IoT Based Automation of Safety and Monitoring System Operations of Mines

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Abstract

The working conditions of mines across the world are quite averse to human health and safety. Several workers lose their lives because they are not able to communicate to the concerned authorities about the emergency situation inside the mine. As because the mines are located under the ground no direct communication channel can be established to monitor the conditions of the mine. In light of all these factors the paper at hand aims to provide a solution to the safety and the monitoring system of a mine without the need of any individual monitoring the mine conditions. The safety equipment targeted in this paper is the safety helmet that the worker uses inside the mine. This helmet is fitted with various environmental sensors like gas, smoke, temperature, humidity and air quality sensors to continuously monitor the mine conditions. All these sensors are interfaced with amicro-controller which is also embedded inside the helmet. The paper also uses the concept of a wireless transmission network to transfer the data from the user's helmet to the central hub using Zigbee technology. The monitoring system consists of the use of IoT (Internet of Things) technology to send collected data to the web server with proper graphical representations such that the conditions of the mine can be monitored anywhere and everywhere.

Keywords: *sensors, IoT, Zigbee, micro-controller, wireless transmission network.*

I. INTRODUCTION

The mining industries in the world are located at remote locations around the world away from human habitation. Also majority of the mines are underground for utilization of the surface resources. This poses a great threat on the safety and security of the workers working inside the mine. According to Donoghue [1] the common threats to the workers working underground may be:

1) Fire accidents
2) Low Oxygen levels deep inside the mine
3) Leakage of poisonous gases like methane and dust due to explosions
4) Flooding of mine

The barrier to the fast rescue and recovery of workers inside the mine during an emergency is due to two main reasons, namely,

1. The absence of proper means for monitoring of the occurrence of adverse conditions inside the mine.
2. The non-availability of wireless communication protocols for communication between the workers and the personnel outside the mine.

Due to such communication barriers several workers lose their lives inside the mine every year.

The most basic gadget that the workers carry inside the mine is a "safety helmet". This helmet is thus taken up as the target on which the improvisation is done without altering the characteristics of the helmet. The problems mentioned can be solved only by proper sensing of the environment. For this purpose, various sensors are used which are interfaced with a microcontroller. According to Kumar and Babu [2] the structure of industrial helmets consists of a vacuum between the outer and the inner layer which can become the most appropriate place for placing the electronic components.

Also there is the problem of communication of data from the helmet to the control room. There can be no routers placed inside the mine as because the dimension of a mine is not constant. This might be achieved by a wireless network to which all the helmets are connected in which the data from the end nodes can be transferred to the coordinator through a mesh [3].

The last object to be dealt with is the monitoring of the internal conditions of the mine. The setting up of a separate control room would involve a large capital which might be reduced by using the concept of IoT. Using this concept, the data received from the miners' helmet can be stored on a web server and can be visualized in multiple forms anywhere around the world.

II. METHODOLOGY

Based on the scenario chosen the paper deals with three important conditions:

1) Receiving data from external environment of the mine
2) Transmission of data wirelessly from the proposed helmet to the control room
3) Uploading data received into the web server for the purpose of monitoring

At the first place the data from the mine have to be collected for analysis. The conditions of a mine can be effectively monitored using effective sensors, namely temperature, Humidity and gas sensors. The sensors proposed should be placed in a safe place away from external pollutants and shock. The layer between the outer and inner layers of an industrial helmet (Fig 1) is proposed for sensor placement.

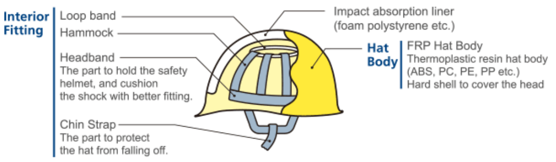

Fig 1: Structure of an Industrial Helmet

The sensors are sensitive to a particular substance in the environment whose output depends on the concentration of the particular substance.

The measured data is stored inside the Arduino nano microcontroller which is processed by checking for the threshold values for each sensor. In case of an emergency the sensor values are expected to be above the threshold level and in such a situation an alarm rings inside the helmet of the worker placed close to his ear to immediately alarm him of the situation. Along with the sensors an additional button is placed inside the device which can be pressed to ring the central alarm of the mine in case the system fails or any undetectable emergency.

The next part of the paper proposes the wireless transmission network established using Zigbee. The Zigbee is interfaced with the microcontroller preconfigured to behave as an end node or router [4]. The block diagram shown in Fig 2 and the schematic in Fig 3 shows the system embedded inside the helmet of the worker.

According to the mesh topology suggested by Hasan and Haque [4] Zigbee modules placed inside the helmets are configured to work as end nodes or routers which transfer data either to the coordinator (router and end nodes) or the router (end nodes).

The receiver section is built around an Arduino UNO microcontroller which is interfaced with the Coordinator Zigbee module (only 1 present for any network) and ESP8266 WiFi module as shown in the schematic in Fig 5. The block diagram in Fig 4 shows that the data coming from the helmet is received finally by the coordinator Zigbee which then is processed and uploaded to the web server. The uploaded data can be visualized in the form of a graph which shows the change with respect to time [6].

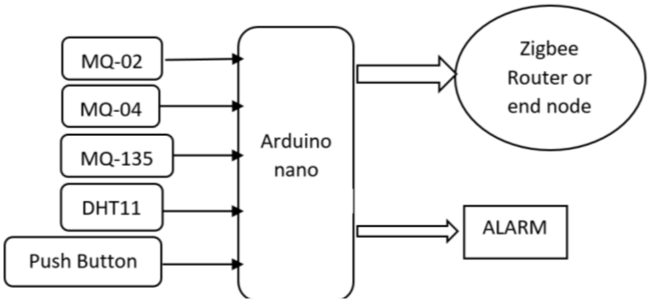

Fig 2: Block Diagram of System Placed Inside the Helmet

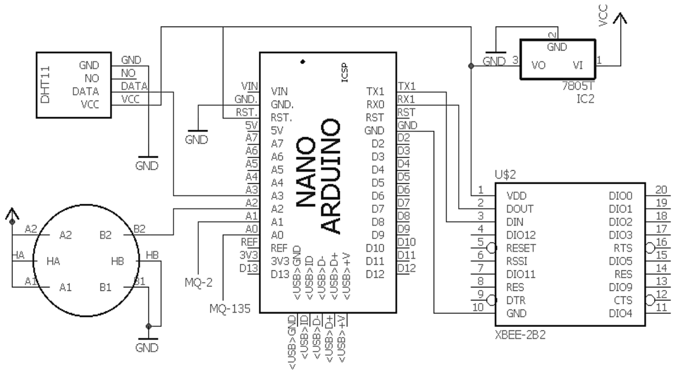

Fig 3: The Schematic of the End Node Module Placed Inside the Helmet

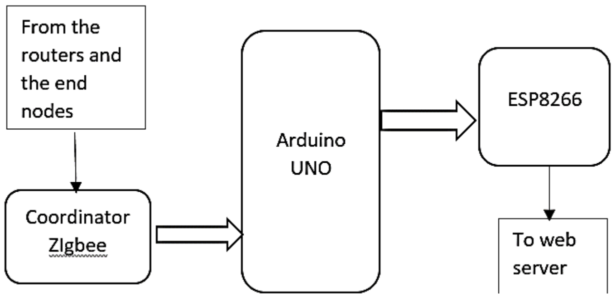

Fig 4: Block Diagram of the Receiver System

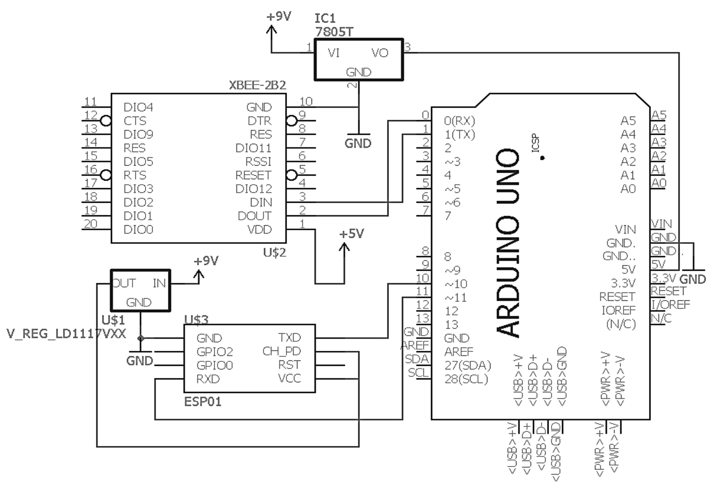

Fig 5: Schematic of the Receiver Module

III. HARDWARE DESCRIPTION

A. Arduino Microcontroller:

The helmets proposed have been tested using Arduino Nano microcontroller which has an on-board ATMEGA328 (for rev 3) microcontroller

[5]. The receiver module on the other-hand has been tested using Arduino UNO board which also has an on board ATMEGA328 (5V, 8 bit). Both boards have 14 digital I/O pins out of which 6 are PWM(Pulse Width Modulation) pins. The UNO board has 6 analog input pins [6] whereas the Nano board has 8 such pins. The ATMEGA328 microcontroller allows UART TTL(5V) serial communication on digital pins 0(RX) and 1(TX). The microcontroller also supports SPI (Serial Peripheral Interface) and I^2C communication with other devices.

B. DHT11 Module:

The DHT 11 is an analog capacitive sensor. It gives analog voltage output which determines the change in the measurable quantity. The DHT 11 module is capable of providing both temperature and humidity values as output. The temperature is monitored such that the inside temperature is within tolerable limits. The humidity level determines the moisture content inside the mine.

C. MQ-04 Module:

This sensor is effective in detection of Methane, Butane and natural gas which might be present inside the mine. The sensor output is an analog signal which corresponds to the level of the gases present (300-10000ppm).

D. MQ-02 Module:

This sensor is useful particularly in coal and cement industries, where the dust content is the main cause of health hazards to the workers. The sensor is particularly sensitive to combustible gas and smoke (500-10,000ppm). This sensor also produces an analog signal. All the MQ sensors have 6 pins, out of which 2 provide heating current and the other 4 are used for detection purpose. The schematic of the sensor is shown in Fig. 6.

E. MQ-135 Module:

This sensor has been used to monitor the air-quality inside the mine. This sensor is particularly sensitive to presence of sulphides, benzene and ammonia in the environment (10-10,000ppm). This sensor provides analog output based on the concentration of the poisonous gases in its surrounding.

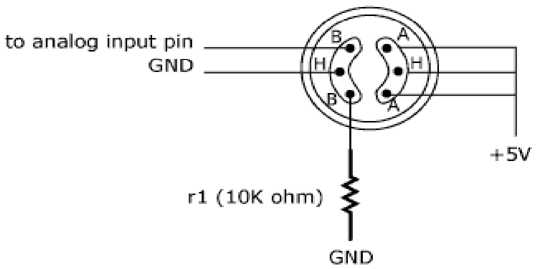

Fig 6: Schematic of MQ-02,04,135 Sensors

F. Zigbee Module:

The IEEE 802.15.4 [7] defines Zigbee specifications as a suite of high-level communication protocols used to create personal area networks built from small, low-power digital radios [8]. The distance travelled by data using Zigbee ranges from 10 to 1000m which is quite small but as shown in Fig 7 Zigbee can be used as a mesh network [4] where there can be three types of nodes: a coordinator(C), Router(R) and end node(E). There can be only one coordinator in a network. The end nodes are very low powered and thus the sensors are attached to such nodes. The coordinator is the one that establishes the network and the router is the one that relays signals from the end node to the coordinator.

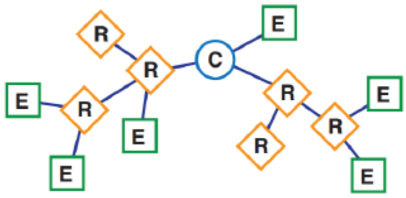

Fig 7: Zigbee Wireless Mesh Network

G. ESP8266 WiFi Module:

An ESP8266 WiFi module sends data to an online server such that the conditions of the mine can be visualized anywhere around the world. The ESP8266 can be configured using AT commands such that the module may connect to a specific network. Figure 8 shows the pin-diagram of the module. The TxD, RxD and GND pins of the module are connected to the RxD,TxD and GND pins of the microcontroller [9]. The mode of communication in this case is UART which makes this module very simple to use. The command that updates the database is sent to the module in plain text format. This module supports baud rates of 9600,115200 or 57600 for communication.

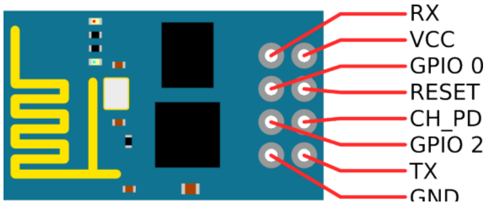

Fig 8:Pinout of the ESP8266 Module

IV. RESULT AND DISCUSSION

The overall performance of the system depends on the accuracy with which the sensors respond to the change in environmental conditions along with the rate at which the data is transferred between the end nodes and the coordinator and the rate at which data is uploaded to the server.

Every element in the system functions at its own specific voltage and current rating. The Arduino UNO and Nano operates at a voltage range of 7 to

12V [6] and so a 5V regulator is used which lowers the 12V supply to 5V. The sensors work typically at 5V and their output voltages also depend on the value of input voltage and current. Due to this reason the 5V supplied to the sensor modules is further filtered using a 10uF capacitor which removes any ripples if present. The ESP8266 module works exactly at 3.3V which arises the need to use a 3.3V regulator to lower 12V to 3.3V.

Assuming that the sensors receive constant input from the source the value received from the sensors are constant at a particular condition,Table 1 shows the permissible range of each sensor along with the threshold values set for each sensor. The threshold values are set in such a way that just as the sensor data crosses this value the alarm starts ringing.Varghese et al [8] has used the MQ-03 sensor which is sensitive to alcohol which is effective for a particular application inside the mine. Also Reddy and Lakshmi[9] has used MQ-04 sensor which is only sensitive to methane, butane and other organic gases. In the proposed system a combination of three gas sensors is used to obtain optimum accuracy such that no condition is left un-monitored. Table 1 shows that the concentration of methane should be very low as because it is highly explosive. The concentration of Ammonia and sulphides do not increase more than 25%. The temperature and humidity levels are maintained based on an assumption that the miners are well trained and healthy.

Table 1.1: Tabulation of Permissible Limits and Threshold Values for Sensors

Sl. no	Sensor Name	Permissible limits	Threshold set
1	DHT11 (Temperature)	25-40deg C	50 deg C
2	DHT11 (Humidity)	15-70 %	70 %
3	MQ-02	Less than 30 %	30%
4	MQ-04	Less than 10 %	12%
5	MQ-135	Less than 25%	30%

Fig 9 shows the prototype of the wearable device emphasising on the positions at which the sensors

Fig 9: Prototype Showing Position of Sensors

are placed. Fig 10 shows the proposed placement of the circuitry inside the helmet. The placement ensures that the sensors are completely exposed to the environment and the placement causes no discomfort to the miner.

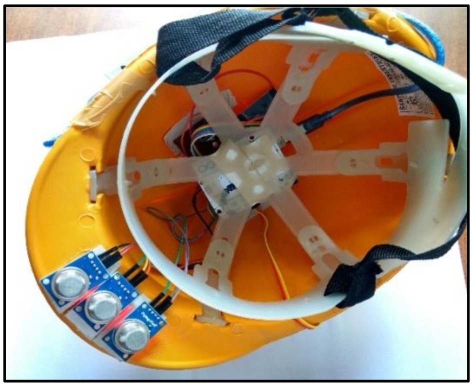

Fig 10: Prototype Showing the Internal Circuitry

The Thingspeak web server is used for testing the IoT component of the proposed system. The server is regularly updated at an interval of twenty seconds. The server accepts data in the form of fields which are graphically represented as shown in Fig 11. The web server also provides options to clear and remove any channel if required so that large amount of data can be managed [6].

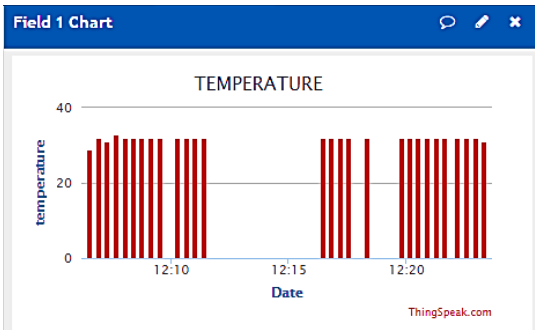

Fig 11: Temperature Value Plot

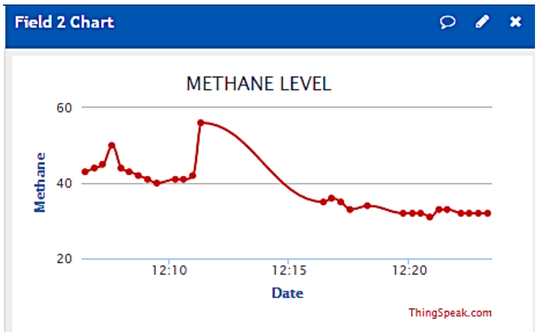

Fig 12: Methane Level Plot

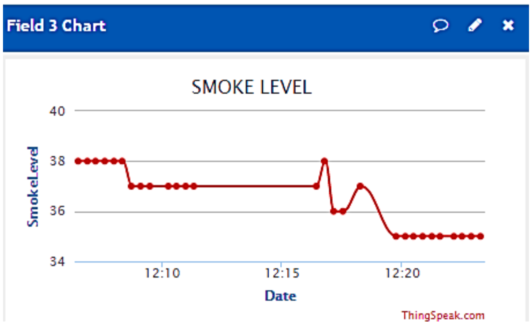

Fig 13: Smoke Level Plot

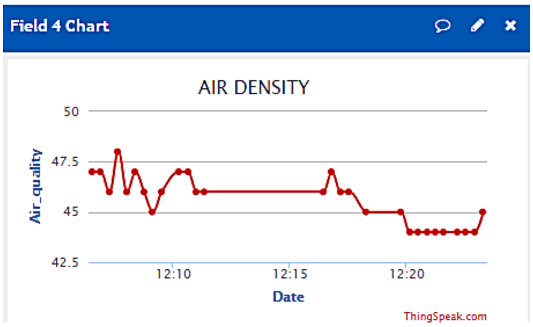

Fig 14: Air Density Plot

V. CONCLUSIONS

The increasing rate of accidents occurring every year in mines, puts forward an urgent need to take proper measures about the safety and health of workers inside the mine. The remote location of mines under the ground puts forward many communication barriers between the miners and the authorities. The proposed helmet not only collects data from the environment of the mine but also provides a fast and safe system to relay this data to the outside world so that the conditions of the mine can be visualized even in the absence of any official on a web server. It is hoped that the proposed system would be able to prevent the occurrence of major accidents in future.

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