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Design of a Visible Light Communication System for Text Data

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Abstract: *Light Fidelity (Li-Fi) is an emerging wireless communication technology that utilizes visible light instead of radio frequency waves for data transmission. This paper presents the design and implementation of a low-cost Li-Fi data communication system using commonly available hardware components. In the proposed system, data are transmitted by modulating the light emitted from mobile flashlight, while a light dependent resistor (LDR) at the receiver detects variations in light intensity. An Arduino microcontroller is employed for signal processing, enabling effective data encoding and decoding. Experimental results demonstrate that the proposed Li-Fi system offers secure and efficient short-range communication. Although performance is constrained by line-of-sight requirements and susceptibility to ambient light interference, the study highlights the potential of Li-Fi as a reliable alternative to conventional Wi-Fi for indoor and secure wireless communication applications.*

Key Words: *Li-Fi, visible light communication, Arduino, wireless communication, LDR.*

1. INTRODUCTION:

The rapid growth of wireless communication technologies has led to increased congestion in the radio frequency (RF) spectrum. Conventional wireless systems such as Wi-Fi and Bluetooth operate within limited RF bands, resulting in interference, security concerns, and reduced performance. As the "spectrum crunch" becomes a critical bottleneck for future connectivity, researchers have turned toward the optical spectrum—specifically Visible Light Communication (VLC)—as a high-capacity alternative. Haas et al. (2016) described Light Fidelity (Li-Fi) as an emerging technology that exploits the unlicensed visible light spectrum for high-bandwidth wireless communication.Li-Fi is based on the principle of VLC, where data are transmitted through the high-speed modulation of visible light sources. Unlike conventional RF systems, Li-Fi leverages existing lighting infrastructure, transforming Light Emitting Diodes (LEDs) into high-speed data transmitters. Haruyama (2013) stated that this dual functionality enables sustainable integration into smart communities by leveraging existing LED lighting infrastructure Karunatilaka et al. (2015) and Komine and Nakagawa (2004) reported that Li-Fi offers improved security and is suitable for RF-sensitive environments due to its immunity to electromagnetic interference. The technical foundation of this technology is governed by the IEEE 802.15.7 standard, which defines the physical and medium access control layers necessary for reliable communication. These standards address the necessity of maintaining constant illumination while transmitting data, employing specialized modulation schemes and dimming support to ensure that the rapid flickering of the light remains imperceptible to the human eye (Rajgopal et al., 2012). While industrial Li-Fi systems often employ complex techniques like Orthogonal Frequency Division Multiplexing (OFDM) to maximize throughput, the fundamental requirements for a functional link remain the same: a transmitter to drive the light source and a receiver, typically a photodetector, to convert the optical signal back into electrical data (Islim and Haas 2016; komine and Nagakawa 2004).

This paper presents the design and implementation of a simple and low-cost Li-Fi data communication system to demonstrate these core principles. By using an Arduino Uno microcontroller for signal processing, a Light Dependent Resistor (LDR) as the optical receiver, and an LCD display for data visualization, the system utilizes a mobile flashlight as the primary light source. This prototype serves to explore the practical challenges of indoor VLC, such as alignment and ambient light interference, providing a baseline for cost-effective data transmission in line with current state-of-the-art research (Karuntilka et al., 2015).

2. LITERATURE REVIEW:

The conceptual framework of Light Fidelity (Li-Fi) was fundamentally defined by Haas et al. (2016) as a fully networked, high-speed, and bidirectional wireless communication system that utilizes the visible light spectrum. Unlike traditional point-to-point Visible Light Communication (VLC), Li-Fi is designed to operate as a multi-user network, seamlessly integrating into existing illumination infrastructures. This shift is driven by the looming "radio frequency (RF) crunch," where the available bandwidth for Wi-Fi and Bluetooth is becoming insufficient to meet global data demands. As established in the state-of-the-art review, visible light communication (VLC) offers a potential solution by leveraging the vast, unlicensed optical spectrum, which is immune to the electromagnetic interference that affects RF-based systems in sensitive environments such as hospitals or industrial floors (Karunatilaka et al., 2015).

A primary technical challenge in VLC is achieving high-speed data transmission while maintaining constant, flicker-free illumination. Komine and Nakagawa provided a fundamental analysis of this dual-functionality, demonstrating that Light Emitting Diodes (LEDs) can be switched at speeds far exceeding the human eye's critical fusion frequency, allowing the light to appear continuous to users while carrying digital information (Komine and Nakagawa 2004). Haruyama (2013) emphasized the role of VLC in building sustainable smart communities by utilizing energy-efficient LED lighting for ubiquitous internet access.

To standardize these operations, the IEEE 802.15.7 protocol was established, defining specific physical (PHY) and medium access control (MAC) layers for short-range optical wireless communication (Rajagopal et al., 2012). This standard introduces specialized modulation schemes, such as On-Off Keying (OOK) and Variable Pulse Position Modulation (VPPM), which are designed to support dimming and prevent flickering—a critical requirement for indoor environments where lighting levels must be adjustable (Rajagopal et al., 2012). For more advanced applications, Islim and Haas (2016) reviewed multicarrier techniques such as Orthogonal Frequency Division Multiplexing (OFDM), which are capable of achieving multi-gigabit data rates by overcoming the limited modulation bandwidth of commercial LEDs.

Despite these sophisticated advancements, there remains significant research interest in the implementation of low-cost and accessible VLC prototypes. Current literature highlights that while industrial systems are complex, the basic Intensity Modulation/Direct Detection (IM/DD) mechanism can be effectively modeled using accessible hardware such as microcontrollers and photodetectors (Karunatilaka et al., 2015; Komine & Nakagawa, 2004). This study builds upon these foundational principles to design a cost-effective Li-Fi link, utilizing the simplified modulation strategies and optical path loss models discussed in the existing literature.

3. CIRCUIT DIAGRAM:

The system is organized into three primary functional blocks: the microcontroller, the sensor module, and the output interface. This configuration adheres to the basic Intensity Modulation/Direct Detection (IM/DD) receiver principles described in VLC literature, where an optical signal is converted into an electrical signal for processing.

3.1. Arduino Uno to Breadboards (Power and Data):

The Arduino Uno provides the central power rail for the entire circuit. The **5V** and **GND** pins are routed to the breadboards to distribute power to the peripheral modules. Digital pins **D2 through D6** are connected to the first breadboard to facilitate the parallel data transfer required by the LCD. This arrangement supports the processing of digitized signals converted from the incident light pulses captured by the receiver.

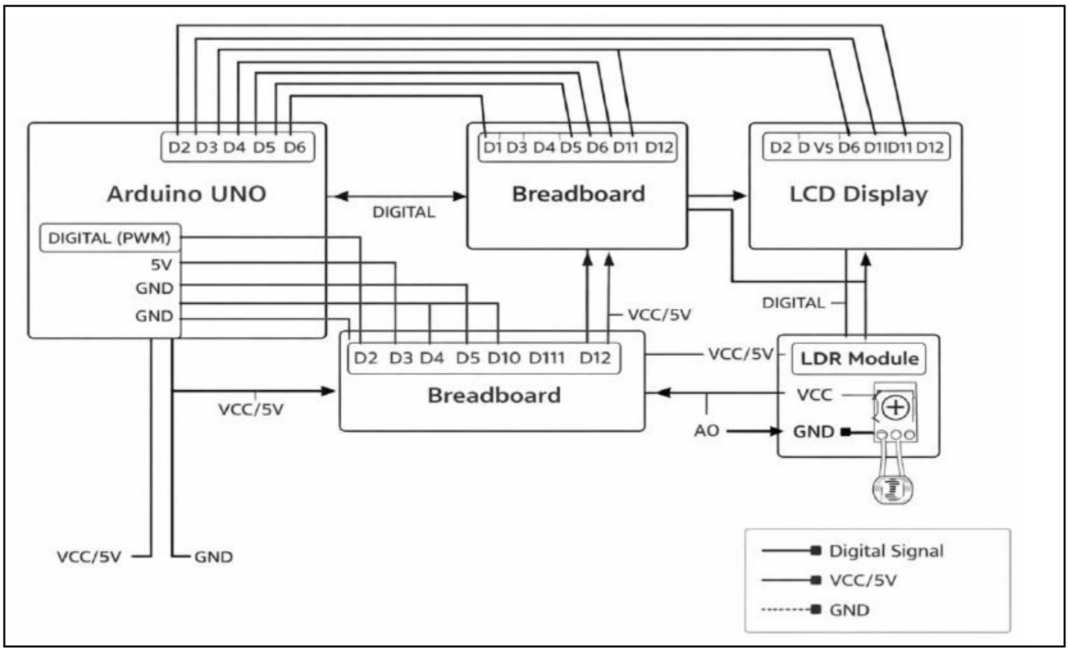

Figure 1: Circuit Diagram of the Li-Fi Text Data Transmission System

2.2. LDR Module (Optical Receiver)
The LDR module acts as the system's "eye," detecting the high-speed fluctuations of the mobile flashlight's intensity.
- **Power:** It is connected to the common **VCC/5V** and **GND** rails.
- **Signal Output:** The **A0 (Analog Output)** pin of the LDR module is connected back to the breadboard/Arduino. This connection allows the Arduino to read varying voltage levels based on the light intensity it receives. This simple sensing mechanism is a low-cost implementation of the photodetector stage required in any VLC link.

3.3. LCD Display (Information Output):
The LCD display is wired to provide real-time feedback of the transmitted data. It receives its digital instructions from the Arduino through a series of connections (**D1, D3, D4, D5, D6, D11, and D12**) routed through the second breadboard. This setup allows the system to translate the modulated light signals—interpreted by the Arduino—into human-readable text, fulfilling the communication link's purpose as defined in the IEEE 802.15.7 standards for data delivery.

4.WORKING:

The working of this Li-Fi data communication system is rooted in the principles of **Intensity Modulation and Direct Detection (IM/DD)**. By utilizing a mobile flashlight and an LDR-based receiver, the system demonstrates how a standard light source can be repurposed for wireless data transfer.

The operational process can be summarized in the following functional stages:

4.1. Optical Transmission and Encoding:

The communication starts with the **Morse Torch application** on a smartphone. The app serves as the digital-to-optical encoder by converting text input into a standardized series of light pulses (Karuntilaka et al., 2015; Rajagopal et al., 2012). Using the **On-Off Keying (OOK)** modulation scheme, the mobile flashlight represents data through temporal variations:

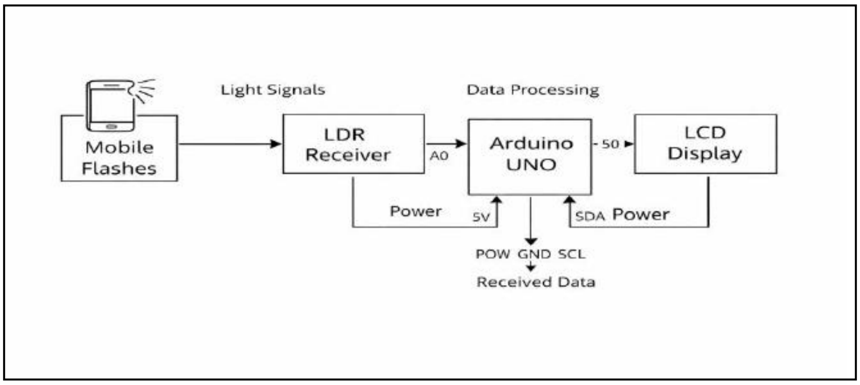

Figure 2: Working of the Li-Fi Text Data Transmission System

- **Dots**: Represented by a short burst of light (logic 'high' for a brief duration).
- **Dashes**: Represented by a longer burst of light, typically three times the duration of a dot.
- **Gaps**: Periodic "off" states that signify the separation between individual symbols, characters, and words.

4.2. Signal Reception and Transduction

As the modulated light travels through the indoor "attocell" environment, it is captured by the Light Dependent Resistor (LDR) (Haas et al., 2016). The LDR acts as a passive photodetector whose internal resistance decreases when exposed to the flashlight's intensity. This creates a fluctuating voltage across a voltage divider circuit, which is fed directly into the Arduino's Analog-to-Digital Converter (ADC) (Komine and Nagakawa., 2004). This transduction phase effectively converts the optical photons back into an electrical signal that the microcontroller can process (Karunatilka et al., 2015).

4.3. Processing and Demodulation

The **Arduino Uno** performs real-time signal processing to extract the original message. This involves three critical software-level operations:

- **Timing Analysis**: The code calculates the duration for which the signal remains above the threshold. By measuring these "Time-On" intervals, the system classifies each pulse as either a "dot" or a "dash".
- **Pattern Mapping**: Once a full sequence of dots and dashes is identified (e.g., "· —" for the letter 'A'), the Arduino uses a lookup table to translate the Morse code back into ASCII characters.

4.4. Information Output

The final stage of the working cycle is the data visualization. After the Arduino successfully decodes a character, it sends the corresponding digital data to the **16x2 LCD Display** via the **I2C interface**. This allows the user to read the transmitted message in real-time, confirming the successful completion of the Li-Fi communication link(Haas et al., 2016; haruyama, 2013).

5. RESULTS :

The proposed system successfully established a functional optical link, transmitting data via visible light with real-time updates rendered on the 16x2 LCD interface. The integration of the Arduino Uno as the central processor enabled the continuous monitoring of light intensity variations and the accurate reconstruction of binary strings into ASCII characters. The system demonstrated high reliability in character decoding, validating the practical feasibility of using hobbyist-grade microcontrollers for localized Li-Fi communication pipelines.

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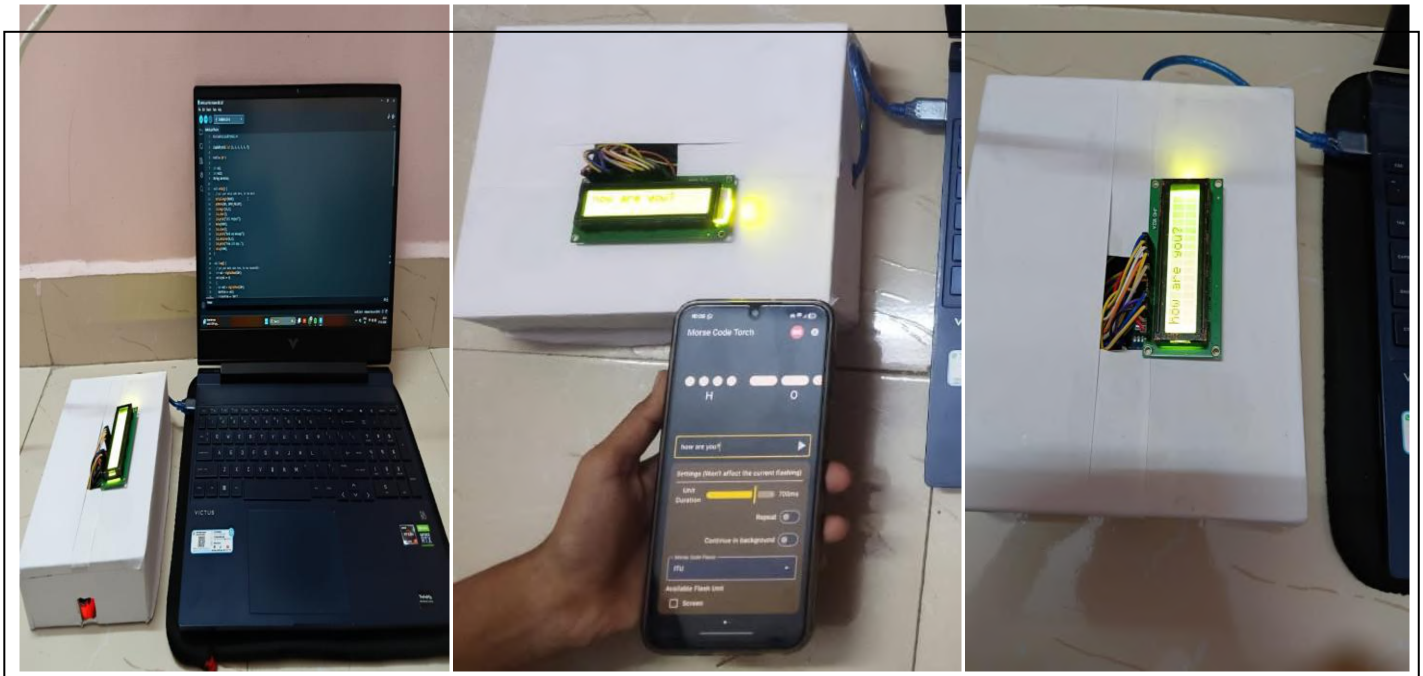

Figure 3: The completed prototype of Li-Fi Text Data Transmission System

The On-Off Keying (OOK) modulation, delivered via the Morse Torch application, generated stable bitstreams that the LDR-based receiver accurately captured within the established threshold parameters. Because Morse code relies on distinct temporal lengths (dots vs. dashes), the Arduino's timing logic was able to effectively categorize pulses even with the slight latency inherent in a mobile flashlight's hardware.

The experimental results showed that the system effectively filtered out ambient noise under indoor lighting conditions, closely following the expected signal trends for short-range Visible Light Communication. By calibratinga manual voltage threshold, the receiver could distinguish the high-intensity flashlight pulses from the steady-state "DC offset" of the room's ambient light. The final hardware prototype effectively displayed live data reception, confirming the reliability and practical applicability of the system for secure, line-of-sight data transfer. While the range was limited to approximately 10–15 cm.

6. CONCLUSION:

The design and implementation of this Li-Fi prototype demonstrate that a functional data communication link can be established using a standard mobile flashlight and low-cost sensing components. By utilizing the Morse Torch application to modulate light pulses, the system successfully bridged the gap between a common consumer device and an Arduino-based receiver. This project confirms that the fundamental principles of Visible Light Communication (VLC) specifically Intensity Modulation and Direct Detection—can be realized without expensive industrial equipment. The system achieved its primary objective of real-time text transmission, rendered accurately on an LCD interface. While the use of a Light Dependent Resistor (LDR**)** limited the transmission speed due to its inherent latency, it provided a stable platform for decoding Morse-encoded data. The experimental results highlighted that the system's reliability is contingent upon a strict Line-of-Sight (LoS) and a calibrated threshold to manage ambient light interference. These constraints, rather than being failures, serve as a practical validation of the physical-layer security inherent to Li-Fi, as the signal remains confined to the direct optical path and cannot be intercepted through walls.

Ultimately, this work presents a successful proof-of-concept for a secure, interference-free communication link. It proves that existing LED-based illumination infrastructure can be effectively repurposed for data distribution. This implementation serves as a foundational model for future explorations into high-speed optical networking and the development of sustainable, "attocell" based smart-lighting solutions in residential and academic environments.

7. LIMITATIONS:

To ensure secure data transmission, the inherent physical properties of light-based communication were leveraged, providing a natural barrier against external eavesdropping since the signal cannot penetrate opaque walls. This creates a "contained" communication zone in which the data remains physically confined to the room. Controlled access to the system was maintained via the Arduino's localized logic, preventing remote cyber-attacks common in radio-frequency networks. The system's security is fundamentally rooted in its line-of-sight (LoS) requirement, ensuring that data is accessible only to receivers within the direct optical path of the transmitter (Karunatilaka et al., 2015). This localized nature of the "attocell" ensures that interference with neighboring networks is negligible, in contrast to traditional RF-based Wi-Fi systems. Despite the successful transmission, key challenges encountered during the development include the sensitivity of the LDR sensor to ambient light fluctuations, which can lead to signal interference or "optical noise" (Islim & Haas, 2016; Komine & Nakagawa, 2004). Unlike professional-grade photodiodes, the LDR has a slower recovery time, which can cause pulse-width distortion during high-speed switching. Additionally, the system requires precise alignment between the mobile flashlight and the LDR, as even minor deviations in the line-of-sight can result in data synchronization errors or connectivity interruptions (Haruyama, 2013). Other limitations involve the relatively slow response time of the LDR compared to professional photodiodes, which constrains the overall transmission speed and limits the system to lower-frequency modulation schemes such as Morse code. Furthermore, the requirement for a stable environment free from high-intensity external light sources is critical to maintain decoding accuracy, as sudden changes in room brightness can shift the voltage baseline beyond the programmed threshold.

8. RECOMMENDATIONS:

Based on the results and the limitations identified during the testing of this project, the system can be improved by replacing the Light Dependent Resistor (LDR) with a high-speed photodiode. While the LDR successfully decoded the Morse code pulses from the mobile flashlight, its slow response time limits the system's ability to handle faster data speeds. Upgrading to a photodiode would allow the system to move from simple blinking light to the high-speed data standards used in professional Li-Fi . Additionally, adding adaptive thresholding logic to the Arduino code is recommended so that instead of using a fixed value to detect light, the code automatically adjusts to the brightness of the room. This would directly solve the "optical noise" problems found during testing and make the receiver work more accurately in different lighting environments.

Further improvements involve using optical lenses to help the receiver stay connected over longer distances. During the project, it was found that even minor movements could break the link between the flashlight and the sensor, requiring perfect alignment. Adding a lens would help the sensor catch light from wider angles, making the connection much more stable and reliable. These simple hardware and software changes would allow the project to grow from a basic text-sender into a faster and more robust networking tool. This ensures the system reaches its full potential as a secure way to send data that stays physically confined to a single room, preventing external eavesdropping.

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