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ENHANCING MINE SAFETY WITH WIRELESS SENSOR NETWORKS USING ZIGBEE TECHNOLOGY

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ABSTRACT

In coal mines, whenever explosions occur, the rescue work is done by rescue workers without any prior knowledge of the environmental condition inside coal mine because the mine monitoring systems may be destroyed or damaged. This makes the life of rescue workers very risky. It also takes some time for the rescue workers to reach the spot. According to the proposed system, a ZigBee network controlled automatic robot has been developed for assisting rescuers. This system works even when a ZigBee node fails. Whenever any explosions occur, the robot automatically detects the explosion, finds the explosion location and enters the coal mine tunnel well before the arrival of rescuers. It finds the location of accident, searches for survivors to give them first aid at right time and informs the rescue team about environmental conditions and about the survivors inside the coal mine.

Keywords: *ZigBee, RSSI, PIC16, Personal area network (PAN), Robot.*

1. INTRODUCTION

In any hazardous work environment mines, safety of human life is an important concern. Mines [1]-[5] and specifically coal mines are places where constantly lives are lost and many countless are injured due to landslides and explosions. Not only this, there are great losses in property too. The present systems installed in many such places are still incapable of saving lives of those who risk their lives for this profession. To improve life safety, many systems have been designed, and have even been implemented in some countries today.

One such design is to send a robot inside a coal mine. A robot equipped with sensors for detecting various poisonous gases and a wireless transmitter and receiver can be our eyes and ears in such an environment. It can navigate through a mine and send back information to the person monitoring its movement from a safe place outside, all that is happening inside the mine and even warn the workers regarding the places that may actually be life threatening. A robot with this given description was designed. In previous efforts, the robots were controlled by the coal miners using remote control and were not automatic. The unique thing about this proposed system is that the robot is automatic. The Zigbee network finds the location using RSSI variation and informs the robot about the condition. The robot navigates itself to location with abnormal RSSI value. In this system, an automated system has been created which by itself detects the explosion location inside the coal mine and navigates the robot to that location. When the robot reaches the explosion site, it scans for any possible survivors in its locality and also sends the environmental conditions such as temperature, presence of poisonous and dangerous gases, which again induces second explosion after the accident. This information helps them to prevent an unnecessary delay in their rescue process. It also enhances life safety.

2. WIRELESS SENSOR NETWORKS

A wireless sensor network [6]-[10] such as one using ZigBee can penetrate walls and be used in places where a wired network is either not suitable or cannot be established. The advances in the wireless technology have made it possible to establish a network just by placing the communicating nodes at the required places and switching on the transmitters in them. It is possible to have great transfer rates even at long ranges. With such usefulness and many more features, a wireless network is the surely needed in mines where it is not possible to establish a

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network in time using wires. Also, in case of cave-ins, or an explosion the wire may get damaged making the entire network useless. ZigBee is used to overcome all the shortcomings of a wired network. With its great range even through solid objects such as walls or in this case, mines, it is the most suited technology for our purpose.

ZigBee [11]-[14] is being used today to make many networks in environments such as homes and hospitals where there are many sensors employed for various purposes. These sensors are installed at various locations and are used for creating a smarter environment. In the proposed model, The ZigBee system is used to find the explosion location by monitoring the variation in received signal strength from ZigBee nodes. The system also navigates an autonomous robot which is used for monitoring the presence of any hazardous gases and survivors in the mine.

3. OVERVIEW OF THE SYSTEM FRAME WORK

Whenever a landslide or explosion occurs, the ZigBee node in that particular area may get damaged or its signal strength may be reduced. Furthermore when any blast occurs or, which is about to occur, the surrounding temperature to that ZigBee node will be very high beyond the limit. Since RSSI is indirectly proportional to temperature, RSSI value decreases in accordance with a corresponding increase in temperature. RSSI value from each node is checked so that it does not go beyond its lowest limit.

The lowest signal strength is fixed by measuring temperature of the same node for many numbers of iterations and taking lowest of all such readings. The other ZigBee nodes in its network carry the information about the damaged node to the coordinator, which is kept at a fixed point in the entrance of coal mine. Then the coordinator directs a ZigBee node in robot to route the robot towards the damaged ZigBee node's location. In case of any unhealthy condition on its way to the destination, the robot sends the information to the coordinator so that the rescue workers can be alerted about the conditions before entering the coal mine.

In this system, ZigBee nodes were installed along the walls of the tunnel in coal mine, with maximum possible distance between any two nodes. Each ZigBee module is connected with a PIC16 series controller. The coordinator is kept at the entrance of the tunnel. The RSSI values of each node are measured continuously by its very next node whose value is measured again by the node next to it. Whenever the signal from a node reduces beyond its limit, the system considers that node as faulty node and blast has occurred in its locality. The message is passed to the coordinator. The coordinator shows its location to the robot through a ZigBee node which is attached to a robot. The robot is navigated towards the faulty node; whose location is already known to the coordinator. Once the robot reaches blast location, it starts a new scan for survivors and when scan is over, it sends that information to the coordinator. From the coordinator, the information can be passed to GSM module or base station.

4. PROTOTYPE DESIGN

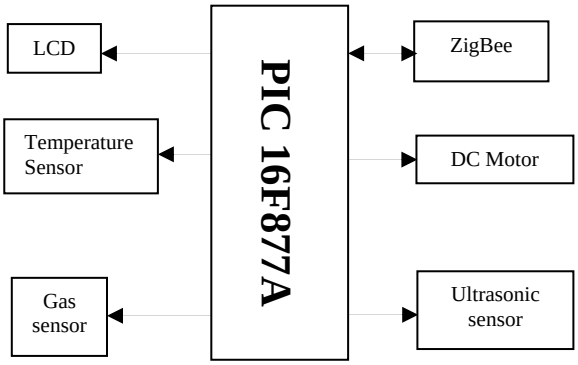

Figure 1: Robot Block Diagram

Figure.1 shows, Robot's block Diagram. The PIC 16f877a controller is connected to an ultrasonic sensor to avoid collision with objects, which are in the robot's path. Four, relays (wheel relays, 12v dc) are used. These relays are connected to microcontroller port pins, which are made high or low accordingly to rotate the robot's wheel motors to be front, back and to turn Right or left. Mine Gas sensors are meant for monitoring harmful gas level.

Temperature sensor lm35 for temperature measurement, robot's ZigBee module is connected serially with the robot's controller for configuration and communication with other nodes in the network. Since the robot is controlled by zigbee system, this system overcomes the disadvantage of manual control for robot. This makes the robot as autonomous one. The Zigbee to microcontroller communication is full duplex or bidirectional.

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Microcontroller to other peripheral communications such as LCD, DC motors, ultrasonic sensor and gas sensor are unidirectional.

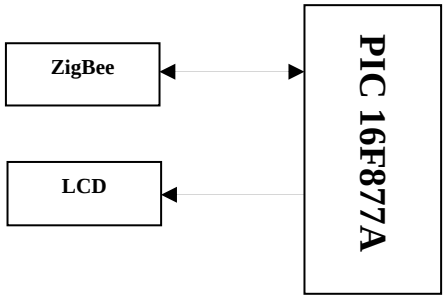

Figure 2: Coordinator Block Diagram

Figure.2 shows Block diagram of Coordinator. Each ZigBee module is connected to a PIC 16f877a controller for monitoring RSSI, for communication with the ZigBee network and for configuring ZigBee nodes. LCD is connected to the coordinator to know about the status of other ZigBee nodes in the network. The coordinator can be connected to a GSM module in order to send the alert message about the explosion location, temperature and CO concentration to the rescuer's mobile phone.

4.1 ZigBee

It is a wireless communication protocol, with a short distance, safe and reliable connection. It is capable of collecting various parameters from different nodes. Since GPS, technology will not work under closed environment; ZigBee was more suitable for this application. Transmission rate of ZigBee is 250kb/s. It is a 20 pin chip. Pin 2 is meant for serial data out and Pin3 is for serial data in. Pin 1 is for supply. Pin 10 is for ground. Pin 6 is meant for RSSI. ZigBee can be configured to form different types of networks like peer to peer, ring type and mesh. ZigBee used here is Tarang. Its outdoor line of sight range is up to 50kms with directional antennas. Transmit power is 1 watt/ 30 db. Receiver sensitivity is up to 107db.

The Tarang uses unique set of AT commands unlike other ZigBee. In order to read the received signal strength from a ZigBee node, the command ATPRS is serially transmitted from PIC16 controller to ZigBee node. The ZigBee node in turn returns a two digit hex value in character format. The value is checked if it is within the limit fixed. ATDB command can be used in case of Xbee, for getting received signal strength value from ZigBee node into the microcontroller.

4.2 Ultrasonic sensor

The purpose of ultrasonic sensor is to identify any obstacles placed in the path. When compared to infrared sensors, this sensor has high detection range and has greater sensitivity. Due to this, it will easily identify if any obstacle is present in the robot's path. The ultra sonic sensor consists of a set of transmitters and receivers which operate at the same frequency. The range of obstacle detection in ultrasonic sensor starts from one meter. The transmitter has two NAND gates which act as multi-vibrator whose output is used to drive a transducer. The trimmer adjusts the output frequency of the transmitter. The receiver uses a transducer to obtain the reflected signal; its output is amplified by a transistor and 741 op-amps. Ultrasonic sensor has beam of angle 30 degree ie, from +15 degree to -15 degree and some can detect obstacle from 6 meters.

4.3 Temperature sensor

For prototype, LM35 Temperature sensor was used for measuring temperature and to give analog value equivalent to the temperature to the controller. It has three pins. One is for supply (5 v DC), second pin is for analog output, and third pin is for ground. The maximum and minimum temperature limits of LM 35 are 150 and -55 degree Celsius.

4.4 Methane & CO sensors

Methane sensor is used to measure the methane level inside the coal mine and CO sensor for measurement of CO gas level. CO sensor module gives an analog value proportional to CO level in the atmospheric air.

4.5 PIC16f877A

PIC16 controller used in prototype forms the heart of both ZigBee network system and robot .PIC16 series used here is highly suitable for this application. It has got greater advantages when compared to 8051, such as speed and inbuilt peripherals such as an ADC. Microprocessors such as ARM series are not necessary for this application. PIC 16 is an 8 bit processor for which; a four megahertz crystal oscillator is used. PIC16 has five ports namely Port A to Port E. Port A has 5pins (RA0 to RA5) used for measuring analog values from sensors such as temperature, CO. port B(RB0 to RB7) used as 8 bit data out for LCD in coordinator, port C(RC0 to RC7), port D

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(RD0 to RD7)has eight pins each. RD0, RD1 and RD2 are used for register select, read/ write and enable. RD4, RD5, RD6 and RD7 are used to activate relays which are meant for moving the wheel motors front and back. RD4 for left wheel front movement, RD5 left wheel backward movement, RD6 for right wheel front ward movement, RD7 for right wheel backward movement. Port E (RE0 to RE2) has three pins. It has eight channel analog to digital port pins. Out of 7 analog inputs, 5 are from port A and 3 are from port E. PIC16 follows RISC type instructions and has the Harvard architecture.

5. DESIGN PROCESS

ZigBee nodes were placed along the walls of Coal mine. Each ZigBee node is connected to a PIC controller which measures the RSSI value (Received Signal strength) from its node. RSSI is the strength of signal received from the ZigBee node which is connected directly with one ZigBee node. The RSSI value is indirectly proportional to temperature and if an explosion occurs, the temperature in that node's environment will be higher than normal condition which can be detected. By measuring RSSI in each node, we can find the temperature variation. For each degree Celsius increase of temperature, there is a corresponding drop in RSSI value from 8db to 10 db. The RSSI value of each ZigBee node is measured under a condition that the value of signal strength does not decrease or increase very much beyond its minimum value, which is calculated from various RSSI values taken from that node when it works under normal condition.

The ZigBee network finds the ZigBee node with abnormal RSSI values, and its coordinator sends the signal to a robot. Even if a ZigBee node gets damaged in the explosion, the missing node's location is identified by the ZigBee network (since the RSSI of that damaged node will be zero) and this information is sent to the robot which also carries one ZigBee node within it. The robot remains in the PAN id of coordinator's network until it reaches the explosion site. Once when it reaches the explosion site, it changes its PAN id to PAN id of nodes carried by coal miners. It changes its PAN id by itself with the help of a controller connected with it in robot. Then it scans for any other node's presence in its locality that is explosion location and acquires the details and sends it to the coordinator.

The coordinator can communicate the information to GSM module attached with coordinator node with which alert message can be sent to the rescuer's mobile once when an explosion occurs or, which is about to occur. PAN id is the identification number or identification address which intimates that the ZigBee node belongs to a particular personal area network formed by a group of ZigBee nodes.

The robot also sniffs for the presence of any harmful and poisonous gases in the explosion site and if the condition of temperature is suitable for human or not. Some of the gases present in coal mine are Methane, Carbon monoxide, Oxides of Nitrogen, Sulphur dioxide, carbon dioxide, hydrogen and hydrogen sulphide. The coal dust in air which is very easily ignited with the presence of methane content in air is also present in the atmosphere inside a mine. It is explosive in concentration of 5 to 15%. At 10% it has maximum explosive violence. This may lead to a secondary explosion.

Carbon monoxide is formed from incomplete burning. 0.4% of CO cause's death. Presence of CO in sealed mine area indicates fire. Hydrogen is a highly combustible gas which is formed from charging batteries, coal dust explosives. Oxides of nitrogen formed from explosives in mine cause's death by accumulation of fluid in lungs resulting in asphyxia. Hydrogen sulphide is highly poisonous and is formed by burning explosives. By detecting the areas with concentration of these gases, precautionary steps can be taken, which will help in improving life safety and prevention of further explosions with the proper disposal systems for these gases.

The robot can also be further developed to provide first aid to people and to provide them with drinking water and first-aid kit by improving its mechanical ability. The following flow diagram explains the whole process of the system. Since we measure signal strength from each node, this system works even if one of the ZigBee nodes in the system fails due to explosion. If any node fails due to explosion, then its receiver node reads its received signal strength as zero. The system has to cross check with usual coal mine parameter monitoring system in order to prevent any wrong explosion warning which may occur due to failure of a ZigBee node due to battery failure. The explosion warning is given by this system only

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when the usual coal mine monitoring system gets damaged or destroyed.

5.1 Flow Diagram

In Figure 3, the flow diagram of the whole system is described. Each node's RSSI is checked continuously. If RSSI is beyond a limit, the next task of the robot is to find the destination place inside coal mine (the explosion location).

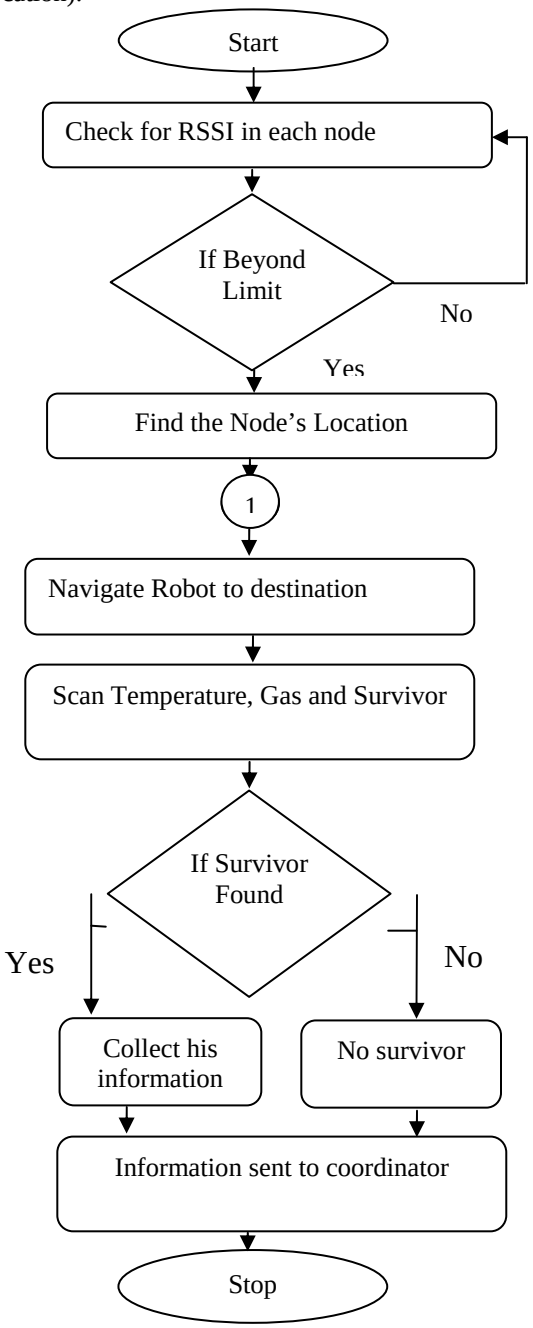

Figure 3: System Flow Diagram

If RSSI is normal or within the limit, then go to previous step (to check RSSI value again) or if RSSI goes beyond limit then go to next step. Navigate the robot to destination location. Scan for survivor's location, if a person is found, collect his information. If no person found, assume no person found. Monitor poisonous gas level and temperature in accident environment. Then send information to coordinator.

6. RESULTS AND EXPERIMENTATIONS

Prototype of the system was developed and checked for indoor environment. Figure 4 shows the ZigBee coordinator node which monitors two ZigBee nodes Z1 and Z2. Figure 5 shows the robot when it changes it s PAN ID from 0001 to 0002 in order to scan for survivors, Temperature and Co level inside coal mine and send the information to coordinator. PAN 0001 is for Coordinator's Zigbee network and PAN 0002 is for Miner's network. Figure 6 shows coordinator displays the received information from robot. If survivor is found in the scan, then his information is sent to coordinator. If no survivors are found in the scan, then Coordinator shows in its LCD as no survivor found. The coordinator can be connected to base station or GSM module in order to inform rescuers well in advance automatically once when explosion occurs.

Figure 4: ZigBee node status shown

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By Coordinator

Figure 5: Robot while changing its PAN ID

Figure 6: Survivor scan, Temperature and CO level shown by Coordinator.

7. CONCLUSION

This work solves the issues like prevention of second explosion caused if the amount of methane gas is high in air by early detection. Time taken for rescue work will be reduced since it is automated. Increase life safety of rescuers and coal mine workers, reduces the risk taken by rescuers and complexity. The ZigBee system works even if a ZigBee node gets damaged by explosion.

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