are mounted at strategic point referred to as high incidence point and areas or premises of the overall process plant or system prone to gas leakages, or areas with higher probability of damage if gas leakage accident occurs. Incident point can be confined or non-confined. In fact, confined space has incidence rating of high values. The incidence rating of an area affects the sensor noses installed and the type of control used. It also affects the concentration set point for the gas detector used. For double assurance and safety integrity of high incidence points or areas, multi-sensors are installed, with each given different gas leaks and gas concentration information to the adjoining control module. The detection techniques could be visual and audio, or in critical cases takes control actions. The control action could be activating a purging system, neutralizer system or automatic cut-off of the process line supplying the gas. For the multi sensor architecture, different alarms and indicators could be assigned to the different sensor information. The warning would then be for the type of gas detected, concentration of gas detected and the severity of the gas leakage.

Gas leakage detection has been an age long practice for almost everyday activities. More so, the detection technologies have also passed through different levels of development. This can be seen in the use of canary birds in coal mines to the use of analytical sensors, and now semiconductor sensors. In the same vein, the detection architecture and system components have also changed overtime, with the advent of hazard safety operations.

Nowadays, gas detection system forms an integral part of the entire plant design, as well as part of the protection and trip interlocks. In fact, gas detection systems are integrated into the main plant controller algorithm and auxiliary trip system. The system controller could be programmable logic controller, microcontrollers or simple logic gates circuitry.

Gas detectors are now being used in areas where cooking gas are used and in generator house to monitor carbon monoxide in exhaust fumes. This is necessary due to the fact that most of our domestic and industrial activities are accompanied by the release of harmful gases, which are flammable or can cause death when inhaled when their concentration in the environment is high, there is need for the installation of devices where these gases are used to detect any possible leakage into the environment to prevent any possible effect that may arise from them.

2 Materials and methods

The modular approach was used in the development of this project work. This method involves breaking down a complex system into smaller parts called modules or skids, which can be independently created, modified, replaced or exchanged between different systems as shown in Figure 1.

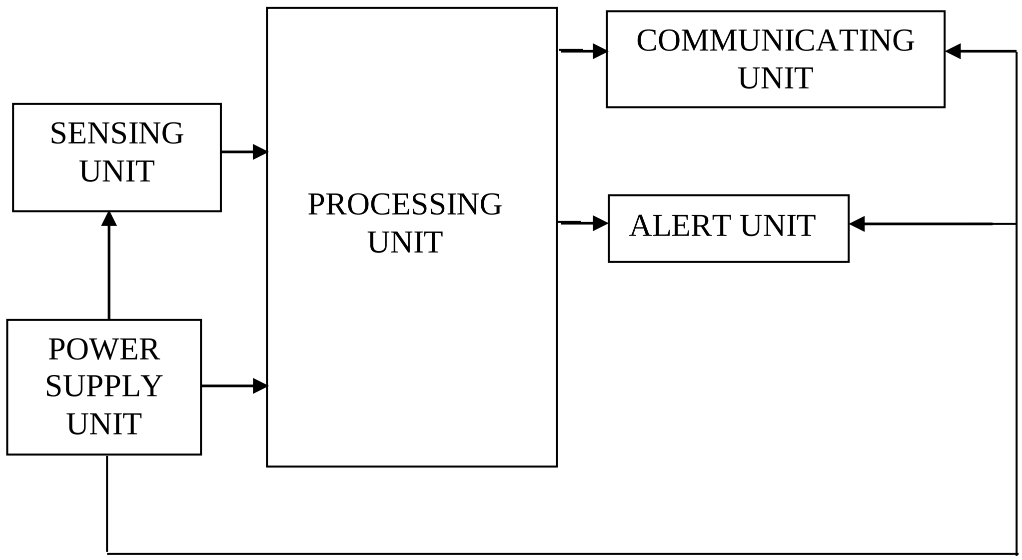

Figure 1: Block diagram of the system hardware

2.1 Power Supply Unit

Figure 2 shows the circuit diagram of the power supply unit. It consists of a step-down transformer, full wave rectifier, filter capacitor and a voltage regulator. The power supply unit provides a regulated 5 Vdc that is used to power the sensing unit, processing unit and a regulated 12 Vdc to power the alert unit and communicating unit.

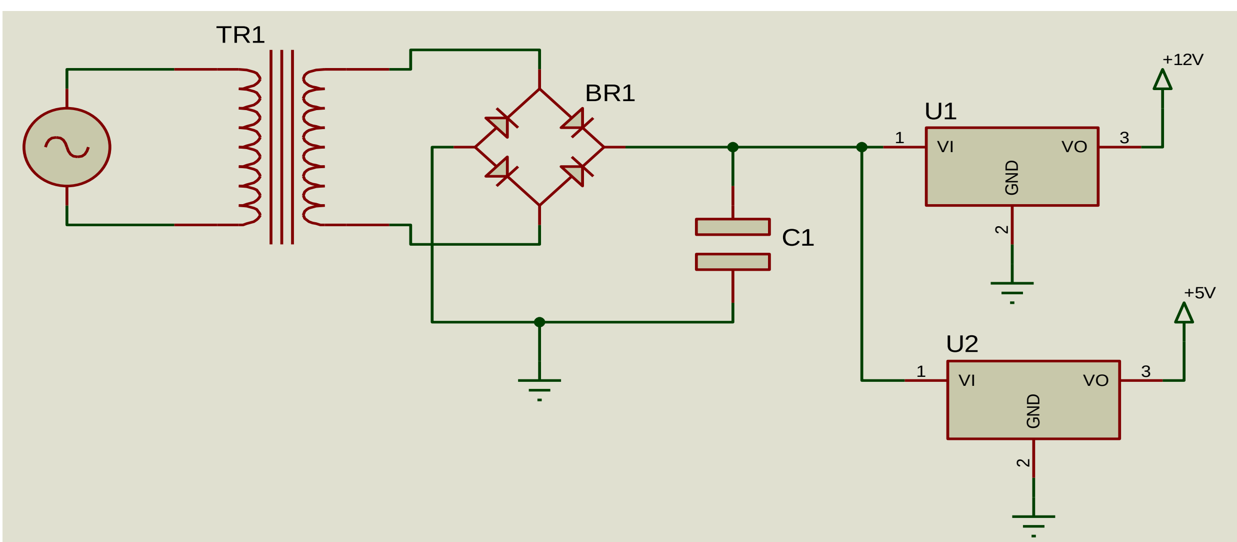

Figure 2: Complete circuit diagram of the power supply unit

2.1.1 Step-down transformer

Transformer TR1 shown in Figure 2 is an iron core step-down transformer which is used to reduce the mains input voltage from 240 Vac to 15 Vac at the same frequency. The maximum output current from the transformer is 2 Amps.

2.1.2 Full wave rectifier

Single phase full-wave bridge rectifiers are of two types, full-wave rectifiers with center-tapped transformer and bridge rectifier (Rashid, 2011). The full-wave bridge rectifier BR1 is used in the paper as shown in figure 2. The full wave bridge rectifier is used to rectify the 15 Vac from the output of the transformer to direct current (DC). The full wave bridge rectifier is used to remove the problem of core saturation (Intan, 2016). The full wave bridge rectifier used has a peak inverse voltage (PIV) or peak reverse voltage (PRV) greater than the output voltage of the rectifier. The peak output voltage from the rectifier with capacitor can be calculated using Equation 1 (John, 2007).

The peak output voltage of the rectifier

$$(V_{peak}) = \sqrt{2} \times Vrms \quad (1)$$

Where V_{rms} = Transformer secondary voltage = 15 Vac

$V_{peak} = \sqrt{2} \times 15 = 21.2$ Volts

2.1.3 Filter Capacitor

The filter capacitor is used to reduce the ripples present in the output voltage from the rectifier (Pyakuryal and Matin 2013). The capacitor C1 Figure 2 was selected to offer very low impedance to the ripple frequency. The full wave bridge rectifier together with the capacitor is expected to produce a peak value (V_{peak}) of about 1.4 times the alternating current root mean square input (John, 2007 and Rashid, 2007). So if using a 15 Vac to supply the input of the rectifier, the output from the rectifier should be about 21.21 Vdc.

The capacitance of the capacitor can be calculated using Equation 2 (Jim, n.d).

$$\text{Capacitance of capacitor (C)} = \frac{0.7 \, x \, I_O}{\triangle V \, X \, F} \quad (2)$$

Where Io = output current from the transformer in amps, $\triangle V$ = peak to peak ripple voltage, F = ripple frequency which is double the line frequency for a full wave bridge rectifier (Jim, n.d).

Peak to peak ripple voltage is the difference between the maximum and the minimum voltage (John, 2007).

$$Vp\text{-}p = Vmax - Vmin = Vrms\sqrt{2} - (Vrms - 2V_d) \quad (3)$$

Where Vp-p = peak to peak ripple voltage, Vmax = maximum output voltage with capacitor,

V_{min} = Minimum output voltage without capacitor,

Vrms = root means square voltage from transformer output,

V_d = diode forward voltage drop.

$Vp\text{-}p = 15\sqrt{2} - (15 - (2 \times 0.7)) = 7.61$ Volts

Therefore, capacitance of capacitor

$$(C) = \frac{0.7 \, x \, 2}{7.61 \, X \, 100} = 1840 \; \mu f$$

Any value between 2000 µf to 3300 µf is preferred because when the capacitance is high, more ripples are removed (Hart, 2011).

The value of the capacitor is chosen according to the ripple voltage it can tolerate. The maximum DC voltage a capacitor can withstand is called the working DC (WVDC) and should be 50 % more than the maximum voltage appearing across the capacitor (Bahattin, 2011). The DC voltage rating of the capacitor is generally selected to be double the maximum voltage i.e Vmax and is given by Equation 4 (Jim, n.d).

$$Vc = 2Vmax = 2Vrms\sqrt{2} \quad (4)$$

Where Vc = capacitor voltage, Vmax = maximum output voltage with capacitor, Vrms = root means square voltage from transformer output,

$Vc = 2 \times 15\sqrt{2} = 42.43$ Volts

2.1.4 Voltage regulator

The voltage regulator helps to maintain a constant voltage across the output under various load conditions. The type of voltage regulator used is a fixed type of the AN78XX series. It has an internal reference voltage of 3 V. The minimum input voltage required for the regulator to operate is given as:

$$V_{min} = V_{out} + V_{ref} \tag{5}$$

V_{ref} = internal reference voltage,
V_{out} = output voltage of the regulator,
V_{min} = minimum input voltage required for the regulator to operate.

For an 8 Volts regulator, V_{min} = 8+3 = 11 Volts
The input voltage for a regulator must be at least 2 Volts above the output voltage. This is required in order to maintain regulation (Theraja and Theraja, 2003).

2.2 Sensing unit

The sensing unit consists of a MQ-6 and MQ-135 gas sensors. This unit is responsible for detecting the presence of the required gas in the atmosphere, and sending signal to the MCU to carry out necessary action. The MQ-6 gas sensor has very low conductivity in clean air (Shaw et al., 2012). The choice of the gas sensor depends on the sensor type, type of gas to detect, input supply voltage and the output waveform of the sensor, whether current or voltage.

2.3 Processing Unit

Figure 3 shows the circuit diagram of the processing unit. It consists of a microprocessor, quartz crystal circuit and a reset circuit.

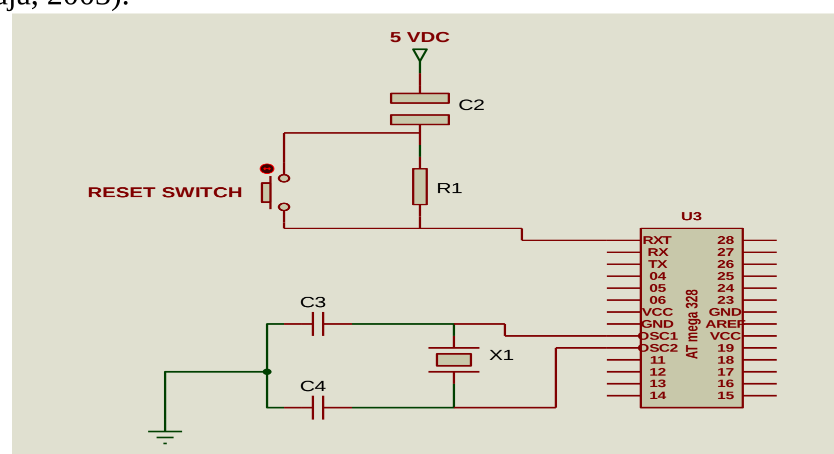

Figure 3: The processing unit

2.3.1 Microprocessor

A microprocessor is an electronic device that receives input from a sensor and processes the input according to the stored program, and gives an output to perform a particular function. The ATmega 328 microcontroller was used in this work instead the Peripheral Interface Controller (PIC) because it consume lower power, have higher memory size and better processing speed (Sameul et al., 2016).

2.3.2 Quartz Crystal Circuit

The quartz crystal circuit in conjunction with the internal oscillator circuit produces the timing signal. The timing signal determines the rate of instruction execution. It consists of a quartz crystal oscillator and a non-polarized capacitor. Quartz Crystal Oscillator produces a sequence of constant square wave pulses whose fundamental frequency is controlled by the crystal itself. This fundamental frequency adjusts the flow of instructions that controls the processor device. The quartz crystal oscillator generates the oscillator frequency and its value is determined as follows:

$$f_c = 16\ x\ f \qquad (6)$$

Where fc = crystal frequency, f = oscillation frequency
The oscillation frequency can be calculate from equation 7 (Lavinia, 2019) as:

$$f = \frac{1}{T} \qquad (7)$$

Substituting equation 7 in equation 6, we have:

$$f_c = 16\ x\ \frac{1}{T} \qquad (8)$$

where T = period of instruction execution and is = 1μs

Therefore, $f_c = 16\ x\ \frac{1}{0.000001}$ = 16 MHz

Capacitor C3 and C4 in figure 3 acts as load capacitors for the crystal and also for smoothening the clock pulses. The value of C3 and C4 can be calculated from equation 9 (Nuga et al., 2017) as:

$$C_L = \frac{C_1 X\ C_2}{C_1 + C_2} + C_S \qquad (9)$$

Where C_L = optimum load capacitance for a given crystal and is given as 20 pF from data sheet, C_S = stray capacitance on the printed circuit board and is given as 5 pF from data sheet.
If we assume $C_1 = C_2$, and making C_1 subject of formula, equation 9 becomes:

$$C_1 = 2(C_L - C_S) \qquad (10)$$

Therefore, C1=C2 = 2(20 – 5) = 30 pF

2.3.3 Reset Circuit

The reset circuit comprises of a resistor, capacitor and a reset switch. The reset circuit is used to reset the microcontroller and restart instruction execution from the beginning of the address location which is known as hardware reset. The reset circuit is basically a resistor-capacitor (RC) circuit. The charging time of the capacitor C is determined by the resistor R, which in turn determines the reset time. Thus, reset time can be calculated from the time constant using equation 11 (John, 2007) as:

$$\text{Time constant } (\tau) = RC \qquad (11)$$

For ATmega 328, time constant (τ) = 1 ms. Making R subject of formula in equation 9 and taking C = 1μF, we have:

$$R = \frac{1\ x\ 10^{-3}}{1\ x\ 10^{-6}} = 1\ k\Omega$$

2.4 Communicating unit

The communication unit consists of a Global System for mobile communication (GSM) module that is interfaced with the microcontroller. The GSM module is used to send short message to a specified mobile number (Murugan et al., 2012). When the sensors detect a gas leakage, the microcontroller sends a signal to the GSM module (Ashish et al., 2013). The GSM module works on a 12 Vdc supply and accept any network subscriber identity module (SIM) with a unique identity number (Ashish et al., 2013).

2.5 Alert unit

Figure 4 shows the circuit diagram of the alert unit. It consists of a buzzer and switching circuit. One terminal of the buzzer is connected to the regulated 12 Volts supply and the other connected to the collector of transistor Q1.

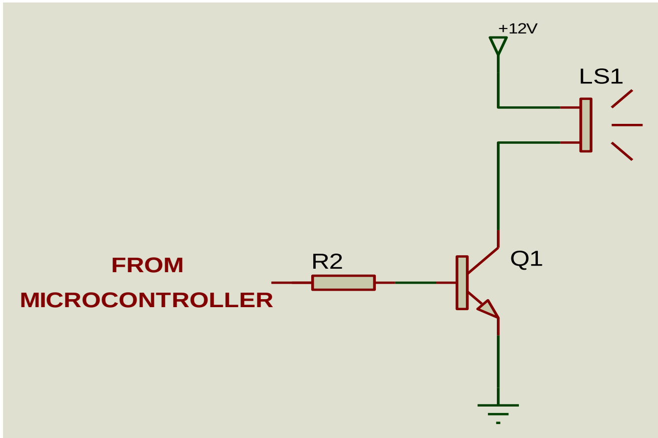

Figure 4: The alert unit

The transistor acts as a switch by connecting ground to turn ON the buzzer each time the microcontroller sends a 5 Volts to the base of the transistor. The transistor operates as a switch in class A mode (Theraja and Theraja, 2002). The base resistor R_2 can be calculated using Equation 12, 13, and 14 (Theraja and Theraja, 2002; Ahmed et al., 2006)

$$V^{+} = I_C R_C + V_{CE} \qquad (12)$$

$$H_{fe} = I_C / I_B \qquad (13)$$

$$R_2 = (V_{in} - V_{BE}) / I_B \qquad (14)$$

Where R_C = resistance of buzzer coil (250 Ω),
V_{BE} = base emitter voltage(0.6V),
V_{CE} = collector–emitter voltage when transistor is turned ON (0 V),
H_{fe} = current gain transistor (150)
V_{in} = V^{+} = output voltage from the MCU (5Vdc), I_C = collector current, I_B = base current, R_2 = base resistor,

Therefore, from Equation 12, I_C = 20 mA and from Equation 13, I_B = 133 μA
Substituting V_{in}, V_{BE}, I_B in Equation 14, we have:

$$R_2 = (5 - 0.6)/(133 \times 10^{-3}) = 33\ k\Omega$$

The circuit diagram of the Carbon monoxide and Liquefied petroleum gas leakage detection and alert system is shown in Figure 5.

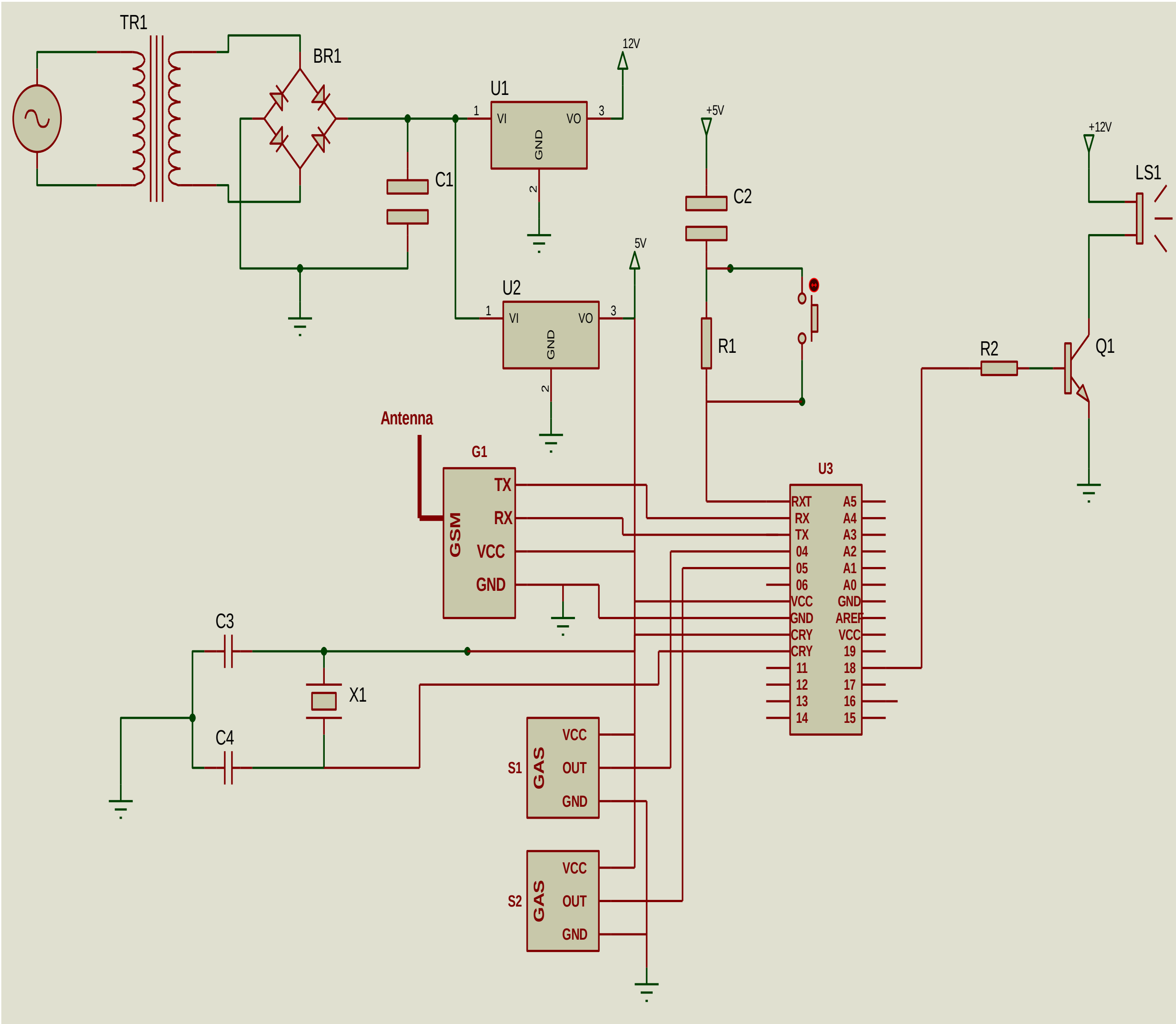

Figure 5: Circuit diagram of the Carbon monoxide and Liquefied petroleum gas leakage detection and alert system

3. Results and Discussion

3.1 Software Development

The Atmega 328 Microcontroller Is The Only Component In The Hardware That Requires An Instruction To Be Written, To Perform Specific Functions. Embedded C Programming Language Was Used In The Programming Of The Microcontroller Using The Arduino Software Integrated Development Environment (IDE) That Helps Write. The IDE Is Used To Write, Compile, Debug And Upload The Written Programme To The Atmega Chip. The Programme is Uploaded To The Chip By Connecting The Arduino UNO Board Through A Universal Serial Bus (USB) Cable To The Laptop Or Desktop Computer Port And Pressing The “UPLOAD” Button To Start The Process Of Transferring The Written Program To The Flash Memory Of The Microcontroller. Figure 6 Shows A Series Of Steps That Was Followed In Developing The Programme.

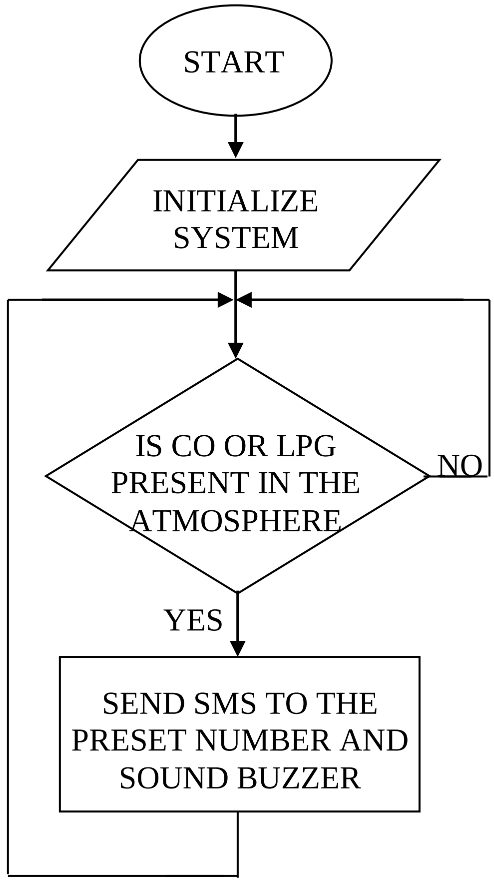

Figure 6: Flowchart of the gas leakage and detection system

3.2 Discussion of results

Figure 7 shows the constructed circuit on a vero board connected with various parts before it was packaged. The packaged circuit together with the metal stand is shown in Figure 8. The performance test carried out on the system and the results obtained is given in Table 1.

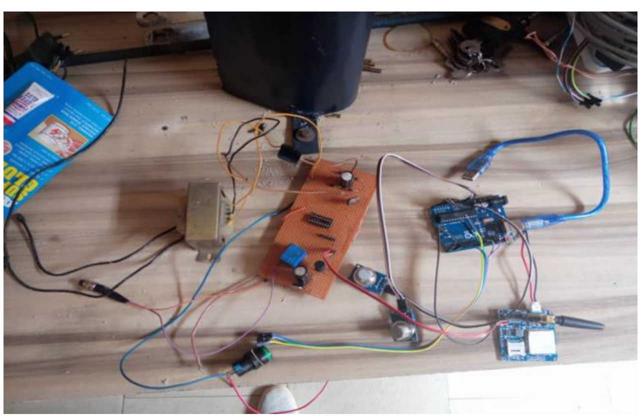

Figure 7: Constructed circuit on a vero board interface with other parts

Figure 8: Package circuit installed on a metal stand

Table 1: Concentration of gas and detection time.

GAS	Concentration (ppm)	Detection time (seconds)
CO	10	120
	100	60
	150	45
	200	30
	250	20
	300	15
	500	10
LPG	10	120
	100	60
	150	40
	200	25
	250	15
	300	10
	500	5

From Table 1, it is clear that for both gases, the higher the concentration of gas in the atmosphere, the faster the detection time. It is also clear that the detection time is not less than one second and this is because the gas sensor needs about one seconds delay to adapt to the environment it is placed. The sensitivity of the gas sensor can be adjusted by varying the sensitivity adjustment knob.

Conclusion

The Microcontroller based Carbon monoxide and Liquefied Petroleum Gas detection and alert system has been designed, constructed and tested. The system was developed to enhance the safety of man and machine at homes and in industries. The main objective of the system is for the early detection of CO and LPG where they are usually used and to sound an alarm to alert the individuals within the environment and to also send SMS to specific number(s) notifying them of the leakage. The system detects these gases before they reach their lowest flammability level (LEL) for LPG and lowest toxicity level (LTL) for CO.
From the tests carried out, it shows that the sensitivity of the system is high and it gives very fast response, accurate detection, and adequate security for individuals.

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