Li-Fi Based Optical Wireless Transmission of Alphanumeric and Temperature Data for Smart Indoor Systems

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Abstract

Light Fidelity (Li-Fi) is one type of optical wireless communication that transmits data over a short distance using visible light. This proposed method is developed with two Arduino UNO boards, a high-brightness LED as a transmitter and a Light Dependent Resistor (LDR) as a receiver. The real-time temperature is combined with alphanumeric message transmission using a DH11 sensor as a transmitter. The message and the sensor data are displayed on a 16×2 LCD serial monitor. Data is encoded using On-Off Keying (OOK) based intensity modulation with a bit length of 150ms providing accurate decoding at the receiver under indoor illumination conditions. The results confirm effective transmission up to a length of 2cm. The performance decreases due to reduced transmitted optical intensity and ambient light interference. This method is an efficient end-to-end indoor optical connection for short-range sensor communication and educational purposes.

Keywords: Li-Fi, Visible Light Communication (VLC), Optical Wireless Communication, Arduino Uno, OOK Modulation, LDR Receiver, DHT11 Sensor, Short-Range Indoor Communication, Alphanumeric Message Transmission.

1. Introduction

Visible Light Communication (VLC) is a short-range wireless communication method that uses the spectrum of visible light to provide safe and interference-free data transfer. VLC has achieved visible indoor communication channels. Li-Fi is a subclass of VLC that encodes digital data using the spectral modulation of Light-Emitting Diodes (LEDs), making optical communications suitable for controlled indoor situations [1-5]. Despite these advantages, the existing Li-Fi prototypes have restricted performance. Most of the systems are limited to transmitting basic text messages and lack real-time sensor integration, organized communication and systematic evaluation of connected performance. Results such as range, latency and ambient-light sensitivity have created an imbalance in VLC when using hardware devices.

The short-range centimeter-level optimal communications have advantages for indoor applications requiring secure end-to-end data transfer such as device authentication, sensor readings in laboratories and short-range communication in RF-sensitive situations. In such cases, a 2 cm distance optical link provides a regulated and secure channel with minimal RF interference [6-10]. These challenges are addressed in this study to achieve the accurate decoding of sensor data and combined messages over a short-range Li-Fi network using simple optical channels under indoor illumination conditions. This study proposes a Li-Fi based optical wireless system that transmits alphanumeric text and real-time temperature data in a structured frame format.

The transmitter controls an LED with ASCII-derived data, while the receiver converts optical channel output to an LDR-based detector that decodes and develops data using thresholds. A fixed bit length of 150ms is used for decoding with the LDR receiver. This result evaluates the effective detection at a distance of 2 cm and the system performance concerning transmission latency and bit error under ambient light conditions.

The main contributions of this research work include:

- Real-time temperature sensor (DHT11) is integrated with alphanumeric data transmission over Li-Fi.

- The development of a structured frame format with a termination identifier to ensure accurate reconstruction.

- Short-range performance is systematically evaluated utilizing a predetermined bit length (150 ms), range (2 cm) and decoding accuracy under indoor illumination.

This study uses structured frame-based transmission of alphanumeric text and real-time temperature data to experimentally evaluate latency, BER and distance-based dependability under indoor illumination compared with previous research studies.

2. Related Work

Visible Light Communication (VLC) has been widely studied as a short-range alternative to RF systems. Early demonstrations such as the research [11] established the feasibility of LED-based optical links and showed that ambient illumination strongly affects link quality. Studies by [12-14] reported that simple VLC prototypes using basic intensity modulation can operate reliably at short distances, but they face range limitations when low-sensitivity detectors such as LDRs are used. Later works focused on improving reconstruction accuracy and bit-level reliability under varying illumination. Encoding techniques such as ASCII-based and Manchester coding were discussed in research [15], which highlighted synchronization and decoding improvements for visible light links.

Several researchers have also integrated environmental parameters such as temperature and humidity into VLC frames for indoor monitoring applications [7], [8]. However, many such systems depend on faster photodiodes for stable operation and improved bandwidth. Channel impairments and detector behavior have been extensively analyzed in the literature, where ambient light is consistently identified as a dominant limitation, especially for slow detectors like LDRs, which cause degradation in range and decoding accuracy under uncontrolled lighting [9]-[12]. Recent studies have used high-power LEDs, photodiodes, and advanced modulation methods to extend range and data rate, but such designs are often hardware-intensive and less suitable for simple educational prototypes [13]-[15].

Overall, previous Li-Fi prototypes frequently focus only on text transmission, lack structured framing, or depend on high-grade detectors. Therefore, a structured short-range Li-Fi prototype that integrates real-time sensing and evaluates delay and decoding reliability using simple LED–LDR hardware is required, as addressed in this research work.

3. Research Gap

The extensive research on Li-Fi and Visible Light Communication (VLC) combines the development and systematic evaluation of low-complexity, short-range Li-Fi systems integrated in real-time sensing using minimal hardware cost. The existing researches focused on high-speed VLC systems obtained photodiodes, advanced modulation methods and signal processing. Also, the previous research has a simple-level of prototypes that limited to simple text transmission with unstructured format of performance. The implementation of those works is not designed for real-time limitations like ambient light interference, response time detection, transmission delay when using the slow optical sensors like LCR. Some studies are implemented based on hardware-based designs which are not suitable for educational and low-cost experimental platforms. There is a lack of standardized frame structure and the performance metrics such as bit error, transmission delay and decoding stability in indoor lighting conditions are not quantified in Li-Fi prototypes. Hence, this proposed model worked for structured design, experimentally validated Li-Fi system shows reliable short-range optical communication using basic LED-LDR hardware by integrating real-time sensor data and providing quantitative performance evaluation.

4. Proposed Work

The proposed Li-Fi system is developed as a short-range optical wireless link capable of transmitting alphanumeric text along with real-time temperature data using visible light. The architecture consists of an LED-based transmitter, an optical propagation channel and an LDR-based receiver. The overall operation includes sensor acquisition, frame formation, binary encoding, OOK modulation, photodetection, threshold-based demodulation and LCD display output. The block diagram and the flowchart of the proposed system are shown in Figure. 1 and Figure. 2, respectively.
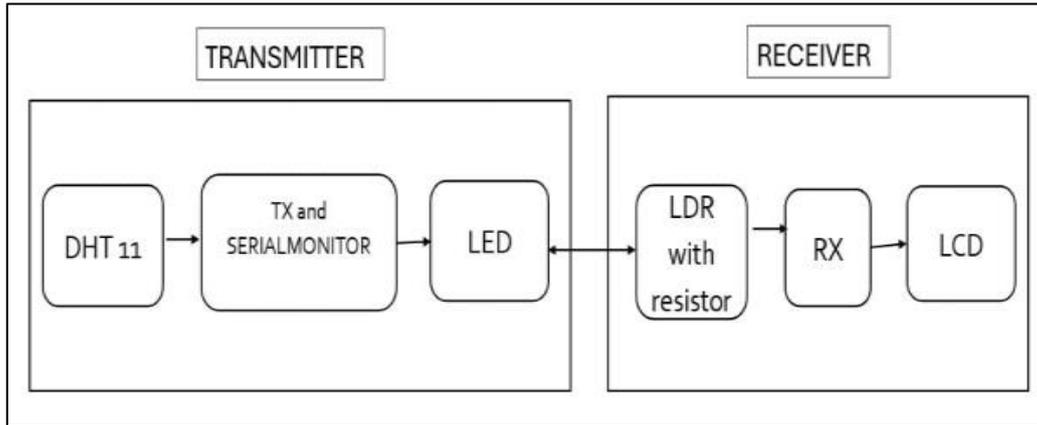
Figure 1. Block Diagram of the Proposed Li-Fi Based Optical Wireless Communication System
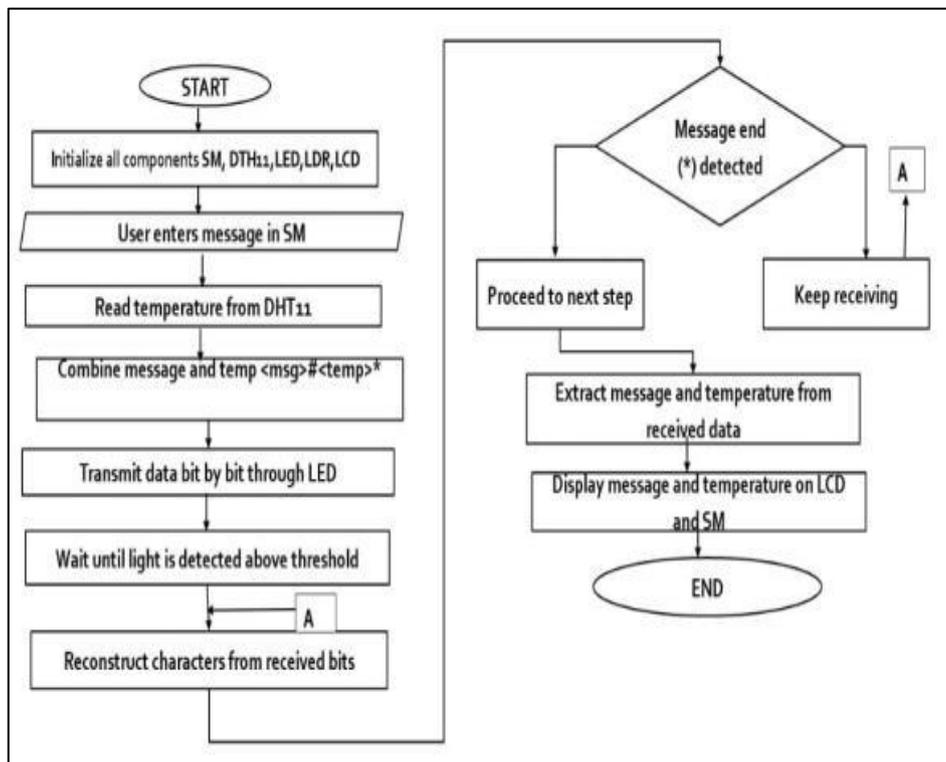

Figure 2. Flow Chart of the Proposed Li-Fi Based Optical Wireless Communication System

Figure 2 explains the flow of the visible light communication (VLC) system designed to transmit a user message along with the temperature data. The process begins with system initialization with all essential components like serial monitor, DH11 temperature sensor, LED transmitter, LDR receiver and LCD display. When the user enters the text message using the serial monitor, the system will simultaneously read the ambient temperature using DH11 sensor. These two data are combined into a single structured frame in the format <message#temperature*>, where the special symbols are used for separation and termination

process. The framed data is transmitted bit by bit using LED employs light intensity to represent the binary values.

On the receiver side, the system continuously monitors the LDR output and hold until the detected light intensity exceeds the predefined threshold, ensures reliable bit detection. The received bits are combined into 8-bit sequence to reconstruct ASCII characters. The system repeatedly checks for the termination symbol "*" to identify the end of the message. If the termination symbol is not detected, the receiver continues to accept data. Once the whole message received, the system will extract the original text message and temperature data from the decoded data. Finally, the received message and temperature values are displayed on both LCD and the serial monitor for the communication process.

4.1 Transmitter Architecture

The transmitter is implemented using an Arduino Uno, a DHT11 temperature sensor, and a high-brightness white LED. The temperature reading and user-entered text message are combined into a structured frame of the form <message#temperature*>, where '#' separates the message and temperature fields and '*' indicates the end of the frame. Each character of the message is converted into its 8-bit ASCII representation and transmitted using on–off keying (OOK), where LED ON represents binary '1' and LED OFF represents binary '0'.

A bit duration of 150m**s** is selected to ensure stable decoding at the receiver. This value is chosen experimentally larger than the effective response and settling time of the LDR-based receiver under indoor lighting conditions, thereby reducing bit misclassification during threshold detection.

4.2 Receiver Architecture

The receiver employs an LDR in a voltage-divider configuration to convert the received light intensity into a corresponding voltage signal. The Arduino Uno samples the voltage and applies a calibrated threshold to classify each received bit as '1' or '0'. The detected bits are grouped into 8-bit sequences to reconstruct ASCII characters until the termination symbol '*' is detected. The decoded message and temperature value are displayed on a 16×2 LCD operating in 4-bit mode. Figure 3 represents the system architecture.
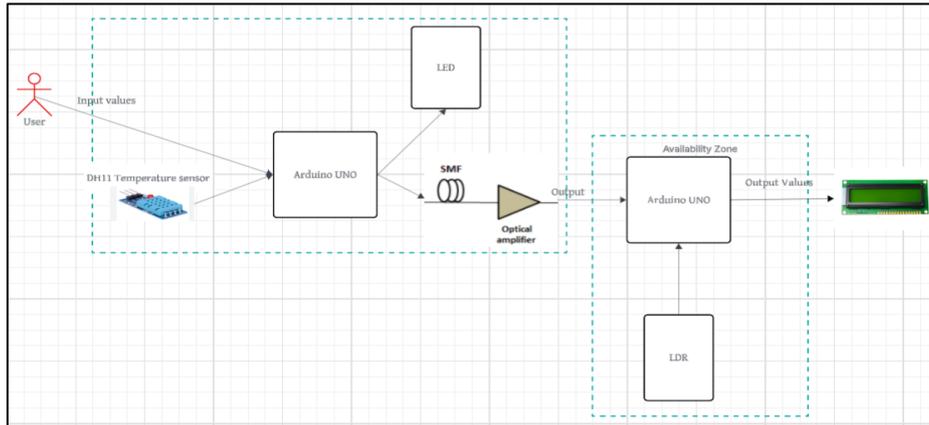
Figure 3. System Architecture Diagram

4.3 Optical Wireless Channel Considerations

The performance of the Li-Fi link depends on the received optical power and signal-to-noise ratio (SNR), which are influenced by LED intensity, transmitter–receiver alignment, ambient illumination, and the response time of the LDR. Under typical indoor lighting conditions, reliable decoding is achieved at a distance of 2 cm.

The bit duration was experimentally tuned by testing 50 ms, 100 ms and 150 ms. Reliable decoding was obtained only at 150 ms due to the LDR rise/fall response time and ADC sampling stability under indoor lighting.

5. Hardware Specification

5.1 Arduino UNO

Figure 4. Arduino UNO

The Arduino Uno [figure 4] is a series of open-source microcontroller board based on a diverse range of microcontrollers (MCU). It is designed for easy-to-use electronics prototyping. It has 14 digital I/O pins, 6 analog inputs, 16 MHz processor and a USB connection. It is widely used for robotics, IoT and DIY.
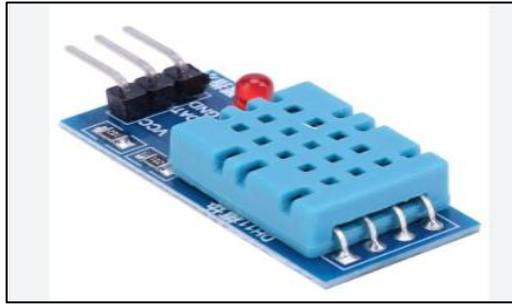
5.2 DH11 Temperature Sensor

Figure 5. DH11 Temperature Sensor

The DHT11 [figure 5] is a low-cost, 3-pin digital temperature and humidity sensor designed for basic environmental monitoring. It uses humidity data and a thermistor provide calibrated digital signal output suitable for Arduino, Raspberry Pi and other microcontrollers.
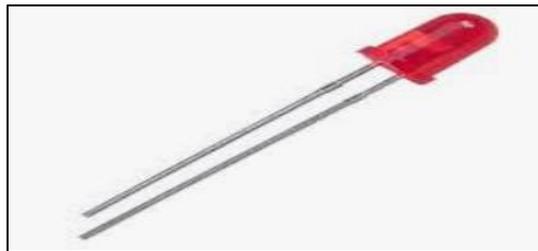
5.3 LED

Figure 6. LED

A Light-Emitting Diode (LED) [figure 6] is a highly energy-efficient semiconductor device converts electricity into visible light using 90% less energy than incandescent bulbs. LEDs emit light when electrons recombine with electron holes, releasing energy as photons. They are resilient, extensive and frequently utilized in lights, displays and electronics

5.4 LDR

Figure 7. LDR

An LDR (Light Dependent Resistor) [figure 7] is a semiconductor sensor with decreased resistance when light intensity increases. It is used for light detection in devices like streetlights and solar trackers where the resistance is very high in darkness and low in bright light.

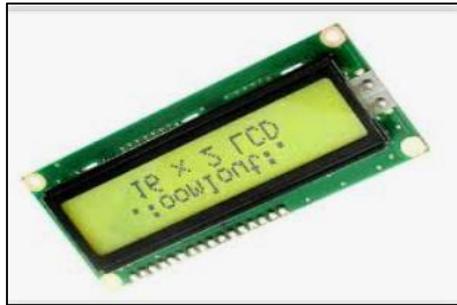## 5.5 16*2 Display Serial Monitor

Figure 8. 16*2 Display

A 16x2 LCD display [figure 8] shows 32 alphanumeric characters across two rows with 16 characters per row. It operates on 5V LED backlight and interfaced with Arduino or Raspberry Pi using 16 pins or just 4 pins with an I2C module.

6.   Results and Discussion

The proposed Li-Fi system was evaluated indoor lighting conditions using a high-brightness white LED-based transmitter and LDR-based receiver. The transmitter sends a structured frame of text form <message#temperature*> using OOK module with a fixed bit duration 150ms. The receiver will perform threshold-based decoding and displays the message and temperature on 16×2 display.

Table 1. Message Transmission Performance at 2 cm (bit delay = 150 ms)

Message	Transmitted frame string	Total characters	Expected time (s)
Hi	Hi#27.0*	8	13.20
Hello	Hello#27.0*	11	18.15
HiKsit	HiKsit#27.0*	12	20.45
Sensoi	Sensoi#28.1*	13	21.45
Test	Test#27.0*	11	18.15

6.1 Message Transmission Performance

Table 1 represents the transmission of five text messages. Each message is transmitted using fixed bit duration of 150ms that approximately transmits 1.65s per character. The excepted transmission time increases overall number of characters in transmitted frame. The measured transmission time matches the excepted time with minor deviations to ambient light fluctuations and the response latency of LDR. Error-free decoding was achieved at a distance of 2cm for five messages in indoor lighting conditions.

Figure 9 represents the hardware implementation of the proposed system. There will be connecting the Arduino UNO with the serial monitor, temperature sensor, white LED and the optical channel for transmitting the given message transmission which will be received in the receiver end connected with LDR, Arduino UNO and LCD for displaying the message.
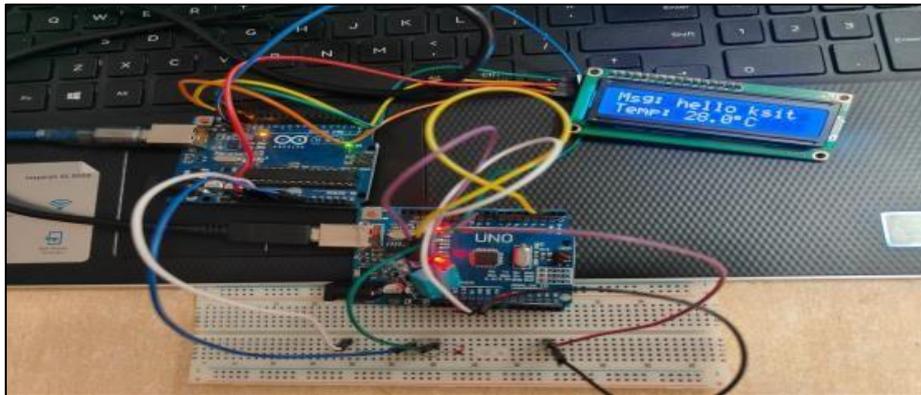

Figure 9. Hardware Implementation of the Proposed Li-Fi System

6.2 Bit Error Rate (BER) Analysis

Bit Error Rate (BER) is a performance metric used in digital communication systems to measure the accuracy of data transmission. The ratio of number of error bit received to the total number of transmitted bits as given in equation 1,

$$\text{BER} = \frac{\text{Number of error bits}}{\text{Total number of transmitted bits}} \tag{1}$$

The measured BER values for the transmitted frame are listed in table 2. The result shows the shorter frames can achieve lower BER and the longer frames achieves higher BER due to the cumulative effect of threshold detection under indoor ambient lighting. The below figure 10 shows the overall BER graphical representation from table 2.

Table 2. Bit Error Observation for Different Test Messages at 2 cm

Message	Transmitted frame string	Observed Error Bit	BER
Hi	Hi#27.0*	1	0.0156
Hello	Hello#27.0*	0	0
HiKsit	HiKsit#27.0*	0	0
Sensor	Sensor#27.5*	2	0.0192
Test	Test#27.2*	1	0.0114
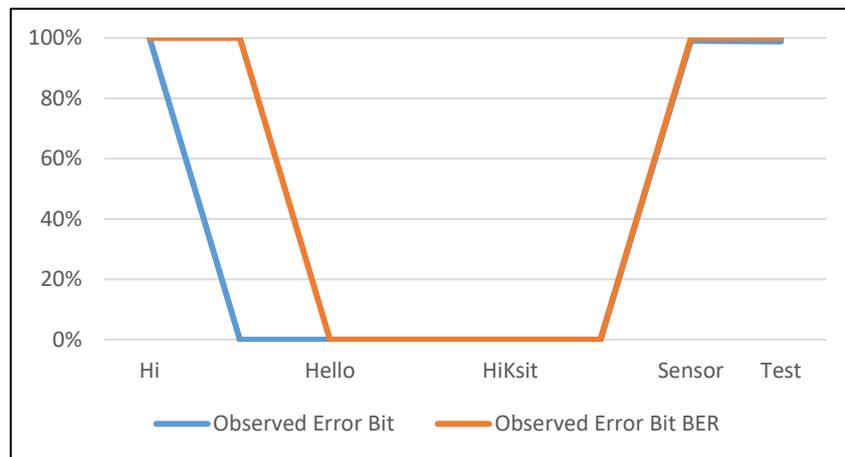
Figure 10. Bit Error Rate

6.3 Distance-Based Link Reliability

Optical link performance depends on received optical intensity and alignment between the LED and the LDR. As the distance increases, the received optical power reduces, which decreases the voltage margin available for threshold detection. Error-free decoding is achieved up to 2 cm, while beyond this distance the received signal becomes insufficient for stable bit reconstruction under the tested indoor conditions.

6.4 Comparison with Existing Li-Fi Prototype Implementations

Most of the researches from Li-Fi/VLC prototypes shows the simple text transmission using LED-LDR links without structured framing, systematic performance evaluation and

sensor integration. When compared to proposed work, the system integrates real-time temperature sensing along with alphanumeric transmission using a structured frame format and also provides experimental evaluation using distance-based reliability and transmission timing. Table 3 illustrates the comparison between the proposed and the previous research works.

Table 3. Comparison of Proposed System with Existing Li-F- Prototypes

Parameter	Existing basic Li-Fi prototype	Proposed research work
Data transmitted	Text only [8]	Text and Temperature sensor
Sensor integration	Not included [5]	DHT11 included
Frame format	Not structured [11]	Structured frame <message#temperature*>
Receiver	LDR based [16]	LDR and threshold decoding
Performance metrics	Not clearly reported [15]	Delay and distance reliability reported
Reliable distance	Not quantified [2]	Reliable decoding upto 2 cm
Output display	Optional [11]	16x2 LCD output

7. Conclusion

This proposed work explains the functional Li-Fi based short-range optical communication system transmitting textual data with real-time temperature data using visible light. The system ensures the reliable data development at the receiver end using structured frame format, OOK module and delimiter-based termination. The results confirms that the reliable communication and successful message transmission upto 2cm under the indoor lighting conditions by matching theoretical experimentations derived from selected bit delay. This will validate the implementation of low-complexity VLC links using basic components like LEDs and LDRs provides an optical alignment on system performance, ambient lighting and detector sensitivity. The prototype demonstrates the feasibility for short-range indoor authentication and sensor node communication by restricting the RF. Finally, this work provides a low-cost experimental system for evaluating VLC links in educational and laboratory environments that enables future extension to photodiode-based systems.

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