Design of a Real-Time GSM-Based LPG Leakage Detector*

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Abstract

This paper is a follow up to an earlier paper, which reviewed the opportunities and threats of the usage of Liquefied Petroleum Gas in homes and industries in Ghana. In this paper, the design of an electronic gas leakage monitoring system in real-time is proposed, to alert people in homes and industries in Ghana of gas leakages through persistent text messages with accompanying beeps. The importance of using such a system in Ghana is due to the increased spate of fire outbreaks in homes where at least one or more gas cylinders can be found. This is because in a developing country like Ghana, the transportation of cisterns for gas storage to homes and industries is not done through piping. The ubiquitous use of mobile phones in Ghana makes it easier for the use of this system to alert occupants of homes and industries about gas leakages from their cylinders.

Keywords: Liquefied Petroleum Gas, Microprocessor, Wireless Communication, Simulation Model

1 Introduction

Households and industries in Ghana are suffering from serious shortfalls of electricity supply. This situation usually has its roots in the mix of energy policy miscues, the country's overdependence on hydro power and its concomitant high oil prices, which have increased the cost of generating electricity. The use of Liquefied Petroleum Gas (LPG) in homes and industries in Ghana, therefore, comes as a relief. There are many opportunities for LPG to contribute to improved living standards in Ghana and the world at large (Inkoom and Biney, 2010).

LPG is finding wide usage in homes, industries and in automobiles as fuel because of its desirable properties, which include high calorific value, production of less soot and very little smoke (Sunithaa *et al.,* 2012; Peatman, 1997). LPG burns to produce clean energy; however, there is a serious threat about their leakages if proper care is not taken in their handling. LPG being heavier than air, does not disperse easily and may lead to suffocation when inhaled. Also, the leaked gas when ignited may lead to explosion. The number of deaths associated with the explosion of LPG cylinders have increased in recent years. Some incidences of explosions in Ghana have occurred due to improper use of LPG, which are chronicled in an earlier paper (Amuzuvi and Ashilevi, 2016). This paper presents the design of an electronic gas leakage monitoring system, which can be used for the detection and prevention of the leakage of LPG (Fraiwan *et al.,* 2011), especially in homes.

2 Resources and Methods Used

In this paper, Global System for Mobile (GSM) communication technology using a GSM module was implemented in conjunction with a microcontroller to achieve the aim of the paper, i.e. the use of such a system to alert people in of homes and industries about a gas leakage from their cylinders.

2.1 Building Blocks of the Proposed System

The system is made up of seven blocks with each module carefully considered and chosen to enhance strong and effective communication link within the unit. This includes; the Power Supply, the LPG Sensor, the Analogue to Digital Converter (ADC), the Microcontroller, the Buzzer, the Liquid Crystal Display (LCD) and the GSM Modem. The conceptual design is presented by the block diagram in Fig. 1.

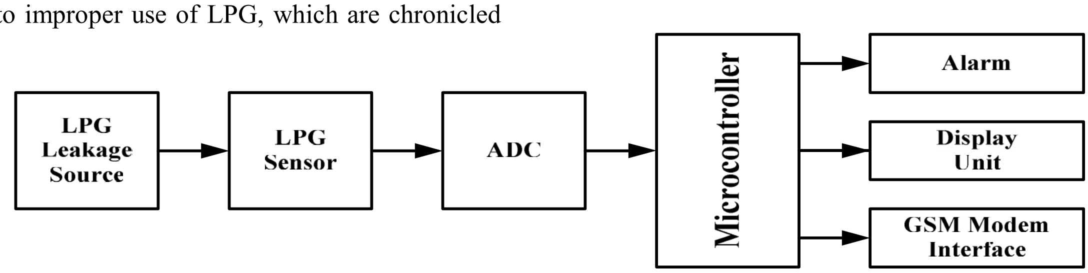

Fig. 1 Block Diagram of Proposed Design

2.2 Hardware of the Proposed System

A general purpose microcontroller board is connected with an ADC board, which has single channel ADC and a gas detecting sensor. The hardware consists mainly of an embedded microcontroller as the main controlling device to which all other devices are connected. An LPG sensor is used to detect the presence of gas. The analogue signal from the gas sensor is converted to a digital signal by an ADC. The digital output from the ADC is fed into the microcontroller and when the gas concentration exceeds a specified threshold level, the buzzer is sounded and also real-time notification is sent to the target number by means of text messaging via wireless technology.

A linear mode power supply is used in this design. A power adaptor is therefore connected to a power socket in the microcontroller board. Fig. 2 presents a circuit diagram of 12 V DC and 5 V DC power supply used for the design.

2.3 The Microcontroller

The microcontroller used in the design is the AT89C51 (Target Processor) microcontroller. It is a 40-pin microcontroller and each pin of the microcontroller is assigned a number of functions, sometimes two and sometimes three. The microcontroller is similar to other Integrated Circuits with the difference being that microcontrollers are not designed to perform a particular function and can be programmed to do many tasks.

The AT89C51 is a low-power, high-performance CMOS 8-bit microcomputer with 4 kB of flash programmable and erasable read only memory (PEROM). The device is manufactured using Atmel's high-density non-volatile memory technology and is compatible with industry-standard MCS-51 instruction set and pin out. The on-chip flash allows the program memory to be reprogrammed in-system or by a conventional non-volatile memory programmer. By combining a versatile 8-bit Central Processing Unit with flash on a monolithic chip, the AT89C51 is a powerful microcomputer, which provides a highly-flexible and cost-effective solution to many embedded control applications. The architecture of the AT89C51 microprocessor is shown in Fig. 3.

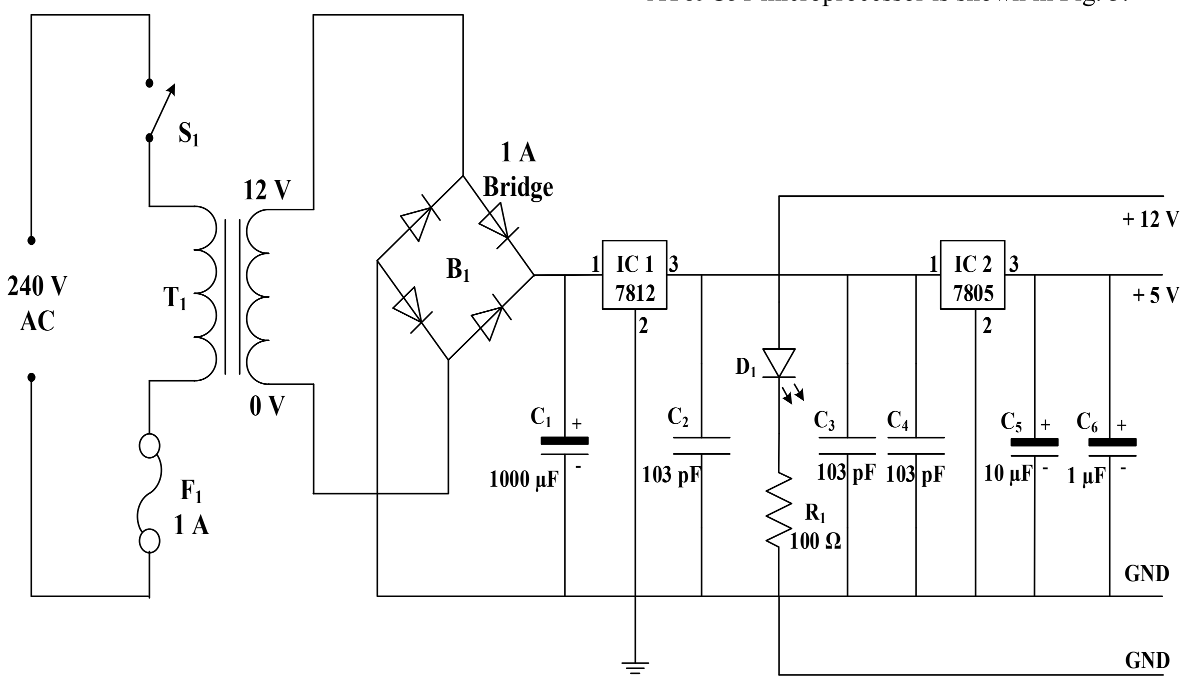

Fig. 2 12 V and 5 V Power Supply Circuit

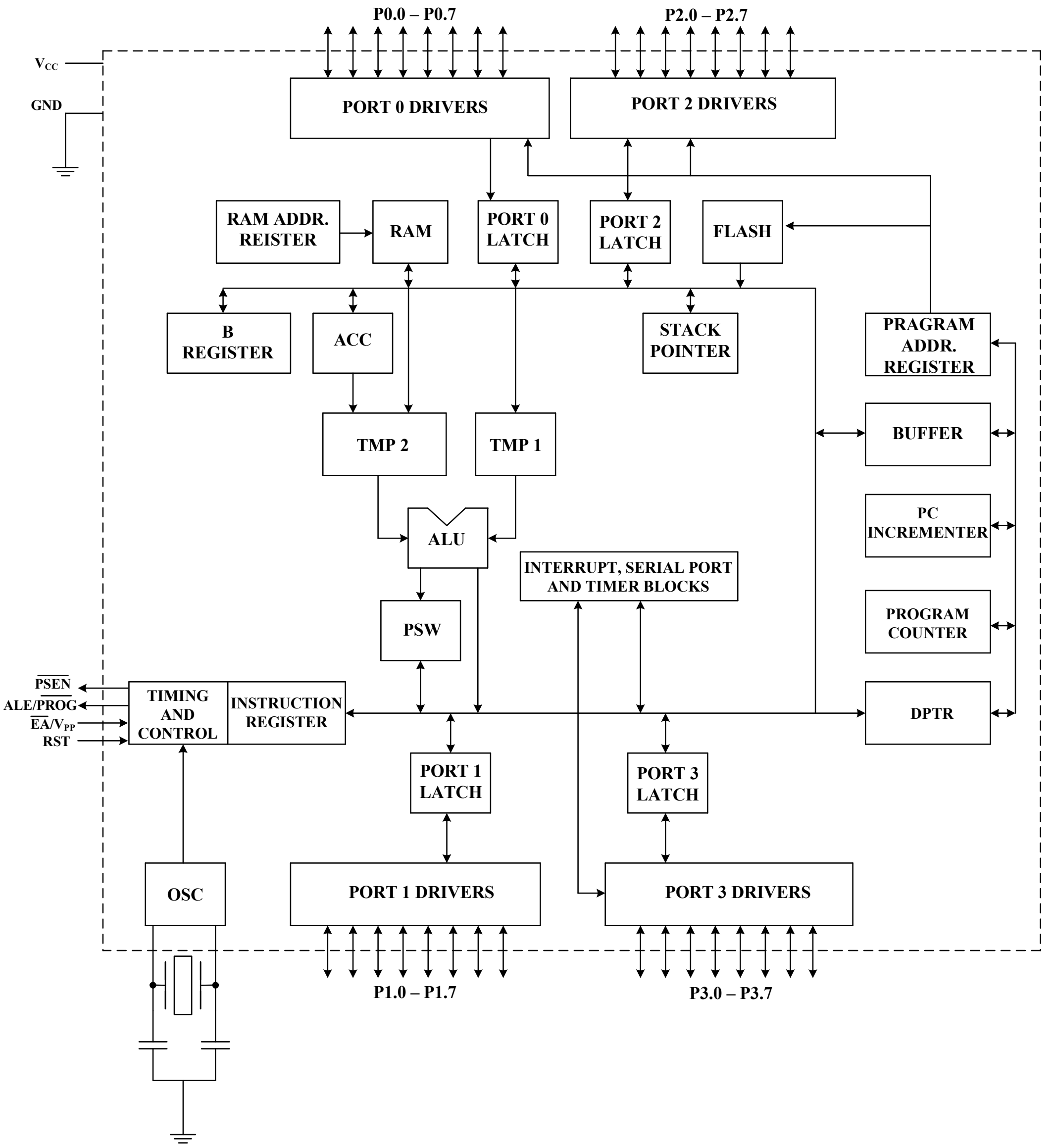

Fig. 3 Architecture of AT89C51 Microcontroller

2.4 LPG Sensor

The sensing element of gas sensors is a tin dioxide (SnO_2) semiconductor, which has low conductivity in clean air. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal, which corresponds to the gas concentration.

The sensor employed in this design is the MQ-5 LPG sensor module. It has high sensitivity to LPG, methane, propane, and butane and it is less sensitive to alcohol, cooking fume and cigarette smoke, making it ideal for natural gas and LPG monitoring. It has a detecting concentration range of 200 ppm to 10,000 ppm and a circuit voltage of 5 V with a tolerance of 0.1. The sensor can detect a wide range of gases, making it an excellent, low cost sensor for a wide variety of applications. MQ-5 sensor has a ceramic base, which is highly resistant to severe environmental temperatures up to 200°C.

The MQ-5 gas sensor is composed of a micro aluminium oxide (Al_2O_3) ceramic tube, a tin oxide (SnO_2) sensitive layer, a measuring electrode, a heater and a stainless steel net. The heater provides the necessary heating conditions for the operation of the sensitive components. It has six pins, four of these pins are used for signals and the other two are used for providing the heating current (Anon, 2013a).

The working principle of this type of sensor is that, the resistance of the metal oxide semiconductor changes when it is exposed to the target gas, because the target gas reacts with the metal oxide surface and changes its electronic properties, hence the resistance of the sensitive layer increases proportionally as the extent of increase of the gas concentration (Stetter, Penrose and Yao, 2003).

The structure and configuration of the MQ-5 gas sensor is shown in Fig. 4a (Anon, 2013b).

Fig. 4b show the basic test circuit of the sensor. The sensor uses two voltages, the heating voltage (V_H) and the circuit voltage (V_C). The heating voltage is used to supply the required working temperature to the sensor whilst the circuit voltage is used to detect the voltage (V_{RL}) on the load resistance (R_L), which is in series with the sensor. The circuit voltage and the heating voltage use the same power circuit with the precondition to ensure the performance of the sensor (Anon, 2013b).

Sensitivity adjustment is very necessary; this is because the resistance value of the gas sensor is different from various kinds and various concentrations of gases. It is highly recommended that the sensor is calibrated for 1000 ppm of LPG concentration in clean air and a value of a load resistance (R_L) of about 20 kΩ is used.

2.5 Global System for Mobile Communications

GSM is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard that would formulate specifications for a pan-European mobile cellular radio system operating at 900 MHz.

In addition to digital transmission, GSM incorporates many advanced services and features, including Integrated Services Digital Network (ISDN) compatibility and worldwide roaming in other GSM networks. The advanced services and architecture of GSM have made it a model for future third-generation cellular systems, such as Universal Mobile Telecommunications System.

2.5.1 GSM Modems

A GSM modem can be an external modem device. You can insert a GSM Subscriber Identity Module (SIM) card into this modem, and connect the modem to an available serial port on your computer. A GSM modem can be a PC Card installed in a notebook computer, such as the Nokia Card Phone.

A GSM modem could also be a standard GSM mobile phone with the appropriate cable and software driver to connect to a serial port on your computer.

A dedicated GSM modem (external or Personal Computer Card) is usually preferable to a GSM mobile phone. This is due to some compatibility issues that can exist with mobile phones, e.g. if you wish to receive inbound Multimedia Messaging Service (MMS).

MMS messages with a gateway, using a mobile phone as a modem, must utilise a mobile phone that does not support Wireless Application Protocol push or MMS. This is because, the mobile phone automatically processes these messages, without forwarding them via the modem interface. Similarly, some mobile phones will not allow you to correctly receive Short Messaging Service (SMS) text messages longer than 160 bytes (known as “concatenated SMS” or “long SMS”). These long messages are actually sent as separate SMS messages, and the phone attempts to reassemble the message before forwarding via the modem interface.

When you install your GSM modem, or connect your GSM mobile phone to a computer, be sure to install the appropriate Windows modem driver from the device manufacturer. An additional benefit of utilising this driver is that; you can use Windows diagnostics to ensure that the modem is communicating properly with the computer.

2.5.2 Architecture of the GSM network

A GSM network is composed of several functional entities whose functions and interfaces are specified. Fig. 5 show the layout of a generic GSM network. The GSM network can be divided into three broad parts. The Mobile Station is carried by the subscriber. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which, is the Mobile services Switching Centre (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations.

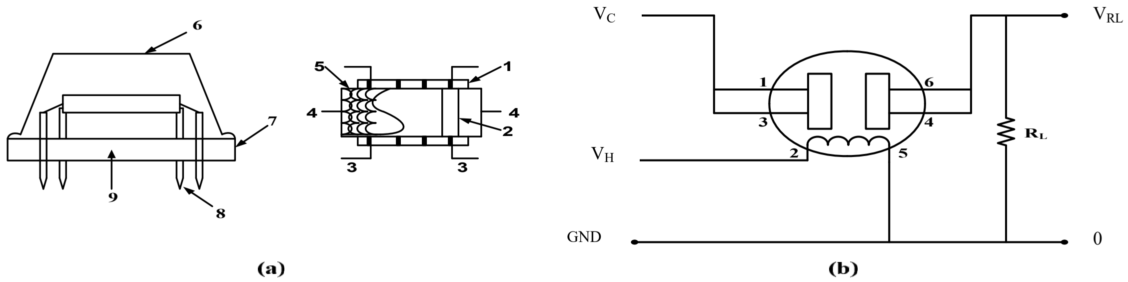

Fig. 4 (a) Structure of the MQ-5 Gas Sensor and (b) Basic Measuring Circuit of MQ-5 Gas Sensor

Key Elements in the Structure of a GSM Network

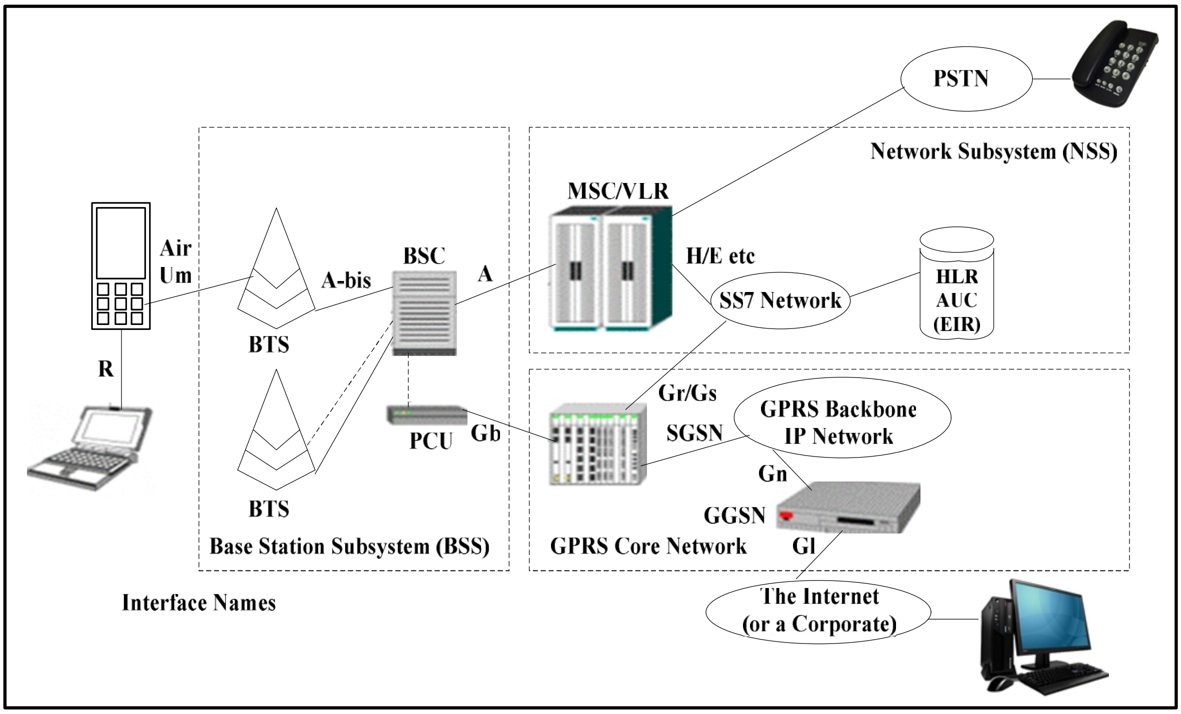

Fig. 5 Structure of a GSM Network

Not shown are the Operations Intendancy Centre, which oversees the proper operation and setup of the network. The Mobile Station and the Base Station Subsystem communicate across the Um interface (GSM air interface), also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Centre across the A interface. Fig. 6 also shows the general architecture of a GSM network.

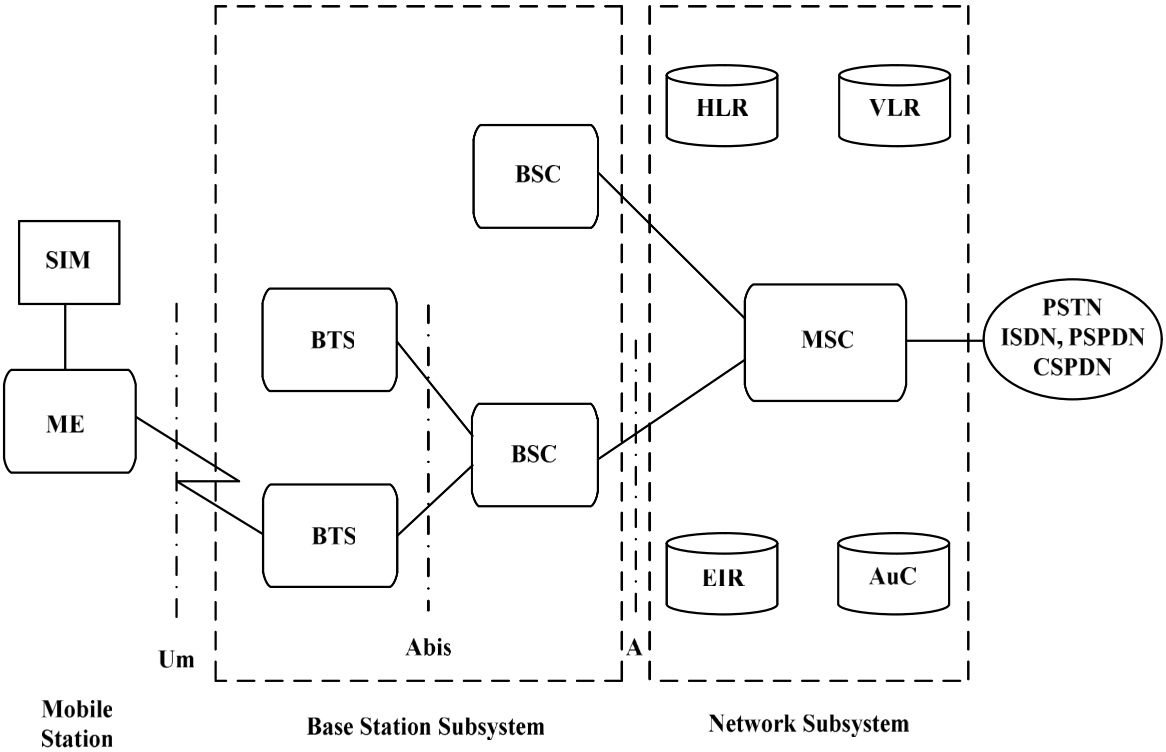

Fig. 6 General Architecture of a GSM Network

2.5.3 Mobile Station

The Mobile Station (MS), consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another GSM terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services.

The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility. The SIM card may be protected against unauthorised use by a password or personal identity number.

2.5.4 Base Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). These communicate across the standardised Abis interface, allowing (as in the rest of the system) operation between components made by different suppliers.

The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Station. In a large urban area, there will potentially be a large number of BTSs deployed, thus the requirements for a BTS are ruggedness, reliability, portability, and minimum cost.

The BSC manages the radio resources for one or more BTS. It handles radio-channel setup, frequency hopping and handovers. The BSC is the connection between the mobile station and the MSC.

2.5.5 Network Subsystem

The central component of the Network Subsystem is the MSC. It acts like a normal switching node of the Public Switched Telephone Network (PSTN) or ISDN, and additionally provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. These services are provided in conjunction with several functional entities, which together form the Network Subsystem. The MSC provides the connection to the fixed networks (such as the PSTN or ISDN). Signalling between functional entities in the Network Subsystem uses Signalling System Number 7 (SS7), used for trunk signalling in ISDN and widely used in current public networks.

The Home Location Register (HLR) and Visitor Location Register (VLR), together with the MSC, provide the call-routing and roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The location of the mobile is typically in the form of the signalling address of the VLR associated with the mobile as a distributed database. There is logically one HLR per GSM network, although it may be implemented.

The VLR contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. Although each functional entity can be implemented as an independent unit, all manufacturers of switching equipment to date implement the VLR together with the MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR, thus simplifying the signalling required. Note that, the MSC contains no information about a particular mobile station and that this information is stored in the location registers.

2.6 The Design Implementation Plan

The implementation of the designed plan requires: usage of microcontroller; implementation of gas sensor; implementation of wireless modem; and the system integration and testing.

The first stage of the implementation involves the LPG gas sensor connected with the microcontroller via the ADC0804. Since the output of the gas sensor is analogue, it is first converted into a digital data. This converted data is transmitted to the microcontroller to process the data.

In the second stage, the microcontroller P89V51RD2 processes the data from the gas sensor output. If the received data is above the specified set level, the microcontroller will send a control signal to the wireless modem to send a data to a target mobile number in the form of SMS and also activate the buzzer.

The third stage involves a wireless modem in the form of a GSM, which is the much needed technology to be used for sending SMS to a target mobile number.

The final stage is integrating the entire module, which will be used for the prototype. The main part is a microcontroller, which controls all of the other peripheral devices.

2.7 System Design and Development

2.7.1 Design Concept and Considerations

A wireless communication based LPG detection system detects the presence of LPG gas, activates an alarm and sends a message to a target number informing it of a gas leakage in the form of a text message. The conceptual design is presented by the diagram in Fig. 7.

2.7.2 System Programming

The microcontroller has to be programmed to execute instructions. Fig. 8 shows the flow chart of the microcontroller programming.

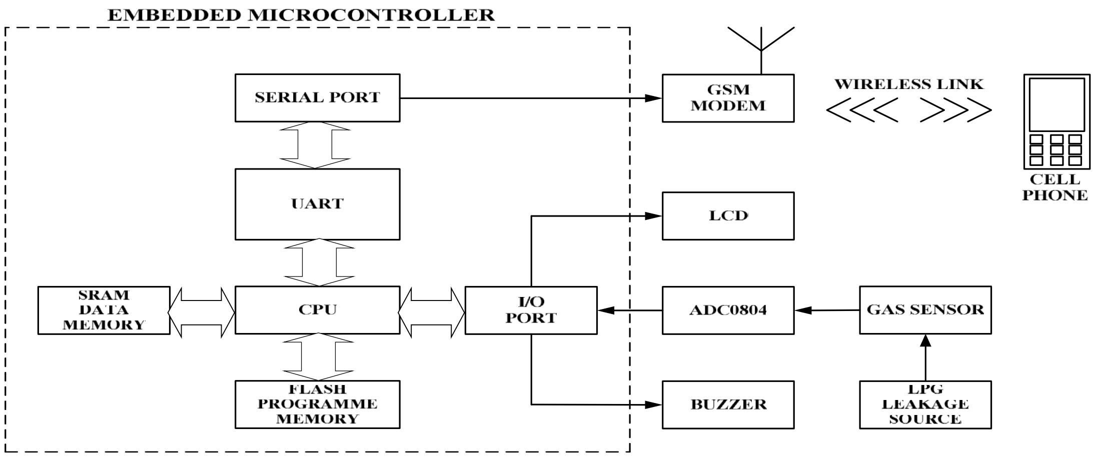

Fig. 7 Design Concept Diagram of the Proposed System

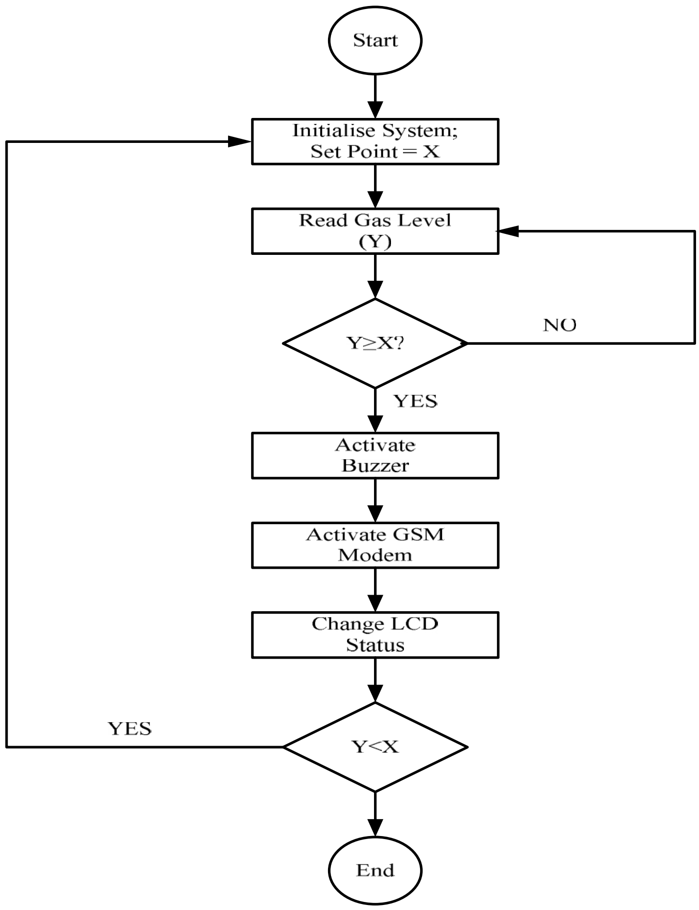

Fig. 8 Microcontroller Programming Flow Chart

2.7.3 Design of the Wireless LPG Detector System

Fig. 9 show the circuit diagram of the wireless LPG detector, indicating the details of the interconnection between the major parts of the system.

2.8 Simulation of the Proposed System Design

Simulation is a vital process in the development and realisation of any design, be it software based, hardware based or both. It is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system will work. The act of simulating requires that a model be developed. This model represents the key characteristics or behaviours of the selected physical, abstract system or process.

The circuit simulator employed for testing this design is Proteus Professional. This software enables the design to be simulated to ensure its functionality before being subjected to the real-life situation, which would be devoid of operational faults. Fig. 10 show the simulation diagram of the LPG leakage system.

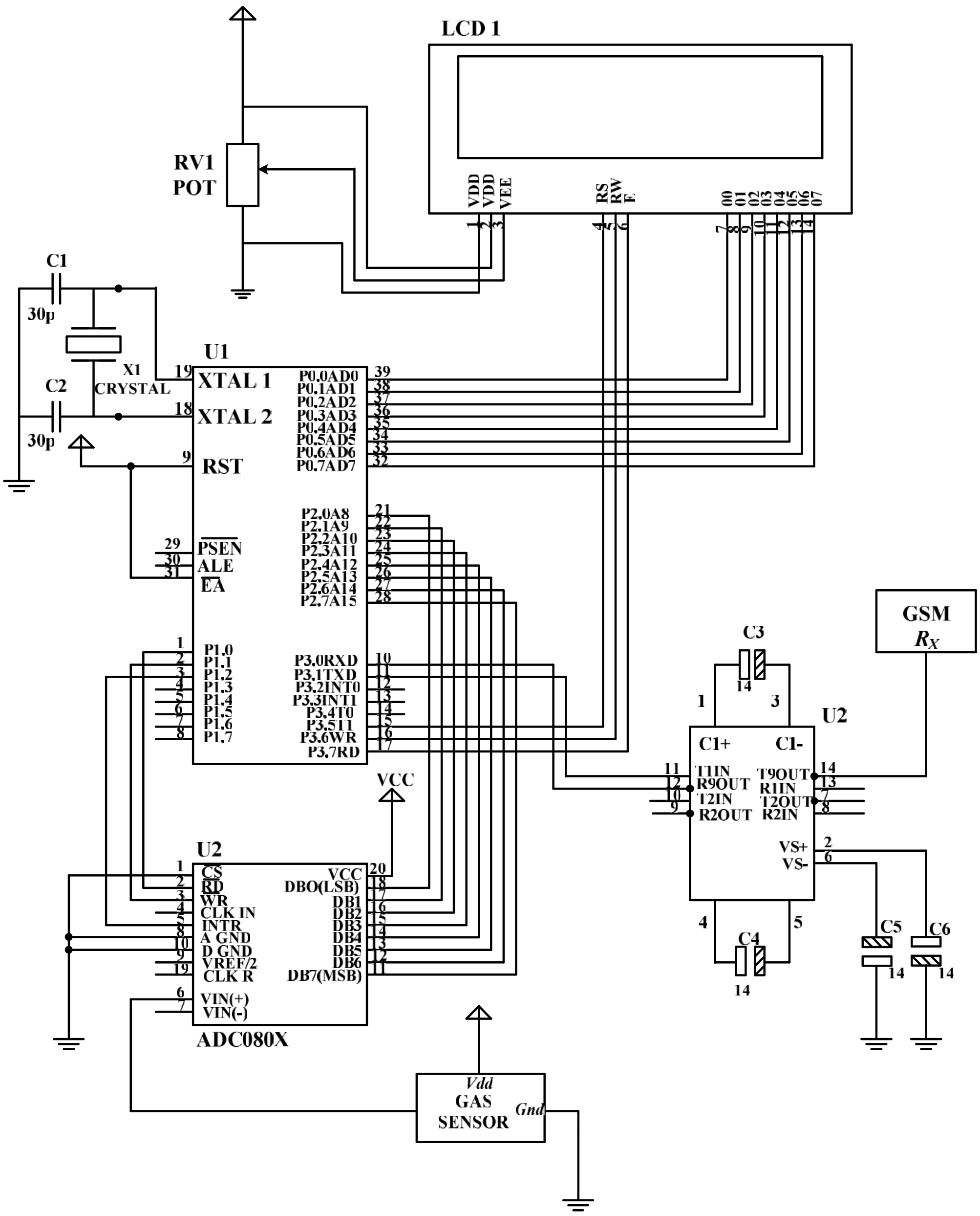

Fig. 9 Circuit Diagram of the Proposed System

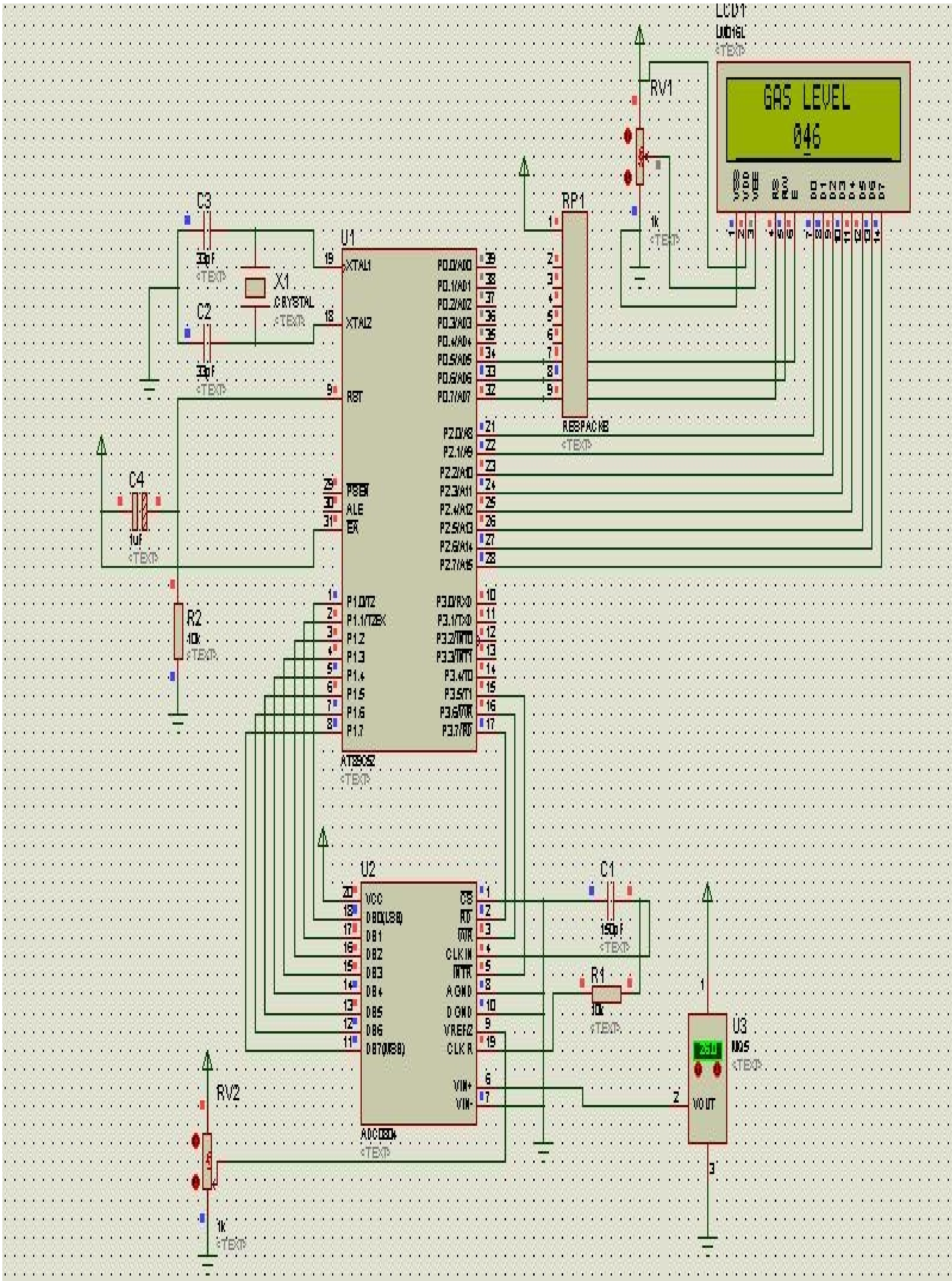

Fig. 10 Simulation Model of the LPG Leakage Detector

2.9 Hardware design of the LPG Leakage detector

Fig. 11 show the pictorial view of the assembled design of the LPG leakage detector.

2.10 Hardware Design and Testing

The procedure followed in achieving the hardware design is as follows:

(i) The general purpose microcontroller board is connected with an ADC board, which has single channel ADC and a gas detecting sensor;

(ii) A power adaptor of 230 V/12 V is connected to the power socket on the microcontroller board. The AC voltage through the adaptor is converted to DC voltage using bridge rectification and filtered by a capacitor to obtain a linear voltage as the transistor in the microcontroller needs constant biasing;

(iii) Four diodes are used, which will act as a bridge rectifier to convert AC voltage into DC voltage;

(iv) The other necessary devices on the board are crystal oscillator and reset. The purpose of using crystal oscillator is to generate a clock pulse for executing instructions. For executing a single instruction, the microcontroller needs 12 clock pulses. The crystal oscillator is therefore the heart of the microcontroller;

(v) Next is the ADC board, which has a gas sensor and a single channel ADC. The operating ADC board requires +5 V that will be provided through a two pin cable from the main board. The ADC conversion needs three control lines RD (read), SOC (start of conversion), EOC (end of conversion) and eight data lines to transfer the data to the controller;

(vi) The microcontroller has four parallel I/O ports. All ports are bi-directional in nature. The data lines are connected to Port 1 and the control lines from the ADC are connected to Port 2 of the microcontroller;

(vii) While connecting the power, the buzzer will generate a sound to show that the sensor is initialising and therefore not taken as an abnormal status. This will stop after a few seconds; and

(viii) The hardware can now be tested by deliberately leaking LPG gas.

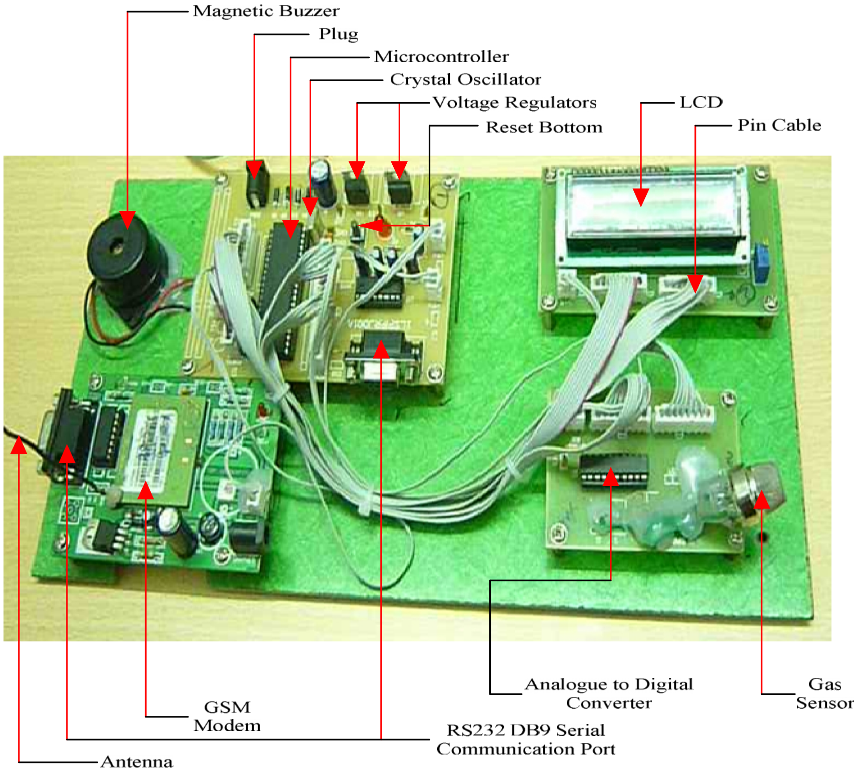

Fig. 11 Picture of the Assembled Design of the LPG Leakage Detector

3 Results and Discussion

This system or module must be placed in close proximity to the cistern that holds the LPG gas.

An Interface Application Software for the gas leakage detection system has been developed to enable the user view the status of the system and most importantly allow the user to make changes. This interface allows the user to change the target mobile number, the message to be sent, starts the GSM modem and also stop the GSM modem. This interface also enables the user to set the gas concentration levels and the threshold level. Microsoft Virtual Studio is the tool used to develop the interface application software for the gas leakage detection system.

3.1 Microsoft Visual Studio

Microsoft Visual Studio is an integrated development environment from Microsoft. It is used to develop console and graphical user interface applications along with Windows Forms, websites, web applications, and web services in both native code together with managed code for all platforms.

Visual Studio supports different programming languages by means of language services, which allow the code editor and debugger to support nearly any programming language, provided a language-specific service exists.

3.2 User Interface Application Software

To login to the user interface application software, the assigned com port for the microcontroller interface board and the GSM interface board must be *select* and the below username and password be entered (Fig. 12a).

3.3 Before Gas Leakage

The graph in Fig. 12b displays the state of the LPG leakage detector when no gas leakage is detected. The graph appears to be stable because there is no high vapour concentration of gas leakage. Initially, when no gas leakage is detected, the gas level falls within the range of 45 ppm to 57 ppm as shown in Fig. 12b.

3.4 After Gas Leakage

When there is a gas leakage, the gas level rises according to the concentration of gas present. When the gas concentration level reaches or goes above the set threshold level, the status is changed from normal to abnormal. The buzzer is immediately activated and a message is sent to the target number. Fig. 12c shows the status of the gas detection model when the presence of LPG is detected.

3.5 Cost Analysis

An estimated cost of UD$32.34 (approx. GHc129.36 Ghana Cedis only with an exchange rate of GHc4.00 per a dollar as at 14th November 2016) is required for the implementation of the design. Table 1 presents the summary of the detailed components cost of the system. The cost of the system or module is within the means of many home users and small industries in Ghana and elsewhere.

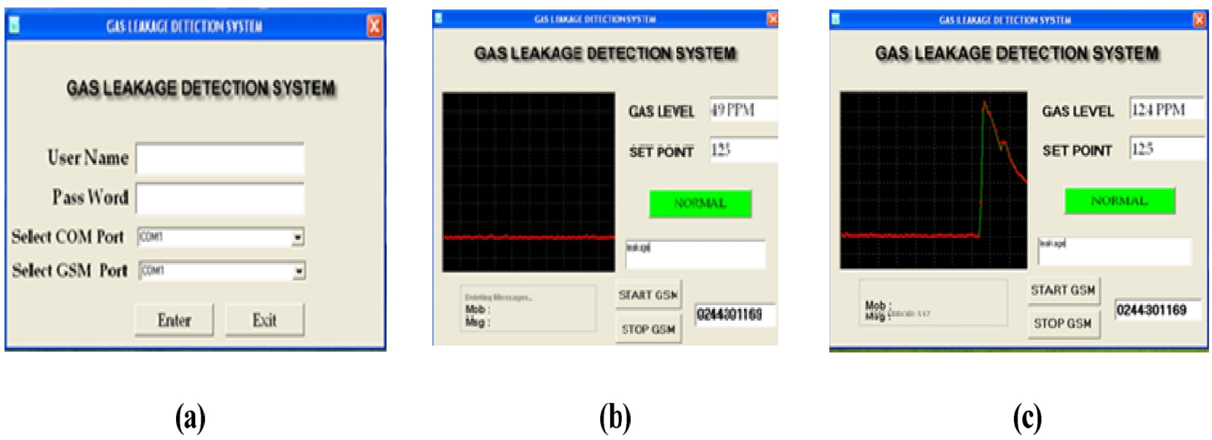

Fig. 12 (a) Login Application Software Interface, (b) Screen View before Gas Leakage and (c) Screen View after Gas Leakage

Table 1 Cost Analysis

Item No.	Item Description	Type	Quantity	Unit Price US$	Total Cost US$
1	Microcontroller Embedded Module Board	AT89C52	1	1.83	1.83
2	GSM Module Board		1	3.33	3.33
3	Gas Sensor and ADC Module	MQ-5	1	4.72	4.72
6	Data Communication Cable	PLUG	2	0.14	0.28
7	Buzzer	ION 820	1	0.26	0.26
8	Reset Bottom Switch	Digital	1	0.33	0.33
9	Light Emitting Diodes (LED's)	RED	1	0.92	0.92
10	Voltage Regulator	IC	2	0.72	1.44
11	Diodes		4	0.29	1.08
12	Fixed Capacitor		3	0.27	0.81
13	Capacitor		3	0.74	2.22
14	Computer Interface Cables	RS232 DB9 pin/out	1	0.65	0.65
15	USB-Serial-4 Cable	ST Lab	1	0.31	0.31
16	Mica Glass		2	1.50	3.00
17	AC/DC Adaptor	230/12 V AC	1	0.74	0.74
18	LCD Module		1	8.42	8.42
19	Bolts and Nuts		20	0.10	2.00
				Total	**32.34**

4 Conclusions and Recommendation

Using wireless communication based real time alert gas leakage detector, gas leakage can now be easily detected in our homes and anywhere gas is used from a remote location. As such, gas sensor, ADC 0804, microcontroller module and a GSM module have been used effectively for monitoring and alerting people of LPG gas leakages in their homes regardless of their location. With this design, gas leakages can be detected in real time to prevent gas explosion to save lives and property. The Wireless Communication Based Real Time Alert LPG Leakage Detector for domestic usage is a unique technology that provides technology solution for detecting LPG leakages in homes. This technology can also be employed in LPG filling stations, schools, hospitals, industries and factories that use LPG as a source of energy.

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