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Full-duplex Star Redundant System for Visible Light Communication

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***Abstract*—The full-duplex star redundant system of visible light communication (VLC) for indoor utilization was developed by adding an IR transmitter into the slave part and an IR receiver into the master part of the previous system, which had only an LED as the transmitter and a photodiode as the receiver. This development allows the system to be capable to transmit and receive images and audios in addition to mere texts as before. The transmitted data were encoded with the technique of Manchester encoding, and then tested with 3 types of photodiodes namely VBPW24R, FDS10X10, and OSD100-E. The data transmission was backed up with 3 LED modules that were controlled by an Arduino microcontroller in case one of the modules is damaged. Moreover, the system has functionality in notifying users via the status monitor to check when malfunction happens with any module.**

Index Terms—wireless optical data transmission system, visible light communication, redundant

I. INTRODUCTION

For operation of this system, the LEDs have to blink all the time during data transmission according to the set baud rate. Since LEDs have high response time, they can tolerate blinking very well. Thus LEDs in this system are expected to function well throughout their operational lifetime. However, the device that controls these LEDs might not be able to tolerate blinking for a long time.

The main objective of this research is to embed full-duplex redundant functionality into the system in order to ensure that the system will function well without errors. What make this system different from the old system are additions of an IR transmitter into the slave part and an IR receiver into the master part. This improvement results in a complete full-duplex redundant system.

In reviewing literature regarding VLC technology, the research of No. [1], was found to study about star redundant systems. Several other researches [2]-[7] were found to involve with VLC systems that employed LEDs and photodiodes. The research of No. [8], studied about a redundant uplink optical channel for VLC. To the author's knowledge, no research so far has applied a full-duplex star redundant system to the use of VLC technology.

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II. FULL-DUPLEX STAR REDUNDANT SYSTEM FOR VLC

This full-duplex star redundant system has been developed in order to allow the previous star redundant system to be capable of mutual communications between the receiver and the transmitter. With this capability, the system will be able to transmit images and audios. This development could be done by adding infrared systems into the existing system [1] so that the transmitter on the ceiling can receive data and the receiver on the floor can transmit data, as shown in Fig. 1.

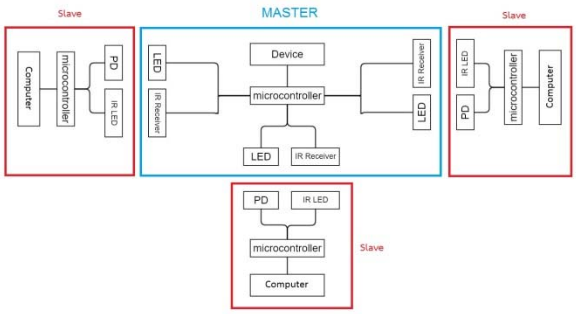

Fig. 1. Full duplex Star Redundant system VLC.

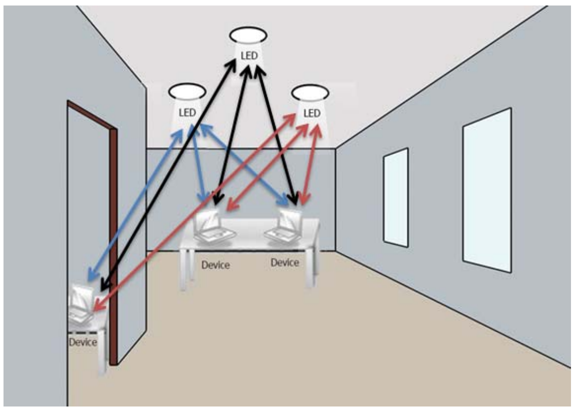

Fig. 2. Full-duplex Star redundant system installed inside a building.

III. DESIGN AND OPERATION OF THE SYSTEM

A. Equations for a full-duplex star redundantsystem

Operation of the full-duplex star redundant system is based on using a microcontroller for controlling 3 sets of LED modules via the relays. The microcontroller sends either On or Off signal to the r*elays that control the LED, the ground, and the IR* receiver of that module. *According to the designed* full-duplex star redundant system in Fig. 1, relevant equations can be written as follows.

$$M_{LED} = MCU(A, B, C) \quad (1.0)$$
$$A = LED_1 \text{--} \wedge IR_1 \quad (1.1)$$

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$$\mathrm{B} = \mathrm{LED}_2 \wedge \mathrm{IR}_2 \quad (1.2)$$
$$\mathrm{C} = \mathrm{LED}_3\text{--} \wedge \mathrm{IR}_3 \quad (1.3)$$

$$MCU(0,1,1)\begin{cases} line_1 = 0 \\ line_2 = 1 \\ line_3 = 0 \end{cases} \quad (1.4)$$

$$MCU(1,0,1)\begin{cases} line_1 = 1 \\ line_2 = 0 \\ line_3 = 0 \end{cases} \quad (1.5)$$

$$MCU(1,1,0)\begin{cases} line_1 = 0 \\ line_2 = 1 \\ line_3 = 0 \end{cases} \quad (1.6)$$

$$MCU(0,1,0)\begin{cases} line_1 = 0 \\ line_2 = 1 \\ line_3 = 0 \end{cases} \quad (1.7)$$

$$MCU(1,0,0)\begin{cases} line_1 = 1 \\ line_2 = 0 \\ line_3 = 0 \end{cases} \quad (1.8)$$

$$MCU(0,0,1)\begin{cases} line_1 = 0 \\ line_2 = 0 \\ line_3 = 1 \end{cases} \quad (1.9)$$

, where M_{LED} refers to the LED module that performs a redundant duty in case of damage happening to one of the modules. $MCU(A,B,C)$ refers to the decision function of the microcontroller when one of the LED modules is damaged. A,B,C are equations for checking the lines that are used for sending data No. 1, 2, and 3. It will be 1 only when both of LED_x and IR_x function properly.

B. Equations for the binary Manchester encoding

The electrical signal *x*(*t*) is encoded with binary Manchester codes by the microcontroller. The encoded signal is then sent to each set of the controlling modules so that the signal will be enhanced and forwarded toward either an LED or an IR transmitter. The method of binary Manchester encoding can be done by converting bit 1 into [+1,−1] and bit 0 into [−1,+1] $x(t)$ according to this equation [1].

$$x(t) = b + \sum_{n} S_{bl}(t)\ , \quad (2.0)$$

$$S_{b1}(t)\begin{cases} +A;\ T_B \le T \le T_{\frac{nb}{2}} \\ -A;\ T_{\frac{nb}{2}} \le T \le T_{nb} \end{cases}, \quad (2.1)$$

$$S_{b0}(t)\begin{cases} -A;\ T_B \le T \le T_{\frac{nb}{2}} \\ +A;\ T_{\frac{nb}{2}} \le T \le T_{nb} \end{cases}, \quad (2.2)$$

C. Equations for binary Manchester decoding

The signal y(t) is the decoded signal that is obtained when the microcontroller has decoded the encoded signal from the receiver devices (i.e. photodiode and IR receiver) that connect to the receiver circuit according to Equation [1].

$$y(t) = \sum_{n} R(S), \quad (3.0)$$

$$R(S)\begin{cases} +A;\ A_L \le S \ge A_H \\ -A;\qquad S < A_L \end{cases}, \quad (3.1)$$

$$S = s_r - b_R, \quad (3.2)$$

The microcontroller takes the converted (encoded) signal to be decoded with the binary Manchester decoding method, which converts [+1,−1] into bit 1 and [−1,+1] into bit 0.

D. Data transmission in the Master/Slave parts

The microcontroller performs a function of sending data through the line as required by the user. After determining whether the data is bit 0 or bit 1, the microcontroller then encodes the data with the binary Manchester coding method; i.e. bit 0 is converted into [−1, +1] and bit 1 is converted into [+1,−1], according to Equations (1.0), (1.1), and (1.2). After the encoding is completed, the microcontroller then modulates the encoded data toward the circuit that controls either the LED module or the IR transmitter through the line as commanded by the user. This research has developed a system that contains 3 lines of data transmission between the master and the slave parts, as shown in Fig. 3 and 4.

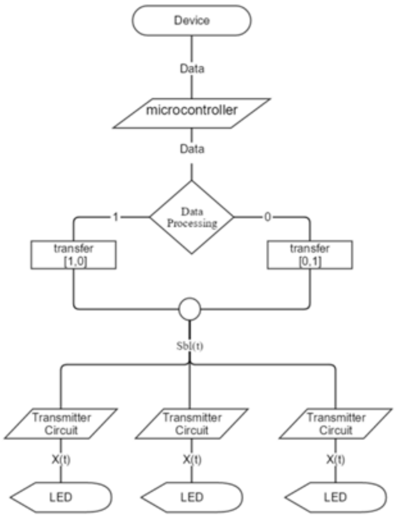

Fig .3. Flowchart showing data transmission in the Master part.

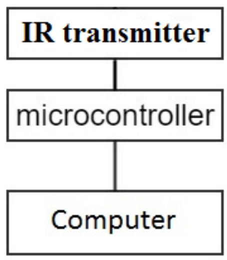

Fig. 4. Flowchart showing data transmission in the Slave part.

E. Data receiving in the Master/Slave parts

Based on the operation according to Equations (2.0), (2.1), and (2.2), the electrical signal is brought from a photodiode (Slave) or an IR receiver (Master) via the receiver circuit in that module. The electrical signal is then forwarded to the microcontroller to determine whether it is in the status of 0 or 1 according to Equation 2.0, before performing the decoding operation. The microcontroller then sends the decoded signal to the device that is waiting to receive the data from the receiver part, as shown in Fig. 5.

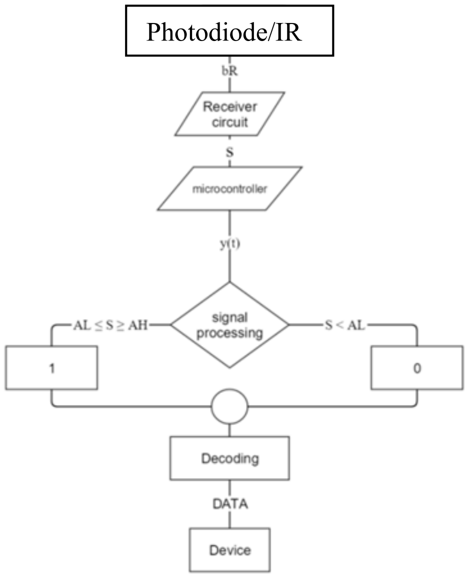

Fig. 5. Flowchart showing data receiving in the Master/Slave parts.

IV. SYSTEM CREATION

A. The transmitter circuit and the receiver circuit

This research created visible light-based transmitting and receiving circuits by using the equations discussed in previous sections. In addition, the operational principle of the whole system is also based on circuit diagrams. The system was tested and assessed in terms of speed capacity in transmitting data without errors by using white LEDs. Three different kinds of light receivers were used, namely VBPW24R Photodiode, FDS10x10 Photodiode, and OSD-1 0 0 E Photodiode . Based on the experimental results, the best receiver was then chosen to be used with the system. The system was turned on to operate continuously for 30 days at a distance of 2.5 meters. For data communication, the receiving circuits and the transmitting circuits can be connected to any devices that have USB ports. In this study, laptop computers were used.

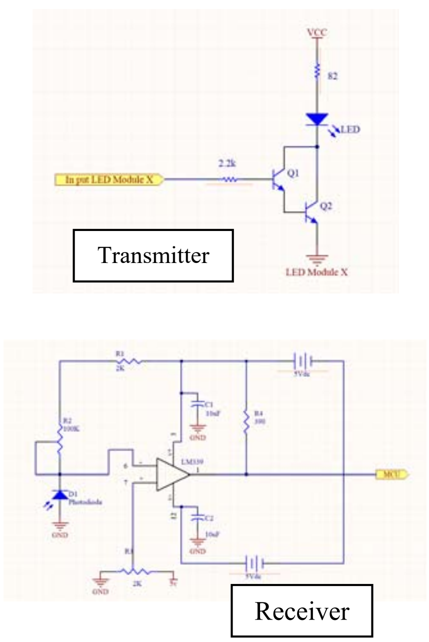

Fig. 6. The transmitter circuit and the receiver circuit.

B. Arduino uno r3

The microcontroller Arduino uno r3 was written by using computer application software called *Arduino* Genuino so that the system can operate according to Equation (1) .Under this system, the user needs to specify the line of data transmission first. The microcontroller will then send a signal to the line's slave to open the data display system in order to prepare for the data transmission. Then the data can be sent. After completion of the data transmission, the microcontroller will send a signal to inform the line's slave to turn off the data display system. In case of damage happening at the module of the selected line, the system will inform the user and propose a solution of using another module next to that line to perform the data transmission duty instead.

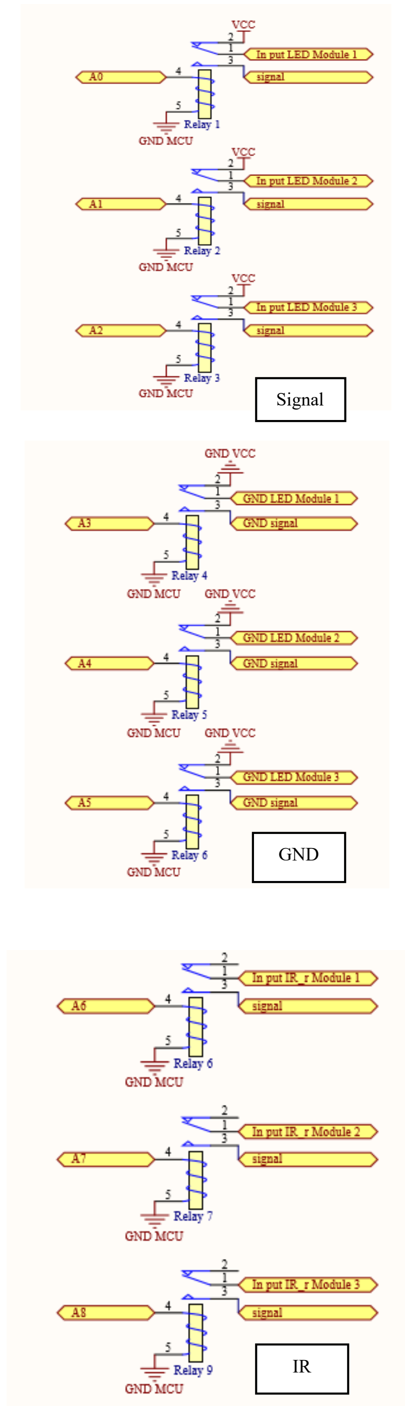

Fig. 7. The Redundant circuit.

According to Fig. 7, the developed system is not limited to be capable of handling just 3 lines of data transmission. However, for the purpose of system testing, this experiment performed data transmission by using only 3 lines. If required, the lines of data transmission can be increased without limitation.

C. Calibrations

Calibrations for the system were conducted by using an Agilent 34401A multimeter .The multimeter was used to check whether or not fluctuation occurred in the current distributed to the LED by the transistor bd139 during the data transmission. The current when there was no data transmission was also checked.

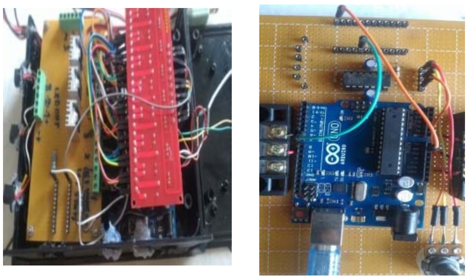

Fig. 8. The visible light transmitter equipped with a Star Redundant system and the visible light receiver.

V. RESULTS OF THE EXPERIMEN AND THE ANALYSIS ON THE SYSTEM REGARDING SPEED IN TRANSMITTING DATA WITHOUT ERROR

A .Results of the experiment

The developed circuit as explained in previous topics was used for communicating with real data. The system was installed by attaching the master part to the ceiling and placing the slave part on the floor. The data used for the experiment was a digital image. The maximum baud rates that the circuit could achieve at each distance were recorded, and then plotted as shown in Fig. 9.

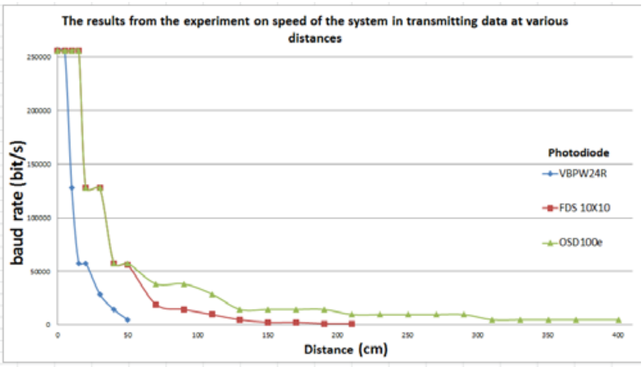

Fig. 9. Graph of the results from the experiment on speed of the system in transmitting data at various distances.

The method that was used for sending the image file is different from the method of sending a text file, where the master performs only transmitting and the slave performs only receiving. In order to send an image file or an audio file, mutual interaction between the master and the slave is required. Before transmitting the data, the master needs to send a signal to the slave to inform that the data is about to be transmitted. Then the master will wait for a response from the slave confirming that it is ready to receive data. After that the data can be sent from the master.

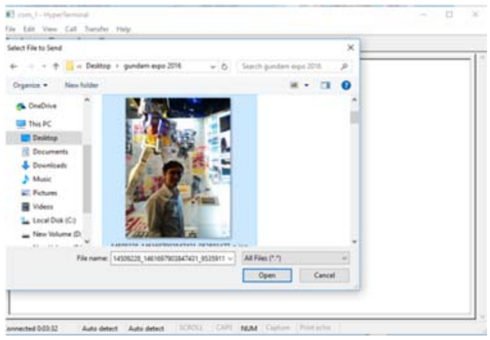

Fig. 10. The file used for the data transmission experiment.

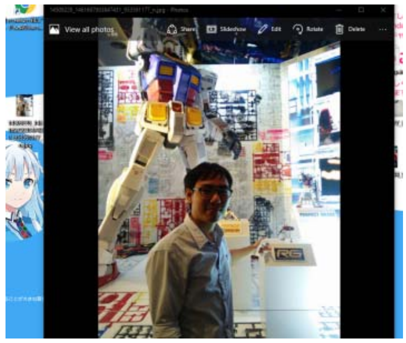

Fig. 11. The obtained results after data transmission via HyperTerminal program that was written using *Arduino Genuino.*

According to Fig. 9, it is apparent that using the OSD-100E Photodiode resulted in the longest distance of data communication at 400 cm. Therefore, it can be concluded that this photodiode is the best one among the 3 photodiode types. Hence, the OSD-100E Photodiode was chosen to be tested on the system that was run continuously for 30 days.

In the experiment of running the system for 30 days continuously, an image file was used as the data that was sent via all of the 3 lines. The lines for sending were selected randomly for 10 times within a day throughout the period of 30 days. The speed of data communication was at 9600 bit/second .That means this system has a processing capacity of transmitting 72,000 bytes of data within 1 minute. The result was that the system could operate without having any errors.

B. The analysis on the experiment results

Since the LEDs and the photodiodes used in this system are the same ones used in the previous research [1], the results from both experiments are similar. This similarity reveals that the developed Full-duplex star redundant system does not affect data transmission.

The developed system could operate continuously throughout the experimental period of 30 days. None of the modules was damaged. In order to check that the Full-duplex star redundant system can function as designed, a scenario was simulated. Under this scenario, one of the modules was set to be damaged, and operation of the microcontroller was observed. The result was that the system could operate according to the design.

This system still has an inherent limitation due to the use of visible light for data communication. A weakness of

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visible light is that it can be interfered easily by external objects. For example, an object may block the receiver so much that it cannot receive light signal of the data from the transmitter.

C. OSI reference layers for VLC communication

The OSI model (Open System Interconnection Model). The Reference Model is a layer of reference. Layer 1 - 7 is Layer 1. Bottom And up to Layer 7, each layer is named after its communication style and function in each layer. Uses light as intermediate between receiver and transmitter. Therefore, there are only 3 layers as shown in Fig. 12.

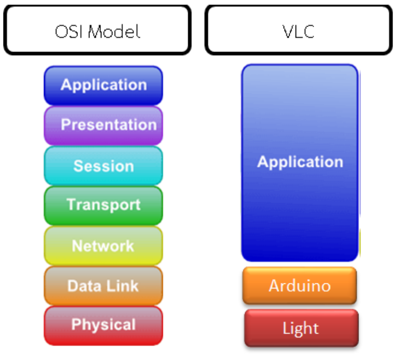

Fig. 12. VLC referenced with OSI Model.

VI. CONCLUSION

This research has developed a Full-duplex star redundant system for data communication by using LEDs and photodiodes as transmitters and receivers, respectively. To ensure that the system can function properly without any errors, it was tested continuously for 30 days non-stop. The results confirm that the system can perform always-on operation for a long period of time, and it causes no effects on data transmission. These conclusions are derived from the experiment results and the assessment on speed of transmitting data without errors, which did not have any changes due to implementation of the system. For the next topic to be studied in the future, speed enhancement for data communication with this system is very interesting and deserves to be studied.

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