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A microcontroller based gas leakage detection and evacuation system

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Abstract. Liquefied Petroleum Gas (LPG) is a major fuel for cooking in Nigeria. LPG is dispensed into cylinders which are in various sizes and storage capacities. Multiple cases of household fires, injuries and fatalities due to LPG leakage and explosion have been recorded in Nigeria. This undesirable trend persists majorly because households in Nigeria don't have gas leakage detection systems, and at best only smoke detectors are available in selected high class homes. The proactive safety approach is to detect gas leakage and evacuate the gas before it is ignited. In this study, a model gas leakage detector and evacuation system are presented. The implemented, microcontroller-based system, activates a buzzer when a gas leak is detected, it shuts the gas supply solenoid valve to stop the gas flow, and also, it evacuates the gas by switching on evacuator fans. To ensure that the house occupant is adequately notified when there is a gas leakage; the system sends a text via short message service (SMS) to a stored mobile number. The status of the system can be remotely determined by the user, by sending codes to prompt the device via SMS.

Keywords: LPG Gas leakage detection, smart system, fire prevention, safety protection system, remote monitoring, SMS system prompt

1. Introduction

Hydrocarbon is a major source of energy, both for industrial and domestic applications. Liquefied Petroleum Gas (LPG) is a flammable hydrocarbon gas which consists of a mixture of propane and butane hydrocarbons. LPG is a product obtained from the refining of crude oil and gas, and it is a source of energy for domestic cooking, industrial ovens, electric power generators, and it serves as fuel for vehicles. LPG can also be used as a propellant, refrigerant and as a petrochemical feedstock. LPG has no odour and as such, Ethanethiol is added to it as a powerful odorant, for the detection of gas leakage via the sense of smell [1].

In Nigeria and globally, fire accidents and hazards caused by gas leakage have been a major challenge in the industries (e.g. oil and gas industry), and even in homes (in the kitchen). Several cases of fire accidents and explosions due to gas leakage from gas pipes, the burners of gas cookers or the gas cylinders have been reported. The 1984 San Juanico tragedy in Mexico City; one of the most severe LPG disaster in history, was caused by undetected LPG leakage [2].

Although, gas leakage detection is very important, but preventing fire requires adequate control of the detected gas leakage. In order to prevent gas explosion, there should be statutory environmental requirements on the use of LPG so as to prevent accidents, and protect life and property from disaster. The safety of life and property is vital in all our daily activities whether domestic or industrial. Achieving utmost safety requires adequate planning, early fault detection, and the use of appropriate forms of protection

Over the years, there have been several accidents caused by the leakage of LPG in homes and industries (especially oil and gas industries) from gas pipes and gas cylinders, which has led to the loss of several lives and properties through fire outbreaks and explosions, poisoning and suffocation due to lack of oxygen. In 2013, a report on LPG related accidents in Japan was filed by the High-Pressure Gas Safety Institute of Japan (KHK). It showed the number of accidents caused by LPG leakage, and a comparison was made with the previous years. As at 2013, there were 206 recorded accidents which left 3 people dead and 52 people injured [3]. From 2014, up to January 2015, there were over 12 recorded LPG leakage

related accidents in Chennai in India, and according to the report, this is an indication that the loss of life and damages caused by LPG accidents is on the increase in India. As at January 2015, in Chennai, two incidents had already been reported which left 3 people dead, and 6 others injured [4].

In Nigeria, although there are no accurate statistics and records on LPG related accidents, there have been cases of fire accidents and explosions in industries, fields, and environments where LPG is processed or used. A good example is an incident that occurred in August 2015, in which a family in Azia community, in Anambra State, took delivery of the bodies of nine of their children, who were roasted to death in their Lagos abode by fire that was caused due to undetected gas leakage [5]. There is no system in place that detects and arrests gas leakage in most kitchens in Nigeria. Even with all the modern building techniques and technologies, installation of gas leakage detection systems in the house, especially in the kitchen, is neglected, and this creates a fire hazard safety gap that can lead to serious disaster.

In this study, a smart, gas leakage detector is designed and implemented to detect gas levels above the normal threshold level, especially in a confined environment. When leakage is detected the system shuts off the gas supply by activating a solenoid valve, and it also evacuates the leaked gas by activating an exhaust fan. The gas leakage detector notifies the residents by activating a loud alarm, and it also sends an SMS text to a pre-configured number, so as to ensure that the residents are notified of any gas leakage even when they are not at home.

2. Smart Systems

Smart systems are systems that combine elements of sensing, actuation, and control for various analyses, and also for making appropriate decisions based on the available information, in a way that promotes versatility and adaptability of the system. Most times, how 'smart' a system is, may be ascribed to autonomous operations which includes; networking capabilities, closed-loop control, and energy efficiency [6]. A smart system should have high degree of reliability, efficiency and sustainability with an intelligent operational management system [6].

Smart systems incorporate many components, some of which are sensors for receiving signal, command and control unit (CCU) which sends instructions and carry out decision based information access and control, and actuators that execute the required task. Smart systems provide undeniable benefits in its use and application [7]. The smart system technology provides a means of addressing highly complex challenges and conditions, for instance, by offering early warning detection capabilities, responding to detected challenges, adapting the response system to manage unexpected challenges, thus enhancing the lifespan of the system. Another benefit is seen in the preventive maintenance of the smart systems. This leads to improved system operation, performance and function.

With the advent of improved technology, there is an increase in the use of smart systems in tackling challenges in the economy, society, and the environment as a whole. Smart systems are employed in various residential, industrial and commercial areas ranging from day to day tasks to very intricate and dangerous missions. Some important areas of application include healthcare, energy sector, manufacturing, transportation, military and defence, logistics, safety and security amongst others. Smart systems in this area are employed to assist in averting and guarding against mishaps, disasters and criminal activities which can negatively affect human lives and properties. Some examples include antitheft sensor systems, hazardous chemical sensing systems, gas sensing systems, radiation sensing systems, and anti-intrusion sensor systems, just to mention a few [8-12].

2.1 Smart Gas Detection

In the study by [13], a smart device was designed to identify and measure methane gas in zones of the flammable gas stockpile site. The device measures the air and water quality, including every parameter that can have deviation as a result of gas leakage in the water or air. The sensors measure the amount of

CH_4 and CO_2 gas in the air while the temperature, pH, and electrical conductivity of the water are monitored. The device is controlled by an Arduino UNO microcontroller that transmits measured data to the database on Raspberry Pi 3.

In [14], a gas detection system employing an MQ-9 sensor was proposed. The study developed an embedded system that triggers a buzzer and a set of LEDs to alert residents in the event of a gas leak. An android based automatic gas detection and indication robot was developed by [15]. When gas leak is detected, the mobile robot instantly interprets the data and sends it to an android mobile phone via wireless Bluetooth communication. An android application for smartphones using the Android OS, which can get data from the robot and also control the robot's motion using Bluetooth, was built. The study by [16], proposed a wireless LPG leakage monitoring system for home safety. The gas sensor sends a signal to the control unit, and after processing the signal, the control unit transmits a signal to the solenoid valve assembly and this triggers an alarm. The status of the gas level can also be determined through a web browser and the GUI.

3. The implemented gas leakage detector and evacuation system

The gas leakage is detected using MQ-2 gas sensor; the sensitive layer of the MQ-2 gas sensor is made of SnO_2. The conductivity of SnO_2 is low at normal operating condition, when the atmosphere is free from gas contamination. When the concentration of target gases such as methane exists in the atmosphere, the conductivity of SnO_2 increases, and this changes the sensor's resistance. The corresponding pulse is fed to the microcontroller. The sensor is powered by a 5V supply. The resistance of the sensor can be determined using equation 1 [17]. The MQ-2 sensor is shown in Figure 1.

$$R_s = \frac{V_c R_l}{V_{rl} - 1}$$

(1)

R_S is the resistance of the sensor
V_C is the voltage supplied to the load cell
V_{RL} is the voltage developed across the load resistance
R_L is the resistance of the sensor

Fig.1 MQ-2 Gas sensor

PIC16F628A; a flash-based, fully static, CMOS, 8-bit microcontroller is deployed as the brain of the whole system to control all the processes. It has an inbuilt ADC. It is connected to the relay, GSM module, buzzer, and the exhaust fans. The SMS based, gas leakage alert message is facilitated through a SIM800L GSM module. The GSM module requires 4.2V DC as the input supply voltage. LM7805 voltage regulator is utilized to regulate the 12V-DC that the power supply delivers to 5V DC. In this design, 4 pins of the SIM800L were used and these are:

- ✦ Vcc pin for supply
- ✦ Txd pin (transmission pin) connected to the receiving pin of the microcontroller
- ✦ Rxd pin (Receiving pin) connected to the transmission pin of the microcontroller
- ✦ Gnd pin (Ground)

The PIC16F628A microcontroller is programed using "MP-Lab" software installed on Windows 8 operating system. "CSS C" compiler is used for building the program. The code developed was dumped to the microcontroller using "PICFLSH" programmer software.

When the gas sensor detects gas leakage, it sends a signal to pin 18 of the microprocessor, the microprocessor processes the information and gives an output to the buzzer, fan 1, fan 2, GSM module and the relay which activates the valve via the following pins; pin 13, pin 10, pin 11, pin 8 and pin 12 respectively. The operation of the gas detector device is explained by the flow chart of Figure 2. The GSM module is connected to the Universal Asynchronous Receiver-Transmitter (UART) pin of the microcontroller. The circuit diagram is shown in Figures 3 and 4.
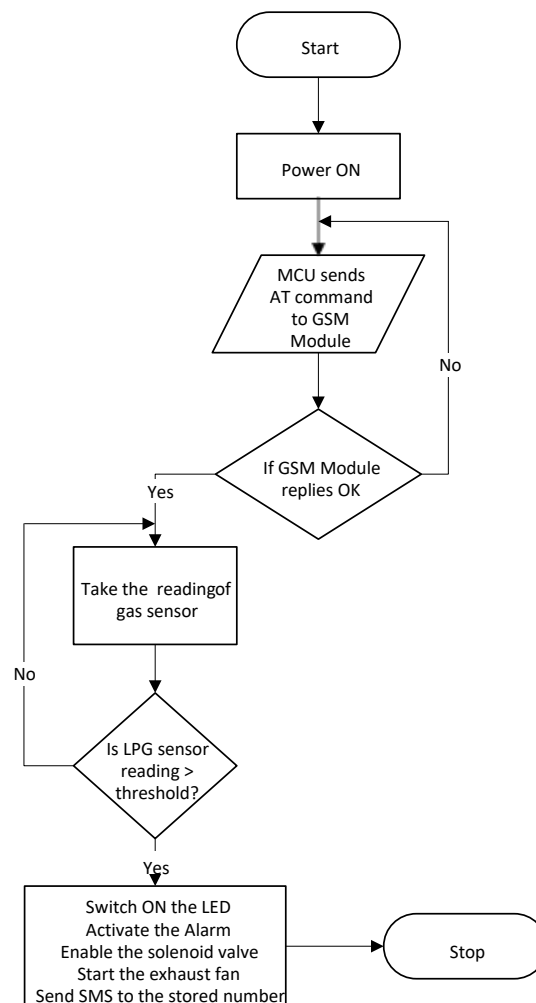

Fig.2 A flow chart of the gas detector operation

The following are the different SMS messages received from the gas detector and evacuation device:
- ✦ system initialization successful
- ✦ gas detected, evacuation procedure enabled
- ✦ gas completely evacuated, environment safe
- ✦ alert: system is on and sensing
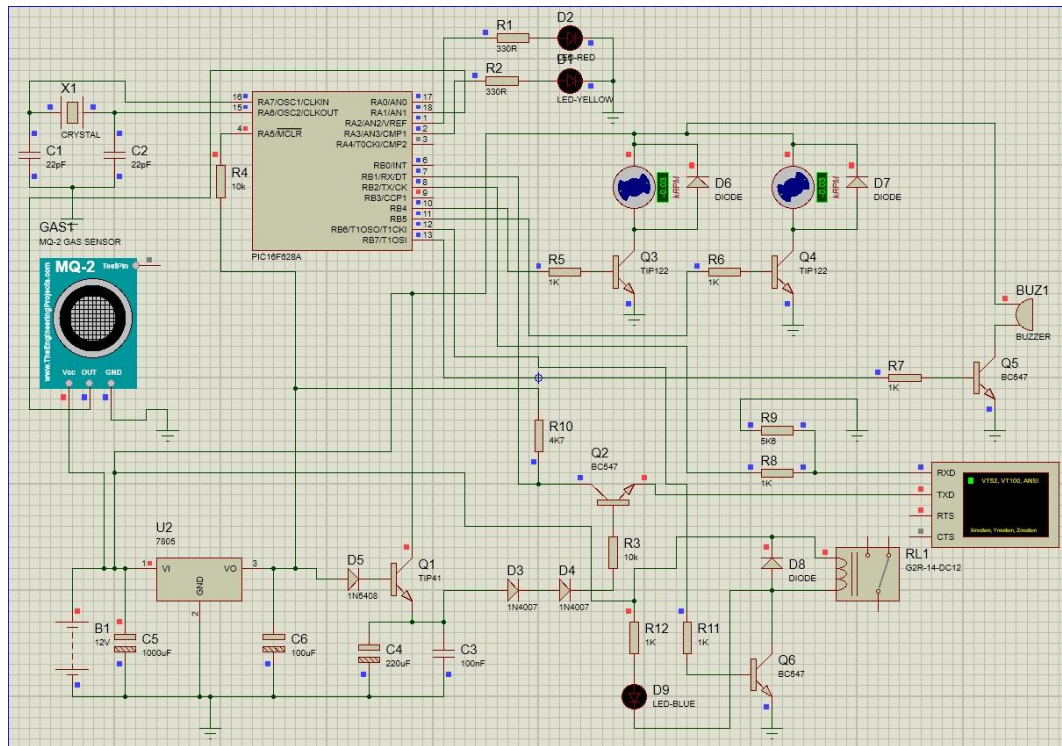- ✦ alert: gas status is okay, environment is clean

Fig.3 The circuit diagram of the Gas Detection & Evacuation System

4. Benefits of the implemented model

The implemented gas leakage detection and evacuation model device offers a number of advantages over dependence on unreliable detection by human sense of smell. The automated gas detection and evacuation process ensures safety by preventing gas induced house fires. The device performs the following:

- ✦ It detects LPG leakage using MQ-2 sensor
- ✦ Activates an alarm upon gas leakage detection, and it stops the alarm once the leakage is under control (gas concentration in the atmosphere is within normal range)
- ✦ It incorporates an SMS based alert mechanism, and it sends SMS text (alert message) to a specified mobile number
- ✦ Shuts off gas supply using a solenoid valve when gas leakage is detected
- ✦ It evacuates the leaked gas from the leakage area using an exhaust fan
- ✦ It incorporates a feature that allows the user to remotely probe via SMS if the gas detection module is ON, and also determine the current gas leakage status by sending unique codes.
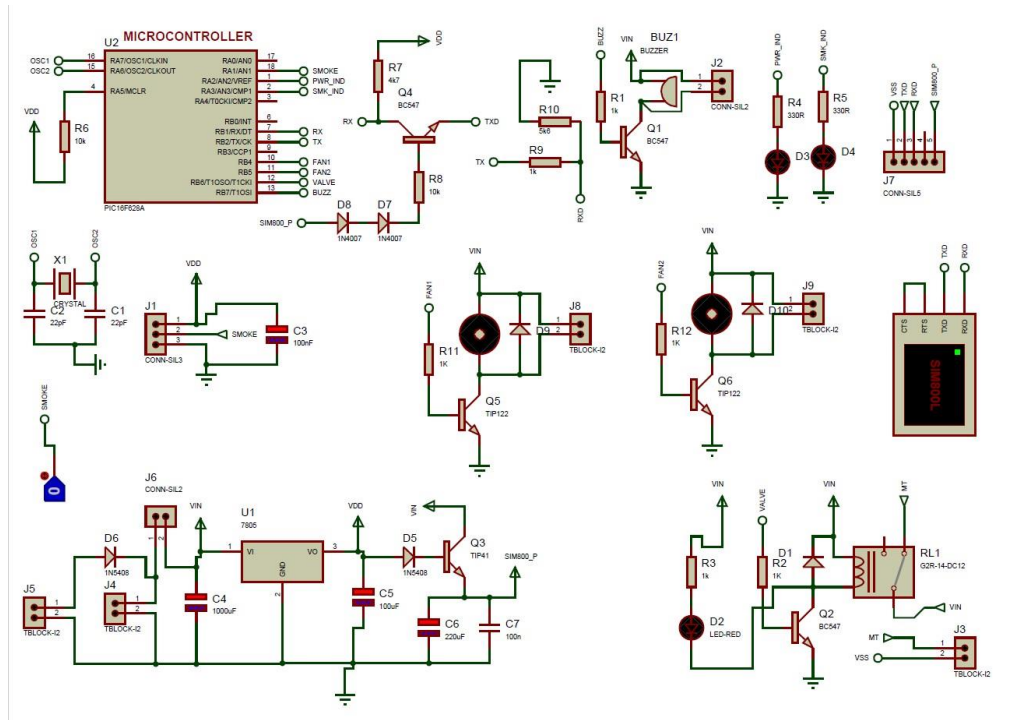
Fig.4 Component arrangement for PC board implementation

5. Conclusion

Safety is the proactive, and the cheapest option to preventing accidents and mishaps. Gas leakage induced fire is a menace that has occurred in different parts of the world. In Nigeria, LPG gas is supplied via cylinders for household use, and cases of gas leakage from the cylinder, the supply hose or the gas burner has been recorded by different users over the years with some resulting in gas explosion, property destruction, injury and fatality. This study presents the design of a model gas detection and evacuation system. After design implementation, the device accurately detected simulated gas leakage, and the SMS and buzzer, user alert system performed exactly as designed. The evacuator fans were automatically activated to suck away the leaked gas from the enclosure so as to prevent a potential ignition and fire. This smart device offers a number of safety benefits that are vital for early gas leakage detection, and response towards preventing LPG leakage related house fires in Nigeria.

Acknowledgments

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