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Design Of Underground Coal Mine Monitoring System

Vaibhav Pandit
M.E. student, Dept. of Electronics & Telecommunication,
S.S.G.M.C.E., Shegaon, India

Prof. U. A. Rane
Dept. of Electronics & Telecommunication,
S.S.G.M.C.E., Shegaon, India

Abstract

Coal mining plays very important role in most of the developing countries to meet the energy demands. But the same time mining industry is facing many problems which mainly include the mine worker's safety. Especially the underground mine environment is very complex. The emissions of toxic gases like methane and carbon monoxide always occur in coal mine. The concentration of these gases above safety threshold level creates risk about mine worker's health and life. Hence a continuous monitoring of such values is necessary. This paper proposes a mine safety monitoring system based on ARM7 and ZigBee to achieve the safety factors. The system collects different environmental parameters from underground mine with the help of sensor node structure and transmits that data for processing. If the environment is so harsh beyond working condition, the alert messages can be informed to take control measures and keep safety standards. The system achieves multiple advantages for monitoring, controlling mine production, safety management along with low power consumption platform.

1. Introduction

A mine is considered to be a plant that produces useful mineral with a given percentage of ore and given quantity, whereas the cost of mining is expected to be minimum price. Geological conditions of any mine are determined by nature. They are unpredictable [1].

The various environmental parameters of mine system, such as methane, carbon monoxide, temperature, oxygen and so on, are currently using the traditional cable transmission. Thus truly mine methane, carbon monoxide gas accumulation area mechanized mining face, such as the dead gob cable security parameters can not be monitored, so they can not predict the alarm [2]. Mining project activity is subject to high risks because of its size, uncertainty, complexity, high costs and mine worker's safety [3]. The emission of toxic gases from coal seam in turn leads to air pollution in mine area. It severely affects mine worker's health [4]. The deeper a mine is, the worse and more dangerous miners' work is and the more expensive miners' work is. The high temperature of the Earth's centre raises the temperature of the underground mine and it will be impossible to work. Fig.1 shows an example of underground ore mining where work is done in different sectors.

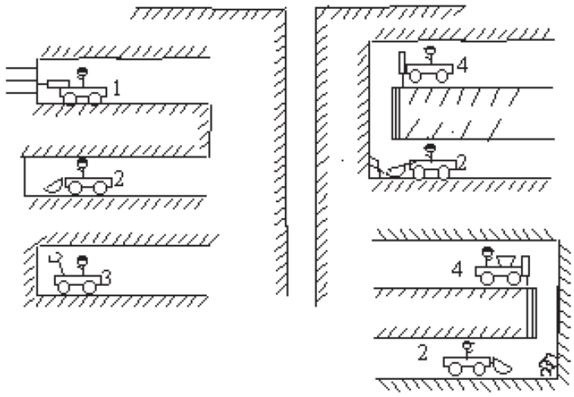

Figure 1- An example of underground ore mining showing work in different sectors: 1- drilling machine; 2- loading-haulage dumping machine; 3- concreting machine; 4- charging machine [1]

1.1 Forms of Mines in India

The coal reserves in India up to the depth of 1200 meters have been estimated by the Geological Survey of India at 285.86 billion tonnes as on 1.4.2011. Coal deposits are chiefly located in Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh, Andhra Pradesh and Maharashtra [5]. The Indian Ministry of Coal has its public sector undertakings, namely Coal India Limited (CIL) and Neyveli Lignite Corporation Limited (NLC) and Singareni Collieries Company Limited (SCCL) [6]. While Directorate General of Mines Safety (DGMS) assist the Ministry in the technical aspects of Occupational Safety & Health in mines [7].

To look at the historical development of the mining industry in India– from the 'Colonial Times' to 'Independence' and today, the comparative coal production is low. Production costs in India are 35 per cent higher compared to Australia, Indonesia or South Africa, which is not due to higher wages, but lower out-put productivity [8]. Though India has abundant natural resource and man power, the reasons for low production are many including lack of modern technologies in mining industry [9]. In 1996, 64 miners drowned in Dhanbad because of flooding of mine. Officially around 800 workers died in mining accidents in Dhanbad area in the two decades between 1980 and 1990s – the unofficial number of deaths in the mines will be higher [10]. So, India has a major challenge of reducing fatalities and maintaining mine worker's safety.

1.2 Challenges in underground environment

In coal mines, the major emission is of methane. The methane released during and after mining operations is called Coal mine methane (CMM). In recent years, there have been many fatalities in underground coal mine explosions in which methane was a contributing factor. Moreover methane is 21 times more potent for greenhouse gas emissions. The concentration of methane if passed through a range between 5% and 15%, it may lead to explosion. This range of methane is known as the explosive range. Methane can be ignited easily in this range with the presence of an ignition source to create a violent methane explosion that may propagate in the presence of combustible coal dust [11]. It is shown in Fig. 2.

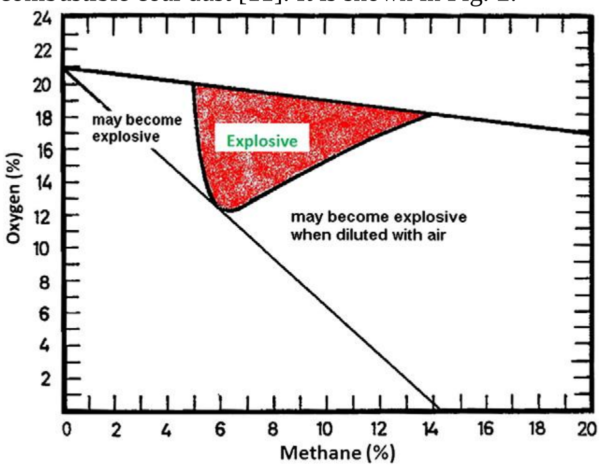

Figure 2- Methane explosibility diagram [11]

Further, capturing and utilizing this gas will not only decrease greenhouse gas emissions, but can be used as additional energy source in near future that otherwise will be lost.

This project proposes such a system where we implant electronic sensors in different sectors. They collect underground mine environment parameters' data and send it to a central monitoring section present on ground. The communication is made possible with ZigBee. Fig.3 show this prototype in which a person sitting at place-5 can monitor the underground mine environment parameters and will be capable to take suitable actions to keep mine workers' safety and reduce fatalities.

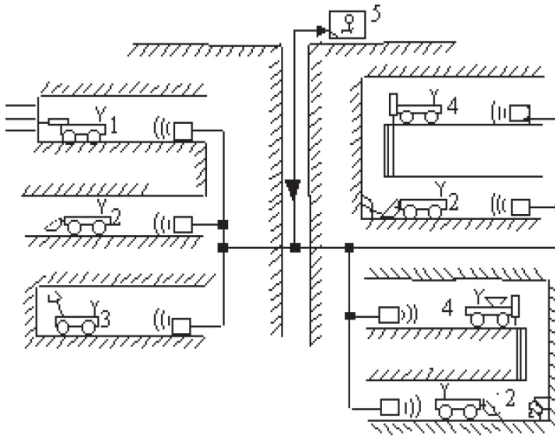

Figure 3- Underground ore mining deployed with Wireless Sensor Network of ZigBee

2. Functional Description

The proposed system can be studied in two parts Mining Unit and Monitoring Unit. They are shown in Fig. 4 and Fig. 5 respectively. Both the units consist of LPC2148 as core microcontroller. They communicate with each other through Zigbee transreceiver. The transceiver used in the mining unit and the monitoring unit is of same type. LCD section is basically meant to show up the status of the project.

2.1 Mining Unit

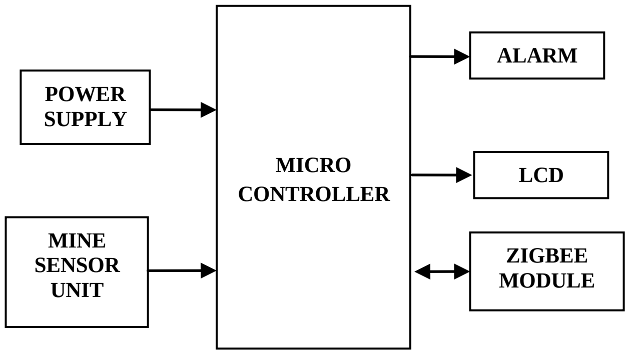

Figure 4- Mining or Underground Unit

The mining unit kit will be located in underground environment of the mine.

2.2 Monitoring Unit

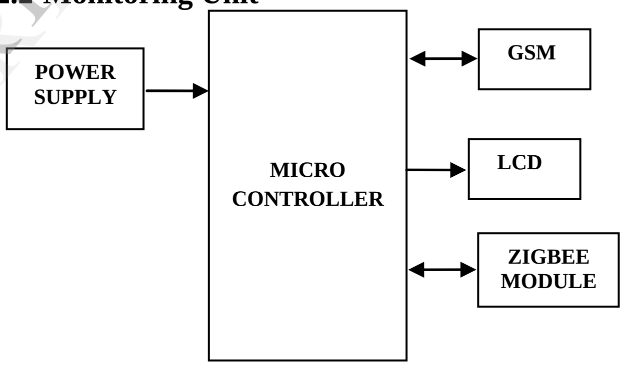

Figure 5- Monitoring or Ground Unit

It is located at ground level outside the mine.

3. Hardware Design

The hardware components used to implement this system are summarized as follow-

3.1 Power Supply

In this project we require operating voltage for ARM controller 3.3V. The 230V ac supply is fed to step down transformer to make it 18V. Then this ac voltage is rectified to dc through bridge circuit of 1N4007 diodes. It is further filtered through 1000µF capacitor. The dc voltage produced is regulated using LM7812 and LM7805 followed by C filters of 100 µF. The system contains different modules like LPC2148, Zigbee for which the power is again regulated through variable power supply LM317.

3.2 Core Controller

The ARM7TDMI is a member of the Advanced RISC Machines (ARM) family of general purpose 32-bit microprocessors, which offer high performance for very low power consumption and price. The ARM architecture is based on Reduced Instruction Set Computer (RISC) principles, and the instruction set and related decode mechanism are much simpler than those of micro-programmed Complex Instruction Set Computers (CISC) [31]. This simplicity results in a high instruction throughput and impressive real-time interrupt response from a small and cost-effective chip. Pipelining is employed so that all parts of the processing and memory systems can operate continuously. Typically, while one instruction is being executed, its successor is being decoded, and a third instruction is being fetched from memory [32]. The ARM memory interface has been designed to allow the performance potential to be realized without incurring high costs in the memory system. Speed-critical control signals are pipelined to allow system control functions to be implemented in standard low-power logic, and these control signals facilitate the exploitation of the fast local access modes offered by industry standard dynamic RAMs. The ARM7TDMI processor employs a unique architectural strategy known as THUMB, which makes it ideally suited to high-volume applications with memory restrictions, or applications where code density is an issue [33].

We have used LPC2148 from NXP semiconductors (founded by Philips). It shows features as follows-

i. 16/32-bit ARM7TDMI-S microcontroller in a tiny LQFP64 package.
ii. 40 kB of on-chip static RAM and 512 kB of on-chip flash program memory.
iii. In-System/In-Application Programming (ISP/IAP) via on-chip boot-loader software.
iv. Two 10-bit A/D converters provide a total of 14 analog inputs, with conversion times as low as 2.44 µs per channel.
v. Single 10-bit D/A converter provide variable analog output.
vi. Multiple serial interfaces including two UARTs (16C550), two Fast I2C-bus (400 kbit/s), SPI and SSP with buffering and variable data length capabilities.
vii. Vectored interrupt controller with configurable priorities and vector addresses.
viii. Up to 45 of 5 V tolerant fast general purpose I/O pins in a tiny LQFP64 package. [34]

3.3 Design of Data Acquisition Unit

3.3.1 Gas Sensor

For detection of methane and carbon monoxide which are the major toxic gases in underground coal mines, MQ-7 gas sensor is used.

Figure 6- Structure & configuration of MQ-7

Sensor composed by micro AL2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 has 6 pins, 4 of them are used to fetch signals, and other 2 are used for providing heating current [35]. MQ-7 sensor is interfaced at $P_{0.30}$ of LPC2148 in mining section.

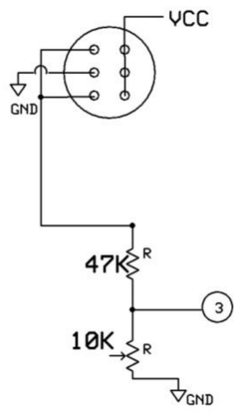

Figure 7- MQ-7 Gas sensor circuit

3.3.2 Temperature Sensor

In the proposed system thermistor is used as temperature sensor. The word thermistor is an acronym for thermal resistor, i.e., a temperature sensitive resistor. It is used to detect very small changes in temperature. The variation in temperature is reflected through appreciable variation of the resistance of the device. Here it may be noted that NTC thermistor has a resistance of about 10kΩ and 100 kΩ at –50 C to 150 C respectively. It means that a temperature change of 200 C has resulted in a 100:1 change in resistance. It is connected to $P_{0.29}$ to LPC2148.

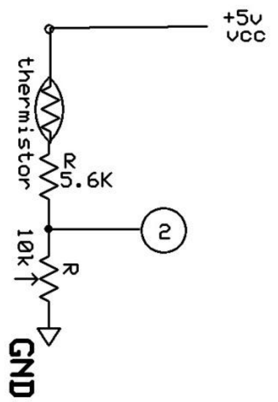

Figure 8- Thermistor sensor circuit

3.3.3 Humidity Sensor

Humidity is the amount of water vapor in the air. In daily language the term "humidity" is normally taken to mean relative humidity. Relative humidity is defined as the ratio of the partial pressure of water vapor in a parcel of air to the saturated vapor pressure of water vapor at a prescribed temperature. The humidity sensor is of resistive type. With the change in humidity, the voltage at terminal 1 in Fig. 9 changes. Terminal 1 is connected to $P_{0.28}$ of LPC2148

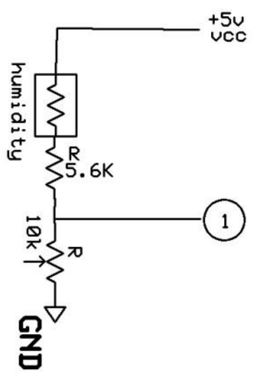

Figure 9- Resistive type humidity sensor circuit.

3.4 Man-Machine Interface

Liquid crystal displays (LCDs) have materials, which combine the properties of both liquids and crystals. By interfacing 4-bit LCD with LPC2148 in both underground and ground sections, mine parameters can be monitored continuously.

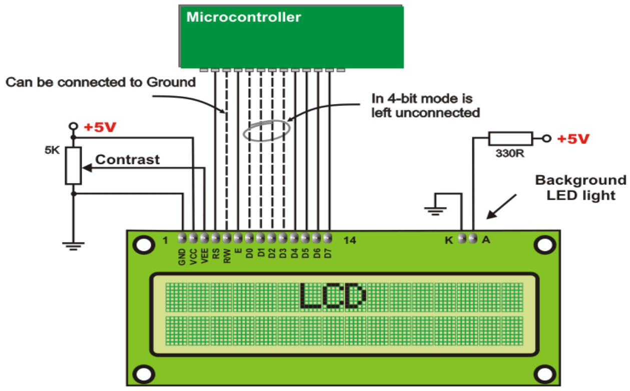

Figure 10 - Interfacing of 4-bit LCD with LPC2148

3.5 Communication Task

This is very important process in mine safety system to convey the message related to risk of fatalities due to uncontrolled emission of deadly gases, or if the mine is very much deep the person cannot work in high temperature which will off course be increasing as we go deep inside mine. Such alerts and information is conveyed with the help of following devices.

3.5.1 Buzzer

In mining or underground section, the different sensors collect data related to environment of underground mine. If the values from these sensors exceed certain threshold level, then there should be alert message to all the mine workers to leave that place. Hence we have interfaced a simple buzzer to LPC2148 at P0.16. The proposed project work has used three sensors viz. temperature, humidity and gas sensor. LPC2148 is programmed to such threshold values that the mine worker can work with safety and good health if the values from sensors are below that threshold level.

3.5.2 ZigBee Module

ZIGBEE is a new wireless technology guided by the IEEE 802.15.4 Personal Area Networks standard. It is primarily designed for the wide ranging automation applications. It currently operates in the 868MHz band at a data rate of 20Kbps in Europe, 914MHz band at 40Kbps in the USA, and the 2.4GHz ISM bands Worldwide at a maximum data-rate of 250Kbps. The ZIGBEE specification is a combination of Home RF Lite and the 802.15.4 specification. The specification operates in the 2.4GHz (ISM) radio band - the same band as 802.11b standard, Bluetooth, microwaves and some other devices. It is capable of connecting 255 devices per network. Range of the transceiver module can be 30-70m in urban areas and 1-1.5km in outdoor (LOS). The transceiver has an on-chip wire antenna and it operates at a frequency of 2.4GHz [36].The data received from the microcontroller is organized based on the ZIGBEE protocol standards and then modulated. The specification supports data transmission rates of up to 250 Kbps at a range of up to 30 meters. ZIGBEE's technology is slower than 802.11b (11 Mbps) and Bluetooth (1 Mbps) but it consumes significantly less power [30]. Here a pair of Zigbee modules is used one to transmit the data from underground section and another to receive this data at ground or monitoring section.

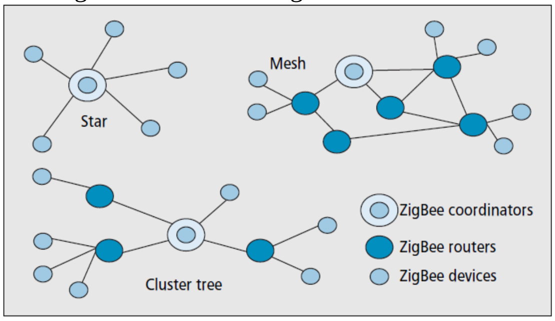

Figure 11 – ZigBee Topologies that can be deployed [29]

Voice communication over ZigBee networks

The performance of ZigBee networks has been extensively investigated in [29]. However, those studies are not specific to voice quality. The authors of reported how they extended their Firefly ZigBee work to provide real-time voice communication capability for underground miners separated by long tunnels. Several characteristics of ZigBee technology can affect its capability of carrying voice communications. First, ZigBee networks have limited bandwidth — only up to 250 Kbps. This limitation confines the maximum number of supportable voice calls or sessions. Second, channel access contentions in ZigBee networks are resolved by the CSMA/CA protocol, which inevitably introduces additional waiting time for transmissions and leads to smaller effective bandwidth and increased delay — both could degrade the quality of voice communications [29].

It can be concluded from study of [29] that ZigBee is capable of supporting voice communications, but with limited ability, that is, a limited number of voice connections/sessions within a small number of hops. With an increased number of hops and the number of voice connections, transmission delay and packet loss ratio go up dramatically, and it becomes impossible to have voice transmissions beyond two hops. Thus, with improvements it is possible to enhance our work for voice communication from underground section to ground section over ZigBee.

3.5.3 GSM Technology

We are using GSM MODEM to communicate with the mobile phone to which we are going to send the message. Whenever an authorized person wants to know the status of parameter or whenever parameters values increases above the threshold value then a message will be sent through modem. This fault is indicated by displaying in LCD. This project will facilitates us to monitor as well as control different parameters at a time which increase accuracy and speed. It is used in ground or monitoring section.

4. Software Design

The system comprises of very simple procedure as- 1) Get the data from sensors in to LPC2148. 2) If the data crosses threshold, raise buzzer. 3) Send data through Zigbee to another LPC2148. 4) Display it on LCD. 5) To send the messages through GSM if required. To complete this flow of task, programs are developed in embedded C language using following software platforms. The tasks can be shown in Fig. 12 and Fig.13.

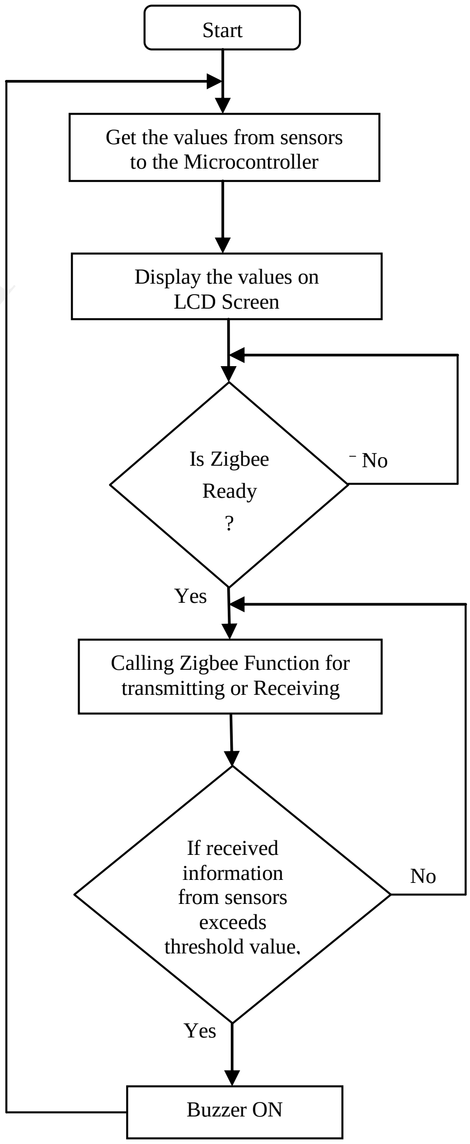

Figure 12 - Flowchart for Mining Unit

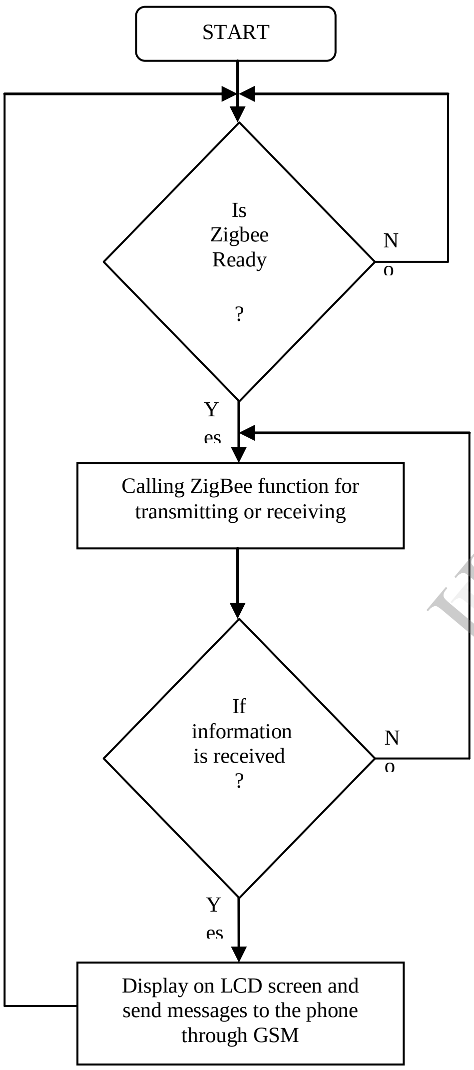

Figure 13 - Flowchart for monitoring section

4.1 KeilµVision4

µVision is a window-based software development platform that combines a robust and modern editor with a project manager and make facility tool. It integrates all the tools needed to develop embedded applications including a C/C++ compiler, macro assembler, linker/locator, and a HEX file generator. µVision helps expedite the development process of embedded applications by providing the Integrated Development Environment. KEIL can be used to create source files; automatically compile, link and covert using options set with an easy to use user interface and finally simulate or perform debugging on the hardware with access to C variables and memory. Unless you have to use the tolls on the command line, the choice is clear. KEIL Greatly simplifies the process of creating and testing an embedded application [37].

4.2 Flash Program Utility

For downloading the application program into Flash ROM, this utility tool is necessary. The program code generated in C language after processing produces object code in hex form. It is referred as .hex file. To dump this hex code in the flash ROM of the controller the facility is provided with Keil version 4. For programming with older versions, the same task is completed with the help of software called Flash Magic [37].

5. Result

Following image is of hardware setup implemented using this paper concept. Brief nomenclature of different parts has been provided on same image.

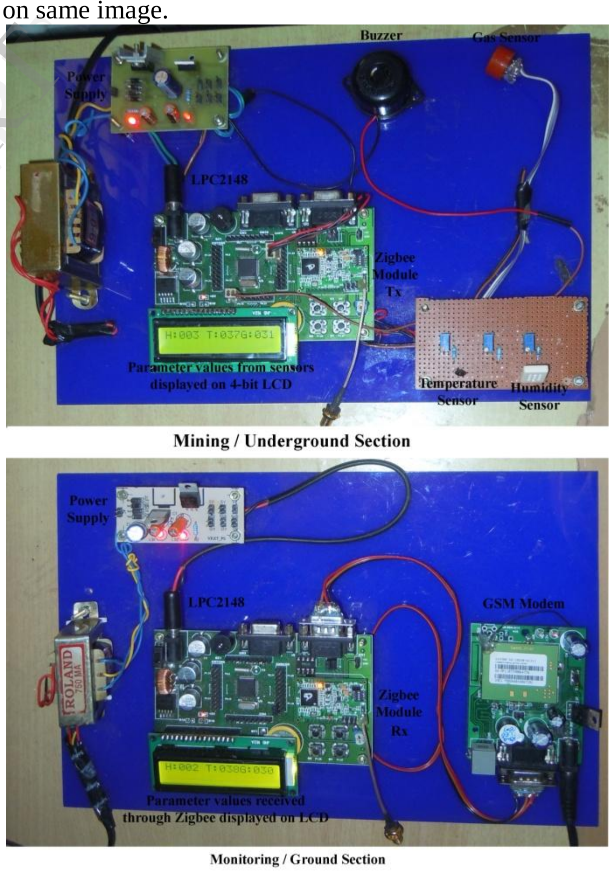

Figure 14 – Hardware structure showing parameter values on LCD

Figure 15 – Alert message through GSM

6. Conclusion

The sensors used for demonstration of concept are general. The MQ-7 gas sensor is more sensitive to carbon monoxide but can sense methane, butane, LPG, hydrogen, smoke, etc. We found more heating of sensor if operated for long time. The ZigBee communication is noise free. ZigBee and LPC2148 provide low power platform. More advanced version of controller like Cortex-M3 can be used for more speed of execution and extreme low power consumption. With use of sophisticated sensors, the system can work with more accuracy in real time. It can be modified in industrial monitoring as well.

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