The Indoor Use Development for Visible Light Communication

Pokpoom Chanthosot[1], Vittaya Tipsuwanporn[2], Viriya Krongratana[3] and Thanaporn Lilawatthananun[4]

***Abstract*—The technology of visible light communication (VLC) for indoor use has LED and photodiode as two main components. Despite many advantages, VLC has a major problem regarding the short distance of effective communication due to limited power of the emitted light from LED. This study aims to improve effectiveness of VLC by increasing its distance of wireless data communication when used indoor. The method was based on using white LED Array. The operational results at different distances were presented by using UART as the connection interface between the transmitter and the receiver. This research was successful in increasing the maximum data transmission distance of VLC to be up to 400cm. The type of photodiode that enabled this success was OSD-100E Photodiode.**

***Keywords*—wireless optical data transmission system, visible light communication**

I. Introduction

Visible Light Communication (VLC) is a technology for receiving and sending data using white light, which is light in the visible spectrum. This technology is suitable to be used for transmitting data inside a building without interfering operations of other equipments such as medical equipments, aviation systems, etc. It was also applied to various forms of operations such as transferring data, showing interactive data [1], and taking photos automatically [2]. A major problem of VLC technology however concerns with the short reliable distance for its data transmission.

The main objective of this research is to improve the reliable data transmission distance of VLC when used indoor by having LEDs as the light sources. LED light bulbs were selected because they use a new technology that has many advantages over traditional lighting devices such as incandescent light bulbs and fluorescent light bulbs.

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There is a trend that people will turn to use LEDs instead of those traditional light bulbs because they can turn electrical energy to light more efficiently. LEDs can provide light just like fluorescent bulbs with some significant differences. Fluorescent bulbs contain mercury, but LEDs do not. Thus they are more environmentally friendly. The lifetime of general LED bulbs is very long, up to 50,000 hours. They also consume 90% less electrical energy when compared with incandescent light bulbs. LED technology is currently used widely in the fields of televisions, computer notebooks, and even mobile phones [1]. This research will present indoor data transmission by using white LED arrays as the data transmitters, photodiodes as the receivers, and UART as the interface. UART was selected in this study because it can communicate with full-duplex communications. That means it can receive data from the transmitter and can send data to the receiver simultaneously. In addition, UART does not require Clock wire for determining pulse of data transmission. UART defines the format and protocol of data communication, and specifies an equal speed of data transmission. Moreover, UART can connect to a computer via USB interface. Thus it is easy to be implemented. In this study, a model was built to explain operations of the transmitting section and the receiving section for ease of understanding in this system.

According to the referenced literature number [1], [3], [4], [5], and [6], VLC operations were studied by using LEDs and photodiodes for indoor applications. The paper number [7] explored VLC by using a method called modulation schemes and dimming support. The research number [8] conducted a study that used LED arrays for communication along the road. The research number [9] analyzed for proper positions of LED arrays in a VLC system. A relay was recently developed to perform the function of full-duplex signal transmission [8]. To the authors' knowledge, there is no research that has used LED arrays for indoor application that transmits data via visible light with UART interface.

II. Methodology

A. The principle of visible light communication

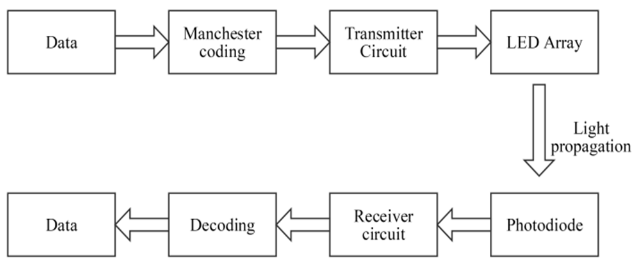

Fig. 1. Diagram of the signal connection for VLC.

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The communication with VLC in this research has a principle similar to the use of basic components in general optical communications [10]. The transmitted data were encoded with a method called binary Manchester coding as shown in Fig.1. With this method, bit 0 was converted into [−1, +1] and bit 1 was converted into [+1, −1]. The difference from general optical communications was that the electrical signal $x(t)$ is sent to the transistor No. BD 139 via an interface called UART. This UART transistor performs modulation functions in order to drive the LED array to shine according to the embedded data. Then the light will be diffused to the photodiode at the receiver. The receiver will convert the received light signal into an electrical signal and forward to LM 339, which is responsible for comparing electrical signals. The function of the received electrical signal *y(t)* can then be derived.

B. Signal transmission

For operation of the signal transmitting sector as shown in Fig. 1, the data signal from computer was adjusted by encoding it with binary Manchester codes. The encoded data were then sent as electrical signal *x(t)* to the transmitting circuit in order to amplify and forward the signal to the LED Array that shines according to the embedded data. The encoding method with binary Manchester codes was chosen to be used for the data signal adjustment. This method converts bit 1 to [+1,−1] and bit 0 to [−1,+1]. A function of the electrical signal $x(t)$ for driving the LED array to shine according to the embedded data was created as follow.

$$x(t) = b + \sum_{n} S_{bl}(t)\ , \tag{1}$$

where b is the noise signal of the transmitting sector's circuit, n is the position of each bit, $S_{bl}(t)$ is the operational function of sending bit 0 and bit 1 when T_{nb} is the time for sending one bit, and T_B is the time starting from sending the first bit until right before sending the current bit. $+A$ is a 'high' level of the signal while $-A$ is a 'low' level of the signal. The operational function in sending bit 0 and bit 1 can be written as follow.

$$S_{b0}(t)\begin{cases} -A;\ T_B \le T \le T_{\frac{nb}{2}} \\ +A;\ T_{\frac{nb}{2}} \le T \le T_{nb} \end{cases}, \tag{2}$$

$$S_{b1}(t)\begin{cases} +A;\ T_B \le T \le T_{\frac{nb}{2}} \\ -A;\ T_{\frac{nb}{2}} \le T \le T_{nb} \end{cases}, \tag{3}$$

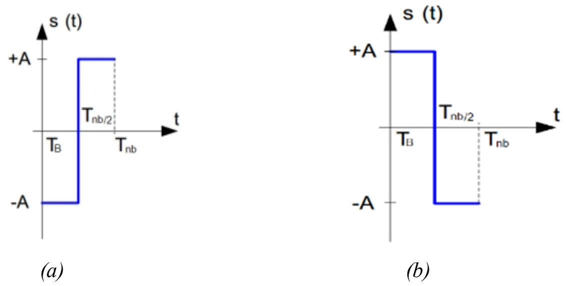

Fig. 2. The signal that was encoded with binary Manchester codes of function $S_{bl}(t)$, (a) sending bit 0 and (b) sending bit 1.

C. Signal receiving

For operation of the signal receiving sector as shown in Fig. 1, the photodiode sends the electrical signal as received from an LED array toward the receiver circuit. The receiver circuit then converts the received light signal into electrical signal. A function of the received electrical signal *y(t)* can then be derived as follow.

$$y(t) = \sum_{n} R(S), \tag{4}$$

$$R(S)\begin{cases} +A;\ A_L \le S \ge A_H \\ -A;\qquad S < A_L \end{cases}, \tag{5}$$

$$S = s_r - b_R, \tag{6}$$

, where n is the signal that enters the receiving circuit $R(S)$, which has a duty of checking the entered signal whether its status is high or low. $R(S)$ operates as represented by (5), where S is the signal that was canceled out within the circuit. It has a value equal to the signal received from the Photodiode (s_r) minus the interfering signal (noise signal) within the receiving circuit (b_R). Equation (6) shows that A_L is the criterion for recognizing the signal to have a 'low' status while A_H is the criterion for a 'high' status.

D. Designing the system of the transmitting sector

This study adhered with the operational principles according to equations (1), (2), and (3). Firstly, the data to be transmitted was processed in order to check whether it is bit 0 or bit 1. Then the data was encoded with the binary Manchester coding method; i.e. bit 0 was converted to [−1, +1] and bit 1 was converted to [+1,−1]. The encoded signal was modulated at the circuit of the transmitting sector. Then the LED was signaled to operate as shown in the flowchart of Fig. 3.

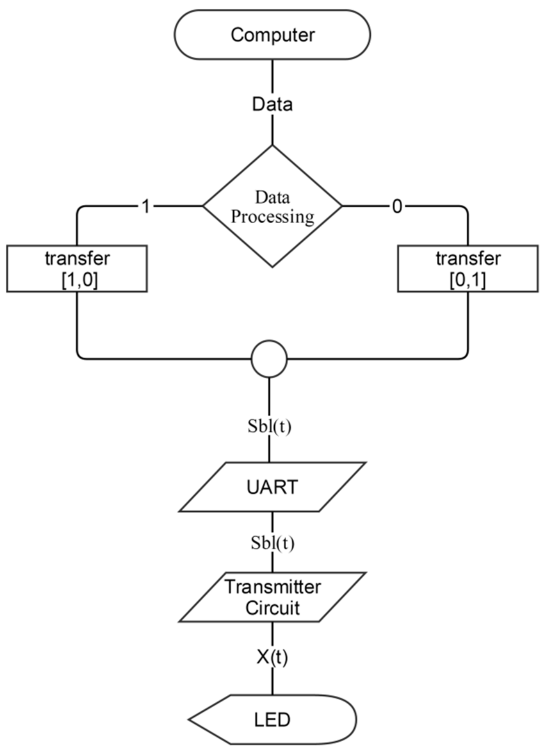

Fig. 3. Flowchart representing operational procedures of the transmitting sector of the system.

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E. Designing the system of the receiving sector

For the receiving sector, the study adhered to the principles in equations (4), (5), and (6). The electrical signal from the photodiode was taken through the receiving sector. It was then determined to have a status of either 0 or 1 according to (4). Then the data was sent for decoding as shown in the flowchart of Fig. 4.

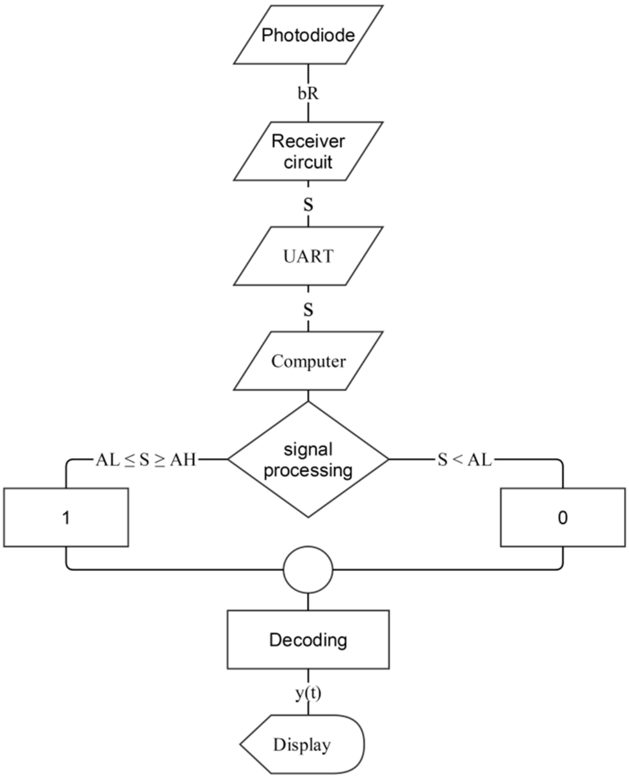

Fig.4. Flowchart representing operations in the system of the receiving sector.

F. System development

The transmitting sector and the receiving sector of the VLC were developed by using a white-light LED array as the light signal transmitters. Three types of light signal receivers namely VBPW24R Photodiode, FDS10x10 Photodiode, and OSD -100E Photodiode were used for the experiment. The afore-mentioned equations and the basic circuit diagram [11] were applied for referencing operations of the whole system. Then the system's capability in terms of the maximum speed for sending data without errors was assessed by using 3 types of different light signal receivers. For data transmission, the signal receiving sector and the signal sending sector were connected to 2 computers via a computer program written by using Visual C++ language.

Regarding calibrations, the electrical current was calibrated at the BD139 Transistor of the transmitting sector that transmits the signal to the LED Array. This calibration was made so that the amounts of flowing current when sending and when not sending the signal are equal. An Agilent multimeter of the model 34401A was used to checking whether the current has not changed.

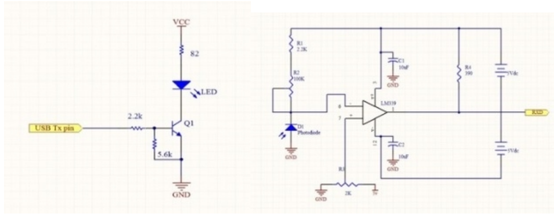

Fig. 5. The basic circuit diagrams of the transmitting sector and the receiving sector.

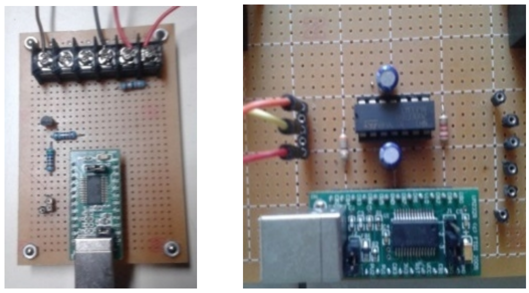

Fig. 6. The receiver and the transmitter of the VLC system.

Fig. 7. The experiment by installing the VLC system inside a building.

III. Results from the Experiment and the Analysis on Speeds of the System in Sending Data without Error of the System

A. Test results

Tests were conducted by sending real data with the circuit developed in the last topic. While sending out some text data, and the maximum baud rates that the system could achieve at various distances were recorded as shown in Table I.

TEBLE I
A summary of test results regarding speed capability in sending data at various distances

Transmitting /Receiving distances	VBPW24R(bit/s)	FDS10X10(bit/s)	OSD100-E (bit/s)
0	256000	256000	256000
50	4800	56000	57600
90	-	14400	38400
100	-	9600	28800
200	-	1200	14400
300	-	-	9600
400	-	-	4800

Table I shows that the VBPW24R photodiode had a maximum data-transmission distance of 50 cm, the FDS 10x10 photodiode had a maximum distance of 200 cm, and the OSD-100E photodiode had a maximum distance of 400 cm. Therefore, it can be concluded that the best photodiode

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among the 3 types selected for this study was OSD-100E Photodiode. This photodiode is not superior to the others in terms of distance only. According to the graph, the OSD-100E Photodiode is also better than the other 2 photodiodes in terms of the achieved speeds at various distances.

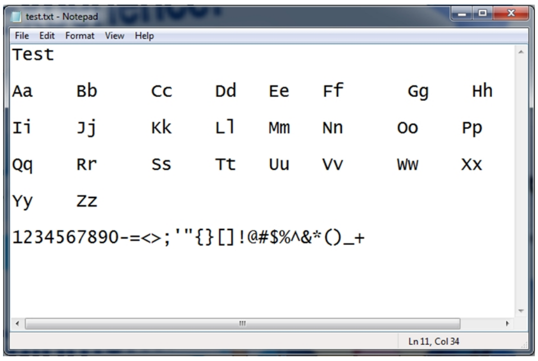

Fig. 8. The file used for testing with data transmission.

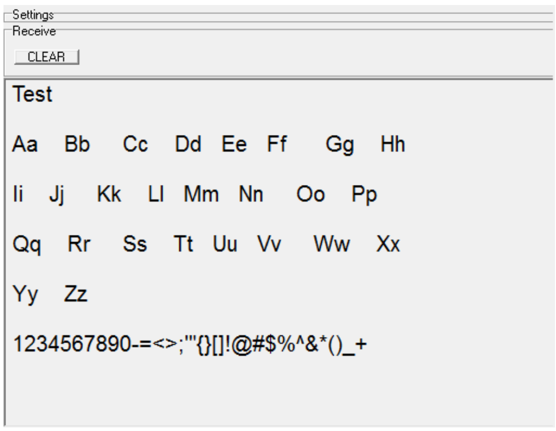

Fig. 9. The obtained results after sending data via a computer program written with Visual C++.

B. *The analysis on the test results*

In this experiment, the LED arrays that were used for transmitting data had to blink all the time while performing the work according to the specified baud rate. These LED arrays are however expected to function well throughout their lifetime because they have high response time that makes them more tolerant to blinking than incandescent light bulbs (bulbs with wire filament). In order to ensure that this system will function well without failure or any mistakes, the system was designed so that the LED arrays can transmit data all the time. The system expected to be use for this purpose is a star system. The principle of this system is to add number of LED Array. The system will consist of several sets of three LED arrays that are placed in proper positions so that the can share the work of data transmission efficiently. This configuration is believed to reduce burden of the LEDs. In addition, when an LED array malfunctions, the remaining LED arrays can take the responsibility instead.

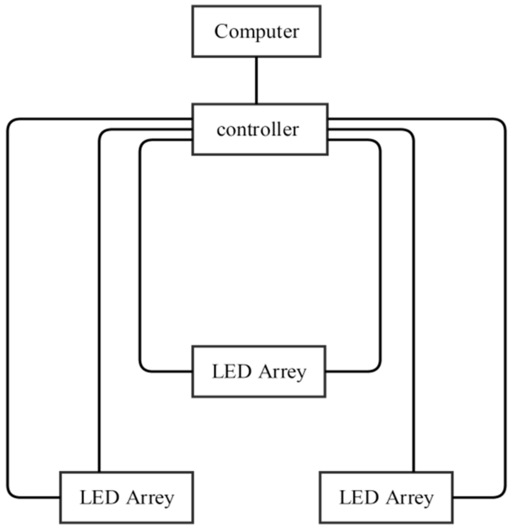

Fig. 10. Structure of a star system.

IV. Discussion Regarding System Stability Improvement

When this system has been operated for a long time, there can be a problem regarding stability of data transmission. The transmitter might stop sending data or fail to operate. This problem can happen when the computers lose connection between the transmitting sector and the receiving sector. In order to solve this problem and to make the system more reliable, a 'watchdog timer' program was written. This program operates when the computers lose connection from either the transmitting sector or the receiving sector. When this connection failure happens, the program will count backward for 5 seconds then reconnect.

After the watchdog timer program [11] was implemented and the system was run for a long time again, it could be confirmed that this system is stable and can be used until the LED light bulbs reach their lifetime limit.

V. Conclusion

In this research, some equations were created to be used in the data transmission. These equations were used as references for the operational principles of the developed circuit when implemented in the real situation. The results from the real experimentation appeared that the maximum data transmission distance that could be achieved was 400 cm.

The topic that the authors plan to study in the future will be about development of a Star system, which had already been designed. The system is planned to be developed so that it can operate without requiring a computer for controlling data transmission. MCU Arduino will be used instead for controlling the system so that it can operate more efficiently.

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