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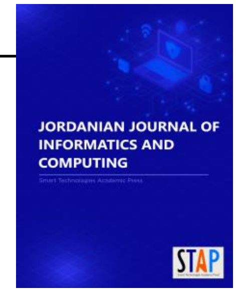


# A Low-Complexity Li-Fi Communication Framework for Short-Range Text Transmission

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## ABSTRACT

Visible Light Communication (VLC) using LED Light Fidelity (Li-Fi) has been proposed as a good substitute for the RF communication, and it uses visible-range electromagnetic spectrum to transmit data. A low complexity text transmission system for short-range LIFI communication is proposed in this paper using low- cost hardware. The proposed one consists of an Arduino-based source and a detector as transmitter and receiver, respectively, where linguistic symbols are used to be encoded in terms of light pulse intensity modulations from the light- emitting diode (LED) and here demodulated in the end back to their respective forms using a Light-dependent Resistor (LDR). The simplistic pulse-duration modulation is used to make symbol detections robust at a minimal amount of computation cost. Details of the entire system, which consists of system architecture, hardware design, and data processing flow, are presented. Experimental results show that it is possible for the accurate transmission of text under indoor lighting at close distances. Due to its low complexity, cost, and immunity to electromagnetic disturbances, the proposed macro-diversity is applicable not only for educational platforms but also for indoor communications where RF communication is limited. The proposed design serves as a workable basis for the future improvements to be made toward higher data rates and more immune V-LC systems.

**Keywords:** Li-Fi, Visible Light Communication, Arduino, Optical Wireless Communication, LED, LDR

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## 1. Introduction

Wireless communication has been an integral part of modern information sharing, and it brings data transfer to numerous applications and diverse environments [1– 3]. The traditional RF-based wireless technology, like WiFi and cellular networks, is based on radio-frequency (RF) spectrum that encounters issues of the spectrum- constrained problem, electromagnetic interference, and security issues for dense indoor and sensitive environments [4–6].

Light Fidelity (Li-Fi), which is a part of Visible Light Communication (VLC) has established itself as an attractive candidate that makes use of visible light to carry information [7–9]. Based on light-emitting diode (LED) technology for both illumination and data transmission, Li-Fi systems inherently possess advantages such as RF interference immunity and improved physical layer security due to the line- of-sight property of radio propagation, in addition to the low-traffic channels in indoor environments[10, 11]. These features render Li-Fi particularly appealing for environments where RF communication is limited or prohibited [12, 13].

Most of the Li-Fi work in the recent literature has been focused on enhancing data transfer rates through elaborate modulation schemes, sophisticated optical receivers, and powerful signal processing methods [14–16]. Although these techniques exhibit remarkable performance, they rely on specialized hardware and computational complexity that is too high for low-cost deployment, prototyping, and educational purposes [17, 18]. Light-emitting diodes (LEDs) can offer this type of optical wireless communication; there is a demand for simple and experimentally confirmed Li-Fi platforms that show basic end-to-end communication with off-the-shelf hardware [19, 20]. Value and practical utility: Simple and low-cost solutions are highly desirable, e.g., for proof- of-concept systems, teaching setups, or initial research studies where practicality and replicability matter the most [21, 22].

Inspired by this deficiency, this paper puts forward a low-complexity Li-Fi system in order to realize lossless short-range text communication through the reasonably simple Arduino. The English letters to be transmitted are encoded into visible light signals by means of a straightforward pulse-width modulation method that is then sent to an LED and subsequently extracted at the receiver side using an LDR. The entire architecture is designed based on low-cost hardware, and the implementation is verified through an experimental test-bed. The main contributions of our work can be summed up as:

- Low complexity, low cost Li-Fi communication framework for short-range text transmission design.
- Realization of an Arduino optical TX/RX system with basic components.
- Experimental verification indicates the realization of successful indoor end-to-end VLP communication.

The rest of this paper is structured as follows. In Section2, related works on Li- Fi and VLC systems are analyzed. The proposed system architecture is discussed in Section3. Hardware and circuit design are described in Section4. The experimental results and discussion are presented in Sec.5. The last sections address perspectives and open issues, as well as concluding remarks.

## 2 Related Work

Light Fidelity (Li-Fi) and Visible Light Communication (VLC) represent an interesting research area as far as alternative solutions to radio-frequency communication systems are concerned. Vasudevan et al. [23] presented an intelligent and secure Morse code–inspired Li-Fi communication that encodes text data into Morse code with a laser module. The optical signals are received and decoded by a microcontroller, and accurate long-distance transmission with low processing delay can be achieved. Rajan et al. [24] proposed an underwater Visible Light Communication (Li-Fi) system for reliable high-density data transfer below the sea surface. As an example, the potential of optical links based on "blue green" light is exploited considering short-to-medium ranges underwater, and their feasibility and performance are evaluated under several kinds of underwater environment conditions. Vijayalakshm et al. [25] explored a Li-Fi aided MANET architecture to improve the security and low-latency data transfer. By combining multipath routing with visible light communication, the developed solution minimizes end-to-end-delay and capitalizes on Li-Fi's speed of operation and spectral efficiency to enhance disaster-resilience in wireless networks. Kusanur et al. [26] study the potential of Li-Fi for underwater wireless communications in various water environments. Results show that the channel characteristic (power spectral density, SNR, and data rate of the system) greatly depends on water quality over a short link distance, indicating that underwater water quality highly impacts performance and proving that Li-Fi is a good candidate for UWC. Lau et al. [27] propose an mmWave – Li-Fi hybrid 5G architecture for vehicular communication in the context of autonomous driving. A reconfigurable MIMO-based PoC is evaluated via simulation and actual Li-Fi experiments, showing low-latency performance of the system with a good potential for low-speed AD applications. Faruq et al. [28] present an analytic study of Light Fidelity (Li-Fi) as a promising substitute for Wi-Fi for secure and high data rate wireless communication. Through visible light, VLC-enabled techniques and optical receivers are shown to demonstrate Li-Fi's potential in LOS/NLOS data communications at high speed. Zhang et al. [29] propose a bidirectional LiRF transceiver, called LiRF, to facilitate the coexistence of VLC with RF-based IoT networks. A prototype with WiFi-6 NICs achieves near Gbps data rates, verifying the feasibility of high-speed, low-latency IoT applications on LiRF. Udu [30] proposes a machine learning (ML) based optimization framework for DC bias in DCO-OFDM Li-Fi systems in this paper. Due to identifying favorable bias settings, it mitigates clipping noise and also improves BER performance, besides its power-efficient behavior as a result of indicating the suitability being promising for adaptive and robust Li-Fi in indoor communication.

A series of Arduino-based Li-Fi and VLC testbeds has been published for educational purposes and proof-of-concept demonstrations. They generally illustrate basic optical communication principles, but do not exhibit an explicit architectural frame- work, systematic circuit design, and experimental discussion, which is good enough to include in research papers. Instead of traditional approaches, which are for high data rates or efficient architectures, this contribution presents a simple yet low complexity experimentally verified Li-Fi Solution for short-range text transmission. The system uses simplistic pulse-duration modulation and cheap optical components, resulting in a feasible, widespread platform, aiming to bridge the gap between LiFi theoretical research and the practical implementation.

## 3. System Architecture

In this section, we illustrate the general structure of the low-complexity Li-Fi communication system. The system is proposed to support short-distance text communication via visible light with low hardware support and computational cost. The prototype considered here adopts a point-to-point communication paradigm, with two devices named Li-Fi transmitter and Li-Fi receiver that can be built at low cost by using Arduino microcontrollers and off-the-shelf electronic hardware.

### *3.1 Overall Framework*

The under consideration Li-Fi system does this by leveraging an energy-independent FS basis whose elements are optical signals transmitted over the wireless communication channel from a transmitter using light-emitting devices (LEDs), that convert input text symbols to modulated light at one end, and by performing an optical sensing mechanism that converts received modulated lights into original characters at the other/ receiver end. In sharp contrast with RF communication, the data is Light emit- ted by an LED source, hence immune to electromagnetic interference, and it has been observed that it offers better physical layer security.

At the transmitting end, user input is made through a keypad interface. The input character is processed by the Arduino microcontroller and transposed to a predetermined pulse-width sequence. This pattern is designed to modulate the ON⁄OFF keying of the LED so that each symbol is identifiable by a distinct duration of light pulse. The fast switching between the LED states is invisible to humans but can be detected by optical sensors.

The incoming light pulse is received by a photo resistor (a.k.a. LDR) and translated into equivalent electrical signals. These signals are processed by an Arduino micro- controller that reads the pulse time duration and decodes the received symbol using calibrated timing limits. Then the ASCII character of the button pressed is shown on a 16×2 LCD screen (end device).

### *3.2 Li-Fi Transmitter Design*

Predetermined period and then off by the digital output pin of Arduino. This pulse- duration modulation technique achieves simple and efficient symbol differentiation without any sophisticated modulation or signal processing schemes. The transmitter architecture is cost-effective and has a simple implementation. A switching stage based on a transistor is used to drive the LED with the necessary current and to provide protection for the microcontroller. This allows for consistent light output and stable transfer over short indoor ranges.

### *3.3 Li-Fi Receiver Design*

As shown in Figure 1, the Li-Fi transmitter subsystem is in charge of transforming text data into visible light. This system is composed of an Arduino Uno as the microcontroller, a 4×4 matrix keypad for user input, and a high-brightness LED (Light-Emitting Diode) used as the optical transmitter.

When you press a key, the built-in Arduino function reads its corresponding character and selects a pulse time to represent that character. The LED is turned on for predetermined period and then off by the digital output pin of Arduino. This pulse-duration modulation technique achieves simple and efficient symbol differentiation without any sophisticated modulation or signal processing schemes. The transmitter architecture is cost-effective and has a simple implementation. A switching stage based on a transistor is used to drive the LED with the necessary current and to provide protection for the microcontroller. This allows for consistent light output and stable transfer over short indoor ranges.

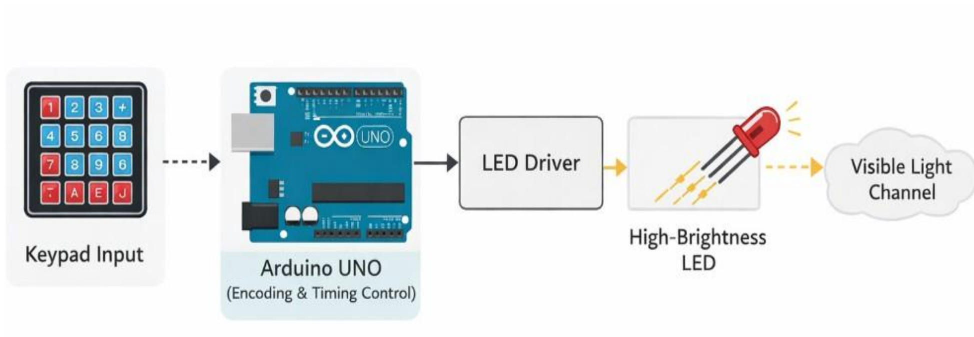


**Figure 1.** Li-Fi transmission circuit based on Arduino

As shown in Figure 2, the Li-Fi receiving sub-system can detect the modulated light signals transmitted by an LED. It is made of an LDR sensor, signal conditioning circuits, an Arduino UNO microcontroller unit, and a 16×2 LCD for data display.

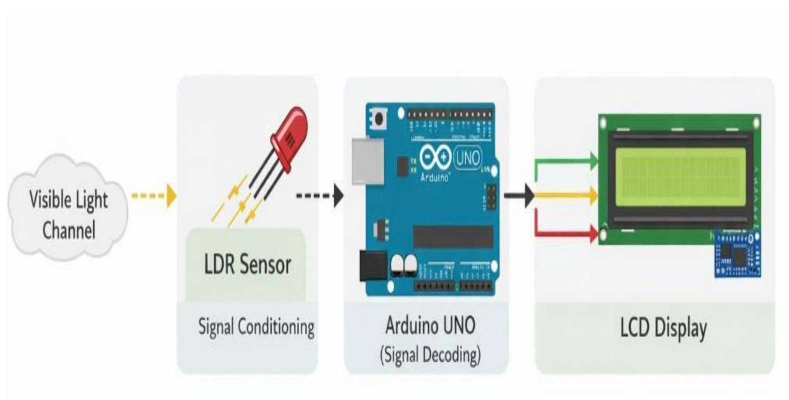


**Figure 2.** Li-Fi receiver circuit based on Arduino

When the LED pulses cause changes in the intensity of light, the LDR reacts to this and generates electric signals. The Arduino reads these signals and uses its internal timers to calculate each pulse duration. According to a certain range for a period of time, we can acquire the incoming pulse to refereed character. A variable resistance is employed to adjust the sensitivity of the LDR circuit in order to maintain stable operation under different light conditions. That affords accurate pulse detection with a simple hardware design. The received text can be viewed on the LCD in real time, making it a friendly user feedback.

## 4. Hardware Components and Circuit Design

Hardware components and Circuit implementation for the proposed low-entitlement Li-Fi communication framework are presented in this section. The design focuses on simplicity, cost-effectiveness, and replication, as well as reliable short-range visible light data communication.

*4.1 Hardware Components*

The developed system is based on electrical components that are readily available with modern PCs, centered on an Arduino-controlled platform. As shown in Figure 3, the main hardware components are summarized as follows:

- Arduino UNO: Serves as the transmitter-side and receiver-side CPU. It manages data encoding, timing control, pulse measurement, and symbol decoding.
- Light-Emitting Diode (LED): As the optical transmitter is employed, a high-brightness 5-mm LED. Rapid ON–OFF switching is applied to modulate the LED intensity to encode textual symbols.
- Light-Dependent Resistor (LDR): Acts as the photo-detector at the receiver. It changes the received variations of visible light to the corresponding electric signals.
- 4×4 Keypad: Provides user input at the transmitter end to select text characters to be transmitted.
- LCD Display: Displays the decoded message at the receiver side while reducing wiring complexity.
- Passive Components: Stabilized resistance units and sliding resistance are employed for signal conditioning and sensitivity control.
- Power Supply: The power is obtained from the regulated supply of the Arduino, which allows all devices work in a stable manner.

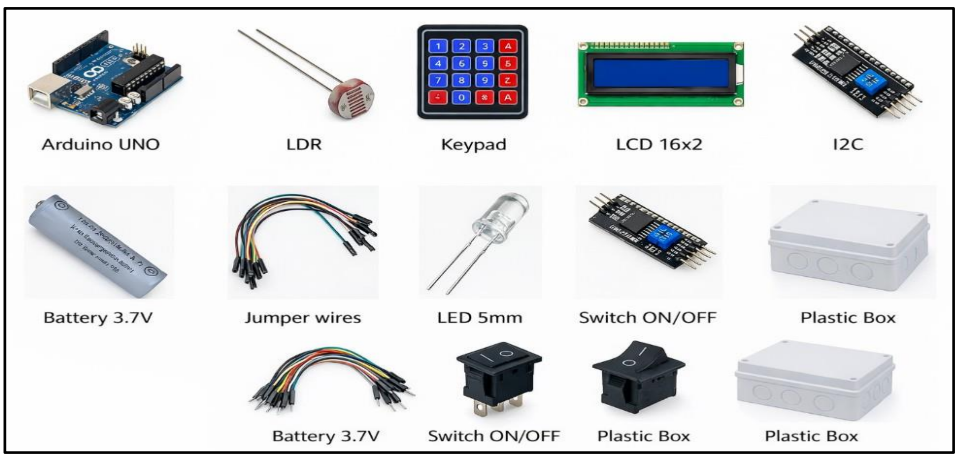


**Figure 3.** Collection of system components

*4.2 Transmitter Circuit Design*

The transmitter circuit is configured to convert digital text input into modulated visible light 18 5 signals. Figure 4 demonstrates that the keyboard is connected with Arduino Uno to input letters which user runs on it. So letters will be

detected by using this method; we went through only that much length in letter combinations that are like evidence. Every character is assigned an associated pulse length in the microcontroller.

**Figure 4.** Arduino-based Li-Fi transmitter circuit

The LED is controlled by the Arduino using a digital output pin to pulse-width modulate signals. To drive enough current and for microcontroller protection, a small switching stage is used. The LED flickers at a rapid speed to create light pulses that represent the encoded text symbols but which are too fast for the human eye to notice. The solution does not include any complicated modulator or amplifier parts, and thus both hardware complexity and power reduction are kept to a minimum.

*4.3 Receiver Circuit Design*

The receiver circuit translates the received optical signal to an electrical signal and reconstructs the transmitted text. As shown in Figure 5, the LDR receives the modulated light from the transmitter and generates a voltage signal according to the detected intensity of the measured light.

A resistive conditioning network provides for stabilizing sensor outputs and compensating for their sensitivity to the presence of different ambient light levels. The conditioned signal is then sent to a microcontroller (Arduino UNO), which records the duration of the pulse using internal timers. Each received pulse is decoded by duration comparison with predetermined threshold times for specific characters. The decoded characters are shown on a 16×2 LCD module via an I2C interface. In this setting, it allows to simplify the wiring of individual sensors and at the same time gives immediate visual feedback on received data.

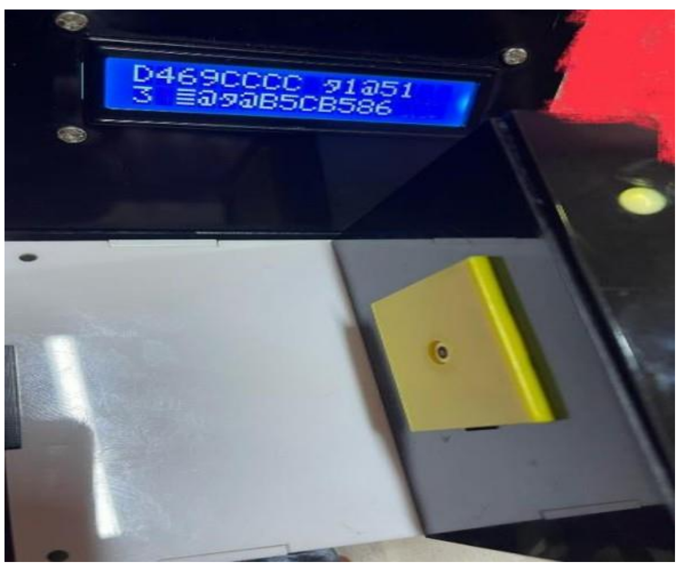


**Figure 5.** Arduino-based Li-Fi receiver circuit.

*4.4 Design Considerations*

Some considerations to ensure that the hardware design of the proposed Li-Fi communication framework is practical, reliable, and easy-to-implement were taken into account.

• Low Complexity and Cost Efficiency: The system has been constructed using a few and easy-to-find devices: an Arduino UNO, one LED, and an LDR sensor. Such a selection minimizes the complexity of circuits and development time, also lowering the cost and making the structure applicable to educational purposes, prototyping, etc.

• Reliable Short-Range Operation: Discussions about the Future. The short communication distance factor is emphasized, to van Stable pulse detection is the focus not high data rates. Pulse duration modulation is chosen due to its simplicity and robustness, and the fact that it works efficiently in resource-poor microcontroller systems.

• Ambient Light Robustness: For compensation of fluctuations in the ambient light, the receiver side comprises a resistive signal-conditioning network with tunable sensitivity. This ensures the reliability of operation using usual indoor lighting conditions.

• Energy Efficiency: Simple ON–OFF switching is used to drive the LED without any additional amplification stages, resulting in low power consumption. It can be powered by the Arduino's regulated supply or by a small battery for portable use.

• Modularity and Scalability: The structure is designed modularly, so the interchange-able parts can be replaced or upgraded separately. Later improvements, such as faster LEDs, optical lenses, or more advanced modulation techniques, could be added without necessitating redesign of the entire sensor.

## 5. Experimental Results and Discussion

The verification experiments on the proposed low-complexity Li-Fi communication model are depicted in Figure 6. The receiver module with the decoded text characters displayed on a 16×2 LCD after transmission through the visible light is shown.

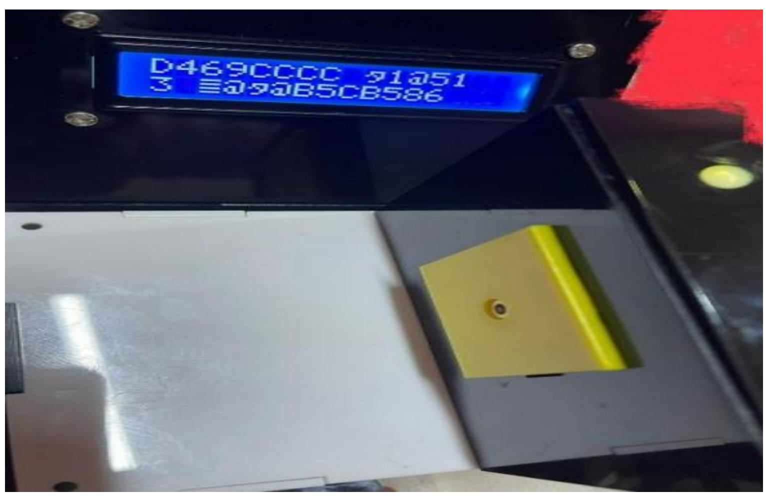


**Figure 6.** Experimental result of the proposed Li-Fi communication system

Text character input was performed with the keypad at the transmitter side, and pulse duration-modulated visible light signals were encoded by an LED during the experiment. The receiver, implemented with an LDR sensor and Arduino UNO micro- controller, was able to receive and decode the transmitted light ON-OFF patterns. The retrieved characters were shown on the LCD, and verified correct end-to-end system performance. This outcome proves that the visible light for short-distance text transfer is practical, and it has very small hardware as well as computational complexity. The good reception of the transmitted data demonstrates the validity of our proposed encoding and decoding mechanism for a line-of-sight indoor environment. While the range and modulation are limited for practical implementation, it stands as a robust proof of concept for inexpensive Li-Fi.

*5.1 Applications*

The low-complexity Li-Fi communication scheme is attractive for various short- distance secure interference-free wireless communication scenarios. For its ease and reliance on visible light, the system is especially suitable for indoor programmed environments.
• Indoor Communication Systems: The scheme can be applied for short-range TX based on situational indoor text communication in the offices, labs, and classrooms where visible light sources are accessible, and LOS connection can be achieved.
• Electromagnetic Interference (EMI)–Sensitive Environments: Because Li-Fi does not depend on RF communications, the proposed system is suitable in RF- limited and/or prohibited environments such as hospitals/medical laboratories and industrial plants.
• Educational and Training Platforms: The hardware and software are quite simple, so that the model can be effectively used for educational purposes. It can also function as a handy educational kit for illustrating visible light communication, optical modulation, and embedded system concepts.
• Smart Lighting and IoT Applications: With minimal modifications, this framework could be deployed with smart lighting infrastructures for transmitting low-data-rate IoT data through off-the-shelf LED lights.

## 6. Discussion

In spite of the increasing interest in Light Fidelity (Li-Fi) and visible light communication, current work is mainly devoted to high-data-rate systems, complex modulation schemes, or advanced optical receivers. Many of these techniques involve custom hardware, complex signal processing, and/or simulation-based validation, making them limited in practical availability for low-cost implementation and educational consumption.

### *6.1 Research Gap*

The end-to-end text communication is experimentally poorly evaluated within Li-Fi low-complexity frameworks, which use concise circuits and low computational hard- ware. Of these, few treatments offer practical setups using off-the-shelf microcontrollers and simple optical parts, with explanations of the system architecture, circuit designs illustrated by hands-on experimentation—all from the frontlines of cutting-edge hacking. The work introduced in this paper fills that gap by designing and evaluating a simple Li-Fi Arduino-based short-range text communicator using pulse-duration modulation together with a low-cost optical sensor and real hardware experimentation.

### *6.2 Open Issues*

Although the satisfactory performance of the proposed low complexity Li-Fi communication scheme has been demonstrated, there are some open issues that still need to be addressed for better performance and implementation in practical systems.

• Limited Data Rate: Due to small pulse-duration modulation and an LDR for reception, a low data rate is supported. Higher-order modulation schemes and faster receivers may also lead to increased throughput.

• Ambient Light: As ambient light changes, it may influence the detection and decoding accuracies. Approaches based on adaptive thresholding or optical filtering can be considered to improve robustness.

• Short Communication Range: System requires LOS and works efficiently in small distances. Optics or higher power LEDs could be used to increase transmission range.

• Reliability and Error Handling: The MNNER system does not include error detection or correction mechanisms, which could make the system less reliable in the presence of noise.

• Scaleability: The support of multiple transmitters and/or even multiple receivers is an open issue that can be addressed from a system extension point of view. Solving these challenges presents a research direction that is expected to lead to more robust, scalable, and application-proven Li-Fi systems [31-33].

### *6.3 Future Work*

Though the suggested simple Li-Fi communications system effectively achieves the short-range visible light text-related transmission, some issues also arise as open problems and prospective areas for future studies.

• Data Rate Enhancement: The present system uses a basic pulse-width modulation and an LDR sensor, which restricts the emission bitrate. Future designs may con- sider faster photo-detectors and other advanced modulation to enhance throughput without increasing complexity, such as power consumption, circuit area, and so on.

• Ambient Light Interference: While the system performs well in normal indoor light-ing conditions, intense ambient light sources can pose a degradation on decoding accuracy. The robustness to different illumination conditions can be improved by adding optical filters, adaptive thresholding, and automatic gain control.

• Transmission Range: The communication range is limited by the power of the LED and the sensitivity of the sensor. Optical lenses and/or higher-power LEDS or improved receiver circuitry can increase the operating distance.

•Error Control and Reliability: Error detection and correction are not supported in the current design. Potential extensions include the incorporation of small error control mechanisms for better reliability in communication.

•Scalability and Integration: Extending the framework to accommodate multiple transmitters or receivers and integrating it with other IoT or smart lighting systems are open research areas.

## 7. Conclusion

In this paper, we introduced a simplified Li-Fi communication system that is capable of short-distance text transmission through visible light with low complexity. In order to achieve a simple, pragmatic prototype, the designed measurement system made use of low-cost hardware equipment and deployed an Arduino-compatible sensor node. Text converted to light-pulse duration modulated signals (at the transmitter by an LED) were successfully recovered at a receiver using an LDR and a microcontroller. Experiments demonstrated proper end-to-end operation of the intended platform in an indoor line-of-sight scenario, with received text displayed correctly on an LCD panel. These results indicate the successful realization of short-range communication based on visible light alone, rather than a radio frequency signal. While the rates and transmission range of the present system are sedate, this is a demonstration that realish world, low-cost Li-Fi can be achieved. Further developments might concern robustness, increasing data rates, and the range of distances for deployment in other indoor communication and educational contexts.

## Conflicts Of Interest

The author declares no conflicts of interest.

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