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Underwater-Communication using IR LED

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Abstract: *This paper investigates the design, implementation, and evaluation of an infrared (IR) LED and TSOP-based communication system for submerged environments. System performance is assessed based on range, signal strength, and data transfer rate. The results indicate that this IR-based approach offers a reliable and efficient alternative to acoustic methods for short-range underwater communication, particularly in clear water conditions. Additionally, the findings suggest potential applications in remote underwater sensor networks and real-time data transmission for underwater vehicles. Future research will focus on enhancing the system's range and noise tolerance, further establishing its viability for underwater communication.*

Keywords: Communication, Underwater, Infra-Red, LED

I. INTRODUCTION

Underwater data communication has become increasingly important due to the rising demand for marine exploration, scientific research, and commercial operations. While traditional acoustic communication is effective over long distances, it is hindered by limitations such as low data rates and high latency. Moreover, traditional wireless communication methods, like radio waves, are ineffective underwater due to their limited range and poor propagation. Infrared (IR) communication emerges as a compelling alternative for short-range, high-speed data transmission.IR communication operates by modulating light signals within the infrared spectrum to facilitate data exchange between underwater devices. Underwater communication systems face numerous challenges due to the distinct characteristics of the aquatic environment, such as high signal attenuation, scattering, and absorption. IR communication, however, presents a promising solution, operating at higher frequencies and shorter wavelengths, which make it less prone to long-range attenuation compared to radio waves.

The main obstacle in underwater IR communication is overcoming the limitations of the medium. Water turbidity can significantly degrade IR signals, reducing transmission distance and reliability. Additionally, the effective range of IR in water is inherently short, further complicating the establishment of reliable communication links, particularly over larger distances or in deeper environments. Environmental factors such as salinity, temperature fluctuations, and water currents also impact the performance and stability of IR communication systems. To address these challenges, it is essential to develop advanced modulation techniques, signal processing algorithms, and adaptive communication strategies that ensure robust data transfer under variable underwater conditions.

Key applications of IR underwater communication include remotely operated vehicles (ROVs), diver communication systems, and environmental monitoring. As technology advances, the adoption of IR communication is expected to enhance underwater data transmission, improving the efficiency and reliability of various marine operations. In [1], this paper examines the use of infrared (IR) sensors for underwater wireless communication, emphasizing the advantages of IR technology over conventional communication methods. The study highlights IR communication as a viable alternative to acoustic methods for short-range, high-speed data transmission in clear water conditions. In [2],this review explores various physical layer techniques employed in underwater communication, including Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) technologies. The paper also addresses key challenges such as signal attenuation, multipath interference, and environmental factors affecting underwater communication. In [3], this study focuses on the security concerns in underwater wireless communication networks (UWCNs). It identifies vulnerabilities in data transmission and proposes efficient security mechanisms to

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ensure secure communication in underwater environments. In [4], this survey provides an overview of the latest advancements in underwater communication, particularly for underwater robots. It identifies research trends, technological developments, and future directions in underwater robotic communication systems. In [5], this paper presents a comprehensive analysis of underwater wireless communication networks, discussing their applications in various fields such as oceanographic data collection, military surveillance, and offshore industrial monitoring. The study also highlights the unique challenges faced by underwater communication networks, including high signal attenuation and energy constraints. In [6], this paper reviews the principles of underwater optical communication (UWOC) systems, analyzing their advantages and limitations in comparison to acoustic communication. The study highlights UWOC's potential for high-bandwidth, short-range communication and its dependence on water clarity and ambient light conditions. In [7], this paper provides insights into underwater acoustic communication, focusing on signal propagation, noise reduction techniques, and the impact of environmental factors on acoustic wave transmission. It also examines the trade-offs between range, data rate, and reliability in acoustic communication. In [8], this paper discusses the design and implementation of underwater sensor networks (UWSNs), emphasizing communication protocols, energy efficiency, and data collection methodologies. It highlights the significance of UWSNs in environmental monitoring, disaster prevention, and scientific exploration. In [9], this study explores communication strategies for Autonomous Underwater Vehicles (AUVs), addressing challenges such as limited bandwidth, high latency, and dynamic underwater environments. It discusses emerging technologies aimed at enhancing reliable data transfer for AUV operations. In [10], this paper reviews communication systems used in underwater environmental monitoring. It highlights the necessity of reliable and efficient data transfer for marine ecosystem studies, climate change research, and pollution tracking.These papers collectively address a range of key issues in underwater communication, spanning various technologies, applications, and challenges.

The main objectives of developing underwater data communication using infrared (IR) technology are to address the unique challenges of underwater environments and enhance system performance. A primary goal is to extend the effective communication range of IR signals by optimizing wavelengths, using more powerful emitters, and improving receiver sensitivity. Additionally, efforts are focused on mitigating environmental factors like salinity, temperature, and water currents that can disrupt IR signal propagation, ensuring stable communication in dynamic underwater conditions. Improving signal quality and reliability is also a key objective, achieved through techniques such as error correction, signal processing, and adaptive modulation to minimize distortion and maintain robust data transmission. Optimizing power consumption is crucial, particularly for battery-powered devices like autonomous underwater vehicles (AUVs) or sensor networks, requiring a balance between range, throughput, and energy efficiency for prolonged operation. Addressing line-of-sight constraints is another challenge, as IR communication requires a clear path between the transmitter and receiver, so solutions must be developed to handle misalignments or obstructions. High data throughput is essential for applications like underwater exploration and real-time monitoring, where large amounts of data need to be transmitted quickly and reliably. Reducing latency and enabling real-time communication is vital, especially in time-sensitive scenarios where delays can compromise mission success.

Achieving these objectives will make IR-based communication systems more efficient, reliable, and practical for a wide range of underwater applications, including environmental monitoring, military operations, and autonomous navigation.

II. METHODOLOGY

The methodology of underwater data communication using Infrared (IR) can be broken down into a series of steps. Below is a flowchart that outlines the key components of the process, followed by a detailed explanation of each step.

Fig.1 represents the complete communication cycle from data generation to data utilization in an underwater IR-based communication system. Each block must be carefully designed and optimized to address the challenges posed by the underwater environment, such as signal degradation and line-of-sight issues. The process of underwater data communication using infrared (IR) begins with data generation, where raw data is collected by underwater devices like sensors or cameras, gathering information such as temperature, salinity, or video footage. This data is then encoded into a digital format, usually binary, to prepare it for transmission. The encoded data undergoes IR signal modulation using techniques like Amplitude Modulation (AM) or Pulse Code Modulation (PCM) to convert it into an infrared signal suitable for underwater communication. The modulated IR signal is transmitted by an IR emitter, such as a laser or LED, through the water towards a receiver. The IR signal is then received by an IR receiver located on another underwater device or monitoring station. After reception, the signal is demodulated to extract the encoded data by reversing the modulation process. The demodulated data is decoded to restore the original sensor readings or video data into a usable format. Finally, the decoded data is utilized for its intended purpose, such as displaying on a monitoring system, controlling an underwater robot, or storing for future analysis. Fig.2 shows Communication between transmitter and receiver in water medium.

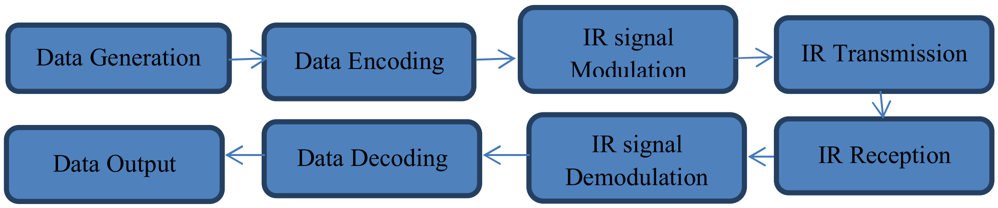


Fig.1. Proposed Block Diagram

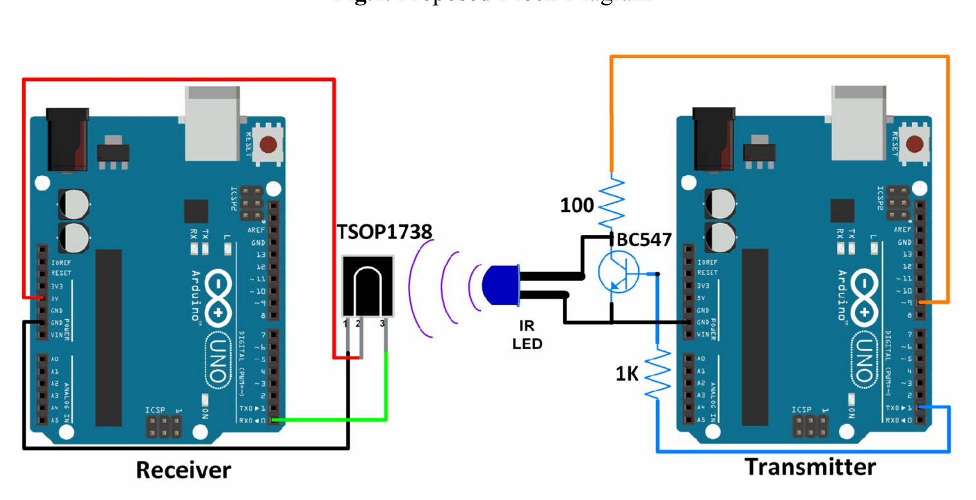


Fig.2. IR Communication Between IR LED And TSOP1738 IR Receiver using Arduino in water medium

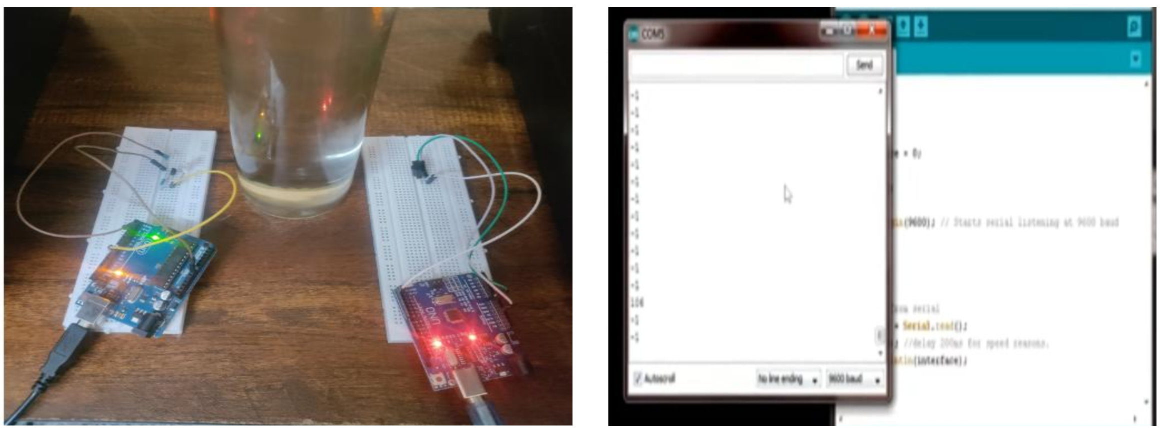
2.1 Arduino UNO: The Arduino UNO is a widely used microcontroller board powered by the ATmega328P microcontroller. It belongs to the Arduino family, which is renowned for its open-source hardware and software platform aimed at making electronics accessible to a broad audience. The Arduino UNO is particularly popular for prototyping and educational purposes, thanks to its user-friendly design, versatility, and strong community support.

2.2 IR LED Transmitter: An IR LED is a specialized type of LED that emits infrared rays, which are invisible to the human eye as they fall outside the visible spectrum of electromagnetic radiation. Humans can only perceive light within the wavelength range of 380 nm (violet) to 750 nm (red). IR LEDs are commonly used in everyday electronic devices, such as television remotes, infrared cameras, and transmission systems.

2.3 TSOP1738: The TSOP1738 is an IR receiver equipped with an amplifier, functioning as both a switch and a converter within a circuit. It features a single input and output that responds exclusively to the incoming IR signal. The primary role of the TSOP1738 is to convert infrared pulses into electrical signals. Each IR receiver operates at a specific frequency, and the TSOP1738 is designed to work with a 38 kHz IR frequency. If the frequency deviates from this value, either being too high or low, the device may experience issues such as current leakage, resulting in suboptimal performance. Built using silicon-based technology, the TSOP1738 operates on a micro-scale, offering high sensitivity and efficiency.

III. EXPERIMENTAL RESULTS

The data from transmitter side is modulated at 38 kHz before transmission. The TSOP1738 is an IR Receiver with the capability to demodulate signals that have been modulated at a frequency of 38 kHz. Any other TSOP17xx receiver like the TSOP1730 can also be used instead of TSOP1738. The only difference is the carrier frequency that it can demodulate. For example, TSOP1730 can demodulate signals that have carrier frequency 30 kHz. Corresponding changes in the modulation scheme need to be made at the transmitter side if TSOP1730 or some other receiver is used. The transmitter transmit the data underwater and the receiver (TSOP1738) receive the transmitted data in the water medium, the receiver uses modern modulation techniques and signal transmitted in the water medium , the change in Refractive index (when transmitter send the data from air medium to water medium) and many aspects leads to addition of noise and also affect the distance of communication. Fig.3 shows the experimental setup and the data transmitted and received.



(a) (b)

Fig.3. (a) Proposed Experimental setup (b) Data Received

The line of sight plays a crucial role in underwater communication. Communication is only possible when the transmitter and receiver are aligned along the same line of sight, making the process much more challenging. The distance at which communication is effective can be affected by changes in the refractive index of the medium. Below are different cases that further illustrate this:

Case 1: Communication in Air (Aerial Medium)

In the air medium, communication can achieve 100% data accuracy, and the distance between the transmitter and receiver can vary up to 2 meters with full efficiency. The maximum effective communication range in the air is 2 meters.

Case 2: Communication in Water Medium

Underwater communication is effective only when the line of sight is maintained, and changes in refractive index must be considered when data is transmitted from the air to glass or plastic, then through water, and back to glass/plastic before reaching the receiver. Several observations are made regarding this process:

Case 2a: Communication with Line of Sight in Water

Underwater communication is possible when the line of sight is maintained. As the distance increases beyond 20 cm, it becomes increasingly difficult to maintain the line of sight, and data loss or modification occurs if the line of sight is deviated.

Case 2b: Communication through Glass Medium

Glass, with a refractive index between 1.5 and 1.6 (depending on the type of glass), reduces the effective communication distance. Communication is most efficient at distances up to 30 cm, but if the distance exceeds 30 cm, the data becomes modified, and special characters may appear due to signal degradation.

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Case 2c: Communication through Plastic Medium

Plastic has a refractive index of 1.5, and the communication range is more efficient at distances up to 70 cm. Beyond 70 cm, the data becomes corrupted or changed. When plastic is used instead of glass, communication distance is improved by 2.4 times, allowing for better performance.

As the distance increases in any of these media, data errors become more frequent, manifesting as garbled characters such as "/////**" or "###?????" indicating signal degradation.

IV. CONCLUSION

The potential of IR LED technology for underwater communication is significant due to its capacity for high-speed, low-power, and secure data transmission. As challenges such as signal attenuation and interference in underwater environments are addressed, IR LED systems are likely to become crucial in advancing various fields, including autonomous underwater vehicles (AUVs), environmental monitoring, deep-sea exploration, and military operations. The integration of IR LED systems with hybrid communication networks and IoT frameworks will further expand their ability to support real-time data exchange and coordination in complex underwater settings. With ongoing advancements in optical technology, modulation techniques, and energy efficiency, IR LED-based underwater communication is set to become a vital element of modern oceanographic and industrial systems, offering reliable and sustainable communication solutions for the future.

The future of underwater communication using IR LED technology is promising, with a wide range of applications in marine science, environmental monitoring, military defence, and autonomous underwater vehicles. As research progresses and technology evolves, IR LED-based systems are expected to enhance existing communication methods, extending their use in areas like deep-sea exploration, oceanographic research, and industrial operations.

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