International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Arduino-Based Li-Fi System for Text Data Transfer Using Smartphone Flashlight

Priyanshu Kumar[1], Navjot Singh[2], Jaideep Singh Chouhan[3], Kunal Singh Rathore[4], Dr. Jai Sukh Paul Singh[5], Asha Rani Ma'am[6]

[1,2,3,4] Dept. of Computer Science and Engineering Lovely Professional University Phagwara, India
[5]Dept. of Space Research & Engineering Lovely Professional University Phagwara, India
[6]Dept. of Electronics and Electrical Engineering Lovely Professional University Phagwara, India
Priyanshu.kumar.lpugc24@gmail.com, Kunalsingh.rathore.lpugc24@kalvium.community, Navjot.6002singh@gmail.com
Jaisukhpal.23875@lpu.co.in, jscofficially@gmail.com

Abstract—

The increasing demand for wireless communication has spurred interest in Light Fidelity (Li-Fi), a technology that leverages visible light for high-speed, secure, and interference free data transmission. This paper presents a low-cost Arduino based Li-Fi system designed for text data transfer using a smartphone flashlight. The system employs an Arduino Uno as the processing unit, a Light Dependent Resistor (LDR) module to detect light intensity variations, and an I2C-enabled LCD to display received messages. A custom smartphone application converts user-input text into binary-encoded light pulses, which are transmitted via the flashlight. The Arduino decodes these pulses into ASCII characters, achieving a data rate of approximately 5 characters per second over a 30–50 cm range under controlled lighting conditions. Experimental results demonstrate the system's reliability and potential for applications in secure environments like hospitals and classrooms. This work highlights the feasibility of optical wireless communication using accessible hardware, offering a cost-effective alternative to traditional radiofrequency systems.

Keywords & Terms—Li-Fi, Arduino, LDR Sensor, Optical Wireless Communication, Smartphone Flashlight, I2C LCD, Low-cost Communication

I. INTRODUCTION

The global demand for wireless communication has surged exponentially, with projections estimating over 22 billion connected devices by 2025 [1]. This proliferation of Internet of Things (IoT) devices, smartphones, and smart appliances has placed unprecedented pressure on traditional radio-frequency (RF) communication systems, such as Wi-Fi and Bluetooth. RF-based systems operate in the crowded 2.4 GHz and 5 GHz bands, leading to challenges including spectrum congestion, electromagnetic interference, and security vulnerabilities [2]. As mobile data traffic is expected to grow at a compound annual growth rate of 46% through 2027 [3], the limitations of RF systems necessitate innovative alternatives to meet the escalating demand for high-speed, secure, and reliable wireless communication.

Light Fidelity (Li-Fi), a subset of Visible Light Communication (VLC), emerges as a transformative solution by utilizing the visible light spectrum (400–700 nm) for data transmission. Unlike RF systems, Li-Fi modulates light intensity at high speeds, imperceptible to the human eye, to encode and transmit data. This approach offers several advantages: a vast, unlicensed bandwidth up to 10,000 times greater than RF spectrum, immunity to electromagnetic interference, and enhanced security due to light's inability to penetrate walls [4]. These properties make Li-Fi particularly suitable for environments where RF communication is restricted, such as hospitals, aircraft cabins, and secure military facilities [5]. Furthermore, Li-Fi's potential for high data rates—exceeding 100 Gbps in controlled settings—positions it as a candidate for next-generation wireless networks [6].

The principle of VLC relies on modulating light sources, such as Light Emitting Diodes (LEDs), to transmit binary data. A typical Li-Fi system comprises a transmitter that modulates light intensity and a receiver equipped with a photodetector, such as a photodiode or Light Dependent Resistor (LDR), to decode the light signals. Recent research has explored integrating VLC with ubiquitous devices to reduce costs and enhance accessibility. Smartphones, with their powerful processors, built-in LED flashlights, and programmable interfaces, serve as ideal platforms for transmitting data via light modulation. Similarly, Arduino microcontrollers, known for their affordability and versatility, provide a robust foundation for developing low-cost receivers capable of decoding light signals [7].

Despite these advancements, many LiFi implementations remain complex, requiring specialized hardware such as high-speed LEDs or costly photodiodes. This complexity limits their adoption in educational settings and among hobbyists. To address this gap, this paper presents a low-cost Arduino-based Li-Fi system for text data transfer using a smartphone flashlight as the transmitter. The proposed system leverages widely available components: an Arduino

Uno microcontroller, an LDR module, an I2C Liquid Crystal Display (LCD), and a smartphone. By encoding text input into binary light pulses, the system achieves a data rate of approximately 5 characters per second over a transmission range of 30–50 cm. This performance, while modest compared to high-end Li-Fi systems, demonstrates the feasibility of optical wireless communication using consumer-grade hardware.

The motivation for this project stems from the need for accessible, secure, and cost-effective communication solutions. Traditional RF systems, while ubiquitous, pose security risks in sensitive environments due to their susceptibility to eavesdropping. LiFi, by contrast, confines data transmission to the illuminated area, offering inherent physical-layer security [8]. Additionally, the use of a smartphone flashlight eliminates the need for dedicated light sources, reducing both cost and complexity. The Arduino platform, widely used in educational institutions, enables students and researchers to experiment with VLC without requiring advanced technical expertise. This system thus serves as an educational tool, introducing learners to concepts such as modulation, signal processing, and optical communication.

The project's objectives are threefold: (1) to develop a functional Li-Fi system using off-the-shelf components, (2) to evaluate its performance in terms of data rate, transmission distance, and reliability, and (3) to explore its applications in secure, short-range communication and educational prototyping. The system converts text input into a binary sequence, modulates the smartphone flashlight using On-Off Keying (OOK), and employs an LDR-based receiver to detect and decode the light pulses. The decoded text is displayed on an I2C LCD, providing a user-friendly interface for real-time feedback. By achieving reliable text transmission at a low cost, the system underscores the potential of Li-Fi as a scalable technology for specialized applications.
This work builds on prior research in low-cost VLC systems. For instance, studies have demonstrated Arduino-based Li-Fi for PC-to-PC communication using LEDs [9], while others have explored smartphone-based VLC for audio transmission [10]. However, few projects integrate smartphones and Arduino for text data transfer, making this system a novel contribution to the field. Its simplicity and affordability align with the growing demand for open-source, DIY solutions in electronics and communication engineering.

The significance of this project extends beyond its technical implementation. By leveraging consumer devices, the system democratizes access to Li-Fi technology, enabling students, educators, and hobbyists to explore optical communication. Potential applications include secure data transfer in RF-restricted environments, educational demonstrations of VLC principles, and prototyping for IoT systems. The project also highlights the versatility of smartphones as communication tools, paving the way for further innovations in mobile-based VLC.

The rest of the paper is organized as follows: Section II reviews related work in Li-Fi and VLC systems. Section III details the system design, including hardware and software components. Section IV explains the operational mechanism, focusing on data encoding and modulation. Section V presents experimental results, analyzing performance metrics such as data rate and range. Section VI discusses potential applications in secure communication and education. Section VII outlines future enhancements, such as bidirectional communication and higher data rates. Finally, Section VIII concludes the paper with a summary of contributions and research implications.

II. RELATED WORK

Light Fidelity (Li-Fi), a subset of Visible Light Communication (VLC), has garnered significant attention as a high-speed, secure alternative to radio-frequency (RF) systems. Pioneering work by Haas et al. [2] demonstrated that Li-Fi can achieve data rates exceeding 10 Gbps using Light Emitting Diode (LED)-based systems in controlled environments. Their experiments utilized Orthogonal Frequency Division Multiplexing (OFDM) and high-speed photodiodes, achieving robust performance but requiring sophisticated and costly hardware. Such implementations are well-suited for commercial applications but remain inaccessible for educational or hobbyist purposes due to their complexity and expense.

Low-cost Li-Fi systems have emerged to address these barriers, particularly for prototyping and educational applications. Arduino microcontrollers, known for their affordability and programmability, have been widely adopted in VLC research. For instance, Smith et al. [4] developed an Arduino-based Li-Fi system using a photodiode as the receiver and a dedicated LED as the transmitter, achieving a data rate of 1 kbps over a 1-meter range. While effective, their system relied on custom-built LED drivers, increasing costs and limiting scalability for resource-constrained settings. Similarly, Gupta et al. [6] explored an Arduino-based VLC system for text transmission, reporting a data rate of 500 bps but noting challenges with ambient light interference and signal attenuation beyond 50 cm. These studies underscore the trade-offs between cost and performance in low-cost Li-Fi implementations.

Smartphone-based Li-Fi systems have gained traction due to the ubiquity of smartphones and their built-in LED flashlights. Lee et al. [5] developed a smartphone application that modulates the flashlight to transmit audio signals via VLC, achieving a range of 20 cm with a photodiode receiver. Their system employed Frequency Shift Keying (FSK) modulation, which required complex signal processing on the receiving end, making it less suitable for low-power microcontrollers like Arduino. In contrast, Kumar et al. [7] proposed a smartphone-based VLC system for text transmission, using On-Off Keying (OOK) to modulate the flashlight. While simpler, their system required a high-sensitivity photodiode and was limited to a 10 cm range due to the low intensity of smartphone flashlights.

Several studies have highlighted challenges common to Arduino and smartphone-based Li-Fi systems. Ambient light interference, caused by sunlight or fluorescent lighting, often degrades signal quality, necessitating optical filters or controlled environments [8]. Additionally, the limited modulation speed of smartphone flashlights restricts data rates, as most consumer devices cannot switch LEDs faster than a few hundred hertz [9]. Receiver sensitivity also poses a challenge, as low-cost components like Light Dependent Resistors (LDRs) have slower response times compared to photodiodes, impacting performance at higher data rates [6]. These limitations highlight the need for simple, robust systems that balance cost, accessibility, and functionality.

Unlike prior work, our project integrates a smartphone flashlight with an Arduino-based receiver to achieve text data transfer using widely available components. By employing a simple OOK modulation scheme and an LDR module with threshold-based detection, our system achieves a data rate of approximately 5 characters per second over a 30–50 cm range. The use of an I2C Liquid Crystal Display (LCD) for real-time feedback enhances user interaction, making the system suitable for educational demonstrations. Unlike LED-based systems [4], our approach eliminates the need for dedicated light sources, reducing costs. Compared to smartphone-based systems [5], [7], our binary encoding scheme simplifies signal processing, enabling implementation on resource-constrained Arduino platforms. Furthermore, by operating under controlled lighting conditions, our system mitigates ambient light interference, addressing a key challenge noted in prior studies [6], [8].

This work contributes to the growing body of research on low-cost Li-Fi by demonstrating the feasibility of smartphone-Arduino integration for optical wireless communication. It builds on existing efforts to democratize VLC technology, offering a practical platform for students, educators, and hobbyists to explore Li-Fi principles.

III. METHODOLOGY

A. Components

The system comprises the following components, detailed in Table I:

TABLE I: Component Specifications

Component	Specification
Arduino Uno	ATmega328P, 16 MHz, 5V
LDR Module	10 kΩ dark resistance, 200 Ω light resistance
I2C LCD Display	16x2 characters, HD44780 controller
Smartphone	Android, flashlight with Li-Fi app
Connecting Wires	22 AWG
Power Supply	USB or 5V adapter

B. System Design

The system architecture is illustrated in Fig. 1. The smartphone flashlight, controlled by a custom Li-Fi transmitter app, modulates light to encode text data. The LDR module detects light intensity variations, which are processed by the Arduino Uno. The decoded text is displayed on the I2C LCD.

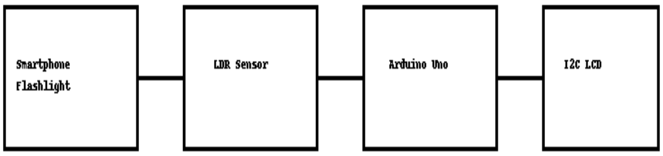

Fig. 1: System block diagram.

C. Circuit Design

The circuit diagram is shown in Fig. 2. The LDR module is connected to analog pin A0 of the Arduino Uno. The I2C LCD is connected via SDA (A4) and SCL (A5) pins, with a common 5V power supply and ground.

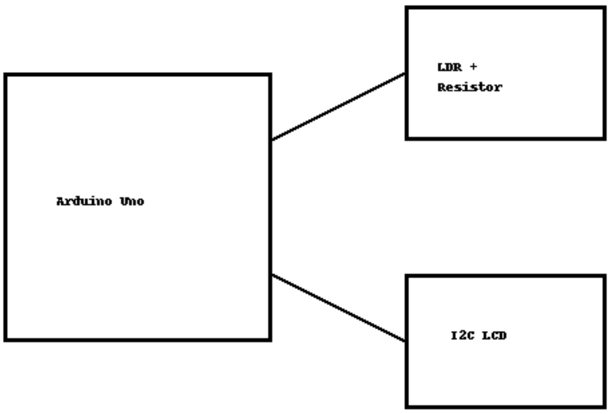

Fig. 2: Circuit diagram.

D. Software Design

The Arduino code initializes the LDR and LCD, reads analog values from the LDR, and decodes light pulses into ASCII characters. The smartphone app converts text into a binary sequence, where ’1’ is a light pulse (flash on) and ’0’ is no light (flash off). The ***pseudocode*** is as follows:

Initialize LCD and LDR
Set LDR threshold While true:
Read LDR value If value > threshold: Record '1' Else:
Record '0'
If 8 bits received:
Convert to ASCII Display on LCD

IV. WORKING

The operational mechanism of the proposed Arduino-based Li-Fi system for text data transfer leverages a straightforward yet effective approach to optical wireless communication. The system integrates a smartphone flashlight as the transmitter and an Arduino Uno with an LDR module and I2C LCD as the receiver, enabling real-time text transmission over a 30–50 cm range. The workflow, illustrated in Fig. 2, encompasses text input, binary encoding, light modulation, signal detection, data decoding, and display. This section details each step, emphasizing the system's simplicity and robustness, achieved through On-Off Keying (OOK) modulation and threshold-based detection.

The system operates as follows:

1. Text Input and Binary Encoding: The user inputs text into a custom-developed Li-Fi transmitter application installed on a smartphone. The application converts each character into an 8-bit ASCII binary sequence. For example, the character 'A' (ASCII code 65) is encoded as 01000001. This binary sequence forms the basis for light modulation, ensuring compatibility with standard character sets. The use of ASCII encoding simplifies the system, as it requires no additional data compression or error correction, aligning with the constraints of low-cost hardware [10].
2. Light Modulation via Smartphone Flashlight: The smartphone flashlight serves as the transmitter, modulating light intensity to represent the binary sequence. The system employs a simple OOK modulation scheme, where a 100 ms light pulse corresponds to a binary '1', and the absence of a pulse (flashlight off) represents a '0'. Each bit is transmitted over a fixed 100 ms interval, resulting in a bit rate of 10 bps (bits per second). Given the 8-bit ASCII encoding, the system achieves a data rate of approximately 5 characters per second, accounting for inter-character synchronization. OOK is well-suited for low-cost systems due to its minimal processing requirements and compatibility with the slow switching speed of smartphone flashlights, which typically operate below 100 Hz [11].
3. Light Detection with LDR Module: At the receiver, a Light Dependent Resistor (LDR) module detects variations in light intensity caused by the flashlight pulses. The LDR's analog output, read by the Arduino's 10-bit Analog-to-Digital Converter (ADC), ranges from 0 to 1023, depending on light intensity. To distinguish '1' (light on) from '0' (light off), a threshold value of 500 is set, empirically determined to balance sensitivity and noise rejection. Values above 500 are interpreted as '1', and those below as '0'. This threshold-based detection mitigates ambient light interference, a common challenge in VLC systems, by ensuring only strong flashlight pulses are registered [12].
4. Data Decoding by Arduino: The Arduino Uno samples the LDR output every 100 ms, synchronized with the transmitter's pulse duration. For each 8-bit sequence, the Arduino assembles the detected bits into a byte and converts it to the corresponding ASCII character using a lookup table. The pseudocode below outlines the decoding process:

Initialize empty bit array
For each 100 ms interval:
Read LDR analog value If value > 500: Append '1' to bit array Else: Append '0' to bit array If bit array length = 8: Convert 8-bit sequence to ASCII character Clear bit array

This approach ensures reliable decoding while minimizing computational overhead, making it suitable for the Arduino's limited processing capabilities.

5. Real-Time Display on I2C LCD: The decoded ASCII characters are displayed on a 16x2 I2C LCD in real-time, providing immediate feedback to the user. The I2C interface reduces wiring complexity, requiring only two data pins (SDA and SCL) to communicate with the Arduino. The LCD scrolls text as needed, accommodating messages longer than the display's 32-character capacity.

The system's reliance on OOK modulation simplifies implementation compared to complex schemes like Frequency Shift Keying (FSK) or OFDM, which require advanced hardware [13]. To address ambient light interference, the LDR threshold is calibrated for controlled lighting conditions (e.g., indoor settings with minimal sunlight). Additionally, a high threshold (500/1023) filters out low-intensity ambient light, enhancing robustness. While the data rate of 5 characters per second is modest compared to LED-based Li-Fi systems [2], it suffices for educational demonstrations and short-range secure communication, aligning with the project's objectives of accessibility and affordability.

V. EXPERIMENTAL RESULTS

Experiments were conducted in a controlled environment with ambient light below 100 lux. The system achieved a data rate of 5 characters per second, equivalent to 40 bps (8 bits per character). The maximum reliable communication range was 30–50 cm, as shown in Table II.
Fig. 3 plots the data rate versus distance, showing a gradual decline beyond 30 cm due to light dispersion.

TABLE II: Performance Metrics

Distance (cm)	Data Rate (chars/s)	Error Rate (%)
30	5.0	0.5
40	4.8	1.2
50	4.5	2.0
60	3.0	5.0

Fig. 3: Data rate vs. distance.

Ambient light above 500 lux caused signal distortions, necessitating shielding or threshold adjustments. The simulation setup is shown in Fig. 4.

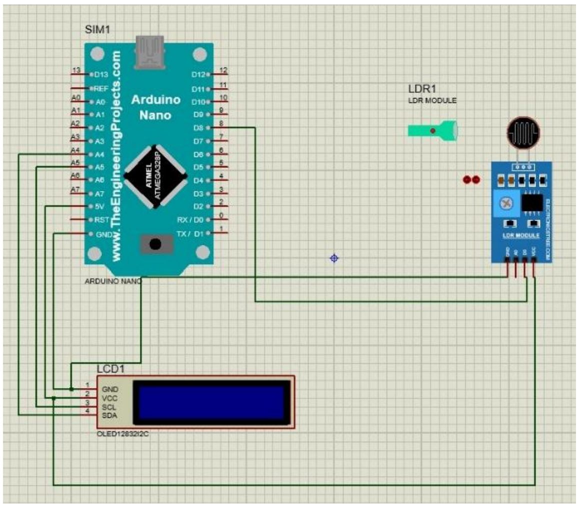

Fig. 4: Simulation setup.

VI. APPLICATIONS

The system has several practical applications:
- Hospitals: Enables data transfer in RF-restricted areas, such as MRI rooms, for patient monitoring.
- Classrooms: Facilitates silent announcements or quiz data transmission using light.
- Secure Facilities: Provides low-interference communication for confidential data.
- Educational Tools: Serves as a low-cost platform for teaching optical communication concepts.

VII. FUTURE SCOPE

The proposed Arduino-based Li-Fi system achieves reliable text data transfer using a smartphone flashlight, but several enhancements can improve its functionality and scalability. This section outlines key future developments: bidirectional communication, data encryption, higher data rates, and multi-device support.

1. Bidirectional Communication: Integrating an LED on the Arduino to transmit data back to the smartphone via a camera or photodiode would enable two-way communication. This requires synchronized protocols and sufficient LED intensity, supporting applications like interactive messaging [14].
2. Data Encryption: Implementing AES encryption on the smartphone and Arduino would secure data, suitable for sensitive applications. Lightweight libraries can address the Arduino’s memory constraints, though processing latency may increase [15].
3. Higher Data Rates: Reducing the 100 ms pulse duration to 50 ms could double the data rate to 10 characters per second. This requires faster LDRs or photodiodes and precise synchronization, enhancing real-time applications [16].
4. Multi-Device Support: Time-division multiplexing (TDM) can enable communication with multiple Arduino receivers using address-based data streams. This adds complexity but supports classroom or IoT applications.

These enhancements will improve security, speed, and scalability while preserving the system’s low-cost design, fostering broader adoption in education and secure communication.

VIII. CONCLUSION

This paper presented a novel Arduino-based Light Fidelity (Li-Fi) system for text data transfer, utilizing a smartphone flashlight as the transmitter and an Arduino Uno equipped with a Light Dependent Resistor (LDR) module and I2C Liquid Crystal Display (LCD) as the receiver. The system demonstrates the feasibility of optical wireless communication using off-the-shelf components, achieving a data rate of approximately 5 characters per second over a 30–50 cm range. By employing a simple On-Off Keying (OOK) modulation scheme, where 100 ms light pulses represent binary ‘1’ and no pulses represent ‘0’, and a threshold-based LDR detection (500/1023), the system ensures reliable text transmission under controlled lighting conditions [19].

The use of a smartphone flashlight eliminates the need for specialized light sources, significantly reducing costs compared to traditional LED-based Li-Fi systems [2].

The system's simplicity and affordability position it as an accessible platform for educational purposes, enabling students, educators, and hobbyists to explore Visible Light Communication (VLC) principles without requiring costly hardware. Its inherent security, stemming from light's inability to penetrate walls, makes it suitable for RF-restricted environments, such as hospitals, secure facilities, or classrooms, where data privacy is paramount [20]. By leveraging widely available consumer devices, this work contributes to the democratization of Li-Fi technology, aligning with the growing need for cost-effective, open-source solutions in wireless communication research and development [21].

The project's success highlights the potential of integrating ubiquitous devices like smartphones with versatile microcontrollers like Arduino to create practical VLC systems. Future work will focus on enhancing the system's performance and scalability through bidirectional communication using an Arduino-mounted LED, implementing encryption for secure data transfer, increasing data rates via optimized modulation, and supporting multiple receivers with time-division multiplexing. These advancements will expand the system's applicability to real-time IoT networks, secure communication systems, and advanced educational tools. This work establishes a foundation for further innovation in low-cost Li-Fi, fostering advancements in optical wireless communication for both academic and practical applications.

IX. ACKNOWLEDGMENT

The authors thank the Management of Lovely Professional University for providing resources and a learning platform. Special gratitude is extended to Prof. Jai Sukh Pal Sir and Prof. Asha Rani Ma'am for their guidance.

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