International Journal of
AI Electronics and Nexus Energy
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0515 www.zesterapublications.com Original Research Paper

Li-Fi Based Secure Communication System Using Arduino for High-Speed Data and Audio Transmission Applications

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Abstract

The increasing demand for high-speed and secure wireless communication has driven the exploration of alternative technologies, with global data traffic expected to exceed 180 zettabytes annually and traditional RF-based systems facing challenges such as bandwidth limitations, interference, and security vulnerabilities. Traditional wireless communication systems like Wi-Fi and Bluetooth operate on radio frequencies, which are prone to interference, congestion, and potential security breaches due to signal leakage beyond physical boundaries. Furthermore, conventional systems may not provide sufficient bandwidth for high-speed data and audio transmission in dense environments. To address these challenges, the proposed Li-Fi communication based secure data and audio transmission system utilizes visible light communication integrated with the Arduino Uno using the UART protocol for efficient asynchronous data transfer. The system employs high-frequency LED flickering to transmit text (hexadecimal data) and audio signals through light waves, which are received and decoded by a photodetector at the receiver end. UART ensures reliable and synchronized communication between modules, enhancing system performance. This optical communication approach provides enhanced security since light signals do not penetrate walls, reducing the risk of interception. The system offers high-speed transmission, low interference, and improved data capacity, making it a robust solution for secure communication applications.

Keywords: Audio Transmission, Li-Fi Communication, Optical Wireless Communication, Secure Data Transmission, UART Protocol, Visible Light Communication, Wireless Communication System

1. Introduction

The increasing demand for high-speed and secure wireless communication has driven the exploration of alternative technologies beyond conventional radio frequency (RF) systems. Global data traffic is expected to exceed 180 zettabytes annually, placing immense pressure on existing communication infrastructure [1]. Traditional RF-based systems such as Wi-Fi and Bluetooth face significant challenges including limited bandwidth, signal interference, and security vulnerabilities. As a result, optical wireless communication technologies like Li-Fi are gaining attention [2], with projected growth rates exceeding 20% annually. In applications such as military communication, healthcare data transfer, industrial automation, and secure indoor networking, there is a critical need for systems that provide high-speed, interference-free [3], and secure data transmission.

Traditional wireless communication systems operate using radio frequency signals, which are inherently susceptible to interference from other devices and environmental factors [4]. In densely populated areas, network congestion can significantly reduce data transmission speed and reliability. Additionally, RF signals can penetrate walls and propagate over long distances, making them vulnerable to

Received: 03-03-2026 | Accepted: 06-04-2026 | Published: 13-04-2026

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unauthorized access and security breaches [5]. Conventional systems also struggle to meet the growing demand for high-bandwidth applications such as real-time audio and large data transfers [6]. Furthermore, these systems may not provide adequate data integrity and confidentiality required for sensitive applications, limiting their effectiveness in secure environments.

In real-time scenarios, these limitations create several critical challenges affecting communication performance and security. Interference and congestion can lead to data loss, reduced transmission speed, and unreliable connections, especially in crowded networks [7]. The risk of signal interception increases the chances of data breaches, particularly in applications involving sensitive information. Additionally, limited bandwidth restricts the ability to transmit high-speed data and audio simultaneously. The lack of secure and confined transmission channels further compromises system reliability [8]. These challenges highlight the need for an advanced communication system based on Li-Fi technology, which utilizes visible light for data transmission, offering enhanced security, higher bandwidth, reduced interference, and efficient performance for modern communication requirements.

2. Literature Survey

Al-Moliki et al. [9] proposed a secret key generation protocol for optical Orthogonal Frequency Division Multiplexing (OFDM) systems in indoor Visible Light Communication (VLC) networks. Zhang et al. [10] proposed a study on physical layer security in Light Fidelity (Li-Fi) systems, analyzing techniques to secure optical wireless communication.

Haas et al. [11] proposed an introduction to indoor networking concepts and challenges in Li-Fi systems, focusing on architecture, interference, and deployment issues. Dahri et al. [12] proposed a review of modulation schemes for Visible Light Communication, analyzing techniques such as intensity modulation and direct detection.

Hamada et al. [13] proposed an analysis of Li-Fi system architecture and modulation techniques, focusing on system design and communication efficiency. Oyelade et al. [14] proposed a Li-Fi-based patient monitoring system that enabled data transmission using light communication for healthcare applications.

Yao et al. [15] proposed a performance comparison of Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Differential Phase Shift Keying (DPSK) in VLC systems. Elamrawy et al. [16] proposed a performance analysis of indoor VLC systems using different Light Emitting Diode configurations and photodetectors.

Chen et al. [17] proposed high-speed Li-Fi transmission systems achieving 100 Gbps indoor access and 4.8 Gbps outdoor communication using laser-based light sources. Arfaoui et al. [18] proposed measurement-based channel models for indoor Li-Fi systems to improve communication reliability and performance prediction.

Palitharathna et al. [19] proposed a neural network-based blockage prediction and optimization method for hybrid VLC and Radio Frequency (RF) systems. Miramirkhani et al. [20] proposed channel modeling and characterization techniques for VLC systems, focusing on signal propagation and environmental effects.

3. Proposed System

Figure 1 illustrates the Li-Fi transmitter (TX) module, which is responsible for converting input data into light signals for wireless communication. The system is powered by a regulated power supply and accepts input data in the form of audio or text. The Li-Fi

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transmitter circuit processes this data and converts it into binary form, where logical '1' is represented by LED ON and '0' by LED OFF. These rapid switching operations are performed at speeds faster than human visual perception, enabling invisible data transmission through light using an LED array.

Step 1: Power Supply Initialization: The regulated power supply provides stable DC voltage to the Li-Fi transmitter circuit and LED array for consistent operation.

Step 2: Input Data (Audio/Text): The system accepts input signals such as audio or text, which are converted into digital binary data for transmission.

Step 3: Data Encoding and Modulation: The Li-Fi transmitter circuit encodes the input data into binary format and modulates it by rapidly switching the LED ON and OFF. This modulation represents digital bits (1s and 0s).

Step 4: LED-Based Optical Transmission: The LED array transmits the encoded data as light signals. Due to high switching speed (less than 1 μs), the flickering is invisible to the human eye.

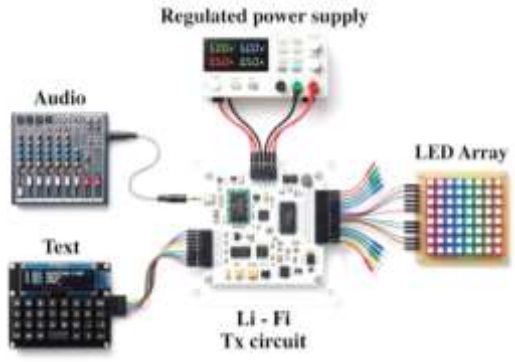


Figure 1. Li-Fi Transmission Module Using LED Array.

Figure 2 illustrates the Li-Fi receiver module, where an Arduino microcontroller acts as the central processing unit. The system uses a Li-Fi receiver circuit (photo detector) to capture light signals transmitted from the LED array. These optical signals are converted back into electrical signals and decoded into original data. The processed data is then displayed on an LCD or output through a speaker. The system is powered by a battery, making it portable and suitable for vehicle-based or mobile applications.

Step 1: Power Supply (Battery): The receiver module is powered by a battery, ensuring portability and uninterrupted operation.

Step 2: Light Signal Reception: The Li-Fi receiver circuit, consisting of a photodetector, receives the modulated light signals transmitted from the LED array.

Step 3: Signal Conversion: The photodetector converts the received light signals into corresponding electrical signals.

Step 4: Data Decoding using Arduino: The Arduino microcontroller processes and decodes the electrical signals to retrieve the original audio or text data.

Step 5: Output Display and Audio: The decoded data is displayed on the LCD screen and can also be played through a speaker for audio output.

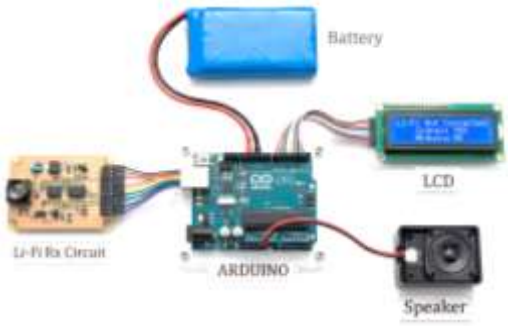


Figure 2. Li-Fi Receiver (RX) Module Using Arduino.

3.1 Working Procedure

Visible light is a new technique for data transmission method as shown in Figure 3. Li-Fi, data is transmitted by modulating the intensity of the light, which is then received by a Photo-sensitive detector, consists of a light source as a transmitter and detector as a

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receiver. Louder the voice, the glow of the LED will be more. The receiver section interprets the incoming light which is detected using a solar panel and converts to the audible sound signal with the help of Speaker. Hence with Li-Fi this method is made sophisticated by using more than one LED and passing more than one data stream at a given time. This way more information can be passed, and hence faster data communication is possible.

In the process of audio communication through the visible light, on the transmitter side an audio signal (any music from mobile) is used as the input signal. This signal is fed to the LED. The light signal from the LED varies according to the intensity of an audio signal. At the receiver side light dependent resister will receive the light signal and correspondingly generate an electrical signal proportional to it. This electrical signal is processed by a low voltage audio power amplifier, which is then fed to a speaker, and it produces the audio signal which was at the input of the transmitter side.

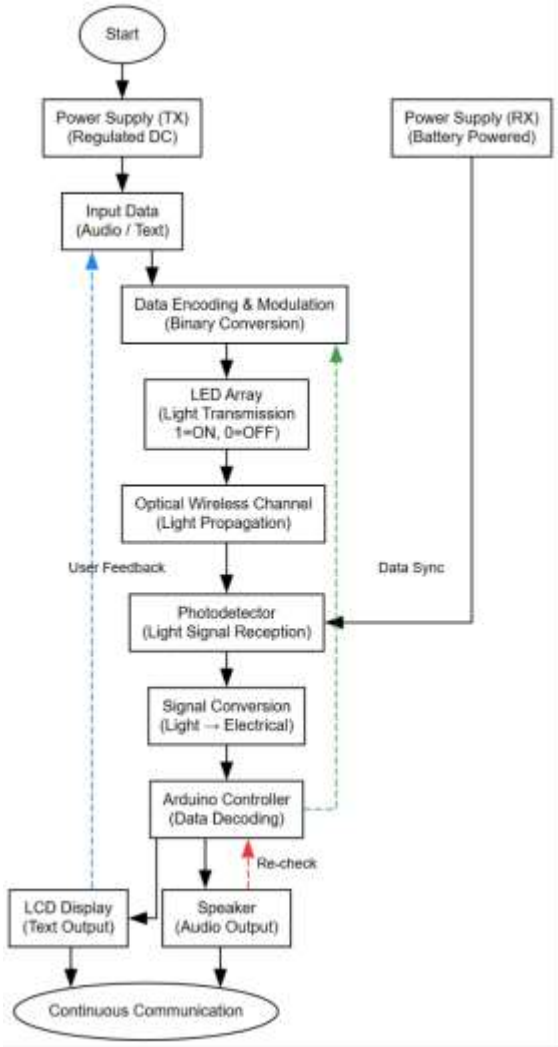


Figure 3. Proposed Flowchart.

Figure 4 illustrates the transmitter (Tx) section of a LiFi-based communication system designed for high-speed wireless data transmission using visible light. The system is powered by a regulated power supply unit consisting of a transformer, bridge rectifier, filter capacitors, and a 7805 voltage regulator to provide a stable +5V output. Input data in the form of PC text or voice signals is fed into a UART module, which converts the data into serial form and forwards it to the LiFi transmitter circuit. The LiFi TX circuit modulates this data onto light signals using an LED array, which acts as the transmission medium. The variation in light intensity carries the encoded information, enabling secure and interference-free communication.

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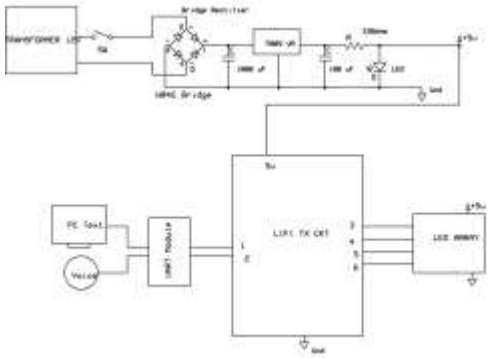


Figure 4. Transmitter Schematic Diagram of LiFi-Based Communication System.

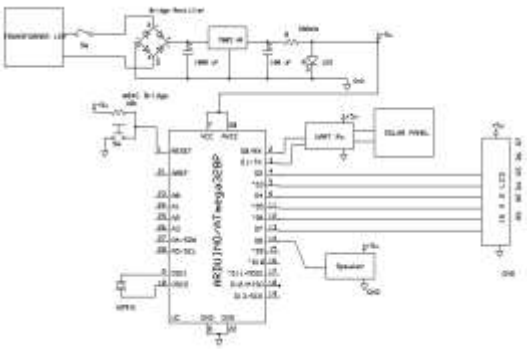


Figure 5. Receiver Schematic Diagram of LiFi-Based Communication System.

Figure 5 presents the receiver (Rx) section of the LiFi-based communication system integrated into a vehicle unit. The system uses a regulated power supply like the transmitter side for stable operation. An Arduino ATmega328P microcontroller acts as the central processing unit, receiving optical signals through a LiFi receiver (UART Rx) module connected to a solar panel or photodetector. The received light signals are demodulated into electrical signals and processed by the microcontroller. The decoded information is displayed on a 16×2 LCD and can also be converted into audio output through a speaker for voice alerts. This system enables reliable vehicle-to-infrastructure communication, enhancing road safety and real-time information delivery.

4. Results and Discussion

The system starts with a 230V AC to 12V AC adapter, then regulated to 5V DC as shown in Figure 6. The stabilized voltage powers a UART and LCD module for data transmission and reception. An Arduino board processes the data, sending it to a transmitter circuit with three ICs. The transmitter converts data into electrical signals, sent to an LED array, producing a light source.

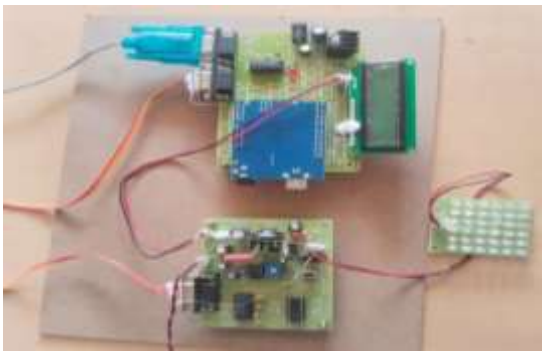


Figure 6. Hardware Design of Transmitter Block.

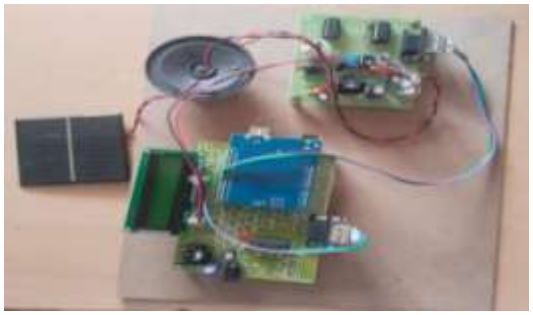


Figure 7. Hardware Design of Receiver Block.

In the receiver section as shown in Figure 7, the LED array's light is absorbed by a solar panel, converting it back into electrical energy. The energy is transferred to a receiver circuit with a single LM386 IC, which processes the signal, separating audio and text data. Audio data is played through a speaker, while text data is displayed on an LCD screen via an Arduino board.

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Figure 8. Visible Light Communication Outcome.

The system transmits data through a Li-Fi transmitter, converting electrical signals into light as shown in Figure 8. The light is received by a solar panel, converting it back into electrical energy. The receiver circuit processes the signal, separating text and audio data. The text data is displayed on an LCD screen via an Arduino board, while the audio data is played through a speaker. The final output is presented in a way that both text and audio can be displayed or played simultaneously.

5. Conclusion

The proposed Li-Fi communication based secure data and audio transmission system presents an innovative and efficient alternative to conventional RF-based wireless communication by leveraging visible light for high-speed and secure data transfer. By integrating LED-based transmission with photodetector reception and utilizing UART protocol through the Arduino Uno, the system ensures reliable and synchronized communication of both text and audio signals. Unlike traditional wireless technologies, Li-Fi offers enhanced security as light signals are confined within physical spaces and do not penetrate walls, significantly reducing the risk of interception. Additionally, it provides higher bandwidth, minimal interference, and improved data transmission efficiency, making it suitable for dense and sensitive environments. Finally, this system addresses the limitations of existing communication methods and contributes to the development of fast, secure, and next-generation wireless communication technologies.

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