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Research Article

Li-Fi Technology for Enhanced Communication and Safety in Coal Mining

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ABSTRACT

In the coal mining industry, numerous hazardous risks such as gas explosions, temperature fluctuations, and humidity variations pose challenges in terms of monitoring and control. This paper introduces a proposed method that utilizes Li-Fi technology for data transmission. Equipped with sensors, this system provides real-time situation updates to coal miners, ensuring their safety. Among the dangerous gases in coal mining, carbon monoxide (CO) is a significant concern. To address this, specific sensors are employed and connected to a core component, the microcontroller, which is strategically placed throughout the coal mine. When the concentration level exceeds a predetermined threshold, an alarm is triggered, and a notification is sent to the central database, alerting the workers. By overcoming issues like slow data transmission or data loss, Li-Fi offers a solution that enhances safety and improves working conditions for laborers in the coal mining sector.

1. Introduction

Safety is crucial matter in all industries, and it's especially vital in the coal mining sector. The reason for this heightened focus is because coal mining comes with inherent risks, and even the smallest mistakes can have devastating consequences. That's why effective communication plays a pivotal role in keeping everyone safe. It is essential to identify and closely monitor any potential risks that may arise [1]. In coal mining environments worldwide, accidents are unfortunately common due to the complex nature of the industry. Therefore, it is crucial to closely monitor working conditions and establish effective communication channels with workers to enhance safety. Traditional wire-based communication systems are not ideal for mining operations due to their high installation costs and vulnerability to damage caused by natural disasters such as earthquakes. To overcome these challenges, wireless communication, particularly Li-Fi, has emerged as a promising solution that addresses these issues. Li-Fi technology is an optical wireless communication (OWC) technology proposed by German physicist Harald Haas in 2011 [2]. Li-Fi uses the visible part of the electromagnetic spectrum to transmit information at a very high speed. The working principle of Li FI begins with visible light as the emission source of the signal by controlling the 'on' and 'off' state of the LED light. When the light is 'on', the digital signal represents "1", and when the light is 'off', the digital signal represents "0". The LED light emits high-speed light and dark flashing encoded information that cannot be detected by the naked eye. The photosensitive sensor receives these changes and uses the decoding chip to recover the same data information as the sender, so as to complete the transmission and reception of wireless data and translate the optical signal into ordinary electrical signals. Currently, the improved LED lights are equivalent to a Li-Fi hotspots. The optical signal emitted by LED lights is similar to the electromagnetic signal emitted by AP (Wi-Fi hotspot) devices [3]. In a nutshell, it uses light to

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transmit the network, and when there is light, there is network. According to a previous study [12], [13], Li-Fi technology is capable of improving data transmission efficiency and safety systems in the mining industry, which will contribute to its understanding and adoption.

Li-Fi, which utilizes light signals for data transmission, offers significant advantages in the mining industry. Firstly, it eliminates the need for extensive wiring infrastructure, reducing installation costs and simplifying deployment in remote or challenging mining areas. This flexibility enables efficient communication throughout the mine, including underground sections that are traditionally difficult to reach with wired systems.

Furthermore, the wireless nature of Li-Fi makes it more resilient to potential damage caused by natural disasters. Unlike physical cables that can be disrupted or severed during seismic events, Li-Fi communication operates through light signals, which remain unaffected by physical disturbances. This ensures continuous communication even in challenging circumstances, contributing to improved worker safety and operational efficiency. Additionally, Li-Fi provides high-speed data transmission capabilities, enabling real-time monitoring of the mining environment and prompt response to potential risks. The ability to transmit large volumes of data quickly enhances situational awareness, allowing for timely detection and mitigation of hazardous conditions. This real-time communication empowers workers and safety teams to make informed decisions promptly, minimizing the likelihood of accidents and improving overall safety outcomes.

By leveraging Li-Fi as a wireless communication solution, coal mining operations can establish a more flexible, resilient, and efficient communication infrastructure. This technology not only reduces installation costs but also enhances safety by enabling real-time monitoring, rapid response to risks, and uninterrupted communication in a challenging mining environment.

Advantages of Li-Fi

Li-Fi technology offers several advantages over Wi-Fi, particularly in areas where Wi-Fi is not yet widely available, such as hospitals, power plants, and other establishments. One key advantage is that Li-Fi utilizes light as its medium, which makes it safe to use in environments like airplanes and hospitals where Wi-Fi is prohibited due to its potential interference with radio frequencies. Additionally, the use of optical bands in Li-Fi eliminates any health concerns associated with radio frequency exposure. Another benefit of Li-Fi is its lower power consumption compared to other technologies, making it well-suited for various Internet of Things (IoT) applications. This efficiency in power usage contributes to its popularity in IoT-related devices. Furthermore, Li-Fi provides a high level of security. Since Li-Fi operates through line-of-sight data exchange, it offers enhanced security measures. Moreover, due to its reliance on light signals, the Li-Fi signal cannot penetrate through walls, which acts as an additional security measure by preventing unauthorized individuals from accessing the signal [9].

Disadvantages of Li-Fi

In order to effectively receive data using Li-Fi, it is crucial to have a clear line of sight between the transmitter and receiver. If any solid object obstructs this line of sight, the signal will be immediately lost. Additionally, since Li-Fi is a relatively new technology, only a limited number of devices currently support it. As a result, it is unlikely that we will see widespread use of Li-Fi-enabled personal gadgets in the near future, mainly because our existing devices still heavily rely on Wi-Fi hardware for networking. While Li-Fi offers faster data transmission rates, this advantage becomes less significant if the internet speeds provided by service providers are not up to par. Deploying a Li-Fi network would not be practical in countries with slower internet connections. To achieve widespread adoption of Li-Fi, it will be necessary for various industries to coordinate their efforts and address these challenges in order to promote the usage and acceptance of this technology [10], [11].

2. Proposed System

The entire system is divided into two parts, the transmitter and receiver, and both play a crucial role in communication between the components. Block diagrams of the transmitter and receiver are shown in Figs 1 and 2, respectively.

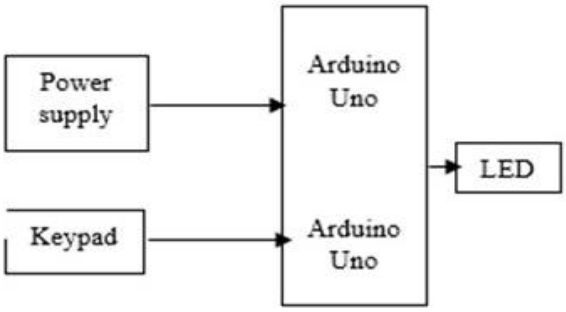

Fig. 1. Block Diagram of Device at Transmitter Side

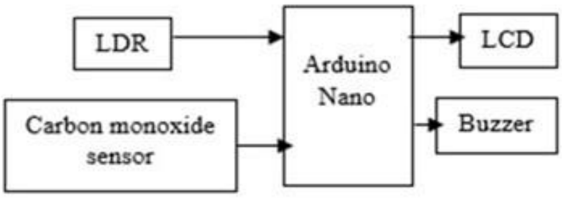

Fig. 2. Block Diagram of Device at Receiver Side

The main components that were used to ensure the functionality of the operation design system are listed below:

2.1. *Arduino uno*

Fig. 3. ATmega328P Arduino Uno

The ATmega328P-based Arduino Uno is shown in Fig. 3 is a microcontroller board. It has 14 digital I/O pins, 6 analogue inputs, a ceramic resonator operating at 16 MHz, a USB connection, a power jack, an ICSP header, and a reset button. The microcontroller can function by simply connecting it to a computer via a USB cable or powering it via an AC-to-DC adapter or battery. As an output, this board is capable of controlling relays, LEDs, servos, and motors and can be interfaced with other Arduino boards, Arduino shields, and Raspberry Pi boards. Its 14 pins can be used for both sending and receiving digital signals. Out of these 14 pins, 6 are dedicated to generating Pulse Width Modulated (PWM) signals, which are necessary for controlling LED brightness. These PWM pins provide connection and communication with a wide variety of external devices, such as sensors, actuators, and displays. Therefore, we have used them in this project to ensure reliable connection between the controller and the connecting devices.

2.2. *Arduino nano*

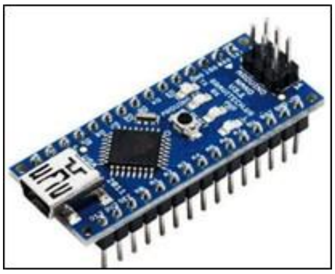

Fig. 4. ATmega328 Arduino Nano

Fig. 4 illustrates an Arduino Nano, a small, complete, and breadboard-friendly ATmega328-based board. It has similar functionality to the Arduino Duemilanove, but in a different package. It lacks a DC power jack and requires a Mini-B USB cable rather than a standard one. The Arduino Nano includes a crystal oscillator with 16 MHz frequency. It is used to generate a clock with a precise frequency by using constant voltage. Arduino Nano is designed to be compact, which means it is suitable for projects with limited space or where size is an important factor. It is often chosen for applications that require a smaller footprint.

When it comes to connectivity, the Nano provides a total of 14 pins that can be used for both digital input and output. Among these pins, 6 of them are capable of producing PWM signals. These signals are particularly useful for controlling devices like sensors, LEDs, and motor drivers. With these pins, you can easily connect and communicate with a wide range of external components, expanding the capabilities of your project.

2.3. *MQ-7 sensor*

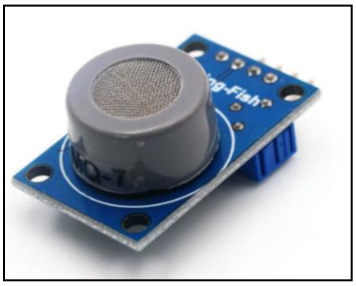

Fig. 5. MQ-7 Gas Sensor

The MQ-7 is shown in Fig. 5, a simple carbon monoxide sensor that detects the Carbon Monoxide (CO)-gas concentrations in the air ranging from 10 to 500ppm. This sensor is highly sensitive and has a quick response time. The output of the sensor is an analogue resistance. The drive circuit is very simple: we simply supply 5V to the heater coil, add a load resistance, and connect the output to an ADC.

2.4. *Keypad*

Fig. 6. 4×4 4×4 Matrix Array/Matrix Keyboard

This keypad has 16 buttons organized in a telephone-line 3×4 grid, plus four extra keys labelled A, B, C, and D as shown in Fig. 6. It's made of a thin, flexible membrane material with an adhesive backing that allows it to be attached to almost anything. Because the keys are connected in a matrix, scanning through the pad requires only 8 microcontroller pins (4 columns and 4 rows).

2.5. *Buzzer*

A buzzer, also known as a beeper, is a mechanical, electromechanical, or piezoelectric audio signalling device. Alarm devices, timers, training, and confirmation of user input such as a mouse click or keystroke are common applications for buzzers and beepers. Fig. 7 shows the Piezo Buzzer used in this prototype.

Fig. 7. MCKPR3-G4210-4136 Piezo Buzzer

3. Development of Li-Fi transmission

This section highlights the procedure used to establish a Li-Fi connection for data transmission usage in the mining sector. The project is divided into four different stages which are planning, designing, execution and monitoring to produce the best possible outcome.

3.1. *Planning the suitability of materials and equipment*

There are two types of sources widely used, Light Emitting Diode (LED) and lasers depending on the type of propagation mode [4]. Since our project is on a smaller scale, the basic material used as the light source is the LED. Next, a Light Dependent Resistor (LDR) is used for light pulse detection on the receiver side. The core of the entire system relies on the microcontroller which is the Arduino Uno and Nano as it is more cost effective and capable of interpreting data such as reading inputs from a sensor and providing an output to another specific device.

Next, carbon monoxide which is produced from incomplete combustion of carbon dioxide is an important risk parameter in the mining environment because it is extremely toxic. It may even cause the death of a person in one to two hours if the level gets as high as 0.2% because it blocks hemoglobin from absorbing and carrying oxygen. It is also flammable and difficult to extinguish compared to other gases [5]. MQ-7 is used to detect the carbon monoxide levels and a buzzer is fixed at the receiver to inform the workers once the concentration exceeds the threshold value. There is also a keypad on the transmitter side to ease communication during crucial moments.

Besides that, a Liquid Crystal Display (LCD) is used at the output to display the current carbon monoxide level of the surrounding environment as well as the relevant data from the keypad input.

3.2. *Designing data transmission via Li-Fi*

For such a small-scale design, all the devices are mounted onto breadboard. When the user presses a number on the keypad, the Arduino Uno interprets the information and sends the data via the output port to the LED. The LED is connected in series with a resistor to form a voltage divider circuit and avoid short circuits. The microcontroller controls the blinking of LED which is detected by the LDR as visible light pulses and converts it to interpretable electrical pulses [6]. Then, the LDR is connected to the input port receiver, Arduino Nano, which receives the pulses and converts them to actual data. The MQ-7 sensor which is used to detect the surrounding carbon monoxide collects the data and is connected to the receiver side of the Arduino Nano. The buzzer will be switched on once the sensor detects a value above 100ppm. The LCD will also display the value of carbon monoxide concentration and the keypad value from the input.

3.3. *Execution of devices in mining sectors*

The project was designed to be implemented as a real-life application in the mining sector. To ensure a wider coverage, the carbon monoxide sensor is placed at different locations and levels within the mining operations. As a next step, the sensors are connected to the embedded system, which is fixated at the central database for data analysis and interpretation. LEDs are replaced with white light and built along the mining routes. LDR are fixated onto the workers' helmets to ease the detection of light. The data will be displayed on a wrist band worn by the workers which comes with an alarm that produces sound and notifies the workers if the concentration of carbon monoxide exceeds the threshold value. Besides, any important announcements that need to be transmitted to deeper underground levels can be done by pressing the numbers on the keypad from 1-9 at the transmitter side which will be received by all workers immediately.

3.4. *Monitoring*

It is important to regularly monitor the device because various environmental factors can impact the accuracy of the MQ-7 sensor. Factors such as temperature fluctuations, humidity levels, air quality variations, and other conditions specific to the mining sector can all affect the performance of the sensor. Performing regular maintenance and calibration on the device is necessary to ensure that it provides dependable and precise readings. This not only ensures the safety of workers but also enhances the overall effectiveness of the monitoring system. By staying vigilant and keeping the device in optimal condition, potential risks can be identified promptly, allowing for timely interventions and measures to protect the well-being of the workers.In certain applications, lasers have become preferred over LEDs (Light-Emitting Diodes) due to their superior characteristics and capabilities. This shift is driven by several desirable features of lasers. One key advantage is their higher power output, which makes them suitable for tasks that require intense illumination or long-range visibility. Unlike LEDs, lasers can provide a more powerful and focused beam of light. Another benefit of lasers is their ability to operate at high speeds. This is due to their monochromatic nature, which allows for rapid and precise data transmission. The coherent and focused light of lasers enables efficient long-distance transmission, making them valuable in various applications, such as telecommunications and optical data systems. Furthermore, lasers tend to have fewer errors, resulting in more reliable and accurate performance. Their consistent output and stable characteristics contribute to improved reliability in different applications. Overall, the shift from LEDs to lasers is motivated by the higher power output, high-speed operation, efficient long-distance transmission, and enhanced reliability and accuracy that lasers offer. These advantages make lasers a preferred choice in specific applications where their unique capabilities are beneficial. The Li-Fi data transmission principle follows a designated flow as shown in Fig. 8 below.

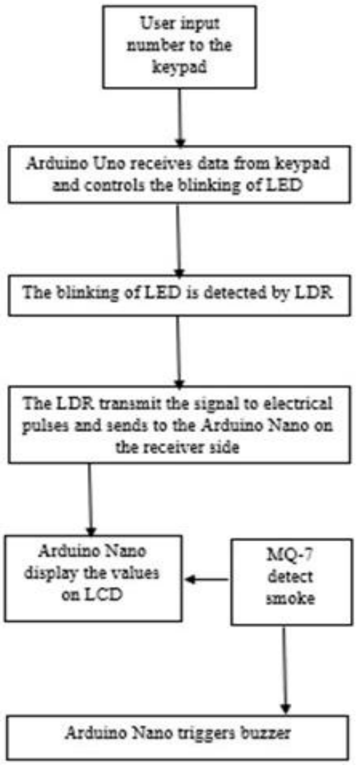

Fig. 8. Flow Chart of Data Transmission

4. Results

This section provides the details of our findings, aiming to provide a thorough analysis of the data collected. Our goal is to identify significant patterns or trends that emerged from the research and discuss their implications in relation to our research objectives. The results presented shed light on various aspects of the phenomenon we investigated, and they contribute to a deeper understanding of the topic. Moreover, we critically evaluated the results within the context of existing literature. By doing so, we draw connections between our findings and previous studies, identifying any discrepancies and offering valuable insights into the broader implications of our research. This critical evaluation helped us situate our work within the existing knowledge base and provides a foundation for future studies in the field.

Li-Fi is a cutting-edge communication that has the potential to be 100 times quicker than Wi-Fi and uses visible light sources to transmit data which acts as a communication medium. The photodiode serves as a receiver that receives the light signals, while an LED works as a light source. We can communicate specific data patterns by managing the light pulse on the transmitter side. The data is then transformed into meaningful information at the receiver side by the photodiode or Light-dependent resistor (LDR) [7].

As depicted in Fig. 9 the hardware setup of data transmission via Li-Fi has the following steps; when the numbers on the keypad are pressed, the LED lights up. As the numbers in the keypad goes higher, the intensity of light also increases. LDR at the receiver side detects the change in light intensity and sends the signal to a Arduino Nano which is connected to an LCD. The LCD module displays the number input in the keypad based on the difference in light intensity detected by LDR. Different time delays were set for the LED to remain at the ‘on’ state as shown in Fig. 10. For instance, when the user inputs the number ‘2’ from the keypad, the LED lights up dimly and only for a short amount of time. The LCD module display the number ‘2’ at receiver side as shown in Fig. 11. If the user input the number ‘8’, then the LED lights up with much brighter intensity and remains ‘on’ for a longer time compared to the first number. This is because an increase in incident light's intensity translates into an increase in photon content. When the quantity of incident photons rises, more photo-electrons are also released, which raises the photoelectric current.

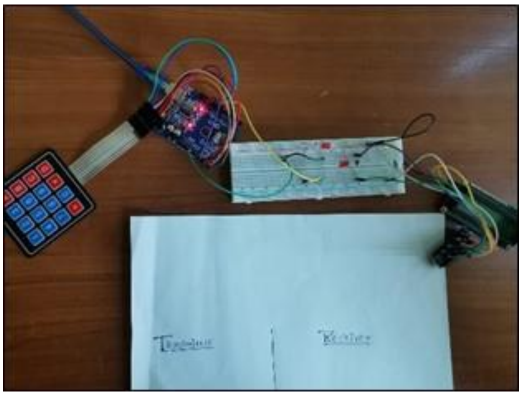

Fig. 9. Hardware Setup of Data Transmission via Li-Fi

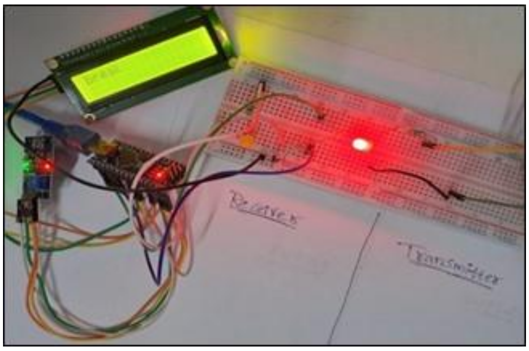

Fig. 10. Data Transmission via LED to LDR when Keypad is Pressed

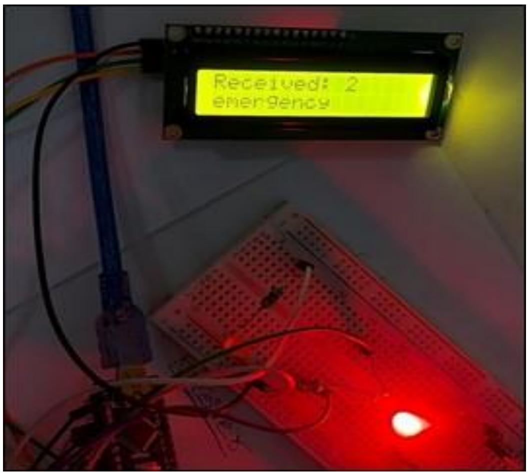

Fig. 11. Input Data Displayed on LCD Screen

Carbon monoxide sensor, MQ-7 is used at receiver side to detect the concentration of this particular gas emitted in the surroundings. This sensor has a small heater inside with an electrochemical sensor to measure different gas combinations. The working principle of MQ-7 depends on a chemiresistor which has free electrons. These free electrons are attracted to the oxygen molecules and push them to the surface of the chemiresistor. This prevents the free electrons from conducting current which helps in the detection of CO [8]. As the gas concentration increases, so does the sensor's conductivity. The sensor may be used to determine which gases contain carbon monoxide and protects coal miners' health by triggering a buzzer when a threshold value is surpassed.

The keypad serves as input for Li-Fi communications at the transmitter portion. This implies that the keypad will be used to select the text to be conveyed. The control unit, Arduino Uno, processes the input and transforms the data into binary pulses that can be transmitted via an LED source. The LED light uses these data to transmit pulses of visible light to the receiver side. The LDR sensor in the reception part absorbs visible light pulses and turns them into comprehensible electrical pulses that are fed to the Arduino Nano (control unit) which transforms it into data and displays it on a 16x2 LCD screen.

5. Future Work

The future work on advancing Li-Fi communication in mining holds great promise for improving safety and operational efficiency in the industry. To further this progress, several key areas should be explored such as optimizing the design and deployment strategies of Li-Fi systems specifically tailored to the unique challenges of mining environments. The present work focuses mainly on unidirectional data transmission. However, it can be improved further by using another LDR at the transmitter module and LED at the receiver side which will light up when the buzzer is triggered. With this, the Li-Fi system can now be bi-directional. In the bidirectional communication system, each microcontroller acts as a transmitter and receiver simultaneously. Considering this case, the user at transmitter module (coal miners working closer to surface ground) can send data to the user at receiver module (deep underground) and vice versa.

6. Conclusion

Li-Fi has evolved into a ubiquitous system technology that has a wide range of applications. Due to its abundance of advantages, Li-Fi is capable of improving safety in many industries especially in coal mining sectors. This paper proposed a method of incorporating such technology to help in efficient monitoring and data transmission which reduce life risks of the coal miners. Carbon monoxide is the prime focus among all other risk factors because it is highly poisonous and can cause death in extreme cases. Li-Fi technology enables coal miners to understand about the condition of environment at high reliability. It is also cost effective compared to Wi-Fi because it offers significant savings in the long run. However, since the technology is still new and under development, various research and development methods have to be conducted to ensure that Li-Fi can meet the demand for connectivity. In summary, Li-Fi, a versatile system technology with a wide range of applications, has emerged as a promising solution for enhancing safety in a variety of industries, particularly in the coal mining sector. This study proposes a method for integrating Li-Fi technology to facilitate efficient monitoring and data transmission, thereby reducing the risks faced by coal miners. Among the various risk factors, the focus is primarily on carbon monoxide, a highly toxic gas that can be fatal in extreme cases. By utilizing Li-Fi technology, coal miners can obtain reliable information about the environmental conditions, enabling them to take necessary precautions. Moreover, Li-Fi proves to be a cost-effective alternative to Wi-Fi, offering significant long-term savings. However, as Li-Fi technology is still in its nascent stages of development, further research and development efforts are required to ensure that it can meet the growing demand for connectivity in coal mining and other industries.

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Authors Introduction

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