

# Performance Analysis of Underwater Communication Using Li-Fi Across different Water Qualities

Vrunda Kusanur, Priyadarshini K Desai \*, Hemanth T. M., Manjunath K. M., and Suhas Gowda H. B.

Department of Electronics and Communication Engineering, BNM Institute of Technology, Bangalore, India  
Email: vrundakusanur@bnmit.in (V.K.); priyadarshini.p.r@gmail.com (P.K.D.); tmhemanth0@gmail.com (H.T.M.);  
kmmanjunath993@gmail.com (M.K.M.); suhasgowda205@gmail.com (S. G.H.B.)

\*Corresponding author

**Abstract**—Underwater wireless communication is a fast-growing area with growing needs for high-speed, reliable data transmission, particularly in scientific, military, and environmental monitoring applications. Due to high attenuation and limited bandwidth, conventional methods such as Radio Frequency (RF) and acoustic communication are often unsuccessful in underwater environments. Li-Fi emerges as a promising alternative, offering high-speed, low-latency, and energy-efficient data transmission using visible light. In this study, the viability and effectiveness of Light Fidelity (Li-Fi), a novel Optical Wireless Communication (OWC) technique for underwater settings, are examined and offers a comprehensive analysis of the performance of Li-Fi communication in various water types that include clear/clean, turbid, and saltwater. The performance metrics considered for the evaluation of proposed model are received Signal strength, Signal-to-Noise Ratio (SNR) and bit rate. In the proposed work, the transmission distance is set to 47 cm, with the underwater depth maintained at 15 cm. Results show that Li-Fi performance is significantly impacted by water quality. The signal strength, SNR and data rate achieved for clear water is high in comparison to the salt water. The proposed prototype shows that Li-Fi technology can be one of the promising technology that can be used for underwater communication.

**Keywords**—light propagation, turbid water, clear water, saline water, Li Fi, underwater communication, optical wireless communication, water quality signal strength, bit rate, Signal-to-Noise Ratio (SNR)

## I. INTRODUCTION

In recent year, lot of research work has been carried out towards optical communication or light communication. It is observed that many applications such as deep-sea exploration, underwater robotics, military surveillance, environmental monitoring and disaster management involve wireless communication especially underwater communication. There are significant problems with

traditional communication methods such as Radio Frequency (RF) and acoustic communication in underwater environment. Although acoustic communication supports long-distance transmission it is limited by low data rate, high latency, and sensitivity to background noise. On the other hand, due to the high permittivity and conductivity of the water medium, especially in seawater, radio frequency communication experiences severe attenuation in underwater environments. Optical Wireless Communication (OWC) can be considered as an alternate and a feasible solution to overcome the shortcoming of acoustic and RF communication in underwater. Optical wireless communication basically uses visible light, infrared and ultraviolet light for communication. A Li-Fi technology is a specific type of visible light communication technology that basically uses high-speed LED modulation to transmit the data. In this research work, the performance analysis of Li-Fi module for under water communication is carried out considering clear, turbid, and saline water. The proposed work provides a prototype, that incorporate Li-Fi transmitter and receiver module at a distance of 47cm and depth of 15 cm. The proposed work also aims to identify optimal operating conditions and assess the suitability of Li-Fi for practical underwater applications. The paper is organized as follows; Section II provides the details of related work; Section III discusses about the methodology and experiment set-up of the proposed work, results and its discussion is provided in Section IV followed by conclusion of the proposed work.

## II. LITERATURE REVIEW

Underwater wireless communication is a growing area of research, particularly with the limitations of acoustic and RF-based technologies. Light Fidelity (Li-Fi), based on visible light communication, offers a promising alternative due to its high bandwidth, low latency, and energy efficiency. Arfan and Lakshminarayana [1] discussed the application of Li-Fi in transmitting audio signals underwater. The system employed LED-based transmission and photodiode-based reception, which was

found to be effective even when there is scattering and attenuation.

Li-Fi in military and industrial applications, with future scope for lasers and cameras to enhance it. Aman *et al.* [2] emphasized Li-Fi's superior bandwidth and data rate over traditional RF systems. Their prototype used LEDs and solar panels as transmitters and receivers, achieving effective audio communication underwater with minimal degradation. Venu and Kumar [3] implemented a Li-Fi system using Frequency Modulation (FM) and Pulse Width Modulation (PWM) to improve data security and efficiency in energy consumption. They found data recovery reliable in normal noise conditions but signal weakening under intense underwater noise. Mahakal *et al.* [4] suggested a Li-Fi system based on IoT that could transmit voice, audio, and text. Their system included Arduino-based hardware, and the authors highlighted the high speed, safety, and ability to create Li-Fi hotspots of the system. Rufo *et al.* [5] presented an underwater communication system implemented through Arduino microcontrollers and laser modules. Their research highlighted the fact that while Li-Fi is promising, at present it needs an unobstructed line of sight for effective functionality. Goh *et al.* [6] studied the effects of varying water qualities on Li-Fi communication. They illustrated how clear water allowed for fast communication, whereas muddy and salty water reduced efficiency, but data transmission was still feasible. Leba *et al.* [7] developed blue-green laser-based m-QAM-OFDM-based underwater communication. They achieved multi-Gbps data rate in short range, validating the suitability of UWOC for high-bandwidth applications. Ibhaze *et al.* [8] used software-defined radio to employ underwater optical communication based on LEDs and lasers. Their adaptable modulation strategy and use of low-cost equipment make their system versatile enough for different underwater environments. Authors found that although IR can perform well in short-range applications, turbidity and salinity have a very negative impact on its performance. Optimized wavelengths and sensitive receivers are essential for its success. The concept of Underwater Optical Wireless Communication (UOWC) is not new, but it has recently gained more attention because seawater has a smaller window for blue-green light absorption. Underwater optical wireless communications can provide larger data speeds at low latency levels than their acoustic and radio frequency counterparts because of its higher bandwidth. Goh *et al.* [9] designed a duplex underwater laser system based on 440 nm and 550 nm lasers. Their optimized modulation significantly reduced Bit Error Rate (BER) and demonstrated improved performance in turbulence and across long distances. Underwater optical wireless communication devices were examined by Krishna *et al.* [10] and concluded that data rate of Mbps-is possible, but in controlled environments, with optical links having strong potential for broadband submarine links. Spagnolo *et al.* [11] proposed it is intended for anyone interested in studying UOWC. It provides a summary of today's technology as well as those that might become available in the near future. Offering a

recent bibliography has received considerable attention, with a focus on the application of single-photon receivers.

Li *et al.* [12] employed a single directional point-to-point link with static arrangement in this study. This system uses only one avalanche photodiode with constant bandwidth. In this work, the experiments were restricted to a 1.5 m × 0.3 m × 0.3 m water tank. This work used an artificial seawater and a submerged pump to simulate flow.

In this study, Zhang and Zhou [13], it experiences major Inter-Symbol Interference (ISI) and jitter at high data rates, makes the reliable communication above 140 Mbps impossible without the use of equalization or error-correction methods because the system's total bandwidth is only 40.3 MHz. Daytime experiments suffered from background illumination, increasing the receiver's noise standard deviation from 1.335 mV (dark) to 3.2 mV (lit), which degrades link margin and BER performance. All experiments were confined to a maximum link length of 10 m due to pool size, with longer distances only assessed via Q-factor analysis. Testing occurred in a still, outdoor pool with permanent water quality and no dynamic currents or changing turbidity, Ref. [14] states that, Underwater Wireless Optical Communication (UWOC) is an economical for deep-sea data transmission because of its high bandwidth and low latency. This work reviewed the latest development in transceivers and signal processing techniques to construct long-distance UWOC structures. Authors also proposed an economical implementation structure for UWOC sea trials and states the first sea trial of a multi-hop UWOC system using this system. This study demonstrated blue-green Li-Fi over tens of meters in sea water, but don't separate different water types.

Mottaleb *et al.* [15] focused on coding schemes (ICSM) in green-spectrum links. This work used clear, de-ionized water to test multi-Gbps throughput, without turbidity or salinity variations in the experiments.

### III. METHODOLOGY AND EXPERIMENT SET-UP

#### A. Methodology

In this work, under water communication is established using Li-Fi technology. The flow chart in Fig. 1, briefs about the underwater communication through Li-Fi.

Initially, the message is sent by the user through microcontroller and LiFi transmitter. The microcontroller is connected to LCD, to display the transmitted information. The IR LED, carries the information in the form of light. The distance between transmitter and receiver module is taken to be 47 cm. If the LiFi receiver module detects or receives the information, the LCD displays the received information. The acknowledgement is sent to the sender for both the cases as "Message sent successful" or "Message failed". Further, performance analysis of LiFi communication link is carried out with different water quality, such as salt water, clean water and turbid water.

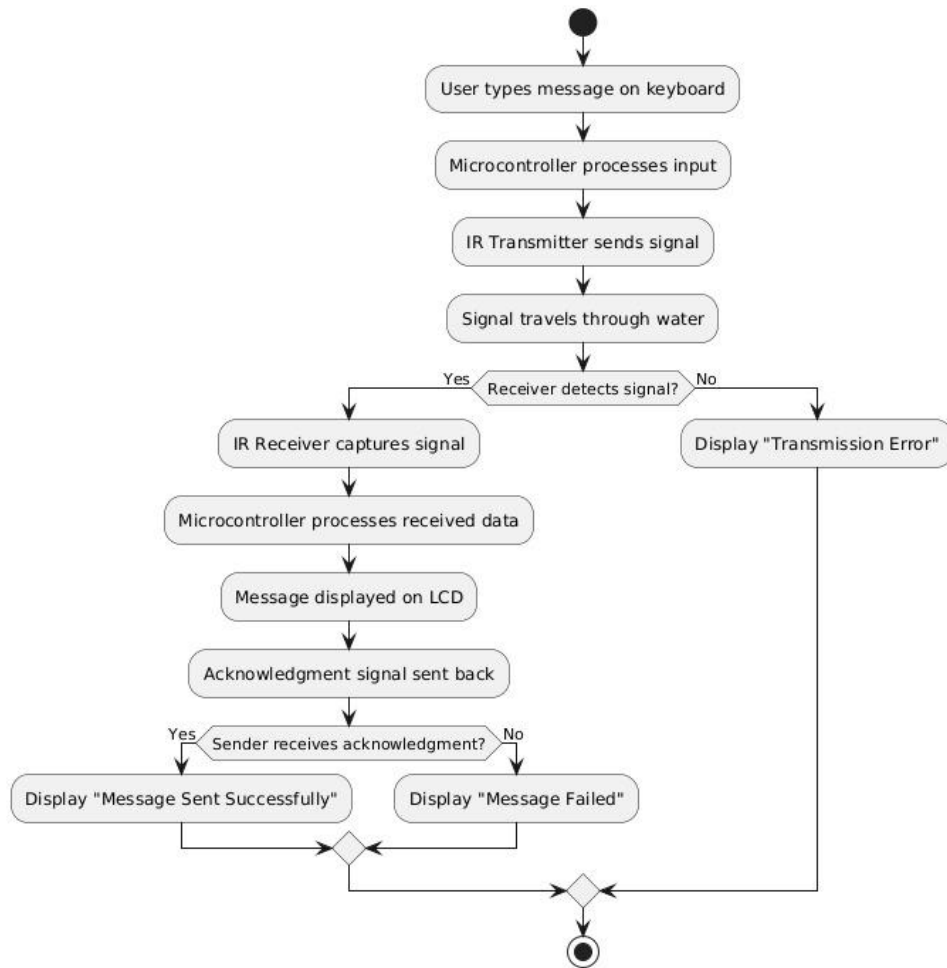


Fig. 1. Methodology of the proposed system.

**B. Experiment Set-up**

The experimental setup of the proposed system includes a transmitter and receiver units as shown in Figs. 2–3.

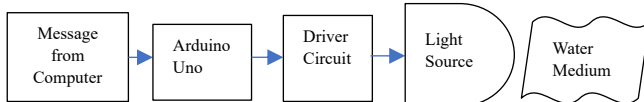


Fig. 2. Block diagram of transmitter module

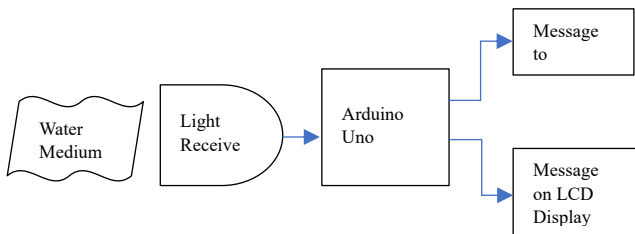


Fig. 3. Block diagram of receiver module.

Transmitter module basically converts the user input data into an appropriate optical signal. In this work, the LCD display is connected to the microcontroller to display the user message, through UART communication. The LiFi transmitter and receiver module used in this work is shown in the Fig. 4.



Fig. 4. LiFi Transmitter and receiver module.

At a fundamental level, LiFi systems consists of LED transmitters that use the intensity modulation to transform incoming electrical signals into information before sending them via an optical channel. The LED transmitter may create a LiFi Access Point (AP) by serving numerous users over the same optical channel and registering new users. Photodetectors (PD), which transform falling light into optical current, are a feature of the receivers. A Light Dependent Resistor (LDR) is used in this work as a photodetector to sense the incoming optical signals. The variation of the LDR value indicates the proper data detection.

The following empirical relation were used in this work to evaluate the signal strength, Signal-to-Noise ratio and Bit Rate.

C. Voltage Calculation

The voltage is measured across the LDR using the Eq. (1).

$$\text{Voltage}(V) = \frac{\text{LDR}(\text{ohm})}{1023} \times 5V \quad (1)$$

A reference voltage of 5V is used, and the Arduino Uno's 10-bit Analog-to-Digital Converter (ADC) converts analog input voltages ranging from 0 V to 5 V into corresponding digital values between 0 and 1023.

D. Signal Power

The received signal strength is measured using power-voltage relationship, given by Eq. (2).

$$P_{\text{signal}} = \frac{V^2}{R} \quad (2)$$

A 1 kΩ resistor is used in series with the LDR to form a voltage divider circuit, and this resistor value is maintained constant throughout the experiment.

E. Signal Strength in dB

The measured signal power is converted in dB using Eq. (3).

$$\text{Signal Strength (dB)} = 10 \log_{10} P_{\text{signal}} \quad (3)$$

F. Noise Signal Strength

In the proposed work, the no signal condition is considered for noise signal strength. The voltage measured across the LDR is 0.25 V and the corresponding power is calculated based on this value. The noise power is kept fixed, for the performance evaluation. The data rate is considered identical to the baud rate.

IV. RESULT AND DISCUSSION

Figs. 5(a) and 5(b) depict the experimental setup, which consists of a container measuring 50 cm × 30 cm × 15 cm.

The LED and detector are placed at a distance of 47 cm as shown in the Fig. 5(b). The LCD display units are placed at the transmitter end and receiver end as shown in Fig. 5(c) to display the transmitted data and received data.

The depth for underwater communication is set as 15 cm in this work. Performance metrics for Li-Fi are measured under different water types.



(b)



(c)

Fig. 5. Experimental Setup, (a). Hardware Assembly of the proposed work; (b). Underwater Li-Fi communication; (c): Li-Fi transmitter and receiver units with LCD displays.

The proposed Li-Fi underwater communication system is comprising of a transmitter and receiver unit. The transmitter includes an Arduino Uno that processes user input and generates a modulated optical signal using an LED. These optical signals travel through water and are collected by a photodiode in the receiver module, which transforms light into electrical form. Another Arduino Uno decodes the amplified and filtered signal. The final output showed via an LCD or computer interface. The setup is driven by 9V batteries and verified in clear, turbid, and saline water to assess the performance of the signal under different underwater environments.

The layout ensures easy observation and debugging of the circuit during testing. The following section presents the experimental results obtained in different environments.

A. In Clear Water

Fig. 6 and Fig. 7 illustrate the output parameters for Li-Fi communication tested in clear water conditions.

```
Enable LDR Value Received
Raw LDR Data: 658
LDR Value: 658, Voltage: 3.22 V
Signal Strength -19.85 dBm
SNR: 24.13 dB
Bit Rate: 4800 bps
```

Fig. 6. Output parameters for Li-Fi communication in clear water.



(a)

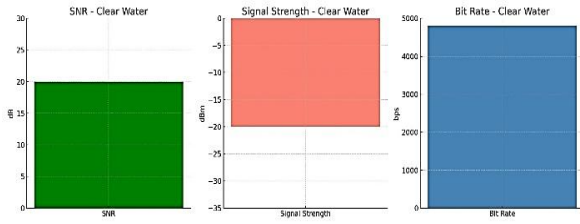


Fig. 7. Graphical representation of output parameters for Li-Fi communication in clear water conditions.

The raw Light Dependent Resistor (LDR) data received is 658 with a corresponding voltage of 3.22V, indicating efficient light signal detection. The signal strength is measured at  $-19.85$  dBm, while the Signal-to-Noise Ratio (SNR) stands at 24.13 dB, reflecting a relatively clean signal with low interference. The bit rate attained during this test is 4800 bps, demonstrating effective data transmission in clear water.

The graphical representation of output parameters for Li-Fi communication in clear water conditions as shown in Fig. 7 demonstrates the system’s performance in a low-attenuation environment. The bar graph illustrates key metrics such as signal strength, Signal-to-Noise Ratio (SNR), and bit rate.

**B. In Turbid Water**

Fig. 8 and Fig. 9 present the output parameters of Li-Fi communication in turbid water conditions.

```

Enable LDR Value Received
Raw LDR Data:412
LDR Value: 412, Voltage:2.01 V
Signal Strength -32.40 dBm
SNR: 13.28 dB
Bit Rate:2400 bps
    
```

Fig. 8. Output parameters for Li-Fi communication in turbid water.

The LDR value recorded is 412 with a voltage of 2.01 V, indicates reduced light intensity due to water turbidity. Signal strength drops significantly to  $-32.40$  dBm, and the Signal-to-Noise Ratio (SNR) is reduced to 13.28 dB, showing higher interference and lower signal clarity.

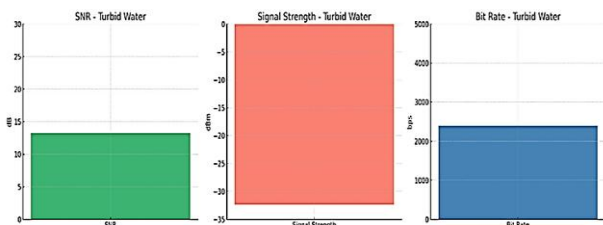


Fig. 9. Graphical representation of output parameters for Li-Fi communication in turbid water conditions.

Consequently, the bit rate drops to 2400 bps, affecting the overall data transmission efficiency. The bar graphs in Fig. 9 demonstrates the drop in SNR, signal strength, and bit rate.

**C. In Saline Water**

Fig. 10 and Fig. 11 depict the output parameters of Li-Fi communication in saline water conditions.

```

Enable LDR Value Received
Raw LDR Data: 531
LDR Value: 531, Voltage:2.60 V
Signal Strength -26.75 dBm
SNR: 17.90 dB
Bit Rate:3200 bps
    
```

Fig. 10. Output parameters for Li-Fi communication in saline water.

The LDR value recorded is 531 with a voltage of 2.60 V, indicating better light reception compared to turbid water. The signal strength is measured at  $-26.75$  dBm, showing an improvement in transmission power.

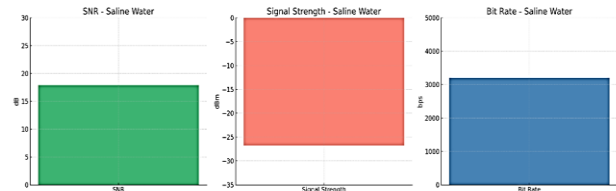


Fig. 11. Graphical representation of output parameters for Li-Fi communication in saline water conditions.

The Signal-to-Noise Ratio (SNR) is 17.90 dB, suggesting reduced interference and clearer signal quality. As a result, the bit rate increases to 3200 bps, enhancing the overall data transmission efficiency. The bar graph in Fig.11 demonstrates the improved SNR, signal strength, and bit rate in saline water.

Fig. 12 presents comparison of Li-Fi performance metrics include SNR, signal strength, and bit rate across clear, saline, and turbid water environments. Clear water exhibits the best performance, with the highest SNR (24.13 dB), strongest signal strength ( $-19.85$  dBm), and maximum bit rate (4800 bps). Saline water shows moderate degradation in all parameters due to dissolved salts causing light scattering. Turbid water demonstrates the lowest performance, with poor SNR (13.28 dB) and minimal bit rate (2400 bps) as a result of suspended particles obstructing light transmission. This graphical analysis highlights how water quality directly impacts Li-Fi communication efficiency.

From Table I, it is evident that clear water allows optimal signal propagation with minimal attenuation and high data throughput, whereas saline water exhibits moderate degradation due to ionic content and turbid water causes the severe scattering, resulting in the lowest SNR and bit rate.

The results presented in Table I indicates that the water quality has a direct impact on the performance of the underwater Li-Fi communication system.

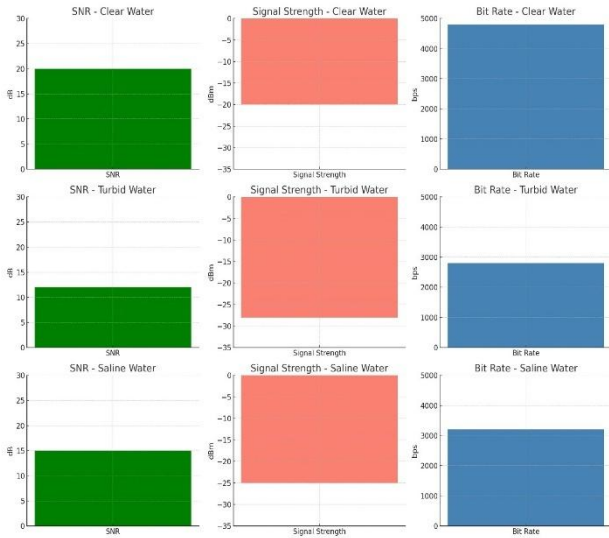


Fig. 12. Comparison of SNR, signal strength and bit rate across clear, saline, and turbid water environments.

TABLE I. COMPARATIVE PERFORMANCE ANALYSIS OF UNDERWATER LIFI COMMUNICATION SYSTEM IN DIFFERENT WATER TYPES

Water Type	Signal Strength (dBm)	SNR (dB)	Bit Rate (bps)
Clear Water	-19.85	24.13	4800
Saline Water	-26.75	17.90	3200
Turbid Water	-32.40	13.28	2400

### V. CONCLUSION

This study presents a framework for a LiFi-based underwater communication system to address the shortcomings of traditional acoustic and Radio-frequency (RF) methods that suffer from limited bandwidth, high latency, and severe attenuation in water. The proposed system relies on visible light transmission and reception through photodiodes and it proves successful in transmitting data in different scenarios of underwater settings. To validate its real-world applicability, the experiments were conducted across three different types of water- clear water, saline (seawater) water, and turbid (muddy) water using a fixed 47 cm separation and 15 cm depth. The results show that in clear water, minimal optical losses yielded the strongest received signal levels, highest signal-to-noise ratios, and bit rates up to 4.8 kbps, with negligible error rates. When tested in saline water, ionic dissolved solids induced moderate scattering and absorption, reducing signal strength by a measurable margin but still maintaining error-free transmission over the same distance. The turbid-water exhibited the maximum performance degradation: suspended particulates caused significant light scattering and absorption, which translated into lower photodiode currents, reduced SNR, and bit rates around 2.4 kbps. In spite of these difficulties, the system ensured fundamental message integrity in all scenarios, demonstrating its feasibility for short-range underwater communication in various water conditions.

The proposed underwater Li-Fi communication system is efficient for short-range communication provided the

line-of-sight transmission and clear water. The system can't handle saline or turbid water. These limits make it hard to use the system for large-scale or real-time applications such as underwater exploration or autonomous robotic swarms.

In future work, the multi-hop optical links would be explored for extended communication distance. Using AI to reduce noise and adjust how the data is sent could make the system more reliable in salty or turbid water.

### CONFLICT OF INTEREST

The authors declare no conflict of interest.

### AUTHOR CONTRIBUTIONS

Vrunda Kusanur supervised the research work, validated the methodology, and provided critical revisions to the manuscript; Priyadarshini K. Desai contributed to the conceptualization of the study, designed the Li-Fi communication framework, and led the manuscript writing; Hemanth T. M. developed the experimental setup, conducted the hardware implementation, and collected the data; Manjunath K. M. carried out performance analysis, including signal strength and SNR computation, and assisted in result interpretation; Suhas Gowda H. B. contributed to literature review, documentation formatting, and graphical illustrations; all authors have reviewed, contributed to the discussion, and approved the final version of the manuscript.

### REFERENCES

- [1] M. Arfan and C. Lakshminarayana, "VLC for underwater operations: Li-Fi solution for underwater short-range communication," in *Proc. 2018 Third International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT)*, 2018, pp. 638–642.
- [2] M. Aman, G. Qiao, and M. Muzzammil, "Design and analysis of Li-Fi underwater wireless communication system," in *Proc. 2021 IEEE/OES China Ocean Acoustics (COA)*, 2021, pp. 1100–1103.
- [3] N. Venu and A. Arun Kumar, "Design of Li-Fi technology based underwater data communication system using IoT," *High Technology Letters*, vol. 29, no. 10, pp. 194–203, 2023.
- [4] J. Mahakal, J. Mahajan, and G. Patil, "Underwater communication using Li-Fi technology," *International Journal of Engineering Science and Computing*, vol. 47, no. 1, pp. 64–66, 2024.
- [5] J. Rufo, F. Delgado, and C. Quintana, "Visible light communication systems for optical video transmission," *Microwave and Optical Technology Letters*, vol. 52, no. 7, pp. 1572–1576, 2010.
- [6] J. H. Goh, A. Shaw, and A. I. A. Hamma, "Underwater wireless communication system," *J. Phys. Conf. Ser.*, vol. 178, no. 9, pp. 835–841, 2009.
- [7] M. Leba, S. Riurean, and A. Lonica, "LiFi – The path to a new way of communication," in *Proc. 2017 12th Iberian Conference on Information Systems and Technologies (CISTI)*, 2017, pp. 1–6.
- [8] A. E. Ibhaze, P. E. Orukpe, and F. O. Edeko, "Li-Fi prospect in internet of things network," in *Proc. FICC 2020 Advances in Intelligent Systems and Computing*, 2020, vol. 1129.
- [9] Y. Y. Goh, B. Ho, and J. L. Ding, "A novel fluorescent protein-based biosensor for gram-negative bacteria," *Appl. Environ. Microbiol.*, vol. 68, no. 12, pp. 6343–6352, 2002.
- [10] K. S. Krishna, A. Ananthula, and N. Venu, "Vehicle fuel level monitor and locate the nearest petrol pumps using IoT," *International Journal for Innovative Engineering and Management Research*, vol. 11, no. 6, pp. 233–240, 2022.

- [11] G. S. Spagnolo, L. Cozzella, and F. Leccese, "Underwater optical wireless communications: Overview," *Sensors*, vol. 20, no. 8, 2261, 2020.
- [12] D. C. Li, C. C. Chen, S. K. Liaw, S. Afifah, J. Y. Sung, and C. H. Yeh, "Underwater wireless optical communication system by varying the environmental parameters," *Photonics*, vol. 8, no. 3, 2021.
- [13] M. L. Zhang and H. Y. Zhou, "Real-time underwater wireless optical communication system based on LEDs and estimation of maximum communication distance," *Sensors*, vol. 23, no. 17, 2023.
- [14] J. Xu, Y. F. Zhang, and C. Cai, "Underwater wireless optical communications: From the lab tank to the real sea," *Journal of Lightwave Technology*, pp. 1644–1651, 2024.
- [15] S. A. A. E. Mottaleb, M. Singh, A. Atieh, and M. H. Aly, "High data rate underwater optical wireless communication systems with ICSM codes within green spectrum," *Optical and Quantum Electronics*, vol. 57, no. 213, 2025.

Copyright © 2025 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited ([CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).