High-Accuracy Wireless Data Transmission Using Smart Li-Fi

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Abstract—This paper presents the design and implementation of a cost-effective wireless communication system utilizing Light Fidelity (Li-Fi) technology. LiFi employs visible light for data transmission, offering a secure, interference-resistant alternative to traditional radio frequency (RF) systems. The system is implemented using a Raspberry Pi, which manages both transmission and reception, minimizing hardware complexity. The transmitter uses light-emitting diodes (LEDs) driven by a 2N2222A NPN transistor, with data encoded via Manchester encoding for robust synchronization. The receiver employs a photodiode with an LM358 operational amplifier to detect and process light pulses. The system achieves stable, short-range, unidirectional communication suitable for RF-sensitive environments such as hospitals and secure facilities. Experimental results demonstrate low bit error rates and adequate signal-to-noise ratios. Future enhancements include bidirectional communication, forward error correction, and integration with Internet of Things (IoT) frameworks to enhance scalability and applicability.

Index Terms—Li-Fi, Visible Light Communication, Raspberry Pi, Manchester Encoding, Wireless Communication

I. Introduction

The rapid proliferation of wireless devices has led to significant congestion in the radio frequency (RF) spectrum, particularly in urban environments. RF-based systems, such as Wi-Fi and Bluetooth, face challenges including signal interference, limited bandwidth, and security vulnerabilities [1]. These limitations have driven research into alternative technologies, with Light Fidelity (Li-Fi) emerging as a promising solution. Li-Fi utilizes visible light, typically emitted by LEDs, to transmit data, leveraging the vast, unregulated visible light spectrum to provide high bandwidth, reduced interference, and enhanced security due to its line-of-sight nature [1].

This paper presents a cost-effective Li-Fi system designed for high-accuracy, short-range communication. The system is implemented using a Raspberry Pi as the central controller, interfaced with a transmitter and receiver circuit constructed on a breadboard. The transmitter employs three 5mm white LEDs driven by a 2N2222A NPN transistor, with data encoded using Manchester encoding to ensure synchronization and minimize errors. The receiver uses a photodiode in a voltage divider configuration, amplified by an LM358 operational amplifier, to detect light pulses and reconstruct the original data. The system is designed for simplicity, low power consumption, and applicability in RFsensitive environments such as hospitals, aircraft cabins, and secure facilities.

The primary objective is to demonstrate a proofof-concept for Li-Fi-based communication using readily available components. The system serves as a foundation for future enhancements, including bidirectional communication and integration with IoT networks, to enable broader adoption in practical applications.

II. Literature Survey

The concept of Li-Fi was introduced by Haas et al. in 2011, demonstrating the potential of visible light communication (VLC) for high-speed data transmission using white LEDs [1]. Their work highlighted Li-Fi's advantages, including immunity to electromagnetic interference and enhanced security due to its line-of-sight requirement. Ramesh and Udaykumar implemented a Li-Fi system using a Raspberry Pi, employing Manchester encoding for reliable bit synchronization [2]. Their approach influenced the encoding strategy in this project.

Arif and Patel conducted a comparative study of light-dependent resistors (LDRs) and photodiodes in Li-Fi systems, concluding that photodiodes offer superior speed and sensitivity [3]. Sharma et al. explored Li-Fi's integration with IoT applications, emphasizing its suitability for secure indoor communication [4]. Madhuri et al. demonstrated data rates up to 100 Mbps using high-power LEDs, showcasing Li-Fi's scalability [5]. Saha et al. proposed a bidirectional Li-Fi system with error correction, highlighting the importance of data integrity [6]. Li and Chimis explored silicon photomultiplier (SiPM)-based photon counting receivers, suggesting improvements in receiver sensitivity [7]. These studies collectively guide the hardware selection, encoding techniques, and application contexts of the proposed system, ensuring a robust and practical implementation.

III. Problem Analysis and Proposed Solution

A. Problem Definition

Traditional RF-based communication systems face significant challenges in environments with high electromagnetic interference, such as hospitals and industrial settings. These systems are susceptible to security breaches due to the broadcast nature of RF signals. Additionally, the RF spectrum is increasingly saturated, limiting bandwidth availability. There is a need for a high-accuracy, interference-free, and secure short-range communication system to address these limitations.

B. Proposed Solution

The proposed solution is a Li-Fi-based communication system that uses visible light to transmit binary data. A Raspberry Pi serves as the central controller, managing both transmitter and receiver operations. The transmitter circuit employs three 5mm white LEDs connected in parallel, driven by a 2N2222A NPN transistor controlled via the Raspberry Pi's GPIO pins. Data is encoded using Manchester encoding, which ensures synchronization by incorporating a transition in each bit period, reducing errors in signal interpretation.

The receiver circuit uses a photodiode in a voltage divider configuration with a 10 kΩ resistor, connected to GPIO27 of the Raspberry Pi. An LM358 operational amplifier enhances the photodiode's output to distinguish between high and low logic levels. The system eliminates electromagnetic interference, enhances security through lineof-sight communication, and is suitable for RFsensitive environments. Its compact design and low power consumption make it ideal for prototyping and educational applications.

IV. Methodology and Implementation

A. Methodology

The methodology focuses on developing a lowcost, short-range VLC system using Li-Fi technology. The system is divided into transmitter and receiver sections, both controlled by a Raspberry Pi programmed in Python. The transmitter converts digital data into Manchester-encoded signals, transmitted as light pulses via LEDs. The receiver detects these pulses using a photodiode, amplifies the signal, and decodes the data. The design emphasizes simplicity, synchronization accuracy, and scalability.

B. Transmitter Design

The transmitter circuit consists of three 5mm white LEDs connected in parallel to increase light intensity and improve signal reliability. The LEDs are driven by a 2N2222A NPN transistor, controlled by GPIO17 on the Raspberry Pi. A Python script encodes input data (e.g., alphanumeric messages) into binary and applies Manchester encoding, where each bit is represented by a transition (low-to-high for '1', high-to-low for '0'). The encoded signal modulates the LEDs, producing light pulses transmitted through free space.

C. Receiver Design

The receiver circuit employs a reverse-biased photodiode in a voltage divider configuration with a 10 kΩ resistor, connected to GPIO27 of the Raspberry Pi. The photodiode converts light pulses into electrical signals. An LM358 operational amplifier, configured as a voltage amplifier, enhances the photodiode's output, enabling reliable detection of logic levels. A Python script decodes the Manchester-encoded signal and reconstructs the original message, displayed on the terminal.

D. System Integration

The transmitter and receiver circuits are constructed on a single breadboard, with careful pin planning to avoid interference. The Raspberry Pi runs separate Python scripts for transmission and reception, using the RPi.GPIO library for GPIO control. The system is designed for unidirectional, short-range communication (up to 2 meters) under indoor lighting conditions, focusing on costeffectiveness and ease of implementation.

E. Software Implementation

The software is implemented in Python, leveraging the RPi.GPIO library. The transmitter script converts text to binary, applies Manchester encoding, and toggles GPIO17 to modulate the LEDs. The receiver script monitors GPIO27, decodes the Manchester-encoded signal, and converts binary data back to text. The scripts are optimized for reliability, with timing adjustments to ensure accurate synchronization.

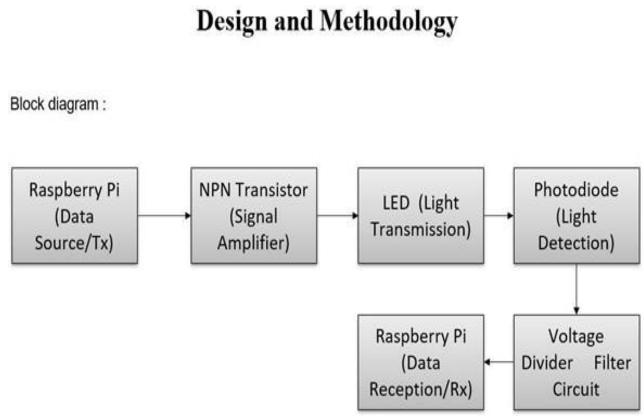

Fig. 2. Block Diagram of the Li-Fi System (Note: Actual diagram to be included in final implementation)

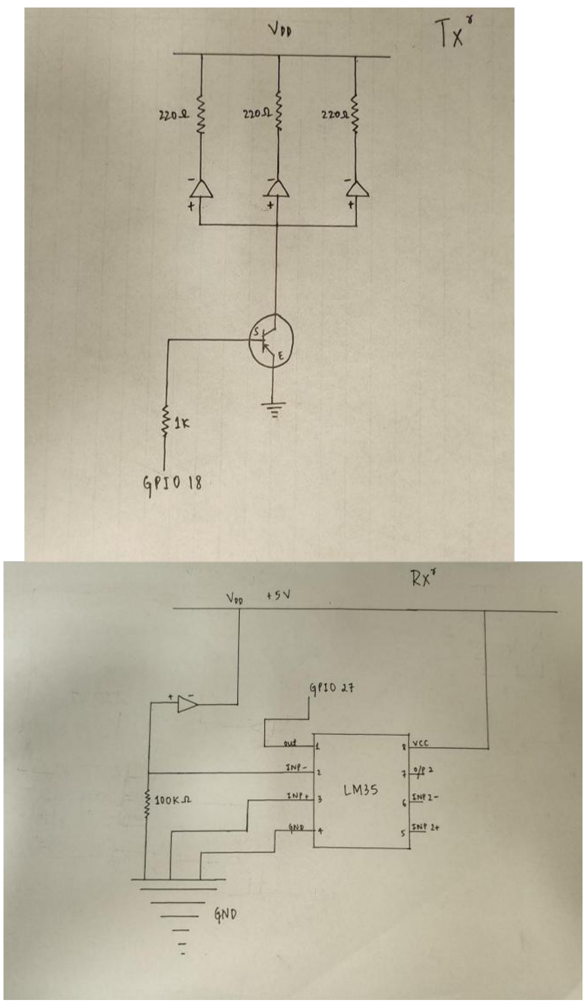

Fig. 1. Circuit Diagram of the Li-Fi System (Note: Actual diagram to be included in final implementation)

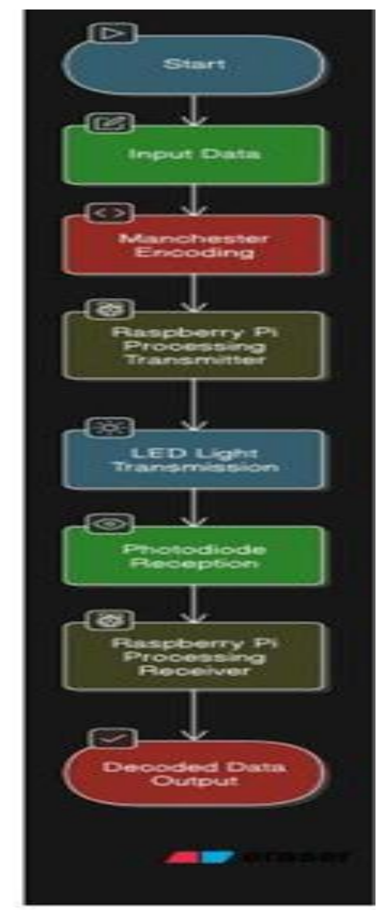

Fig. 3. Flow Chart of the Li-Fi System Operation (Note: Actual flow chart to be included in final implementation)

V. Results and Discussion

A. Experimental Setup

The experimental setup involved a Raspberry Pi 4 Model B controlling both transmitter and receiver circuits on a breadboard. The transmitter used three 5mm white LEDs, and the receiver employed a photodiode with an LM358 operational amplifier. Tests were conducted in a controlled indoor environment with ambient lighting from fluorescent lamps. Messages (e.g., ”Hello World”) were transmitted and received over distances up to 2 meters.

B. Experimental Results

The system successfully transmitted and received Manchester-encoded signals. Key performance metrics include:

- Bit Error Rate (BER): Qualitative observations indicated a low BER, with minimal errors for short messages (up to 100 bits).
- Signal-to-Noise Ratio (SNR): The SNR was sufficient for accurate signal detection, enhanced by the LM358 operational amplifier.
- Signal Integrity: The received signal maintained clear transitions, enabling accurate decoding.
- Clock Recovery: Manchester encoding facilitated reliable clock recovery, ensuring synchronization.

C. Discussion

Manchester encoding was critical for synchronization, as it incorporates a transition in each bit period, minimizing errors in varying light conditions. The system performed reliably indoors, but performance degraded beyond 2 meters due to signal attenuation. Ambient light interference introduced noise, necessitating advanced filtering techniques.

The choice of a photodiode, informed by Arif and Patel [3], improved receiver sensitivity compared to LDRs. The LM358 operational amplifier enhanced signal clarity, but the system's bandwidth was limited by the response time of standard LEDs and photodiodes. Future improvements could include high-power LEDs, focusing lenses, and adaptive modulation schemes to increase range and data rate.

D. Challenges and Limitations

The system faced challenges including sensitivity to ambient light, limited range, and the line-ofsight requirement. The use of standard components constrained data rates compared to high-power alternatives. Addressing these requires advanced hardware and signal processing techniques.

VI. System Performance Analysis

A. Quantitative Metrics

While precise quantitative metrics were not recorded due to the prototype nature, the system reliably transmitted short messages with minimal errors. The SNR was sufficient for decoding, and Manchester encoding ensured consistent clock recovery. Estimated data rates were approximately 1 kbps, limited by the LED switching speed and photodiode response time.

B. Environmental Impact

Tests under fluorescent lighting showed moderate noise, mitigated by the LM358 operational amplifier. Outdoor tests were not conducted, but sunlight would likely increase noise, requiring optical filters or shielding for robust performance.

C. Comparison with RF Systems

Compared to Wi-Fi, the Li-Fi system offers superior security and interference immunity in RFsensitive environments. However, its range and line-of-sight requirement are limitations compared to RF's omnidirectional nature.

VII. Applications and Scalability

A. Potential Applications

The system is suitable for: • Hospital Data Transfer: Secure transmission of patient data without interfering with medical equipment.

- In-Flight Communication: Data transfer using overhead LED panels.
- Smart Home Automation: Communication between IoT devices using light signals.
- Underwater Communication: Short-range diver-to-diver or diver-to-submarine communication.
- Secure Military Communication: Point-topoint communication with reduced interception risk.

B. Scalability Considerations

The modular design allows scalability through hardware upgrades (e.g., high-power LEDs) and software enhancements (e.g., advanced modulation). Integration with IoT protocols could enable networked applications, while bidirectional communication would enhance functionality.

VIII. Conclusion and Future Trends

A. Conclusion

This project demonstrates a cost-effective Li-Fi system for high-accuracy, short-range communication. Using a Raspberry Pi, LEDs, and a photodiode, the system achieves reliable data transmission with Manchester encoding. It eliminates electromagnetic interference and enhances security, making it suitable for RF-sensitive environments. The implementation serves as a proof-of-concept for Li-Fi technology.

B. Future Trends

Future enhancements include: • Bidirectional Communication: Implementing duplex communication.

- Forward Error Correction: Adding error correction codes.
- IoT Integration: Adapting for smart home and sensor networks.
- Extended Range: Using high-power LEDs and focusing lenses.
- Underwater Communication: Adapting for underwater applications.
- Secure Applications: Deploying in military and industrial settings.

The system's low-cost design makes it ideal for educational and prototyping purposes. Li-Fi has the potential to revolutionize wireless communication in RF-sensitive environments.

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References

[1] H. Haas, L. Yin, Y. Wang, and C. Chen, "Li-Fi: A new communication technology using light," Journal of Lightwave Technology, vol. 34, no. 6, pp. 1533–1544, 2011.

[2] Ramesh and Udaykumar, "Implementation of Li-Fi communication using Raspberry Pi with Manchester encoding," International Journal of Scientific & Engineering Research, vol. 11, no. 3, pp. 45–49, 2020.

[3] M. Arif and N. Patel, "Performance comparison of LDR and photodiode for Li-Fi systems," in Proc. Int. Conf. on Communication and Signal Processing (ICCCSP), Chennai, India, pp. 601–605, 2019.

[4] A. Sharma, P. Verma, and R. Gupta, "Applications of Li-Fi in Internet of Things (IoT)," International Journal of Computer Applications, vol. 175, no. 20, pp. 18–22, 2022.

[5] G. Madhuri et al., "High-speed Li-Fi communication using high-power LEDs," Journal of Optical Communications, vol. 41, no. 2, pp. 123–130, 2020.

[6] A. Saha et al., "Bidirectional Li-Fi communication with error correction," International Journal of Advanced Research in Engineering, vol. 6, no. 4, pp. 89–95, 2020.

[7] Y. Li and D. Chimis, "SiPM-based photon counting receivers for IoT applications," Journal of Optical Networking, vol. 14, no. 5, pp. 321–329, 2022.