Low Cost Light Fidelity (Li-Fi) System Employing On-Off Keying Data Modulation in Half-Duplex Asynchronous Transmission Mode

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Abstract. In recent years, Light Fidelity (LiFi) technology has gained more and more attention due to its ability to transmit large data in a short time, and prevents interference and radiation compared to conventional WiFi communication. Therefore, it is more preferable to be employed in health care related sector. In this paper, a low cost wireless data communication using Li-Fi Technology is presented. This project employed On-Off Keying (OOK) Modulation Technique to encode and decode messages. A pair of prototype transceivers were developed and adapting Half-Duplex Asynchronous Transmission Mode. The overall hardware is employing Arduino Nano and LEDs and hence the price was kept around USD 25. The entire system was being tested on four different aspects and they were data transmission duration, distance between transceivers, the transmission angle of the transceivers and the message capacity. These tests were being evaluated by Word Error Rate (WER) to acquire the accuracy. In short, the transceivers were able to transmit and receive all the alphabets, numbers and symbols on the ASCII computer keyboard. It works optimally with the transceiver angle of ±10° in a distance of 20cm with the minimum delay of 102ms. The data modulation techniques and the hardware selection were believed as the factors to improve the system performance.

Index Terms— Li-Fi, OOK Modulation Technique, Half Duplex, Asynchronous, Transceivers

1. Introduction
Li-Fi uses visible light as medium for data transmission between wireless electronic devices. Therefore, all the data are being transmitted and received through the Visible Light Spectrum instead of the Radio Wave Spectrum which is used by all the wireless devices in the market place. As a result, information signals that are transmitted using visible light medium are not being interfered by other radio waves due to the different spectrum band of operation. In addition, Li-Fi provide higher wireless data transmission speed as the frequency spectrum of Li-Fi is 10000 times wider than Wi-Fi, Hence, more data can be allocated and maximize the overall data traffic in the Li-Fi spectrum [1]. Furthermore, Li-Fi offers higher security in terms of data security. Since, Li-Fi uses visible light as the medium for wireless data communication. Visible light that cannot penetrate through concrete walls improve the data security in an enclosed space [2]. As an example, the wireless infusion pumps and the Electronic Medical Record (EMR) that connected to each other requires high data security to
prevent modifications on the patients’ medical prescriptions and records by the hacker. Implementing Li-Fi technology to support the Hospital network system can improve the data security and better healthcare management services can be provided.

The current LiFi data transmission system can be costly for a complete implementation. Therefore the motivation of this paper is to produce a low cost data transmission system employing light spectrum. The objectives for this research are listed below:

1. To design & develop a data transmission algorithm for Li-Fi application.
2. To produce the transceiver hardware with low cost component (< 50USD).
3. To evaluate the performance of the proposed Li-Fi system in terms of data accuracy.

Consequently, in this paper, a pair of prototype transceivers were built with low cost materials and being tested with various environment setup. These prototype transceivers were able to encode input information into binary. The binary information was being transmitted through the white light band emitted from the LED. On the other hand, the transceivers were able to decode the information from the light signals emitted from the transmitter LED. The encoding and decoding technique was On Off Keying (OOK) method in Half-Duplex Asynchronous Transmission Mode, where the wireless transmission of data can occur bidirectionally but cannot be executed simultaneously. Moreover, an additional self-aligned mechanism was included to the transceiver to enhance the flexibility of tranceiving angle. Self-aligned mechanism helps the transceivers to maintain line of sight condition in case the transceivers were out of sight. Several accuracy tests were carried out to test the system reliability.

2. Related Work
Several Hardware Implementation Techniques and Data Modulation Techniques were reviewed and highlighted based on the previous researches. For hardware implementation techniques, Nagdev et al. [3] used Microcontroller Atmega89c2051 as the microcontroller unit (MCU) to process the signal information. The signal information to be transmitted is in the form of binary signal. These binary signals were transmitted through a beam of visible white light via LED. The transmitted signals was then received by an NPN Phototransistor. The input information was processed by using MATLAB. While, the Graphical User Interface (GUI) was created using Visual Basic software. With these setups the system developed by Nagdev et al, was able to transmit and receive a normal image file in jpeg format (~2MB).

Bharath et al. [4] proposed a Bidirectional Communication in Li-Fi Technology by a pair of transceivers. The MCU used for the transceivers is ULN2803. Signal information was processed in binary by the MCU. Processed information was then transmitted through LED by flickering On and Off quickly. The transmitted information was received by a Photodiode. An inverting amplifier is used to amplify the received signal. Shakeera et al. [5] proposed a research on PC to PC File Transfer using Li-Fi Technology. The researchers developed a transmitter and a receiver. Both the transmitter and receiver used Arduino Uno Board as the system MCU. LED acted as the transmitter and Photoresistor (LDR) acted as the receiver. Both components were connected to respective MCU. The file was loaded into the Processing software and sent to the Arduino IDE software for data processing. The data was converted to binary format and transmitted via LED by flickering On and Off.

On the other hand, several related journals and conference papers were being reviewed with regards to the Data Modulation Techniques. Porselvi, Bhagyalakshmi & Sumna [6] proposed a Healthcare Monitoring System (HMS) using Li-Fi Networks. The prototype was developed for simulating the monitoring system. The researchers used On-Off Keying Non-Return-to-Zero (OOK-NRZ) modulation technique to modulate the original information signal into binary format. The modulated signal is transmitted via LED and the received signal is demodulated and the original information is retrieved.

Pradana, Ahmadi & Adiono [7] proposed a Visible Light Communication (VLC) using Pulse Width Modulation (PWM) technique for data transmission and reception of running texts. A series of tests were carried out to evaluate the accuracy of using PWM in VLC system. The researchers
deduced that the accuracy of PWM is decreased as the frequency and the number of PWM bits used increases. Besides that, as the distant between the transmitter and receiver become further, the lower the PWM accuracy. In addition, the Bit Error Rate for the system using PWM modulation technique showed best accuracy with 1 Bit PWM. Finally, the researchers have noted that the PWM technique is most applicable for low data transmission rate application. Yildirim et al. [8] proposed a Low-Cost Li-Fi Communication Setup. The proposed Li-Fi system used On-Off Keying (OOK) Data Modulation Scheme for transmitting modulated data through the transmitter via LEDs. Then, the data was received by the receiver via the light dependent resistor (LDR). The modulated data was demodulated by the receiver circuit.

Rahul, Akshay & Sandhya [9] proposed a Li-Fi based system to transmit information data such as text, audio, picture and video via PCs. The researchers proposed 3 different modulation schemes for the development of the system. First of all, the On-Off Keying (OOK) Modulation Scheme was tested. The information data was transmitted by turning the LED on and off. When the LED is on the status is in 1 state and LED is off the status is in 0 state. This modulation scheme was considered to be simple to generate and decode. The second proposed modulation scheme was the Variable Pulse Position Modulation (VPPM). This method uses the pulse position within a set period of time to encode the information. In order to determine different pulse position, the set period of time must be in a suitable duration. The principle of Pulse Position Modulation is the positive pulse is represented by a 0 at the starting of the period and then followed by a negative pulse. While the negative pulse is represented by a 1 at the starting of the period and followed by a positive pulse. This modulation scheme allows the light to be dimmed. Lastly, the Color Shift Keying (CSK) modulation scheme. This method is used for illumination system that implemented with RGB LEDs. The output information data is carried by the color produce from the RGB LED. One of the disadvantage for this modulation scheme was the complexity of the system’s transmitter and receiver. In short, the developed system was able to transmit text and image file. However, the modulation technique used was not specified in the paper.

Sharma [10] proposed a project on design & implementation of VLC System. OOK Modulation was being used for data modulation and demodulation where the LED was turning on and off rapidly to transmit digital signal. The implementation of this modulation technique to the transmitter and receiver has successfully transmitted and received the temperature sensor value. The maximum transmission distance was 1.5 meters and the system has achieved a transmission rate of 500 bps.

3. Processed Methodology
In this paper, the proposed Li-Fi system consists of two transceiver units with On-Off Keying as the data modulation technique. The core components are the MCU (Arduino Nano Board), LED and Photodiode Sensor Module. The proposed system is bidirectional where it enables two-way data communication. Healthcare Centre that consist of many work stations, medical devices, surgical rooms, etc. which requires a seamless communication between one another. A device that allows two-way communication can be helpful in facilitating the work process or procedures efficiently and effectively.

3.1 Transceiver design
The system’s data demodulation processes were illustrated in Fig. 1. The PC station supply power to the MCU, as well as communicating serially with the MCU. The Photodiode Sensor detects the blinking of LED. Information was then stored into the MCU to be further processed. For the Servo Motor, it was controlled by the MCU to revolve from 0° to 180° and stop at the position where LoS was achieved between transceivers. Then, the information was being demodulated and finally displayed on the PC Station.

The system data modulation processes were displayed in Fig. 1(b). Similarly, PC station supply power to the MCU, as well as communicating serially with the MCU. Then, texts were being send to the MCU via serial communication between PC Station and MCU. Input texts then go through data modulation procedure and the texts were processed to become binary information. Finally, the LED of
the Transceiver emits lights according to the binary information where “1s” is represented by On and “0s” is represented by Off.

An overall system flow chart is shown in Fig. 2(a). The system flow chart can be separated into three main parts which comprised of Transceiver Light Align (middle), Data Modulation (right) and Data Demodulation (left). The fundamental concept of the entire system used Point-to-Point Line Configuration where the two prototype transceivers communicate between each other using Li-Fi technology. Besides that, the system is not designed to transmit and receive signal simultaneously. It is also known as Half-Duplex Transmission Mode.

3.2 Working Principle of entire System

Furthermore, the data of the system is being encoded into binary data format and is being transmitted away from the LED by flickering On and Off. The binary “1’s” is represented as “On” and the binary “0’s” is represented as “Off”. As for the receiver (photodiode), it detects the On and Off status of the LED. The receiver differentiated the incoming light signal by two voltage levels where LED “On” represents 5V and LED “Off” represents 0V. These analogue representations were converted into digital signal of “1’s” and “0’s” by the receiver itself. Hence, the acquired data can be recognized by the MCU and is feasible to be demodulated with the system program.

Lastly, since the data is being encoded to be transmitted through visible light. Therefore, it is necessary for both the transceivers to have achieved LoS to effectively and accurately transmit and receive the light signals. Hence, one of the transceivers that built-in with a Servo Motor is able to
revolve around from $0^\circ$ to $180^\circ$ to trace the best transmission position between transceivers to best facilitate the data transmission.

4 Experimental Results and Discussions

The test objective for the developed prototype (transceiver) is to evaluate the performance of the built system in terms of the data transmission range, data transmission angle and the data transmission accuracy. These data are significant for the user reference, future improvements and development. There were total 4 tests carried out such as the Data Transmission Time Test, Distant Test, Angle & Distant Test and Data Capacity Test. The test results of all 4 tests were interrelated to each other. Besides that, Word Error Rate (WER) was being used to formulate the accuracy of data received.

\[
WER = \frac{S + D + I}{S + D + C}
\]

(1)

where, \( S \) is Substitution, \( D \) is Deletion, \( I \) is Insertion, \( C \) is Correct.

4.1 Data Transmission Time Test.

In this test, the data attained can significantly shows the relationship between System Delay Time (ms), time taken to complete transmission and the Word Error Rate (WER). This can help to determine the best delay time for the system to facilitate data transmission accurately. According to the testing result, the fastest System Delay Time was discovered which was 102 ms. With 102 ms system delay time, the 10 characters can be completely transmitted and received in 11.35 s. Where the overall system speed was improved by 0.65 s (12 s – 11.35 s). The relationship between the system delay time and the time taken for the system to completely sent and received the signal is directly proportional. The shorter the system delay time, the shorter the time required to completely transmit and receive signal. Besides that, the data collected provide a significant information where the Word Error Rate (WER) is 0 % when the system delay time was set above 102 ms. However, the WER is 100 % when the system delay time was set below 102 ms. A 0 % WER represents no words error was encountered during data transmission. While, a 100 % WER represents complete error was encountered during data transmission.

4.2 Data Transmission Distant Test.

The objective of this test was to discover the maximum distance for the transceiver to work properly. The reason to keep the System Delay Time at 102 ms was because using 102 ms provides the fastest transmission speed for the system. The testing results showed that both the transceivers were able to work perfectly well at distance below 20 cm and the system was able to achieved a 0 % WER within the distance of 20 cm. However, the result may vary for different lighting environment. For example, in a brighter environment the effective distant of the system may be reduced, while in a dimmer environment the effective distant of the system may be increased.

4.3 Data Transmission Distant and Angle Test.

The objective of this test was to discover the best transmission distant with the widest transmission angle for the system to work properly. A significant relationship can be deduced based on the distant, angle and the WER. The visible angle of transmission for both the transceiver falls on any angle in between $80^\circ$ to $100^\circ$ from the normal axis of $90^\circ$. Besides that, in order for the transceiver to be able to send and receive signal successfully within the mentioned range of angles. The distant in between the transceiver had to be no further than 9 cm.
5 Conclusion and Future Work.

All in all, a pair of functioning prototype transceiver is developed, the algorithm for data modulation and demodulation is developed and the data transmission accuracy tests were being carried out to determine the data accuracy during data transmission between the transceivers. The highest system transmission speed was at 102 ms per bit interval. The system is capable of transmitting and receiving a maximum of 65 characters in a row with two transceivers being placed 20 cm apart from each other and achieved a 100% data transmission accuracy. Besides that, a 100% data transmission accuracy can be achieved with the transceivers being positioned with a viewing angle between 80° to 100° and were being placed apart at a maximum distant of 9 cm. This system is suitable to be used in enclosed area to isolate the direct WiFi communication to the surrounding while still enabling the data transmission without physical connection. It is also suitable for special compartment which require radiation free condition especially in a health care related institution.

The proposed system can be further enhanced such as the system’s data transmission speed by using different data modulation techniques such as, OOK Manchester Encoding Technique. Besides that, the hardware can be fabricated professionally by using CNC machine for precise mechanical work and using Printed Circuit Board to further scale down the overall physical size and weight of the prototype transceivers.

References

[1] Prof. Jadhav, P., Khatib, S. and Maner, K. (2017) Data Transmission Through Li-Fi. International Research Journal of Engineering and Technology (IRJET). 4(2). p. 1 – 4.

[2] Poojashree, N. S., Haripriya, P., Muneshware, M. S. and Anil, G. N. (2014) Li_FI Overview and Implementation in Medical Field. International Journal on Recent and Innovation trends in Computing and Communication. 2 (2). p. 1 - 4.

[3] Nagdev, J., Sher, D., Nathani, R. and Kalwani, G. (2013) Wireless Data Transfer Using Light Fidelity. International Journal of Science and Research (IJSR). 2 (6). p. 1 – 3.

[4] Bharath, B., Digumarthi, Y., Ravi, T. and Jegan, G. (2016) Bidirectional Communication in Li-Fi Technology. ARPN Journal of Engineering and Applied Sciences. 11 (13). p. 1-4.

[5] Shakeera, S., Manideep, P. S., Begum, M. S., Bhargav, V. V., and Rao, P. D. N. M. (2017) PC to PC File Transfer using Li-Fi Technology. International Journal of Engineering Trends and Technology (IJETT). 45(3). p. 143 – 145.

[6] Porselvi, S., Bhagyalakshmi, L. and Sanjay, K. S. (2017) Healthcare Monitoring Systems Using Li-Fi Networks. Innovare Journal of Engineering & Technology. 5 (2). p. 1 – 4.

[7] Pradana, A., Ahmadi, N. and Adiono, T. (2015) Design and Implementation of Visible Light Communication System Using Pulse Width Modulation. In The 5th International Conference on Electrical Engineering and Informatics 2015. Indonesia and 10th – 11th August 2015. p. 1-6.

[8] Yildirim, G., Ozen, O., Yuksel, H., and Naci Inci, M. (N.D.) A Low-Cost Li-Fi Communication Setup. Bogazici University, Physics Department. N.A. p. 1 – 6.

[9] Sharma, R. R., Sanganal, A. and Pati, S. (2014) Implementation of A Simple Li-Fi Based System. International Journal of Computing and Technology. 1(9). p. 437 – 443.

[10] Sharma, S. (2017) Design & Implementation of Visible Light Communication System. Tallinn University of Technology, School of Information Technologies. N.A. p. 26 – 31.