Automatic robotic scanning and inspection mechanism for mines using IoT.

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Abstract. The mining industry has been recognized as one of the most hazardous industry. With the growth of the industry, the number of human casualties has increased. The mines can be very lethal for workers or in the event of an accident or with high humidity and temperature leading to workers fainting. Some of the problems that besets are of air blast, ground movement, dust explosion, inundation etc. This study reviews the common problems associated with Carbon Monoxide content with temperature and humidity. In this paper, we assemble an automatic robotic scanning and inspection mechanism for mines that is designed and assembled to recognize Carbon Monoxide (CO), humidity and temperature variance inside the mines. The proposed system employees a mobile robot that can be manually controlled by a self-developed mobile application and an Internet of Things (IoT) system. The sensors included take the input from the air and transmit them to the mobile application using Bluetooth module. The experimental results show that the IoT achieved an accuracy of 97.5 \% for the mobile robot and the sensor system.

1. Introduction

With the latest advancement and the rapid progress of the technology, demand for automation of industries has spiked. These include the natural resource industries. Human workers have been replaced with big machines to increase the efficiency and the profits. The aftereffect of these machines is the unbalance of the natural environment at these extraction sites [1].

Mining industry is generally classified as the most hazardous industrial sector. Mining activities usually emit physical and chemical hazards in the workplaces and impose negative effects on the workers’ health [2]. Many of incidents in the hazardous industry take place because of human error, the control of which would enhance safety levels in working sites to a considerable extent [3]. However, even with the introduction of various mobile robots by universities and companies, the industry still faces common issues like the design specification and functionality of the robot, in terms of size, weight [19] and the movement of the robot, including, the raw material of the robot and the sensors that were attached. Due to the air content inside the mines, the robots need to be dustproof and inflammable [18]. The robots did not do well with the still water in the mine and were stuck; and the functionality of the robot is compromised. The flammable gas content in the air needs flameproof protection for the components [4]. This paper is targeting some very important questions such as the safety of mine workers and the monitoring of mine air conditions.
The aim of this paper is to develop and use a robot to gather data inside a mine and transmit it wirelessly using IoT. The four sensors utilized in the proposed rescue robot are Carbon Monoxide (CO), humidity and temperature variance inside the mines. The core of the car is an Arduino MCU and the connection between the mobile app and the car is realized via Bluetooth.

The remainder of this paper is organized as follows: Section 2 discusses the related works. Section 3 introduces the proposed methodology of this work, while section 4 presents the experimental results. Finally, the paper has been concluded in section 5.

2. RELATED WORK

The fundamentals of this section are to identify the design specification and the working mechanism of a mobile robot for data acquisition inside a mine and the trends of robots used in the mining industry for the data acquisition. This allows the design specification of the robot to be scaled according to the requirements. It also investigates the different mobile robots developed by researchers for data gathering.

Rescue operation in the coalmine is extremely dangerous due to several factors. It is particularly very harmful to the rescuers to get into the coal mine tunnel in disaster without the prior knowledge of environment because the subsequent explosions may likely to occur at any time it is therefore essential to detect the explosive environment details such as toxic gases, high temperatures [5-17].

Added to the above reasons is the problem of spontaneous combustion, which is more common. Spontaneous combustion, if not detected in the early stages, could be fatal in terms of both material loss as well as the loss of life [6].

In one research [7] on the results of gases, emissions from the Lotts Creek coal mine fires. This study shows the analysis of the types of gases and their contents in the air after a coal fire. The environment effect of the coal fires is tremendous and thus does not lead to the halt of work. The results and analysis will show the need for an automated robot to analyze the environment for the health and safety of workers. Concentrations of CO2, CO, CH4, and H2S in vent emissions were determined with an Industrial Scientific MX6 iBrid portable gas analyzer. The iBrid gas analyzer was calibrated with zero and 2000 ppmv standards prior to each field campaign.

Another research [8] on the Assessment of mine ventilation systems and air pollution impacts on artisanal tanzanite miners at Merelani, Tanzania, shows the study of air quality in five mines in Tanzania. The researcher set up the study for these five mines. A study done was by [9] on terahertz measurement of indicator gas emission from spontaneous coal combustion at low temperature. National Natural Science Foundation of China supported the study. The experiment was conducted on the temperature range between 0 to 200 degrees Celsius. The gas emissions in the mine were SO2 and CO. In the experiment three samples of coal according to their ranking were studied and the. The researchers use gas coal, long flame coal and fat coal for the experiment to analyze and evaluate the emissions for coals of different quality ranks, with the increasing oxidizing temperature, the CO emission rise for any sample. The long flame coal releases a massive amount of CO in the air at higher temperature. The experiment is conducted to understand the effect of coal spontaneous combustion at low temperature, and the study was successful; however, the researchers could have employed more sensors to get the readings of other toxic gases.

In one research [10] on the study of unmanned vehicles (robot) for coal mines, talks about the deaths fatal accidents that happened in the mines in India. The Indian mining industry contributes to 8% of GDP and is in constant growth. The research suggests the use of the unmanned robot for the inspection of the geo-mining environments inside the mines through wireless communication. The aftermath of the attack on the world trade center lead to the introduction of robots for urban search and rescue. The study suggested different robots that have been developed and discusses about the problems that are faced by these robots. The problems addressed by the researchers are divided into three categories, addressed of searching, inspection and mapping and debris removal. In summary, their needs to be smarter software and hardware solutions for the robot to provide better inspection and analysis for the rescue teams, while maintaining better navigation through the complex mine structures.
According to [11] rescue robots can be classified into four major types as follows:

1. Unmanned Ground Vehicles (UGVs) - These mobile robots are best suited for the maneuver on ground.
2. Unmanned Surface Vehicles (USVs) - These robots are better suited for maneuver on water surface and are unsuitable for ground movement.
3. Unmanned Underwater Vehicles (UUVs) - These robots are designed and developed to be waterproof and can move underwater.
4. Unmanned Aerial Vehicles (UAVs) - These robots can be called drones. They maneuver in the air and may meet ground for takeoff and landing.

An efficient robot can be either one of the above or a combination of any of the four. While they need to be developed according to the required factors

| Robot                        | Figure                               |
|------------------------------|--------------------------------------|
| Wolverine V2                 | ![Wolverine V2](image)               |
| Reddy, Kalyan & Murthy[12]   | ![Gemini scout](image)               |
| Gemini scout                 | ![Numbat](image)                     |
| Reddy, Kalyan & Murthy[12]   | ![Ground hog](image)                 |
| Ground hog                   | ![Sub-terranean Robot](image)        |
| Reddy, Kalyan & Murthy[12]   | ![GMRI](image)                       |
| Sub-terranean Robot          |                                       |
| Ray et al., [13]             |                                       |
| GMRI                         |                                       |
| Kasprzyczak, Trenczek and Cader,[14] |
In one study [11] compared the performance of multiple mine rescue robots. Some of these robots were designed for military purposes and later developed into rescue robots, while some were developed for research purpose only. The focus of this research was on the Unmanned Ground vehicles; the robots that took the focus of this research were highly functioning yet had many limitations.

Table 1 illustrates the comparison of the robots and their results. According to the findings, not many robots have been successful due to the complexity in the environment. While the only robot that had actual success and is still employed in the industry is the groundhog. However, GMRI and the Mine Bot are not industrial robot-like groundhog [14], wolverine V2, Gemini scout, they showed satisfactory result, and the worst performance was of Wolverine V2 as it did not serve the purpose it was designed for.

Another study conducted by [15] on the hazardous gas detecting rescue robot in coalmines. The instruments inside the robot helps to tolerate the rest of the subsystem and assists in control by the control system, the movement of the robot and a communication system that enables in the efficient transmission of data acquired by the camera and the sensors. In addition, it can carry some food and medicine to the miners trapped in the disaster. However, the robot was never deployed in a mine but tested inside a controlled environment. The limitations of this robot are that it is not flameproof, and that can be a big set point inside a mine. The robot also does not work efficiently in higher temperature; 40-degree Celsius is the temperature set point of the robot. Besides, the higher transmission is needed, as the robot cannot travel a greater distance. Changes to the camera also need to get better quality images inside the mine.

In one study by [3] presents a various robotic system for harsh environments and safety application. The robotic systems present in the study are developed to assist human to monitor and can be deployed in various types of places to measure different parameters. The applications are these robots at various harmful environments such as pipes, mines, and tube systems, for real-time monitoring the environment to reduce the economic and life risks. Each of these robots is equipped with different sensors/actuator, wireless communication networking and navigation system.

In the study [16] robot was deployed at the pyramid as while people survey the pyramid for evidence and research problems, damage can occur to the pyramid. The robot is deployed for video survey while protecting the pyramid from damage, and the robot was successful as no surface marks were left at the shaft walls. During the lab testing, the Minebot successfully performed its task; however, the drawback was its operational distance of 200m only. The other robot developed is LetterBot. The LetterBot was developed to access buildings with ease through the letterbox. The robot performance was successful; however, due to its complexity, it is not very reliable. The Minebot faced with the limitation due to its weight, so it cannot go more than 200m, and however, adding more weight will require the reconfiguration of the whole robot. The limitation for the Djedi robot is that the climbing speed is too long; in the experiment, it took the robot four hours for its mount.

According to the intensive research works done on mobile inspection robots, the robots are as good as their designer. They need to be designed and developed according to the factors that can affect its functionality and efficiency. The robots mentioned in Table 1 faced with several limitations. The wolverine v2 was too heavy and required too much power to operate. The robot transmits data through the fiber optic cable. It is due to the rather constant evolution of the mine and its unstructured nature that there are major limitations for the robot’s application in the underground mines. The major robot, as addressed in Table 1, are heavy and bulky that limits their movement and are not suited for easy transportation. Their deployment in the mines may arise the risk of failure to maneuver and may lead to the risk of damage. The communication methods applied by many of the robots, as mentioned in this section, are not reliable and not efficient. The application of tethered communication method applied by these robots introduces different unnecessary complications for the maneuver. The cables prove data transmission, and the feed is efficient, but due to wear and tear, it compromises the robot’s ability. The wolverine V2 was not a big success, and it faced many problems with the movement as the cables limited its range and were being overrun by the robot. The other problem was with the wireless transmission, as the mine structure is so complicated the major problem that arises for the
developers is that of the communications. Hence, before the deployment of the robot, the structure of the specific mine should be studied and accordingly, the best solution needs to arise. This dilemma can be very challenging as the consistent wireless communication that was used by the robots were not reliable as it required the user to maintain the line of sight. The other factors concerning the limitations were of the presence of water, low roofs heights, and the wiring inside the mines.

3. RESEARCH METHODOLOGY
Figure 1 illustrates the block diagram of the proposed system. The system comprises of two sensors, MQ7 that gives the readings for the Carbon Monoxide content of the air and DHT11 gives the readings for the humidity and the temperature. The L293D Motor Controller IC is connected to the Arduino where it communicates with the microcontroller to output signals for the control of the DC motors. The Micro Controller controls the purposed system by acting as the channel for different components. The Mobile application is connected to the Arduino microcontroller using the HC06, and the power supply is connected to the DC motor and the Arduino.

The mobile app’s block diagram is illustrated in Figure 2; the mobile app works in coordination with the Arduino Uno using the Bluetooth to transfer data wirelessly. The application is developed using the MIT inventor application, an open-source web application and can be downloaded from MIT inventor or later from Google play store. The user must enable the Bluetooth of their cell phone and pair up with the HC-06 Bluetooth module, attached to the mobile robot. The mobile app allows the user to control the robot and get the data from the sensors. The objective of the mobile app is to allow the user to control the mobile app while simultaneously display the output data from the sensors. The data flows in two directions; one is the output for the movement of the prototype and inputs the data from the sensor system to display on the GUI.
Figure 3 illustrates the working principle of the proposed system and can be referred for visual understanding. According to Figure 3, the mobile robot and the mobile application is initialized. During the process, the built-in code is triggered; this is the internal self-check that illustrates the robot’s movement capabilities. Following this process, open the mobile app on the smartphone and enable the Bluetooth on the device.

![Flow Chart](image)

**Figure 3. Working principle Flow Chart**

The next stage is ensuring a wireless connection between the mobile robot and the mobile robot, which is done by connecting the Bluetooth on the prototype and the mobile app. The mobile application will illustrate four sensor readings; this is the self-test of the sensor system. If there are no readings illustrated in the GUI of the mobile app, it is recommended to initialize the mobile robot and the mobile application again. The user must send movement instruction to the mobile robot to test its response. If the prototype is not responding, once again a system initialization is needed due to connection issue.

Once the mobile robot and the sensor system are working fine, the proposed system can be deployed to carry out the task. The GUI’s control panel can command the mobile robot for maneuver on the field and get the sensor readings on the mobile application. Once the task is finished, the readings can be saved and used for analysis. The robot should be retrieved from the site, and power should be offed.

4. EXPERIMENTAL RESULT

This section illustrates the hardware design and simulation results of the proposed system and the mobile app. Figure 4 shows the final design of the GUI developed for the mobile app. The GUI was designed to illustrate the data of the sensor and enable the user to control the robot wirelessly. The
GUI created consists of the Bluetooth connection button that enables the connection with the mobile robot. To control the mobile robot, a control panel was created in the GUI that consists of four buttons, illustrated with the arrow images. These buttons enable the movement control of the robot. Moreover, the red octagon button in the center of the control panel acts as a safety button for the robot. This button stops any movement by the robot and halts the data output from the robot. The GUI also consists of the data display space labelled as the sensor system data. The sensor system in a mobile robot continuously transmits data to the mobile app, as illustrated in the bottom of the GUI. The data displayed is for the humidity and temperature levels. It also displays the temperature readings. All the readings are real-time. However, in the code, there is a time delay to ensure the GUI is not spammed with the readings, and the time delay is set to 2 seconds.

In addition, Figure 5 illustrates the real-life testing of the GUI. The proposed system connected to the mobile application and the sensor system is sending the data for the temperature and the humidity level. The results are shown at the bottom of the GUI, and the font is a yellow color. The readings are from an indoor location hence high humidity of 78% and 28°C temperature.

Figure 4. GUI: Humidity and Temperature results

Figure 5. Carbon Monoxide results

Figure 4 illustrates the sensor data displayed on the GUI. It shows the result of the Co, temperature, and humidity together. If the level of Co is exceeding the safe amount, the font of the text with the change to red and the limit will show as one. Figure 6 illustrates the final design of the experimental mobile robot. The sensors and Bluetooth module are placed on the breadboard, while the Arduino Uno is wired with the breadboard and all the electrical components are attached on the top side of the acrylic body of the prototype. The Bluetooth module allows communication between the mobile application and the prototype. Moreover, the battery is connected towards the back of the main body. Lastly, the blinking LEDs for each component illustrates the working condition and that correct initiation has been achieved.
There are four types of testing conducted in order to analyses the accuracy of the proposed system. The testing as follow:

4.1. Carbon Monoxide

The sensor system is exposed to clean air in an indoor location and then placed in an open environment. The readings are conducted periodically. However, the last subtests are conducted with high exposure to CO gas using burning items such as near a cigarette, candle, and a burning paper. Moreover, for the exposure, the sensor system is placed inside a glass container with the burning item. To know the correct value of the air toxicity, a digital CO sensor was placed near the sensor system this ensures that the sensor is working according to the industrial standards and if there is a need for further calibration. There are 10 Sample tests conducted which consists of five indoor locations and five outdoor locations. The code is altered to get a single reading every 30 seconds for 50 samples for indoor locations and 30 seconds for 50 samples for outdoor. A carbon monoxide sensor was used to correlate with the readings from the sensor system, to understand the accuracy and the quality of results.

By measuring the carbon monoxide content in the indoor locations and the outdoor locations, the experiment illustrated that the results varied according to the locations. The indoor location had an accuracy of 94.4%, which is due to the limited air contents, and needed introduction of carbon monoxide contents in the air, Figure 7 illustrates the accuracy of the indoor results. The accuracy of outdoor locations was 94.8%, as illustrated in Figure 8. The number of gases present in the air is limited indoors. At the same time, outdoor there are different varying gases and includes higher carbon monoxide content due to the emissions from vehicles and other machines. However, the accuracy for the indoors is between 92% and 96%, while the accuracy for the outdoors is between 88% and 98%. Furthermore, according to the results, the accuracy of the indoors and the outdoor is nearly the same with indoor at 94.4 % and outdoor at 94.8%. Hence, it can be concluded that the accuracy of the system is useful in regarding the location.
4.2. Temperature Sensor

The sensor system was conveyed in a various environment with varying conditions. The readings were taken at an interim of 1 minute. A sum of 50 samples was collected at each location, and the outcomes acquired were noted down. Nevertheless, a digital thermometer was conveyed with the system with same exact conditions and time interims. The readings collected from the thermometer were noted down for correlation with the sensor system.

Figure 9 shows the results of testing the accuracy of the temperature sensor in the proposed system with a correlation with a digital temperature sensor. The results illustrate that the temperature sensing capability of the proposed system is excellent, with an accuracy of 97.80%. Figure 9 shows the highest accuracy of 100% at three locations, APU University, parking lot and south city, while the lowest accuracy of 92% at the Sungai Besi LRT. The highest being indoors while the lowest at the outdoor. However, with the lowest accuracy of 92% after taking 500 training samples at 10 different locations, it can be concluded that the temperature sensor is very reliable. While the reason for the lower accuracy of 92% at the LRT station can be assumed that due to the constant change in the environment that is due to the moving cars and trains, with many people moving around, these variables could have affected the accuracy of the sensor.

4.3. Humidity Sensor

The sensor system was placed in locations with high humidity and low humidity. Moreover, to measure the legitimacy and the accuracy of the humidity sensor in the proposed system, a digital humidity sensor was placed next to the system to get real-time values. Figure 10 illustrates the humidity accuracy of the proposed system. The results obtained show the minimum accuracy of 88% at South City with the highest accuracy of 100% at APU University, LRT, and Park. While, the accuracy results of the other locations are varying between 94% and 96%. The overall humidity accuracy is the lowest in the indoors as the humidity is constantly changing due to the human inputs as the area of testing is a small room a slight change can have a more significant impact on the results.
However, the accuracy of the humidity sensor of the proposed system is 96% with ±4 error; the results show that the humidity sensor is reliable and gives good results.

![Humidity accuracy](image)

**Figure 10. Humidity accuracy**

4.4. **IoT Experimental Results**

The system was tested to know the accuracy of the response of the experimental robot over the distance of 2m to 20m; Figure 11 illustrates the results of 250 commands sent from the mobile app to the mobile robot and the correct response comprehended by the bot. Moreover, Figure 12 illustrates the time delay in response by the mobile robot over the varying distance from the smartphone.

The accuracy is varying from perfect 100% for 2m to 10m and then gradually decreasing to 92% at 20m. The decrease in the accuracy is due to the increasing distance and the loss of packets in the connection of Bluetooth. However, the accuracy is still decent, and the number of wrong output movement commands are two at 20m. Moreover, the maximum delay in response at 20m is of 1.00s, which is also acceptable; however, it can be improved. Hence, the initial delay is of 0.50s, which is due to the human error. This delay could be reduced using alternative automatic ways of calculating. However, the delay is also caused by the code in the mobile app and the communication between the two machines.

![IoT experimental results](image)

**Figure 11. IoT experimental results**

![Response Time for Mobile Robot](image)

**Figure 12. Response Time for Mobile Robot**

5. **Conclusion**

To conclude, a mobile robot was designed using 3D printers and developed to go inside the mine. A sensor system was developed to detect the temperature, humidity, and carbon monoxide gas content in the air. For prototyping purpose, a mobile application was designed and developed to pilot the robot and to illustrate the data from the sensor system. The mobile application was developed to be deployed on the smartphone to be more sustainable.

For future work, Bluetooth 5.0 can be employed in the system that would give a greater range with improved speed. Increasing the price but simultaneously increasing the range to 60 meters and this would be a major upgrade to the system. Hence, the users can send and control the mobile robot...
from a higher distance. Moreover, the speed would be increased to two Mbps that would drastically reduce the system response delays, hence giving faster results and reducing the errors.

Furthermore, the proposed system could increase the number of gas sensors to detect more gases that are toxic. Hence, enabling more analysis and data content for the users. Moreover, use four dc motors instead of two as greater road grip and ease of maneuver. This would increase the movement speed of the robot also.

Lastly, developing a database for the sensor data and enabling sharing. Currently, the proposed system does not have the database for the results, and this limits the functionality, introducing it would be more user friendly and useful.

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