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Original Article

Application of Light Fidelity in Underground Mines: An Opportunity to Overcome Communication Hurdles

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Abstract - *This paper describes the design, development, and testing of a high-speed, economical, and efficient wireless text data transmission system through Visible Light Communication (VLC), also known as Light Fidelity, for underground metal mines. It deals with the importance of a stable communication system for underground situations, where Radio Frequency communication systems are limited. The proposed work consists of the design, fabrication, and analysis of a Light Fidelity communication system setup, coupled with Arduino microcontrollers. The simulation test is performed through Proteus ISIS software for the validation of circuit designs. Voltage versus Distance analysis demonstrates the system's effectiveness, as the data transmission is observed without distortion up to a certain voltage threshold. The study concludes that Li-Fi may offer a promising solution for enhancing communication and resolving line of sight problem in underground mines, using existing LED (Light Emitting Diode) lighting infrastructure for transmission. In this study, the analysis of the distance vs. voltage depicted that when a minimum 25% of the input voltage from the transmitter end is received at the receiver's end, then the data transfer occurs without any distortion.*

Keyword - *Li-Fi, Transmitter-Receiver, Underground metal mines, Voltage- Distance analysis.*

1. Introduction

In underground mines, it has often been observed that proper communication has always been a vital issue [1]. In underground metal mines, effective communication is crucial for both safe operation and productivity reasons. To align with the demands of the business environment and the lifestyles of miners, the transmission process must handle the required volume and velocity of data transmitted through the communication medium. Most of the accidents that occur in a mine can be efficiently dealt with minimum damage if the communications with the surface emergency services and the other subsequent mine workplaces always remain functional [1, 2]. It is generally observed that the present-day radio frequency-based communication systems have suffered from various underground mine environments and structural parameters and have failed to provide optimum outcomes.

These waves have always been prey to distortion due to frequently changing line of sight, deposition of dust on sensor surfaces and circuit failure due to high temperature, excessive humidity and seepage of water from mine walls, etc. [3-5]. Communicating data effectively through radio waves becomes problematic in the depths of underground mines due to the irregular propagation of data and the restricted frequency range of 3 kHz to 300 GHz [6, 7]. In this context, a more mine environment-friendly, perfect, and versatile system for data communication in underground mines is required to be developed. Visible Light Communication (VLC), comprising long-distance laser and Light Fidelity (Li-Fi) technology, may prove to be a replacement for the conventional radio frequency-based communication system. Li-Fi is a technical innovation interrelated to the transmission of signal (data) for the sake of data transmission using the very fast on-off property of LED lighting devices. This appears straightforward since significant data volumes can be transmitted at exceptionally high rates through visible light communication. The Li-Fi procedure can theoretically achieve speeds of up to 01 giga-byte per second [6-10].

The major focus of the proposed approach is to increase the efficiency of the data transfer between the surface base and the underground station [11, 12]. Currently, the Wi-Fi technology is being utilized for the information exchange in combination with the delay, which results in speed issues with the data, as well as the loss of information being transferred. The above problem will be addressed with the aid of the proposed solution. In this system, the working process is the same as Wi-Fi but uses the light wave from the lighting system in the underground mine instead of radio waves, whose power consumption is also very low [13-15]. The VLC system consists of the Li-Fi circuit driver that receives signals from the base station in the form of light. The device contains a photo detector that receives the light signal to send the signals to the monitoring part of the underground metal mine. By using the Li-Fi method, the transferring speed of the information can be improved to the monitoring sections. Worldwide, there are around a few billion light bulbs used in mines; they need to be replaced with LED ones that transmit data. VLC, being ten times more cost-effective than Wi-Fi, utilizes light instead of radiofrequency signals. This characteristic makes it suitable for various applications such as aircraft, medical devices, and hospital environments where Wi-Fi usage is restricted. Moreover, VLC can operate underwater, where Wi-Fi signals are ineffective [16]. The advantages of the proposed VLC comprising Li-Fi system over the current underground Wi-Fi network system are illustrated below:

- Security: The wireless signals are openly broadcast in the air and can easily be picked up by other people, which makes them more accessible to hackers compared to wired networks. Without adequate security measures, wireless networks are more at risk than others. Interference from neighboring networks, also known as “network congestion,” is a common occurrence in daily situations, considerably influencing both the speed and dependability of wireless connections.
- Roaming Switch: While creating a wireless LAN, lots of access points are placed in order to increase the coverage area. While the user is moving inside the LAN, the device has to switch from one access point to another. The traditional switching process, in the context of Wi-Fi networks, is known as the “cut first, then connect” process. This will ensure that while switching, the device cuts the connection from the existing access point before initiating the switching process. The process will cause more than 300 ms of delays.
- Stability: The openness of the wireless channel makes wireless networks vulnerable to disruption from other signals nearby, causing instability in Wi-Fi signals and subsequently affecting service quality. Stability is bolstered through measures taken during processing and in specific locations. Key factors influencing wireless network stability include microwaves operating above 2.4GHz, cordless phones, and mutual interference among WLAN networks.
- Adverse effect during blasting: The existing Wi-Fi system uses components that are prone to damage during blasting, but in Li-Fi, we will use the existing LED light systems, and the other components that will be used are very compact and cheap, so it is a better option in case of dealing with the adverse effects of blasting.
- Cost parameters: Components of Li-Fi are cheaper than those of Wi-Fi.

Using Li-Fi Technology will provide a solution to all these problems explained above, especially security, because Li-Fi will work on the light propagation principle, and so when there is no light or opaque medium between two structures, there will not be any security issues [8, 13, 17, 18]. Comprehensive literature reviews also depicted a few success stories relating to the application of Li-Fi technology in different scenarios. Petrosino et.al. [23] reviewed a number of technical papers and found that the Li-Fi technology has been deliberately used to upgrade the IoT applications, achieving energy efficiency and design the indoor and outdoor communications. Various researchers affirmed that the Li-Fi technology can be successfully implemented in different IoT applications due to numerous traffic features [24], elevated energy efficiency [25], improved security system [26, 27], huge bandwidth [26, 28], low-cost mechanisms [28], isolated electromagnetic interference [25-27, 29] and proficiency of accommodating a large number of IoT nodes [24, 27]. Researchers [30, 31-33] also found that the integration of Li-Fi and RF can fulfill future IoT requirements. Different inventors and authors [33-36] have proposed solutions relating to achieving energy efficiency through Li-Fi in IoT scenarios. Besides this, studies and experimentations have been conducted by several researchers to establish outdoor communication systems [37, 38] and indoor communication systems [34, 39, 40] using Li-Fi networks. They explored the enormous possibility of modernizing indoor and outdoor communication systems by using Li-Fi technology. It is also found that a combination of hybrid RF (Radio Frequency) and Li-Fi networks may be more prolific for establishing the communication system in large underground mines and longer tunnels, as RF provides extensive coverage, while Li-Fi guarantees high data transmission rates. Again, RF and Li-Fi can work together without interfering with each other [21, 41]. As the underground mine communication system can be perceived as a sequential combination of outdoor and indoor communication systems, Li-Fi is expected to be very useful for establishing a failsafe and effective communication system.

The present study illustrates the preliminary experimental phase of developing a high-speed, failsafe and low-cost wireless data transmission system using VLC comprising Li-Fi for underground metal mines, tunnels, and other underground/similar facilities where RF is generally obstructed. The prime objective of this study is to utilize the existing underground mine illumination system for establishing an effective communication system and eliminating the problems relating to line of sight observed during the testing of the Wi-Fi system, due to frequent turning of mine roadways. Apart from the superior technical feasibility, the use of Li-Fi will reduce the cost of Wi-Fi installation and maintenance. Again, the study is expected to address the United Nations’ Sustainable Development Goal (SDG9) describing the essence of ‘Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation’ [42]. As the Indian underground mines have statutory restrictions regarding the usage of voltage, the voltage vs. distance analysis is considered to be the most essential prerequisite of the study.

Analysis of the distance between the transmitter and the receiver and the voltage received in the receiver circuit has been conducted to find out the threshold voltage for uninterrupted data transmission at the optimum distance**.**

2. Methodology

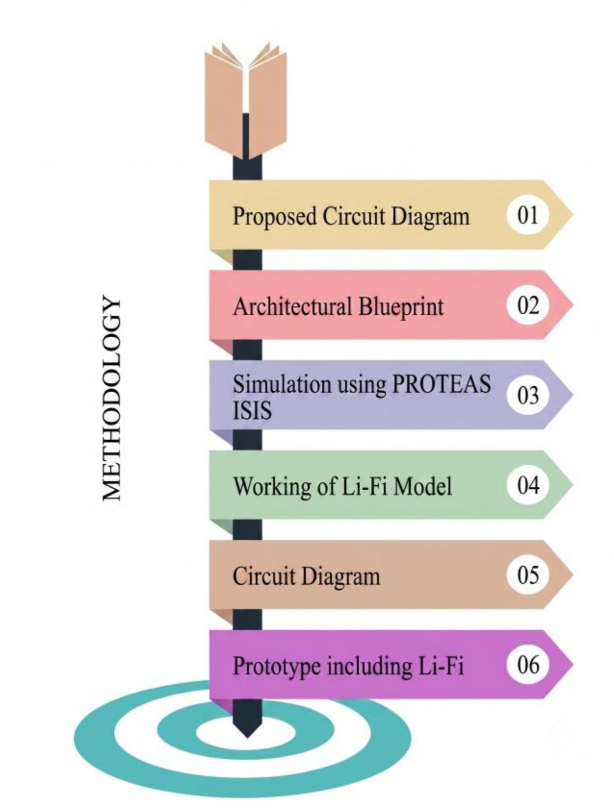

Fig. 1 Flow chart of methodology

A comprehensive literature review was conducted prior to designing the Li-Fi module for developing the communication system for underground wireless communication. Figure 1 illustrates the different steps and workflow pattern for developing a targeted Li-Fi module. At the beginning, a detailed functional analysis of the literatures were done to establish the practicability of the Li-Fi system over Wi-Fi application. Then, after*,* the technical analysis of the literature was conducted to hypothesize the architectural blueprint wherein the proposed circuit diagrams and the components to be used in the circuit were identified and finalized. The specifications of the components were determined by laboratory trials, and fabrication of the model was initiated. The necessary coding has been done to burn the code into the module. The working module was tested in the laboratory and mine after the module was ready. Major steps associated with module development, laboratory testing and field experimentation are described below.

2.1. Proposed Circuit Diagram

Various researchers [19-22] have used different Li-Fi circuit arrangements during their investigations. Taking input from their studies, the proposed circuit diagram has been designed and shown in Figure 2.

In the *Transmitter section,* binary data from a PC is transmitted to an Arduino Uno through port 0 (RXD) with a 01 kΩ resistor in line. This data is then fed into the base of a BC547 transistor (Q1). The emitter of the transistor is grounded, while the collector is connected to a reverse-biased LED diode in series with a 100 Ω resistor. The circuit operates at either 05V or 12V, ensuring appropriate current limiting and voltage regulation for the LED.

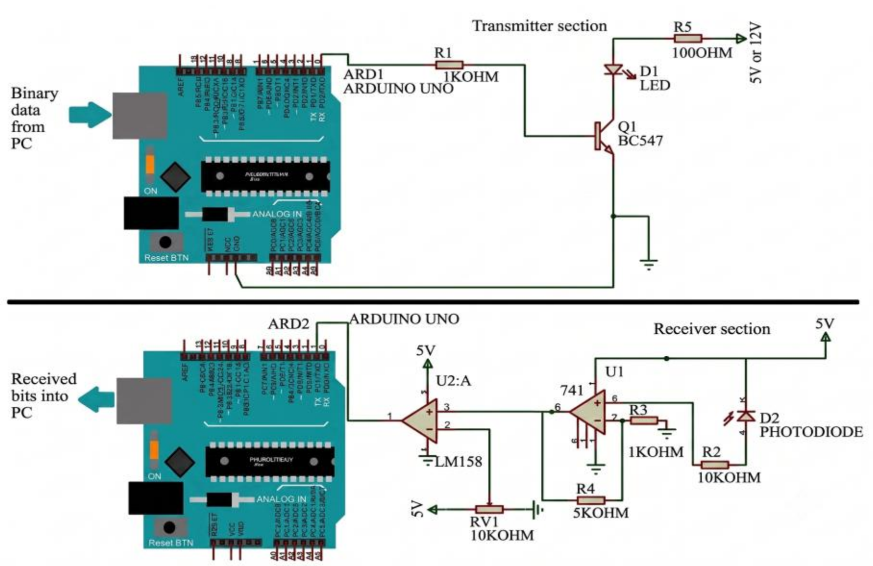

Fig. 2 Proposed circuit diagram [22]

Further in the *Receiver section* involving buffer U1 (741), one input is connected to a 05V supply through a photodiode and a 10 kΩ resistor in series, while the other input is grounded via a 01 kΩ resistor. Additionally, a 05 kΩ resistor links the negative input terminal to the output of the same buffer. The output of buffer U1 is then fed into the positive input of another buffer, U2: A. The negative input of U2: A is grounded through a 10 kΩ resistor, and the buffer is earthed using an LM158. The output from buffer U2: A is subsequently connected to port 1 of the Arduino Uno (ARD2), enabling the transmission of bits/signals to the PC.

2.2. Architectural Blueprint and Work Plan

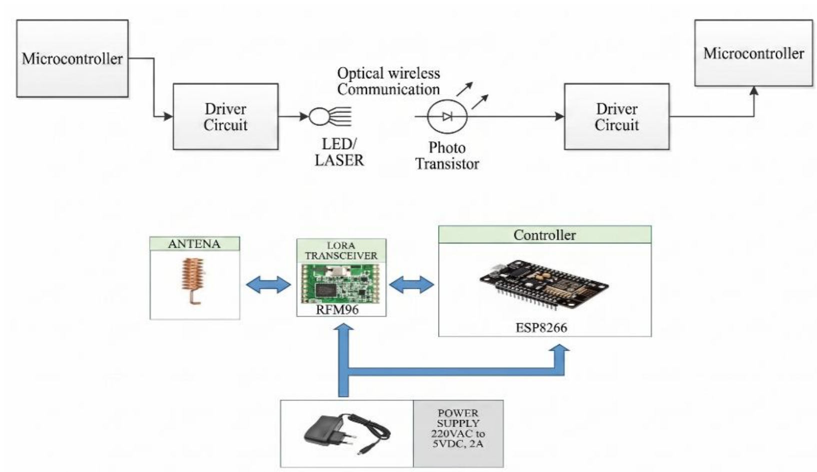

Fig. 3 Work plan [19-22]

In this optical wireless communication system, the microcontroller starts the process by sending signals to a driver circuit. The driver circuit further modulates these signals and sends them to an LED or a laser. The optical signals transmitted through the LED or laser travel in free space and are received by a photon transistor. The role of this photon transistor is that of an optical-to-electrical signal converter. It converts the optical signals into electrical signals, which are further sent into a driver circuit where the signals are processed and sent to a secondary microcontroller. This seamless integration of components enables efficient and reliable wireless communication between microcontrollers, facilitated by optical signals. The composite work plan, i.e. the representation of how the circuit will work, is shown in Figure 3.

2.3. Simulation using PROTEAS ISIS

PROTEAS ISIS is an embedded system software and a hardware design simulation platform. Before the fabrication was done, a simulation of the entire model was done in PROTEAS ISIS. The module will comprise two units like transmitter unit and a receiver unit. The transmitter unit will have BJT (Bipolar Junction Transistors), and the receiver circuit consists of an OP-AMP. The transmitter circuit and the receiver circuits, as designed by using the PROTEAS ISIS software, are shown in Figures 4 and 5, respectively.

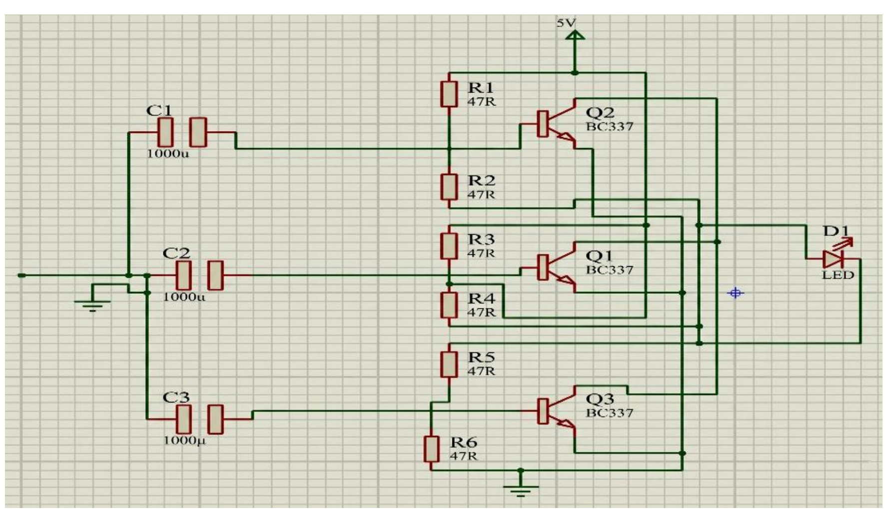

Fig. 4 Transmitter circuit using PROTEAS ISIS[19-22]

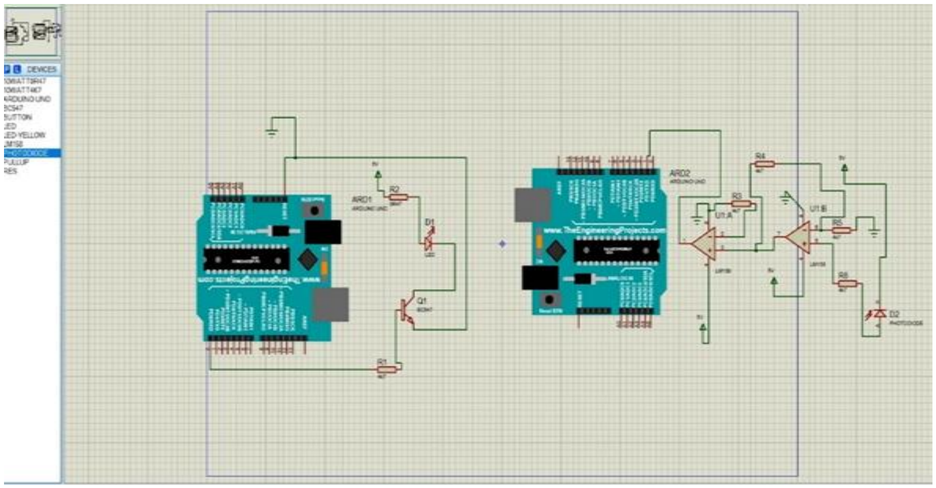

Fig. 5 Transmitter and receiver circuit of Li-Fi[19-22]

3. Designed Li-Fi Model

The designed Li-Fi Module has two circuits, a transmitter circuit and a receiver circuit. The components would be connected to the Arduino microprocessor as shown in Figures 6 and 7. Then, using Arduino IDE, the code for the circuit and components would be written. The major steps here are to convert the hexadecimal data input of Arduino into binary data, use light for the transmission via binary data and then again convert the binary data to the hexadecimal data. The transmission of data is based on the fluctuating property of the LED/Light.

3.1. Circuit Diagram

The final circuit that was to be made using the components described and by taking references from the PROTEAS ISIS circuit designs had the transmitter and receiver circuit design as shown in the Figure 6 and 7.

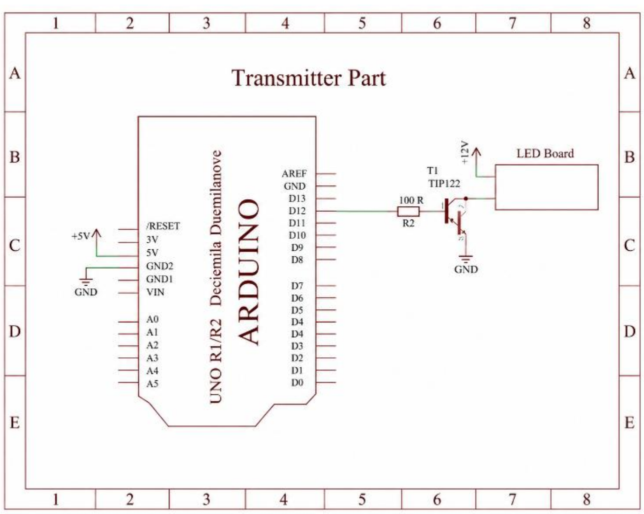

Fig. 6 Transmitter circuit diagram

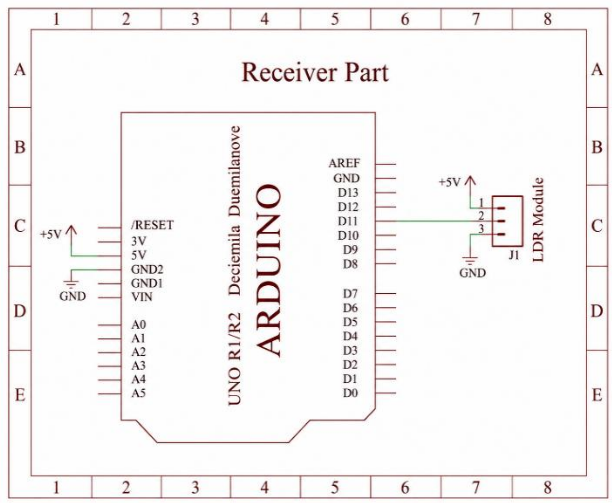

Fig. 7 Receiver circuit diagram

3.2. Prototype including Li-Fi

The pictures of the prototype models that were fabricated using the circuit as shown in the circuit diagrams, Figures 6 and 7, are shown in Figures 8 and 9.

Fig. 8 Receiver circuit

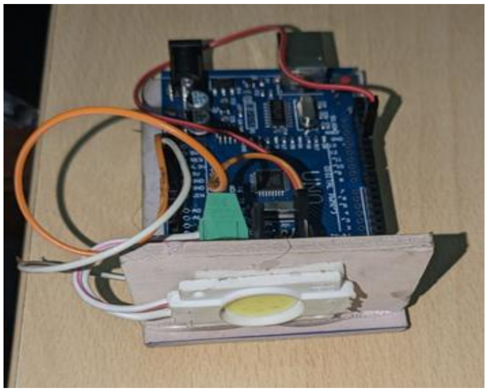

Fig. 9 Transmitter circuit

The designed VLC system prototype, based on Li-Fi, showcases the capabilities of its transmitter and receiver circuits in facilitating fast and secure wireless data transfer. The transmitter circuit, consisting of a microcontroller and a driver, efficiently modulates the data into the LED light signal, and the receiver circuit, with the photodetector and the photon transistor, flawlessly receives and converts the light signal into an electrical signal. Both these circuits are designed to provide optimal performance with increased bandwidth, security, and reduced electromagnetic interference, unlike RF communication.

4. Voltage vs. Distance Analysis

4.1. Experimentation on Voltage vs. Distance

A voltage of 12V is supplied to the LED by an external power source, and this is received by the solar cell. When the solar cell receives 12V voltage, it is stepped down to 5.5V in the receiver circuit because the capacity of the Arduino board used in the prototype is 5.5V – 6V. So, an analysis was conducted with respect to the distance and the amount of voltage received in the receiver's circuit. (Table 1) Moreover, a graph was plotted between the distance and the voltage received (Figure 10).

It was observed that the data transmission occurred without any distortion till the distance of 65cm, i.e. when the voltage received by the receiver's circuit was 2.99V. Now the supply voltage was around 12V, and the data transmission occurred until 2.99V was received by the receiver's circuit. So, the percentage of voltage of the original supply voltage received by the receiver's circuit until which data transmission occurs = 2.99V/12V*100% = 25% (Approximately). So, it can be perceived that till 25% of the original supply voltage is received by the receiver's circuit, the data transfer will occur efficiently.

In future, the effect of the intensity of light on the data transmission efficacy of the Li-Fi module will be tested to determine the threshold of the intensity of the LED. The study will further investigate the actual illumination status of the mine through an illumination survey. By acquiring and analyzing the data from these experiments, an appropriate type of Li-Fi system for long-distance transmission of data in a mine environment will be fabricated and tested for implementation.

4.2. Linear Regression Analysis determination in MATLAB software

In this experiment, Distance (cm) has been taken as the independent variable and Voltage received (V) was considered as the dependent variable. The data set shown in Table 1 has been used for linear regression analysis (using MATLAB software), and a polynomial fit of 2nd degree was obtained. The outcome of linear regression analysis is depicted in Figure 10. The relation between Distance (cm) and Voltage (V) can be described from the obtained Equation (1).

$$V = 0.0004 \times D^2 - 0.0664 \times D + 5.4315 \tag{1}$$

Where V = Voltage Received (V) & D = Distance (cm)

It is found that the Voltage Received (V) and Distance (cm) are strongly correlated with an R^2 value of 0.978 and an adjusted R^2 value of 0.974, and an RMSE (Root Mean Square Error) value of 0.121. Therefore, it may be concluded that distance is a suitable predictor of the amount of voltage received in the receiver's circuit, and with the increase of distance, the voltage received also decreases, as is evident from the curve obtained in Figure 10 below.

Table 1. Showing distance and voltage received

Sl. No.	Distance (cm)	Voltage received (V)
1	5	5.3
2	10	4.86
3	15	4.44
4	20	4.07
5	25	3.9
6	30	3.78
7	35	3.62
8	40	3.49
9	45	3.31
10	50	3.22
11	55	3.11
12	60	3.07
13	65	2.99
14	70	2.81
15	75	2.62

4.2.1. Determination of the MAPE of the derived model

The Mean Absolute Percentage Error (MAPE) was derived for the above model. On determining MAPE, it was found that the MAPE is 2.96%, which means that the derived model from Equation (1), as aforementioned, is 97.04% accurate and can be used for the prediction of Voltage (V) received from Distance (cm).

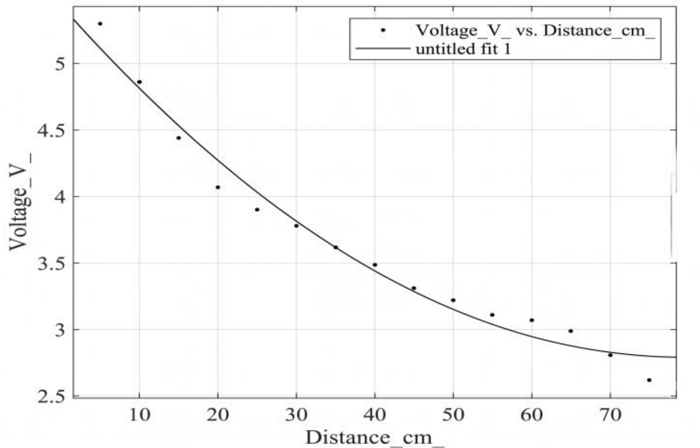

Fig. 10 Distance vs voltage received curve

5. Field investigation scheme

The capability of the designed Li-Fi module was tested in an underground hard rock mine. A cross-cut of length 10 m with turnings at both ends was chosen as the experimental zone (shown in Figure 11). A total of 13 designed Li-Fi modules were assembled end to end and 65 to 75 cm apart from each other to cover a 10 m distance, keeping transmitters and receivers in line. The transmission of text data was successfully achieved along with the negotiation of turnings.

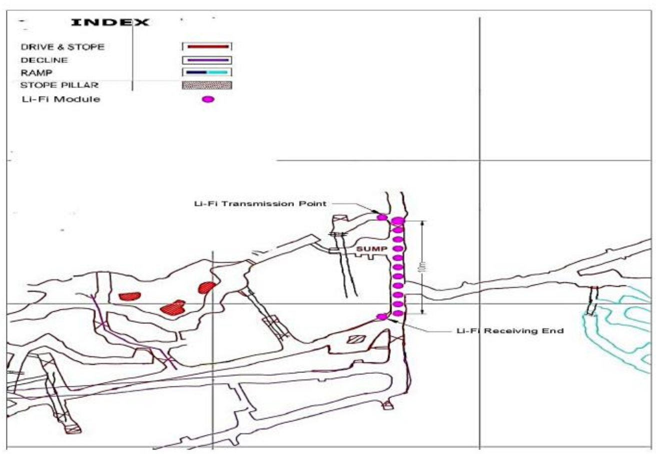

Fig. 11 Field experiment scheme of the Li-Fi module

6. Challenges, Limitations and Future scopes

Data transmission within the context of underground metal mining is beset with a host of external factors that pose considerable challenges. Geological complexity factors, such as the presence of solid rock formations, irregular tunneling, and existing mineral composition, may well hamper or weaken the signal transmission, especially within wireless communication networks. The presence of humidity, high temperature, and dust particulates within the underground environment further compounds these factors, thereby contributing to degradation within the electronic and signal devices. Electromagnetic interference caused by mining machinery, along with other equipment, is another factor that adds complexity, resulting in a weakened signal strength. Moreover, factors like water bodies, loose soil, or reactive materials in mines can affect signal conductivity. All these factors highlight an important requirement for robust communication technologies that can resist harsh conditions prevalent in mining sites. Uninterrupted data transmission critical for operational efficiency and safety.

There are various important factors related to the practical deployment of Li-Fi technology in underground mining that need thorough consideration in order to make a complete evaluation of its functionality. Firstly, the changes in the levels of lighting common in underground mining present a significant challenge. This is a result of the fact that the lighting systems used in underground mining are a mix of fixed lighting systems, like LEDs, and hand-carried lighting systems utilized by the miners. Apart from these issues, underground mining is marked by physical barriers in the form of rocky surfaces, mining equipment, and moving machinery.

This can result in the blocking of the line of sight, which is a requirement for the successful working of Li-Fi technology. Another crucial aspect, which needs thorough consideration with regard to the functionality of Li-Fi technology, is its integration with the mining communications system. Mines tend to incorporate the use of both wired, wireless, and hybrid communication solutions, developed in efforts to deal with the particular conditions brought about by underground environments. Incorporating Li-Fi communication into this setup would require careful consideration to ensure compatibility and interference-free communication with the current infrastructure. At the same time, the harsh conditions associated with the underground environment pose questions about the ability of the Li-Fi communication equipment to withstand these conditions effectively. To investigate the robustness of the designed module, the setup was kept for 02 weeks near a mine working face to see the effects of the said environmental parameters. The result of voltage distance analysis remained unchanged after two weeks, demonstrating the system's environmental adaptableness. These factors make it imperative to conduct an in-depth analysis and test the Li-Fi technology in an appropriate environment to understand its applications in the mining environment that takes place below the Earth's crust. This will ensure that different hurdles present in the mining environment are also addressed because, otherwise, the application or implementation of Li-Fi technology in a mining environment may seem very optimistic and unrealistic.

The study shown in this research may be considered as an initiation of Li-Fi technology implementation procedure in the Indian underground hard rock mining scenario. The study has revealed some promising attributes of the Li-Fi system with a few limitations, such as: (a) The study has been conducted by keeping the intensity of the LED constant in the transmitter section. A change in intensity can shed more light on the threshold data of transmission distance. (b) Instead of Arduino, other options like Zigbee and LoRa may be tested for data transmission. (c) The study has not investigated the working of the Li-Fi module using the actual illumination conditions of mine. By conducting experiments comprising the elimination of these limitations, an appropriate type of Li-Fi system for long-distance transmission of data in a mine environment may be developed and implemented effectively.

In the case of underground metal mining, there is no need to incorporate intrinsically safe and flame-proof properties in the designed Li-Fi module. In future, the designed module may be incorporated with such features and can be tested for possible applications in underground coal mines also. The Li-Fi system can be integrated with Wi-Fi and LASER etc., and the efficacy of the system may be tested for underground applications. Comprehensive research on the Li-Fi system can create a new communication environment underground, and the limitations of the Wi-Fi system can be overcome successfully.

7. Conclusion

With increasing advancements in the technological sector, it is now possible to establish a secure, cost-effective, and fail-safe communication system in the underground metal mines. Of the two available options, i.e. RF Data Transmission and VLC data transmission, the VLC data transmission system does seem to be a better option. The major advantage of the VLC data transmission system would be its cost-effectiveness and the ease of installation in the underground mines. This is because the normal use of ample LED lights in mines for maintaining the standard of illumination imposed by statutory bodies. To make the Li-Fi system working all that is required is to install transmission and receiver modules only. In this study, a VLC data transmission system using Li-Fi has been fabricated and tested, and the analysis of voltage and distance was also conducted. It can be concluded from this analysis that when using the Li-Fi module, the most important factor that contributes towards the data being transmitted without any distortion would be the voltage received in the receiver's circuit.

From the above experimentation, it has been observed that when the voltage received in the receiver's circuit is around 25 % of the voltage that is transmitted from the transmitter circuit, the data transfer occurs without any distortion. To be on the safer side, the authors recommend a buffer of +5 % and can assume this value to be 30% and then design the module accordingly. It will lead to the establishment of a secure communication system that will ensure the prevention of accidents and better management of the entire mine. This, in turn, will reflect in the production of the mine as the communication network will make sure that all the activities that happen across the mines are in line with one another and thus increase productivity.

Conflicts of interest

The authors are not connected with any conflicts of interest to disclose that are noteworthy to the considerations of this article. This is to confirm that the paper submitted by us is a result of our ingenious research. We have endorsed all the resources and research from which the concepts and designs have been introduced. The paper comprises no major replication of earlier academic works.

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Reference

[1] J.N. Murphy, and H.E. Parkinson, "Underground Mine Communications," *Proceedings of the IEEE*, vol 66, no. 1, pp 26-50, 1978. [CrossRef] [Google Scholar] [Publisher Link]

[2] Prasant Misra et al., "Safety Assurance and Rescue Communication Systems in High-Stress Environments: A Mining Case Study," *IEEE Communications Magazine*, vol. 48, no. 4, pp. 66-73, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[3] Alok Ranjan, H. Sahu, and H.B Sahu, "Communications Challenges in Underground Mines," *Communications*, vol. 5, no. 2, pp. 23-29, 2014. [Google Scholar]

[4] David P. McGraw, "*Analysis of Factors Affecting Wireless Communication Systems in Underground Coal Mines*," Graduate Theses, Dissertations, and Problem Reports, 1979. [CrossRef] [Google Scholar] [Publisher Link]

[5] Toni Besjedica et al., "Evolution of Hybrid LiFi–WiFi Networks: A Survey," *Sensors*, vol. 23, no. 9, pp. 1-28, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Anurag Sarkar, Shalabh Agarwal, and Asoke Nath, "Li-Fi Technology: Data Transmission through Visible Light," *International Journal of Advance Research in Computer Science and Management Studies*, vol. 3, no. 6, pp. 1-12, 2015. [Google Scholar]

[7] Siddhan Meshram, and Sangit Meshram, "Light Fidelity (Li-Fi): A Wireless Technology," *From the Editorial Director's Desk*, vol. 7, 2020. [Google Scholar]

[8] Ritesh Pathak, and G. Akilarasu, "Li-Fi based Data Transmission with Network Security," *International Journal of Innovative Science and Research Technology*, vol. 7, no. 1, pp. 622-626, 2022. [CrossRef] [Publisher Link]

[9] D. Ramananda et al., "Design and Implementation of LiFi Communication System," *IOP Conference Series: Materials Science and Engineering*, vol. 594, no. 1, pp. 1-7, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mohamed Sufyan Islim, and Harald Haas, "Modulation Techniques for Li-Fi," *ZTE Communications*, pp. 1-16, 2016. [Google Scholar] [Publisher Link]

[11] Sankalp Raghuvanshi, and Kalpana Singh, "Light Fidelity: The Future of Data Communication," *International Journal of Engineering Research and Technology*, vol. 9, no. 5, pp. 129-134, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Harald Haas et al., "What is LiFi?," *Journal of Lightwave Technology*, vol. 34, no. 6, pp. 1533-1544, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[13] Mehmet Fatih Isik, Busra Yartasi, and Mustafa Resit Haboglu, "Applicability of Li-Fi Technology for Industrial Automation Systems," *International Journal of Electronics and Electrical Engineering*, vol. 5, no. 1, pp. 21-25, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[14] Rozin Badeel et al., "A Review on LiFi Network Research: Open Issues, Applications and Future Directions," *Applied Sciences*, vol. 11, no. 23, pp. 1-35, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Sanjana Prasad et al., "Audio Transmission with Li-Fi Technology," *International Research Journal of Engineering and Technology (IRJET)*, vol. 9, no. 1, pp. 66-71, 2022. [Google Scholar] [Publisher Link]

[16] Arun Agarwal, Chandan Mohanta, and Gourav Misra, "Li-Fi Technology: Principle, Future Scope, Challenges and Applications," *American Journal of Electrical and Electronic Engineering*, vol. 10, no. 1, pp. 1-5, 2022. [CrossRef] [Publisher Link]

[17] Yujian Guo et al., "A Tutorial on Laser-based Lighting and Visible Light Communications: Device and Technology [Invited]," *Chinese Optics Letters*, vol. 17, no. 4, pp. 1-15, 2019. [Google Scholar] [Publisher Link]

[18] Yaseein Soubhi Hussein, and Amresh Chetty Annan, "LiFi Technology: High Data Transmission Securely," *Journal of Physics: Conference Series*, vol. 1228, no. 1, pp. 1-11, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[19] Hanaa Abumarshoud et al., "LiFi through Reconfigurable Intelligent Surfaces: A New Frontier for 6G?," *IEEE Vehicular Technology Magazine*, vol. 17, no. 1, pp. 37-46, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] Changmin Lee et al., "Advanced LiFi Technology: Laser Light," *Light-Emitting Devices, Materials, and Applications XXIV*, San Francisco, California, United States, vol. 11302, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[21] Mohammad Reza Ghaderi, "LiFi and Hybrid WiFi/LiFi Indoor Networking: From Theory to Practice," *Optical Switching and Networking*, vol. 47, pp. 1-24, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] E. Ifada et al., "Implementation of a Data Transmission System using LiFi Technology," *2019 2nd International Conference of the IEEE Nigeria Computer Chapter (NigeriaComputConf)*, Zaria, Nigeria, pp. 1-7, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[23] Antonio Petrosino et al., "Light Fidelity for Internet of Things: A Survey," *Optical Switching and Networking*, vol. 48, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[24] Ilker Demirkol et al., "Powering the Internet of Things through Light Communication," *IEEE Communications Magazine*, vol. 57, no. 6, pp. 107-113, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[25] J.R Dinesh Kumar et al., "An Experimental Analysis of LiFi and Deployment on Localization based Services and Smart Building," *2021 International Conference on Emerging Smart Computing and Informatics (ESCI)*, Pune, India, pp. 92-97 2021. [CrossRef] [Google Scholar] [Publisher Link]

[26] Mithileysh Sathiyanarayanan, Vignesh Govindraj, and Nandakishor Jahagirdar, "Challenges and Opportunities of Integrating Internet of Things (IoT) and Light Fidelity (LiFi)," *2017 3rd International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT)*, Tumkur, India, pp. 137-142, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[27] Pascal Lorenz, and Louiza Hamada, "LiFi Towards 5G: Concepts Challenges Applications in Telemedecine," *2020 Second International Conference on Embedded and Distributed Systems (EDiS)*, Oran, Algeria, pp. 123-127, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[28] Jaina Patel, Pranati Trivedi, and Drashti Patel, "A Performance Analysis of "Light Fidelity" and "Internet of Things" and it's Application," *2017 International Conference on Transforming Engineering Education (ICTEE)*, Pune, India, pp. 1-4, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[29] K.L. Bober et al., "A Flexible System Concept for LiFi in the Internet of Things," *2020 22nd International Conference on Transparent Optical Networks (ICTON)*, Bari, Italy, pp. 1-4, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[30] Sondos Alshami, "Performance Analysis of OFDMA, UFMC, and FBMC for Optical Wireless Communication," *2020 1st International Conference on Emerging Smart Technologies and Applications (eSmarTA)*, Sana'a, Yemen, pp. 1-4, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[31] Kanchan Tiwari Swami, and Asmita A. Moghe, "A Review of LiFi Technology," *2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE)*, Jaipur, India, pp. 1-5, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[32] Loreto Pescosolido, Emilio Ancillotti, and Andrea Passarella, "Performance Evaluation of Switching between WiFi and LiFi under a Common Virtual Network Interface," *2022 International Conference on Smart Computing (SMARTCOMP)*, Helsinki, Finland, pp. 275-280, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[33] Muhammad Asad, and Saad Qaisar, "Energy Efficient QoS-based Access Point Selection in Hybrid WiFi and LiFi IoT Networks," *IEEE Transactions on Green Communications and Networking*, vol. 6, no. 2, pp. 897-906, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[34] Dil Nashin Anwar, Rizwana Ahmad, and Anand Srivastava, "EnergyEfficient Coexistence of LiFi users and Light Enabled IoT Devices," *IEEE Transactions on Green Communications and Networking*, vol. 6, no. 2, pp. 930-950, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[35] Chen Chen et al., "NOMA for Energy-Efficient LiFi-Enabled Bidirectional IoT Communication," *IEEE Transactions on Communications*, vol. 69, no. 3, pp. 1693-1706, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[36] Iman Tavakkolnia et al., "Energy-Efficient Adaptive MIMO-VLC Technique for Indoor LiFi Applications," *2018 25th International Conference on Telecommunications (ICT)*, Saint-Malo, France, pp. 331-335, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[37] N. Partheeban et al., "An Improved Internet of Things Enabled Wireless Data Transmission using Visible Light Communication," *2022 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI)*, Chennai, India, pp. 1-7, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[38] Hamada Alshaer, Harald Haas, and Oluwatayo Y. Kolawole, "An Optimal Networked LiFi Access Point Slicing Scheme for Internet-of-Things," *2022 IEEE International Conference on Communications Workshops (ICC Workshops)*, Montreal, QC, Canada, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[39] Chirrareddy SaiSankeerth Reddy et al., "Appliance Automation using LiFi with MQTT in Hybrid Star and Tree Network Setup," *2018 International Conference on Research in Intelligent and Computing in Engineering (RICE)*, San Salvador, El Salvador, pp. 1-6, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[40] Ahmet Burak Ozyurt, and Wasiu O. Popoola, "LiFi-based D2D Communication in Industrial IoT," *IEEE Systems Journal*, vol. 17, no. 1, pp. 1591-1598, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[41] Tanya Verma et al., "Intelligent Resource Allocation in Hybrid RF/LiFi Networks Via Deep Deterministic Policy Gradient based DRL Mechanism," *AEU International Journal of Electronics and Communications*, vol. 187, pp. 1-8, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[42] SDG 9 and interlinkages with other SDGs – Industry, innovation and infrastructure, United Nations, 2026. [Online]. Available: https://hlpf.un.org/2026/programme/sdg-9-and-interlinkages-with-other-sdgs-industry-innovation-and-infrastructure