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REAL-TIME UNDERWATER VISIBLE LIGHT COMMUNICATION USING PULSE WIDTH MODULATION AND LIGHT DEPENDENT RESISTORS

Ali Sher[1], Muhammad Izhar[2], Ilyas Khan[3], Subhi Mahmood Fadhl Hussein[4], Wasim Habib[5], Bilal Ur Rehman[*6], Humayun Shahid[7], Muhammad Kashif Khan[8]

[,1,23,4,5,*6,8]Department of Electrical Engineering, Faculty of Electrical and Computer Engineering, University of Engineering and Technology, Peshawar, Pakistan.*
[7]Department of Telecommunication Engineering, University of Engineering and Technology, Taxila, Pakistan

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Corresponding Author: *
Bilal Ur Rehman

Abstract
Visible Light Communication (VLC) has emerged as a groundbreaking technology, utilizing light as a medium for wireless data transmission. This paper introduces an innovative Underwater Visible Light Communication (UVLC) approach for real-time imaging transmission. The proposed system employs Pulse Width Modulation (PWM) and an integrated Light Dependent Resistor (LDR) to achieve fundamental light detection capabilities. Our system can transmit data at 160 bits per second (bps) over substantial distances underwater, utilizing Light Emitting Diodes (LEDs) as optical transceivers. This setup ensures robust and efficient communication in aquatic environments and demonstrates visible LEDs' dual functionality for illumination and optical communication.

INTRODUCTION

The fast development of communication technologies has pushed the boundaries of data transmission to the utmost, bringing up new technologies like Light Fidelity (Li-Fi). Li-Fi utilizes visible light as a wireless data communication system; it is an alternative to radio frequency communication systems. This dissertation discusses the application of Li-Fi in the water surroundings to convey pictures. This field has attracted much attention because of its possible use in underwater exploration, monitoring, and communication [1].

The Underwater Visible Light Communication systems are based on the capabilities of visible light to transmit data over water, which otherwise invokes limitations to the traditional wireless communication techniques. Our UVLC system is feasible and cost-effective since its core is based on readily available hardware; this is the essence of the system. The transmitter module includes a 1602 LCD, trigger button, LED module, and Arduino Nano microcontroller. Such configuration is used to transmit data through modulated light signals. The receiving system has an LDR (light-dependent resistor), another Arduino Nano, and a USB to serial-converter, which records the data received to another computer. It is processed with the help of a Python script that reconstructs it into a JPEG image displayed [2].

Performance-based on water as the transmission medium introduces special challenges and opportunities since light behaves in water differently than in air. The present research will determine and

solve such issues to provide confidence in the data being sent and received. Incorporating other components in the circuit, the 9V to 5V buck converter and a 9V switched-mode power supply
Visibly emitting LEDs (LED) are also gaining popularity as an energy-efficient and long-lasting light source used in domestic and commercial light systems (SMPS) that provide the receiver and transmitter circuits with a stable power supply [3]. In addition to lighting, these LEDs have great potential as sources (transmitters) in optical wireless communication systems. Unlike infrared light, which has been used daily in remote controls and other communication devices, visible light is harmless to the human eyes. It does not affect the radiation; hence, it is a perfect medium through which data is transmitted in different environments. The paper considers the theoretical and practical aspects of a UVLC system regarding image transmission. We study the characteristics and behavior of visible LEDs as optical transmitters with numerical results and computer simulations. The results indicate that the potential of using visible light in data communication, especially in difficult-to-tackle underwater space, will lead to future solutions in underwater exploration technologies and indoor optical transmission devices.

1. LITERATURE REVIEW

Traditionally, Light Fidelity (LiFi) systems were first conceptualized as terrestrial, but this has advantageous prospects of presenting a high-speed wireless connection through visible light. The research in LiFi aims to improve data rates, widen the coverage range, and develop the concept of interconnection between LiFi and wireless networks. Optimization of UVLC systems requires a good knowledge of the physical properties of the underwater medium, including water attenuation and scattering. There is also a fascinating study concerning the issues and developments of underwater acoustic, RF, and optical communication to enhance the efficiency and reliability of the data delivery. Additionally, similar studies have been conducted on the application of underwater sensor networks, autonomous vehicles, and environmental monitoring, and they have indicated new approaches to solve the challenges specifics of underwater communication. The researchers are working on LiFi systems that can provide extremely high velocity, encrypted, and bio-safe communication systems, utilizing good bandwidth and high-frequency pulsed light instead of radio and microwaves [4]. The systems use modulated light wavelengths from various standard sources, including indoor and outdoor lighting, displays, illuminated signs, televisions, computer screens, and digital cameras, mostly by light-emitting diodes (LEDs). Some of these technological issues that may be solved by the use of LiFi technology are the short supply of traditional bandwidths to electronic devices, the possibility of disrupting sensitive electrical devices, the security of the data sent out over the technology, and the issue of health risks about the high level of radio frequencies and microwave. Many universities, companies, and organizations worldwide are researching how to implement LiFi components in daily technology. They are also guided by the constitution of standards, including the 2007 standards by the Malaysia Japan Electronics and Information Technology Industries Association (JEITA) of a visible light ID system and the 2008 Specification Standard by the Visible Light Communications Consortium (LIFIC). Also, the wireless personal area networks working group 802.15.7 Task Group 7 of the Institute of Electrical and Electronics Engineers (IEEE) is developing a standard on LiFi technologies, which was expected to be completed at the end of 2010 [5].
LiFi technology research is done by such prominent organizations as Casio, Eurescom, France Telecom, NEC Corporation, Orange, Panasonic, Samsung, Sharp, Siemens AG, Telefonica, Toshiba, Universita di Roma, Universita Dortmund, Universita Ilmenau, University of Athens, University of California, and the University of Oxford [6]. LiFi systems based on LEDs are regarded as a beneficial contribution to future technological progress that promises to communicate at ultrahigh speed wireless systems. The scientists seek a transfer speed of 100 Mbps in offices and homes using light modulated on upgraded light systems. When properly developed, this technology would solve many problems related to existing infrared, radio wave, and microwave communication systems and provide an easy option of a more friendly signal for industries and the

general body of people [7]. The water on Earth is 98% oceans, and most of the oceans are yet to be explored [8]. Physical variations in water bodies that have already been explored are often changing, such as temperature, salinity, turbidity, depth, noise, and pollution. Such factors impact the survival of wildlife, marine interests, and military activity [9].

The underwater condition is a special scenario regarding sound and stable communication, which is categorized as wired or wireless. Wired communication gives a reasonable data rate and non-stop traffic among nodes, constraining depth, scope, and mobility [10]. Moreover, it makes adding a new node or network discovery difficult. Therefore, wireless communication is considered more important in future underwater conditions. The techniques included in this review's scope are underwater acoustic, RF, and optical wireless communication. Several factors influence any underwater wireless communication, including power consumption, movement of fluids, and change in conditions. The power consumption limits submerged time because it is more challenging to recharge or refuel the nodes to keep transmitting and receiving data [11]. There is a potential for high-speed underwater communications at a distance of about 20 meters in the visible light spectrum (400-800 Terahertz (THz) [12]. The type of water (clear, intermediate, murky) and data rate and ranges are determined by the characteristics of the given type. The best wavelength of optical communication in waters is 450-575 nanometers in the blue light on clean oceans to a green color in foggy seashores [13]. Underwater Visible Light Communication (UWVLC) has experienced high popularity in recent years, and many other researchers have begun developing the potential of this technology in a vast number of applications. Notable success has been recorded with VLC technology companies like LiFi, especially in closed spaces. Nevertheless, they have found it vulnerable to operate VLC in outdoor or auto situations, leading to a dearth of advancements in such directions [14].

Some research teams have faced some drawbacks while constructing high-performance VLC systems. For example, a few meters range and tens of bytes/sec data rate are typical restrictions in some VLC data transmitters outdoors and indoors. Some systems designed in [15] have higher speeds (115,200 baud), yet they operate within a 2.3m span at night and 1.76 m in the daytime. The 3% error rate is caused by the fact that this system uses an unamplified direct-to-digital comparator without ambient light compensation.

One Pulse Width Modulation (PWM) variant is employed to develop a unique system [16]. Their transmitter was an 18-watt panel light in an office, and their receiver was a panel light whose photodetector was a BPW34, and their data rate was 78 bytes per second. The system's performance and range were susceptible to ambient light. In [17], a pulse-count-based VLC system is designed. The receiver has an analog-to-digital converter of the Arduino microprocessor that measures light level changes. Despite the innovative design, the system has a data rate of 50 bits/sec at one foot.

In [18], high-speed optical data transfer devices are premised on the Application-Specific Integrated Circuits (ASICs). The transmitter has a rate of 1GB/s with color-shift keying and multi-channel color, and the receiver has sensitive avalanche photodiodes that support complex protocols. In vehicle-to-vehicle VLC communication, [19] tested a system that transmitted vehicle CAN bus data at 20 meters and 500 thousand baud. Though their design experienced cases of sunlight interference, they proved potential VLC for vehicles. Similarly, [20] devised a car-to-car VLC network, which gives a 38,400 bauds transmission at a distance of up to 11 meters at night, yet reduced to 2 meters during the day. More developments come in the form of a simulation in [21], with an effective range of 30 meters in IEEE 802.15.7 digital modulation and multi-hop re-transmission. [22] created a system with a data rate of 100 kilobits per second and a span of 101 meters, which is highly resistant to both interference and ambient light.

Our research contributes to this evolving field by proposing a novel underwater visible light communication (UVLC) approach for real-time imaging transmission. Our system employs Pulse Width Modulation (PWM) with an integrated Light Dependent Resistor (LDR) to achieve fundamental light detection capabilities. Capable of transmitting data at 160 bits per second (bps) over substantial distances underwater, this system utilizes Light

Emitting Diodes (LEDs) as optical transceivers. This innovative setup ensures robust and efficient communication in aquatic environments and demonstrates the dual functionality of visible LEDs for both illumination and optical communication.

2. MOTIVATION

Efficient and secure communication technologies have become in high demand due to the increased use of wireless devices and high-speed data transmission. Optical wireless is a radiation-free wireless technology primarily based on visible light, and it has proved itself to be an exciting option over traditional radio frequency (RF) systems, with a wide variety of benefits regarding bandwidth availability, security, and minimal interference. This study investigates the possibility of using optical wireless communication, Underwater Visible Light Communication (UVLC), as a new way of providing wireless communications in the RF-impossible/limited environments.

3. AIMS AND OBJECTIVES

This research aims to design an effective underwater visible light communication (UVLC) system to transfer high-speed real-time images in a water medium. It aims to prove the possibility of applying visible light to reliable data transmission in the underwater environment and test the performance and reliability of the designed UVLC system. There is also the need to develop a Python script to process the data received by the receiver and convert it correctly into a JPG image, employing the integrity of image data in underwater transmission.

4. SYSTEM DESIGN

A. HARDWARE COMPONENTS

UVLC system is designed to have two major components: transmitter and receiver. Modulation and data transmission by the transmitter using light-emitting diodes (LEDs) consists of one visible light. Simultaneously, the receiver has a photodetector that captures and interprets the photon signals into legible data. The key hardware used in the system is as follows:

Arduino Nano: It plays the master controller role in receiving and sending activities.

LED Modules: The modules offer the light needed to transmit the data.

LCD: Displays the transmitting data at the receiver end.

Light Dependent Resistor (LDR): Plays the role of the photodetector of the receiver module.

USB to Serial Converter: This converter helps transfer data between the computer and the Arduino so that it can be processed and displayed.

Pulse Width Modulation (PWM) is the modulation approach incorporated into the system, aiming at real-time image transmission. PWM varies the strength of the LEDs and allows responsive and adaptable signal strength depending on the data transmission rates. This method increases the efficiency and reliability of the system due to the increased resistance to distortion of the signal in the system. Through the PWM, the system has possessed the integrity of data sent out, which has enabled excellent communication even in changing conditions.

Various considerations have been made to ensure maximum performance and reliability in the system's design. When it comes to data transmission, the selection of the hardware components matters in terms of accuracy and efficiency. Hence, it is ensured by the Arduino Nano, which is small but versatile and provides firm control of the transmission and reception process. The LED modules used are chosen by their brightness and the ability to modulate them, whilst the LDR is explicitly adjusted to sense the light signal and translate it effectively into the electrical circuit. The LCD makes the deciphered data well-accessible and clear to the receiver.

Besides the hardware, the PWM must be integrated to stand against environmental changes and data rates. PWM gives the system the capacity to vary the light intensity of LEDs; it will be able to cope with the number of changes in signal strength and preserve data integrity. This flexibility is critical in communicating consistently across various situations, such as those with different background light states and sinusoidal signal interference.

B. BLOCK DIAGRAM

Fig. 1 illustrates a data transmission system whose transmitter transmits information through light pulses to a receiver. The system in this configuration is such that the transmitter made using an Arduino Nano controls a 12V LED module using a transistor TIP122 and presents information on a 1602 LCD. On the receiving board, also comprising an Arduino Nano, these data-carrying light pulses are received by a Light Dependent Resistor (LDR) package. The received light pulses in the form of the light signal are transduced into appropriate digital signals by the LDR module. These digital signals are processed by the receiver's microcontroller and sent to a computer through a Serial to USB converter. A Python script running on the computer accepts the data stream, reconstructs image data from the pulses received, and converts this into a JPEG image. It is the idealization of the effective combination of optical communication and digital information processing, which allows transferring and reconstructing the information.

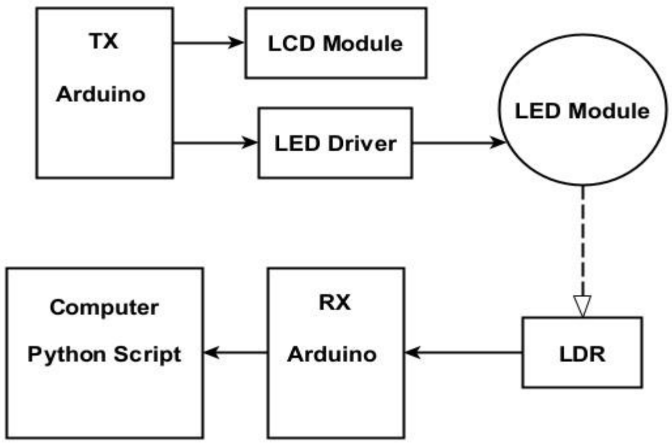

Fig. 1. System Block Diagram

C. SIMULATION PROCESS

The simulation will be initiated by designing a detailed flowchart or an algorithm, which is intended to describe how the whole system will work. Individual flowcharts or algorithms of the transmitter and receiver circuits described their individual functionalities and data processing mechanisms. The next step is to develop the code for transmitter and receiver circuits using the Arduino Integrated Development Environment (IDE). Arduino IDE The user-friendly interface allows us to conveniently write, debug, and upload the code to the microcontroller to develop and test the transmitter and receiver codes efficiently. Following the development process using Arduino, the focus gets to the receiver side, where a Python script is developed. The script is a component that will complete the processing duties of the data sent by the microcontroller. Python is selected because of the availability of comprehensive libraries and convenience in the manipulation and handling of data and the communication process; hence, it is ideal for extending the functionality provided by the system in the computer and to be integrated with other independent systems. The compatibility of both Arduino IDE to code microcontroller and Python as a higher-level processor makes the research work flexible and practical in software implementation.

D. SYSTEM FLOWCHART

The system flowchart begins with the transmitter section, where data is initially processed. Based on the binary representation of the data (1s and 0s), an LED is toggled on and off. When the data bit is '1', the LED turns on. When the data bit is '0', the LED turns off, creating a series of light pulses corresponding to the binary data as displayed in the Fast-paced development in communication methods has persistently extended the limits of data passage, resulting in cutting-edge techniques like Light Fidelity (Li-Fi). Li-Fi is a means of sending data via light that can be seen. It is an alternative to radio frequency-based systems, and it has also gained popularity, particularly for underwater environments with much potential for exploration, monitoring, and communication. Through visible light, Underwater Visible Light Communication (UVLC) systems take advantage of data transmission using water as the medium to tackle other conventional wireless forms of transmitting messages amid stiff resistance offered by water as an obstacle for electronic signals from coming into contact with humans.

The system comprises hardware parts that are commonly used and thus worthy of being attempted and cheap. A modulated light signal carries data from an LED module, trigger button, and 1602 LCD fitted in an Arduino Nano microcontroller on the sender end while on the receiver end, a light-dependent resistor (LDR), another Arduino Nano, and a USB to serial converter sends received data to the computer where a Python script turns it into a JPEG image for visualization. The stability of power coming into both transmitter and receiver circuits is guaranteed by including components like a 9V to 5V buck converter and a 9V switched-mode power supply (SMPS).

LEDs visible to the naked eye are commonly applied because they utilize little energy and last long. In addition to other uses, they can work well in optical wireless communication systems. The advantage of visible light compared to infrared radiation is that it is safe for human vision, and in various environments, it does not interfere with radio frequencies; hence, it is best suited for transferring data. In this study, we look at both the theoretical and practical aspects of implementing a UVLC system designed explicitly for image transmission in an underwater context. We explore the properties and performance of visible LEDs as optical transmitters through numerical analyses and simulations. Thus, these results support our hypothesis that using visible light for data communication is realistically possible, especially when used underwater, furthering its revolutionary development in underwater exploration technologies and indoor optical transmission systems.

Reducing optical noise and thus achieving an equivalent drinking water turbidity level of less than 0.1 NTU for the UVLC systems utilizing Arduino Nano microcontrollers illustrates their viability for wireless applications in the future. The fact that high-power visible LEDs can change the face of next-generation lamps validates this research concerning optical communication and lighting technologies, as shown in Fig. 2.

A photodetection mechanism is implemented at the receiver side to capture these light pulses. A Light Dependent Resistor (LDR) module converts the light pulses into electrical signals. These signals are then amplified using an operational amplifier to ensure they are strong enough for further processing. The amplified signals, representing binary data, are then processed to reconstruct the original data. Finally, this processed data is received and can be used for further applications or analysis, ensuring accurate and reliable communication between the transmitter and receiver.

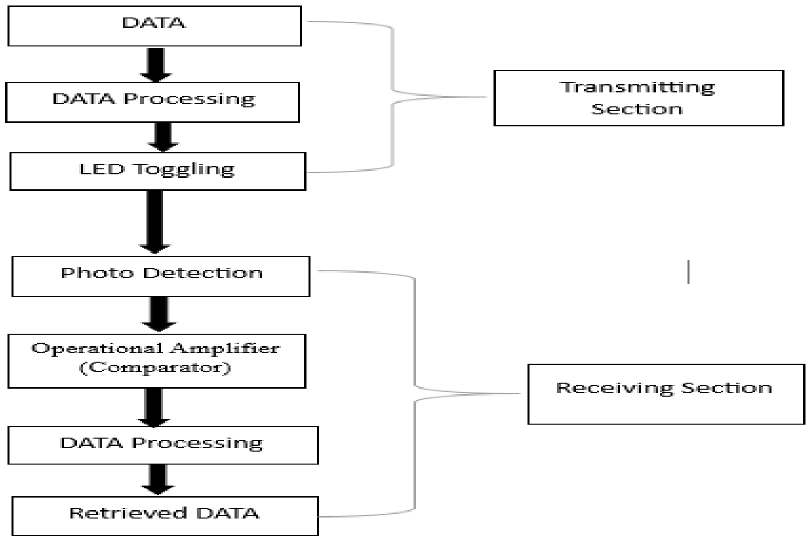

Fig. 2. System Flowchart.

E. TRANSMITTER CODE

The transmitting code was developed to control the 12V LED module, as shown in Fig. 3. The Arduino Nano converts text into light pulses displayed on the 1602 LCD. Based on the Arduino signals, the TIP122 transistor controls the LED module.

F. RECEIVER CODE

The receiving code on the Arduino Nano processes input from the LDR module, converting light pulses back into text, as given in Fig. 4. This text is then sent to the computer via the Serial to USB converter. The Python script on the computer processes the data, converting the incoming JPEG image strings into JPEG images.

G. PYTHON SCRIPT FOR IMAGE RECEPTION

The Python script integrates with a serial device, likely capturing data transmitted over a specific COM port. Initially, it initializes variables and sets up serial communication parameters. It then enters a loop to continuously read data until a termination signal (a space character) is detected. Once data reception is complete, trailing spaces are removed, combined with a known JPEG header, and proper Base64 padding is ensured. The script subsequently attempts to decode this data into an image format using the base64 and PIL libraries, displaying the image if successful. Error handling ensures robustness, managing potential decoding or image loading issues gracefully, as depicted in Fig. 5. This script effectively demonstrates the handling and processing real-time data streams from serial devices, showcasing Python's capabilities in data acquisition and visualization tasks.

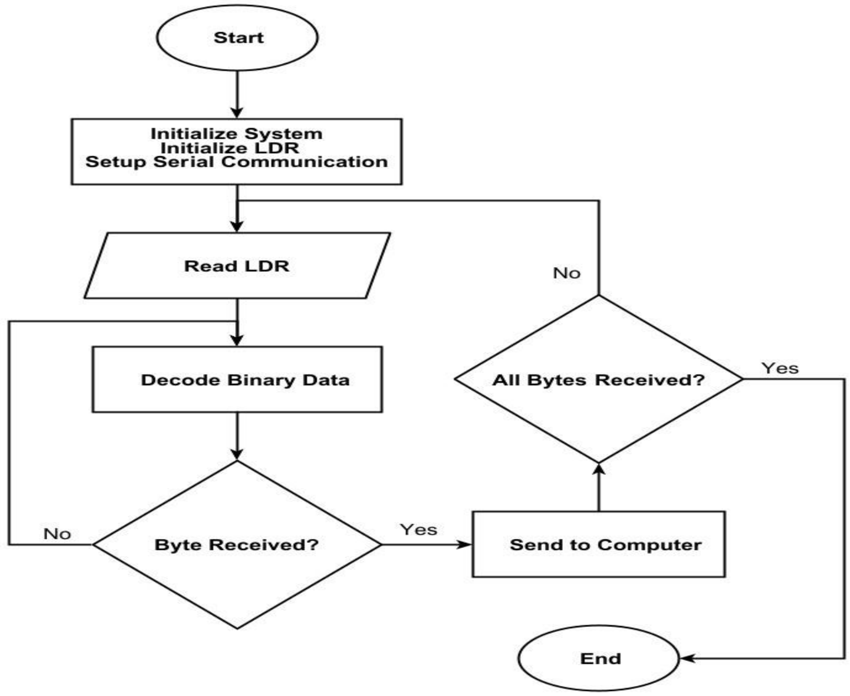

Fig. 3. Flowchart of Transmitter

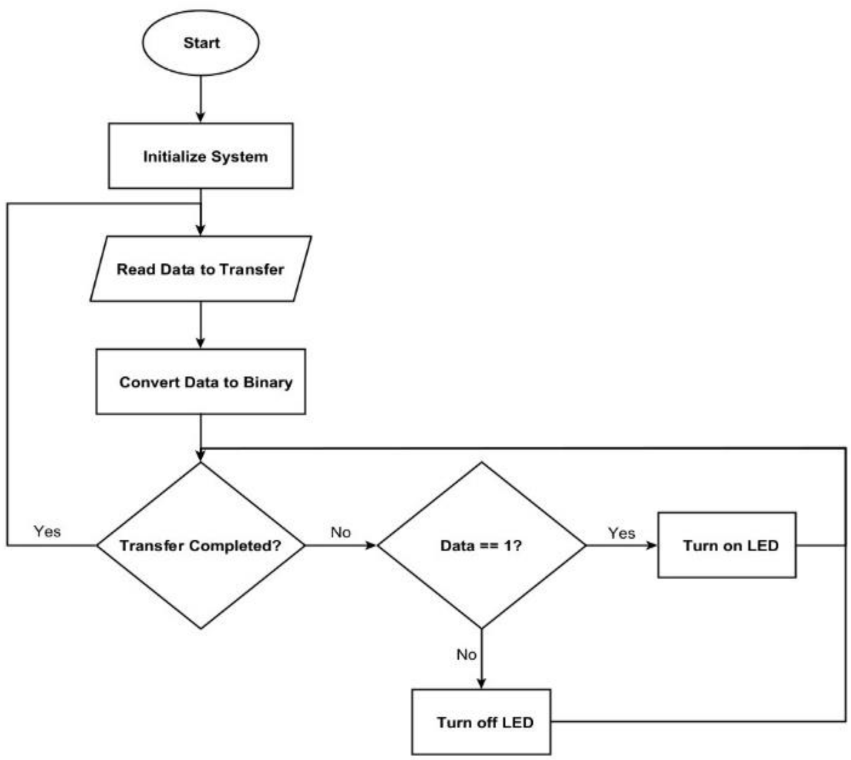

Fig. 4. Flowchart of Receiver

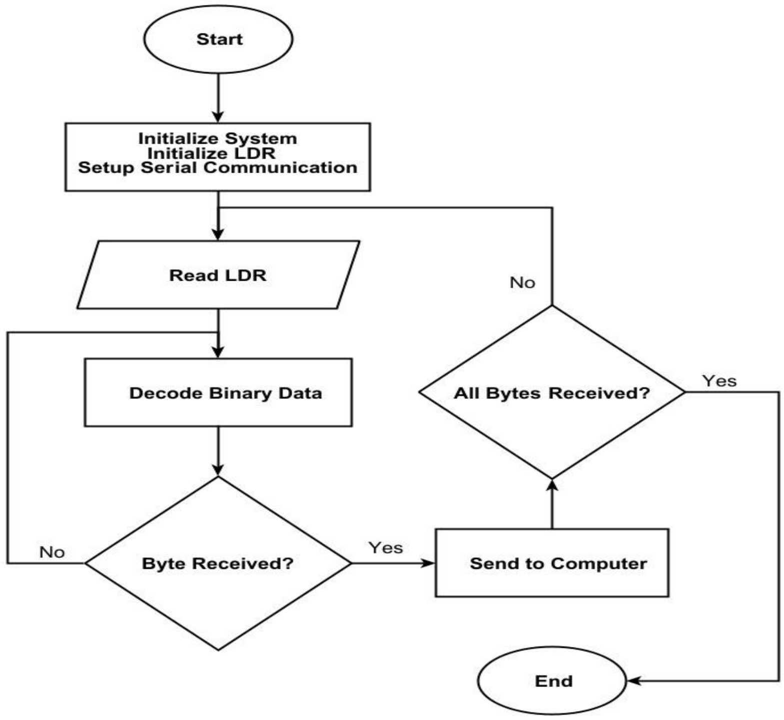

Fig. 5. Python Script Flowchart

5. EXPERIMENTAL SETUP

In this section, various components transmit the image at the receiver end based on underwater visible light communication.

A. TRANSMITTER FOR UVLC

The transmitter receives input from the Arduino Nano and uses the TIP122 transistor to control the 12V LED module. The 1602 LCDs have relevant information, allowing for real-time monitoring and adjustments as shown in Fig. 6.

B. RECEIVER FOR UVLC

The receiver captures light pulses using the LDR module and processes them through the Arduino Nano, as shown in Fig. 7. The Serial to USB converter then sends this data to a computer. The Python script processes the incoming JPEG image strings, converting them into JPEG images for display and analysis.

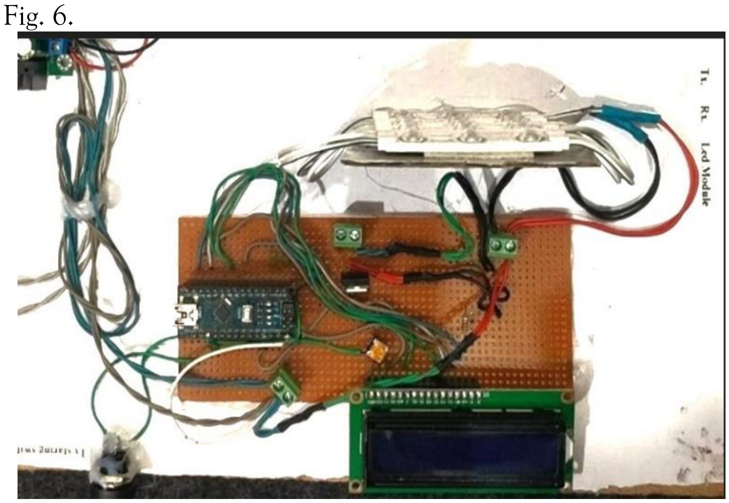

Fig. 6. Hardware components of the UVLC Transmitter

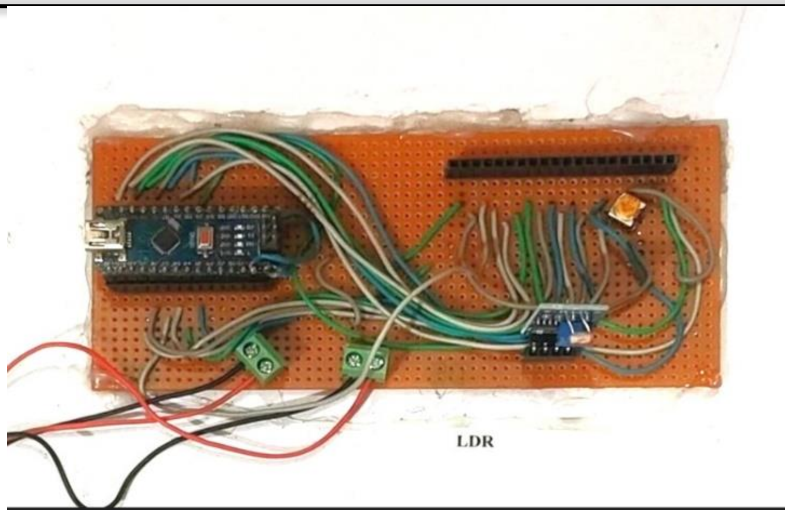

Fig. 7. Hardware components of UVLC Receiver

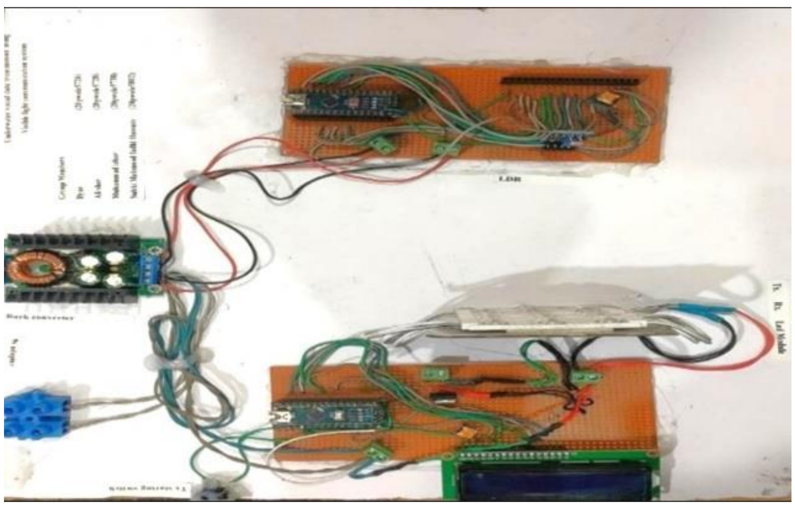

Fig. 8. Initial Setup

INITIAL SETUP

The first step, depicted in Fig. 8, involves connecting the circuit components. The transmitter and receiver circuits are connected as per the schematic diagrams, and all connections are tight. Before the circuits are powered, a visual inspection is performed to check the components' position.

C. POWERING UVLC TRANSMITTER

When the power is supplied to the transmitter circuit, it remains in standby mode, awaiting activation through the push button. Upon pressing the push button on the transmitter, the LED module starts blinking, as displayed in Fig. 9. This blinking represents the conversion of the image string data into light pulses, which correspond to the binary representation of the data being transmitted. Each blink of the LED signifies a '1' in the binary code, while the absence of a blink denotes a '0'. The transmitter processes the image data byte by byte, translating each bit into a sequence of light pulses. Hence, the data should be accurately encoded into the optical signals and ready for transmission to the receiver. The consistent and precise blinking of the LED module indicates the proper functioning of the data encoding mechanism within the transmitter circuit.

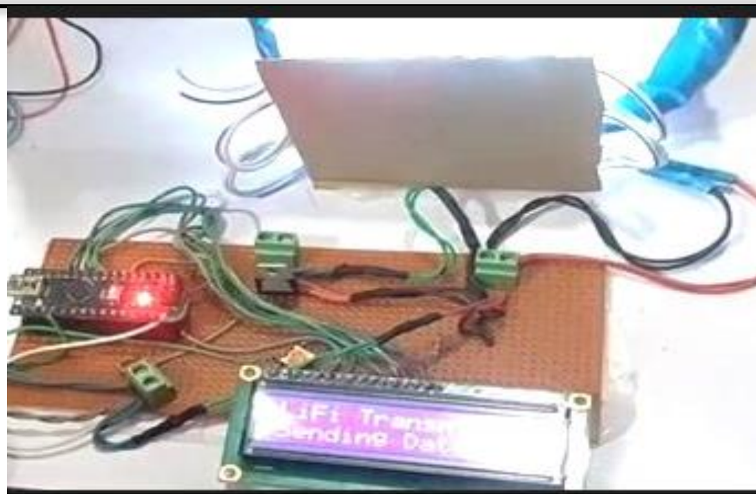

Fig. 9. UVLC Transmitter Operation

D. DATA RECEPTION

The receiver circuit, equipped with an LDR (Light Dependent Resistor), detects the incoming light pulses, as shown in Fig. 10. The LDR's resistance changes in response to the light intensity, converting the light pulses into electrical signals. These signals are then processed through an operational amplifier to amplify the signal strength. The amplified electrical signals are fed into the Arduino nano, which decodes the binary data. Each light pulse detected by the LDR corresponds to a '1' or '0' in the binary code. The Arduino nano then processes this data, reconstructing the original image string bit by bit. Once all the data is received and processed, the Arduino forwards the binary data to the computer running a Python script, which converts the binary data back into the respective image, completing the transmission process.

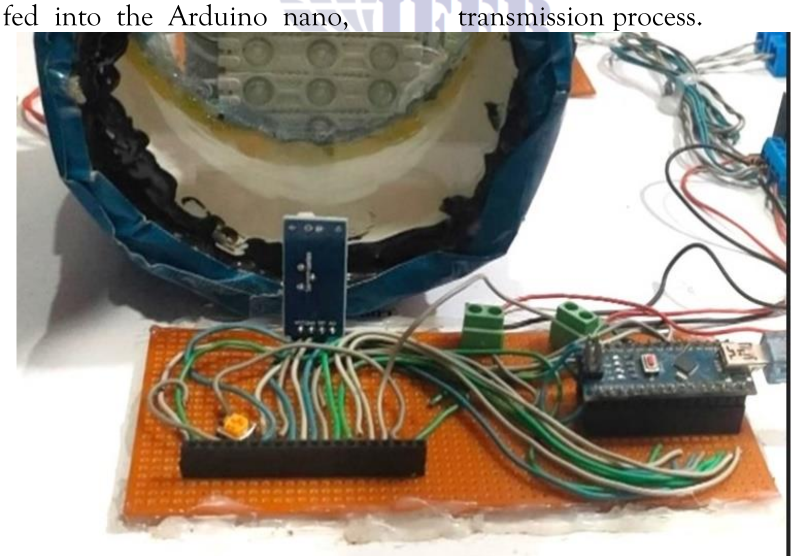

Fig. 10. Data Reception

E. DATA PROCESSING AND CONVERSION

The data processed by the Arduino is transmitted to the computer, where it is further processed in binary form. The Arduino will format the data correctly and send the data to the computer using serial communication over the USB cable at 9600 baud. All the bytes the Arduino sends are received using a Python script run on the computer. In this script, the file is initialized at the beginning by searching for a valid JPEG header to show where the initial image data commences. When the header is found, the script does the padding necessary to complete the data integrity and translate the received binary data to image format. Lastly, the script replicated and projected the picture; hence, the light pulses are confirmed to have been successfully transmitted and converted into a digital picture.

The Python program pins the serial port with a baud rate of 9600 bps and awaits data reception. When the data is received, they are added in a string until a space character is reached, marking the end of transmission. The received string is then modified, trailing spaces are removed and concatenated with a recognized JPEG header. The script has proper base64 padding before they look to decode image information. The base64 string is decoded, after which a byte stream is created, and the image is rebuilt using the PIL library to show the image on the screen. This sequence checks the correct transmission and reconstruction of the image data of the Arduino Nano to the computer.

The last stage of the process is to show the restored picture, as seen in Fig. 11, which can be regarded as visual evidence of successful data transmission decay and a display of the alphabetic decryption. After the Python script has downloaded all the data sent out by the Arduino Nano through the serial port, the data is processed into its standard image format. The last picture captured based on Python Imaging Library (PIL) reflects the relayed information clearly and shows the efficiency of the communication system. This counter shows the result of the entire process of encoding data and taking them to the destination and their effective reception and decoding of the image.

Fig. 11. Received Image

6. EXPERIMENTAL VALIDATION

The system was evaluated underwater to determine data rate, transmission range, and image clarity. The transmitter and receiver were placed in a tank of water at different distances, and the system's capability to transmit and receive images accurately was evaluated. These experiments were carried out using the entire hardware configuration provided in the system design section, which entailed Arduino Nano microcontrollers, LED modules, LDR modules, and other power management elements.

The Underwater Visible Light Communication (UVLC) system recorded the highest data rate (160 bits per second (bps)) when transporting text and images. This performance excellence was foremost due to improvements in modulation techniques, especially Pulse Width Modulation (PWM), which supported effective communications in conditions of light intensity variation. The operating depth of this system underwater was 11 centimeters, making it remarkable considering light attenuation and scattering in water. A higher-power LED and sensitive LDR were used to increase signal detection's signal strength and accuracy, as indicated by the block and hardware schematic diagrams (Figures 9 and 10). Each component was carefully chosen to maximize the system's functioning through the increase in signal strength and accuracy of detection.

To drive the LED module, it would have been tactical to use the TIP122 transistor, which offers good switching performance and is vital in ensuring the data's integrity. On the receiving end, the LDR module played well in converting the light pulses into electrical currents with very little noise since it responds well to changes in light. The USB-to-serial chip was also instrumental since it transferred data from Arduino Nano to a computer where Python script decoded the data sent as images. This recovery mechanism in image recovery prevented all the errors that could have occurred during the reconstruction, thus leading to the proper recovery of the distorted images.

Several tests were performed on the system in a controlled study, such as placing a transmitter and receiver at different distances inside a water container. The findings consistently showed how the system could pass and properly reconcile a high-fidelity picture to the furthest test distance of 11 centimeters. The same performance pattern at various distances in this domain justified the reliability and robustness of the UVLC system for underwater data communication. Comprehensively, the UVLC system, due to its properly designed hardware components and fully integrated software, managed to address the usual challenges of underwater communication. It had a high data rate, provided good signal integrity, and performed well over short distances, proving that it has capabilities in real-world exploration and monitoring under the sea.

7. CONCLUSION

This paper illustrates that underwater visible light communication (UVLC) systems could be used to transmit images in water, and a data rate of 160 bits per second (bps) with an effective transmission length of 11 centimeters was achieved. These findings support the possible usage of visible light communication (VLC) as another alternative communication mechanism in water compared to the traditional and conventional communication mechanisms, especially in applications that expect large amounts of data at a short distance. The research studies done in the future will focus on achieving a greater transmission range coupled with a better data rate through the study of more advanced modulation schemes and the incorporation of error-correcting codes.

REFERENCES

[1] F. Omar, N. Jahan, and R. Mosa, "Li-Fi Technology Based Long Range Free-Space Optics Data Transmit System Evaluation," ICST Trans. Mobile Commun. Appl., (2023).
[2] "Study on the Influence of Underwater LED Illumination on Bidirectional Underwater Wireless Optical Communication," Journal Name, (2023).
[3] S. Laila and T. Xu, "Underwater Communication Acoustic Transducers: A Technology Review," Journal Name, (2023).
[4] "Image and Text Transmission Using Li-Fi Technology," Int. J. Adv. Res. Sci. Commun. Technol., (2023).
[5] "Multi-Node Li-Fi Communications Compliant with IEEE 802.15.7 Standard," Journal Name, (2022).
[6] H. Habib, "Cost-Effective Communication Through Visible Light," Journal Name, (2018).
[7] G.P. Egorychev, "A 1 Gbps VLC System Based on Daylight and Intensity Modulator," Journal Name, (2022).
[8] I. Lövin, "Climate Change Poses a Threat to Our Oceans," Journal Name, (2017).
[9] Y. Gil and D.G. Yoo, "Physical Property Interpretation of Sediments in the Southwestern Slope of the Ulleung Basin, East Sea, Using Downhole Log Data," J. Mar. Sci. Technol., (2016).
[10] F. Demim, R. Bouguessa, A. Rouigueb, and A. Nemra, "A Systematic Overview of Underwater Wireless Sensor Networks: Applications, Challenges, and Research Perspectives," J. Comput. Sci. Res., (2023).
[11] S. Kaveripakam, M. Hamdi, R. Chinthaginjala, G. Pau, A. Ksibi, R. Anbazhagan, M. Abbas, and M. Usman, "Reliable Data Transmission in Underwater Wireless Sensor Networks Using a Cluster-Based Routing Protocol Endorsed by Member Nodes," Electronics, (2023).

[12] P. Pandey, G. Matta, and M. Aggarwal, "Impact of Variable Aperture Area of Receiver on High-Speed OOK Underwater Visible Light Communication System," Journal Name, (2022).
[13] A. Boyle, "Experiment-Based Channel Characteristics for Underwater Wireless Optical Communication Over Medium-and-Long Distance," Opt. Eng., (2023).
[14] C. Wang, S.-Y.R. Li, and K. Wang, "High-Speed Underwater Optical Wireless Communication with Advanced Signal Processing Methods Survey," Photonics, (2023).
[15] "Efficient and Low-Complexity Rate and Dimming Control of VLC for Industrial IoT Applications," IEEE J. Emerg. Sel. Topics Ind. Electron., (2022).
[16] X. Li, Z. Ghassemlooy, S. Zvanovec, and P.A. Haigh, "A 40 Mb/s VLC System Reusing an Existing Large LED Panel in an Indoor Office Environment," Sensors, (2021).
[17] C. He, C. Chen, and J.M. Kahn, "A Review of Advanced Transceiver Technologies in Visible Light Communications," Photonics, (2023).
[18] M.G. Al-Hamiri and H.J. Abd, "Designing a LiFi Transceiver Based Space Time Block Coding with Different Pulses," Journal Name, (2022).
[19] Y. Yang, F. Zhang, Z. Zeng, J. Cheng, and C. Guo, "Visible light communication for vehicular applications: A novel architecture with proof-of-concept prototype," China Commun. 20(6), 249-259 (2023).
[20] B. Aly, M. Elamassie, and M. Uysal, "Vehicular Visible Light Communication with Low Beam Transmitters in the Presence of Vertical Oscillation," IEEE Trans. Veh. Technol., (2023).
[21] M. Morales-Cespedes, "Interference Management in Visible Light Communications Based on Reconfigurable Photodetectors for Industrial IoT," Journal Name, (2023).
[22] T. Ali and W. Balani, "A Robust Pre-Coding and Hybrid Equalization Assisted MIMO-MU Visible Light Communication System for QoS-Centric Indoor Communication," Telecommun. Syst., (2019)