Design of an Adaptive Coal Mine Rescue Robot using Wireless Sensor Networks

V. Gomathi, Ph.D.
Associate Professor (Sr.Grade)
Department of CSE
National Engineering College (Autonomous)

Sowmeya S, Avudaiammal P.S, Ganeshia R
UG Scholars
Department of CSE
National Engineering College (Autonomous)

ABSTRACT
In early decades, rescue operation in coal mine was treated as a dangerous task. After explosions occur, when rescue workers get into the tunnel without environment conditional awareness, they are facing heavy damages due to consecutive explosions [1]. This bring the necessity to detect the status of the mine environment details such as toxic gases, high temperatures through wireless sensors to perform remote inspection of mine conditions, before trapped into the collapsed tunnel. Hence, this paper aims to design an adaptive coal mine rescue robot using Wireless Sensor Network (WSN). The test bed composed of sensing and controlling mechanism with monitoring subsystems and also assembled with motor control mechanism. In addition to that, a reliable wireless communication with ZigBee is made to transfer the sensed environment data through gas and temperature sensors. This sensor based real-time information guide the rescuers to learn the situations by themselves while planning the rescue operation remotely. With the help of this mobile robot, it is possible to reduce the loss due to coal mine disaster and efficient rescue operation can be carried out.

General Terms
Wireless Sensor Networks, Coal Mine

Keywords
Coal mine rescue robot, temperature sensor, hazardous gas detector.

1. INTRODUCTION
Coal mine is generally an underground tunnel system with special characteristics. If there are some accidents due to hazardous gas explosion, like CO, CO_2 low O_2, and/or fire accidents such as, high temperature, smoke, coal dust, etc. All such types of accidents will damage the human lives severely. The CH_4 gas is released during mining tasks and flame current may cause a destructive gas explosions. When the tunnel was filled with CH_4, CO, CO_2 and coal dust, the working people could immediately be affected by these poisonous gases and fire accidents. In addition to that, fire may cause a second explosion. Rescuers on ground daren't go into the explosion mine tunnel. Because from outside the tunnel situation is not known, any time it may cause a second explosion too. So, detection of mine tunnel situation is the first mission to the rescuers. An environment adaptive rescue robot is an ideal tool to handle the coal mine disaster. The robot used in coal mine tunnel must have many special features like flame-proof body parts which are different from other on-ground robots. It must be designed in a way to avoid malfunction of components due to high temperature. These sensitive obstacles must be carefully addressed during design.

Wireless Communication is another major issue in coal mine tunnel because the electromagnetic waves are absorbed and echoed within the coal tube. Also, due to many corners in the tunnel, electromagnetic waves cannot cross these corners easily. In this work it is proposed to provide good wireless communication between user (control room) and robot (coal miner) using Zig-Bee transceiver.

2. RELATED WORK
The earlier studies reveal that large number of accidents occurs in a coal mine during and after a disaster [1]. The main reasons being, gas accidents, explosives, etc. They forced the development of a system that can help and minimize the human as well as material losses that are happens during rescue operations in the coal mines. The idea of a mobile robot in coal mine is able to aid the rescue team to be picked up with the tremendous upliftment in the wireless technology [2]. The mobile robots are conventionally used to enter into the disaster zone and get involved in rescue research operations. These robots can go into the tunnel and detect hazardous gas contents/levels, temperature, etc. These details can be sent to the controller in monitoring room. Thus, usage of sensors for detecting the gas became mandatory in the robot to be deployed. The mobile robots in explosion environment, climbs over uneven surface areas, check gas, and provided where in it can carry food and first aid kit to the workers trapped inside. Different types of legged robot had been used [3] and after experience, a belt type robot was developed. The conveyor belt as seen on the military tanks would move over debris and rough terrains easily than normal ones [4]. For establishing the communication, In the early work [5], they discuss the method of Mine Safety Monitoring System based on Zig-Bee and simulated the experiments in NS2 environment. This Zig-Bee protocol is an IEEE 802.15.4 standard wireless sensor network protocol in existence and can handle the situations like low-power, low-cost, low maintenance monitoring and control the coal mine systems with the interactions in sensor networks. Once the communication and sensing of robot was finalized the focus is shifted on how to make it more reliable. Wireless sensor network based robot is highly capable platform and show great potential in environments to disaster discovery. Mobile robot wireless sensor networks had multimedia surveillance and provide the great strategies based on multi sensor integration. It introduces in details the structure of the robot system, the technology of obstacle avoidance by using various sensors, and collection of information, wired, wireless transmission modules, local area network, wireless cameras, including gas sensors and temperature sensors.

3. PROPOSED METHODOLOGY
This section introduces in details the structure of the robot system, the technology of obstacle avoidance by using various sensors, and collection of information, wired, wireless transmission modules, local area network, including gas sensors and temperature sensors. The experimental setup for

coal mine rescue robot is carried out using MIKRO C language. In this work, a rectangle tunnel like test bed area was simulated, inside that region the rescue robot assembly will be operating like a adaptively movable obstacle sensing car.

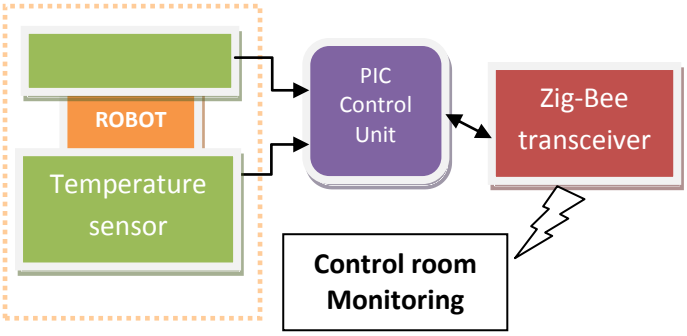

Fig 1: Proposed Rescue Robot Architecture

3.1 Transmitter unit of rescue robot

This robot assembly contain gas sensor, temperature sensor, micro controller unit, Zig-Bee transceiver, which is used to detect the gas in the mine and temperature level. If the gas level is increase the threshold level than the controller give the instructions (stop and survey in depth). If the gas level is less than the threshold level than the controller give the instruction (move either left or right). On the top of the box inject the gas (CO_2) than the robot moves that place identify the gas level. IR transceiver used to find the location of the robot. The functional flow of the proposed work are depicted in Fig.(2-3).

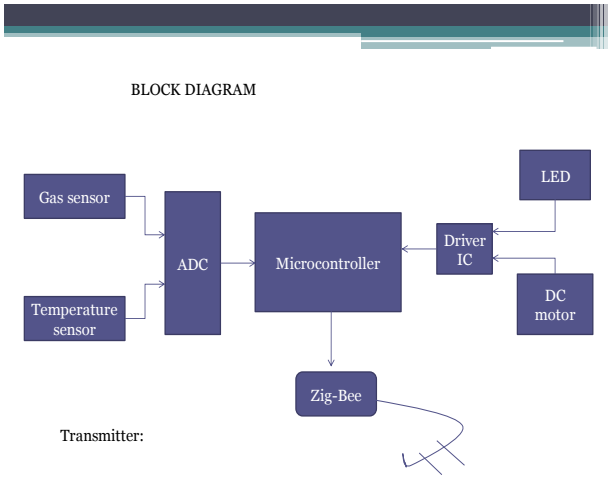

Fig 2: Transmitter Unit of Rescue Robot

Here, The robot driver unit mechanism is primarily concerned about the movement of the robot in forward and backward directions as per the direction from control room PC. The Zig-Bee transmitter module is mounted on the rear end of the robot. As the sensors receive details, this will transfer to the control room for every time period of measurement in the order of milliseconds durations. The functionalities of the blocks are controlled by the central processor PIC16F877A Microcontroller. The LED helps to identify the working condition of the transmitter unit. The DC motor was controlled to in three ways such as STAY, MOVE_FORWARD and GO_BACKWARD to adapt the movement of the rescue robot.

3.2 Receiver unit of rescue robot

The Zig-Bee transceiver had showed flexible and highly efficient, reliable wireless communication in many practical applications with low data rate and low power consumption.

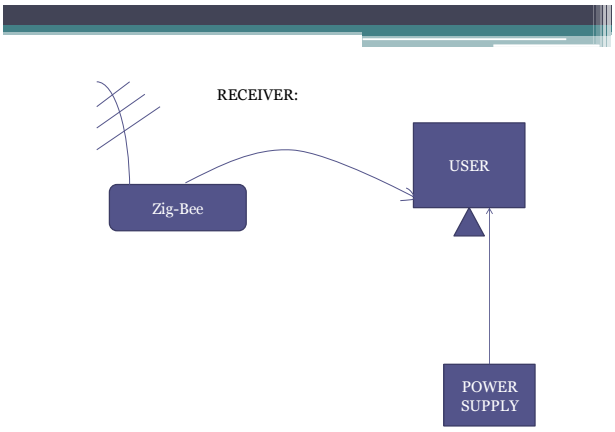

Fig 3: Receiver Unit of Rescue Robot

The receiver side application is developed in text editor of MPLAB IDE by in MIKRO C language. The simulation code was saved in .c file extension. Then that file is compiled by using CCS compiler to convert it into .hex file extension. During debugging, the logical errors were rectified and error-free code is ready to burn. Thus, the final code was burned into the microcontroller by using PROMOTE II device by connecting through ICSP Cable.

3.3 Wireless Communication

Since, the robot was tested in the embedded system design lab, where many such works are being carried out, the process of configure Zig-Bee RF module to Unicast communication mode, allows embedded UNO to communicate only with the dedicated I/O device without interrupting other Zig-Bee RF within the same network ID.

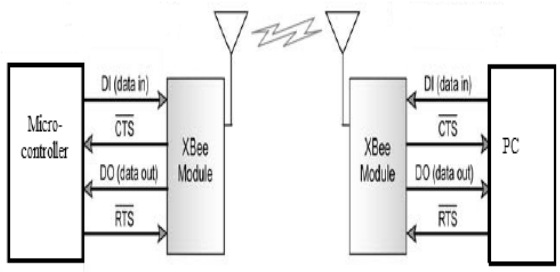

Fig 4: Communication between Robot and Control Room

4. IMPLEMENTATION

PIC is a family of modified Harvard architecture microcontrollers made by Microchip Technology [6]. PICs are popular with both industrial developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming capability. PIC architecture is RISC type.

A sensor or detector is a converter that analyzes a physical property and converts it into a signal which can be read by an observer or by equipment. Four sensors are used. They are gas and temperature sensors for which MQ-6 and LM35 sensors

are used respectively. Gas sensors will be used to detect harmful gases such as methane, butane, propane etc and check the level of such gases in the surrounding atmosphere. The MQ-6 can detect gas concentrations anywhere from 200 to 10000 ppm. The LM 35 has a range of 0-110 degree Celsius. The robot driver module is concerned about the movement of the robot. The wheels are run by two DC motors of 200rpm and one DC motor is used for arm. The DC motors are drive the robot to move in forward, reverse and turn left and right. The complete motion endorses up on these DC motors. The robotic arm is used for pick and move operations. To each motor L293D IC supply is used. DC motors are widely used in robotics.

The Circuit implementation and layouts is done by OrCad 6.5. VR Bot module is programmed by EASY VR Commander version 3.4.10.

4.1 Rescue alerting Algorithm

Zig-Bee is targeted mainly for battery power applications where low data rate, low cost and long battery life are main requirements. IEEE 802.15.4 are used to design transceiver for this applications which uses wireless technology.

1. Initialize the gas sensor and temperature sensor thresholds.

2. Initialize the directional data of robot using DC motor assembly.

3. Identify the ports for audio alert to control room.

4. Repeatedly scan the coal mine prototype area as stated below:

If (control room command is 'S')

a. GoBackward_tilt0degree(currPos, robot assembly control)

else, If (control room command is 'Rd')

b. GoBackward_tilt45degree(currPos, robot assembly control)

else, If (control room command is 'Rb')

c. GoBackward_tilt90degree(currPos, robot assembly control) else MoveForward_robot(update currpos)

5. Read two analog inputs from gas sensors and digital input from temperature sensor.

6. From Zig-Bee receiver, the receiver side code interprets the coal mine zone's risk status as,

a. If (LM35_temp >45°C) alerts 'Temp. – High zone'

b. If (MQ6_data>100 ppm) alerts 'CO Gas detected'

c. If (MQ6_data>600 ppm) alerts 'CO_2 Gas detected'

5. EXPERIMENTAL RESULTS

The proposed coal mine rescue robot assembly is shown in Fig.5. The GUI helps to view the status of tunnel environment under rescue and remotely monitored using the software part developed in micro C. At high temperature, CO2 was resulting in. This prototype has its safety threshold values as, for CO set at 100 ppm, for CO2 set at 600 ppm. The set point for temperature is 45 degree Celsius. Once the measured value goes beyond these set points, in control room monitor alert message is displayed with alarm.

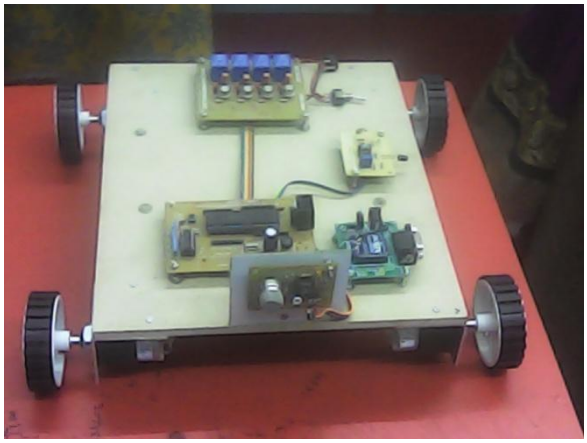

Fig 5: Proposed robotic assembly using WSN

5.1 Scenario 1 setup

In this work, a tubular shaped ('T') coal mine tunnel like test bed model was simulated using thin film plastic sheets, inside that region the rescue robot assembly was allowed to move. There are holes made on the surface to inject the hazardous situations.

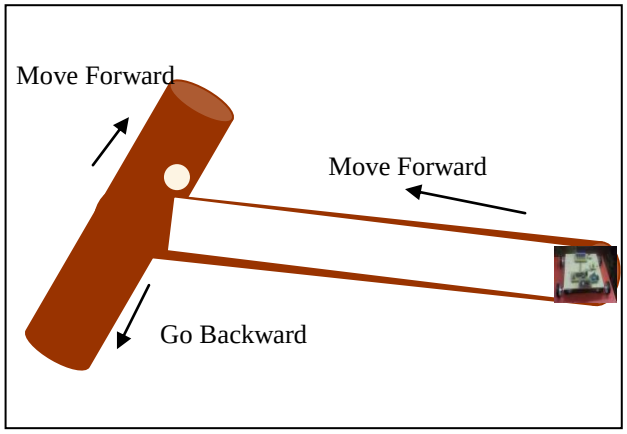

Fig 6: Tunnel surface in testing phase

This robot assembly contains gas sensor, temperature sensor, PIC micro controller unit, Zig-Bee transceiver, which are cooperatively programmed to detect the gas leak in the mine-like tunnel and the surrounding temperature level. Artificially, the fire flames are injected via holes.

When the gas/temperature level increases above the specified threshold level, then the rescue worker in control room will give the instructions to PIC controller (to stay and survey in that position by stopping the robot). If the gas/temperature level was less than the threshold level, then the rescue worker in control room will give the instructions to PIC controller (to move either forward or backward).

5.2 Scenario 2 setup

This section is aiming to sensitize the accuracy of sensing the field at a distance. Here, instead of injecting the artificial hazards through the allotted holes, it was experimented at near by rooms at a distance of 5m, 10m and 15m with walls and turns as path obstacles. The receiver unit was kept inside the observation study room. The rescue robot was shifted away at a distance from it.

5.3 Performance Analysis of test scenarios

The measured sensor parameters for scenario 1 are displayed on control room monitor. Their values at t=5sec sampling intervals. This study showed that all injected hazardous events are accurately monitored and alerted to the control room receiver on time.

The experimental study made through scenario 1 shows that, the proposed prototype has the ability to forewarn the rescue workers about coal mine conditions. It was observed that on normal conditions of the tested tunnel environment, the robot had a normal directional movement. Meanwhile when scenarios of hazards are injected, the robot was instructed the PIC controller to monitor the field at every 5millisec delay period. In order to learn the path obstacles, the IR transceiver is used to correct the location of the robot within boundary levels.

Similarly, the measured temperature sensor parameter alone for scenario 2 at three different distances from the tunnel is displayed on control room monitor. The experimental study made through scenario 2 shows that, the injected temperature and hazardous gases were correctly reported by the Zig-Bee module for all these stages of observations. Hence, this scenario reveals that, the proposed rescue robot can reliably communicate with the remote system.

6. CONCLUSION

The adaptive mobile robot for coal mine disaster surveillance was designed with their proposed characteristics of reliable, low-power, efficient wireless communication. The robot was a test run and it was allowed to move autonomously well on debris and over rough terrains. The sensors were tested for their performance and conducted the tests on two scenarios, through any other source of smoke being brought near to the MQ6 sensor. This prototype robot has its safety values of CO, CO_2 and temperature. Further, implantation of an arm on the robot can help the robot pick up samples or remove small debris from path inside the mine. In future work, design of an unmanned robot to check the geo-mining atmospheric conditions through wireless control for rescue team will produce recent technology based mechanism. They can reach places between rubble and hazardous places where rescuers cannot, and effectively gather critical information.

7. ACKNOWLEDGEMENTS

This work is sponsored by The Institution of Engineers (India), Kolkatta and implemented in National Engineering College, (Autonomous), K.R.Nagar, Kovilpatti, Tamil Nadu. The authors thankfully acknowledges the financial support provided by The Institution of Engineers (India), Kolkatta for carrying out Research & Development work in this subject.

8. REFERENCES

[1] Zeng Weixin, “Exploration for Human Factors in the Design of Coalmine Safety and Rescue Devices", IEEE International Conference on Robotics, July 5, 2006.

[2] GAO junyao, GAO xueshan, ZHU jianguo, ZHU wei, WEI boyu,WANG shilin, ”Coal Mine Detect and Rescue Robot Technique Research", IEEE International Conference on Information and Automation, June 22 -25, 2009.

[3] Zhu Jianguo, Gao Junyao, Li Kejie, Lin Wei, Bi Shengjun,“Embedded Control System Design for Coal Mine Detect and Rescue Robot", IEEE, 2010.

[4] Mr.Sabarish Chakkath, S.Hariharansiddharath, B.Hemalatha, “Mobile Robot in Coal Mine Disaster Surveillance”, IOSRJEN, October 2012.

[5] Pranoti Anandrao Salankar, Sheeja S. Suresh, “Zigbee Based Underground Mines Parameter Monitoring System for Rescue and Protection”, IOSR Journal of VLSI and Signal Processing (IOSR-JVSP), Volume 4, Issue 4, Ver. I (Jul-Aug. 2014), pp.32-36.

[6] Muhammad Ali Mazidi, J.G. Mazidi, R.D. McKinlay, “The 8051 Microcontroller and Embedded Systems” using Assembly and C, 2nd Edition, Pearson, 2008.