A Prototype Implementation of Visible Light Communication Based Electrocardiography Data Transmission

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Abstract. VLC-based data transfer technology is one of the concepts of energy efficiency by utilizing existing light sources as media transfers. VLC is proposed to be part of the 5G technology so that its development and application is predicted to be very wide. The application of VLC is one of them in medical instrumentation. In this research, we proposed the prototype of VLC as an electrocardiograph (ECG) signal transfer media. This system consists of a transmitter and receiver using half-duplex mode. Transmitters use LEDs as light sources arranged in arrays and equipped with P-N-P type transistors as LED drivers. The receiver uses a light sensor in the form of a phototransistor. We carry out transmission testing in rooms with several lighting levels (0, 15, 30, 100, and 200 lux). From the test results, analog ECG signals able to sent with a maximum transmission distance of 450 cm.

1. Introduction

A radio wave has become one of the popular wireless communication media used in daily life. The use of radio waves requires a dedicated frequency to operate. At present, the need for radio-based communication continues to increase so that radio frequency spectrum resources become very limited. This problem became a critical issue which needs to be solved, and one of the solutions is by providing another type of carrier wave. Visible light considered as a proper solution for this problem [1]. Visible Light Communication (VLC) is one of the developments in telecommunications technology that currently developed. The continuous development of VLC technology offers various advantages compared to previous wireless technologies, namely Radio Frequency (RF) and Infrared (IR) [2].

The advantages offered by VLC include being able to transfer data quickly, will not experience electromagnetic interference, can overcome the limitations, frequency spectrum, and VLC supports Green Technology because its implementation can use existing infrastructure. Besides, using VLC data is harder to be captured because light waves cannot penetrate solid objects. As in previous studies [1,3], which are still focused on VLC performance. Even though VLC considered capable when applied in various fields of technology. One of them was possible to be applied in the field of a medical instrument such as monitoring ECG signal. The aim is to utilize existing light resources at health services center to monitor patients’ heart health. In this research, we designed a VLC prototype which applied to ECG instrument. The VLC designed in this research adopts the previous research design [4] and able to transmit the analog data received by the ECG machine. It is designed for real-time data transmission so that ECG data can be accessed as long as the receiver is in the room.
2. Method

2.1. Visible Light Communication
Visible Light Communication is one type of unguided light communication system where the type of light used is visible light. Currently, VLC development is focused more on indoor applications adapted from conventional infrared communication systems [5,6]. VLC has a general configuration similar to infrared communication. The main difference is the wavelength used to operate. The basic concept of a VLC is send the data using logic 1 by turning the light on, and logic 0 by turning the light off [7,8]. This method called as on/off keying modulation.

2.2. Light Emitting Diode
Light Emitting Diode (LED) is a semiconductor device that emits visible light into an electric current. The output of the LED can respond from red to blue-violet, the wavelength is about 700 nm to 400 nm. Some energy emits radiation (IR) (830 nm or more). This device is known as an infrared emitting diode (IRED). LED or IRED consists of two types of materials called P-type semiconductors and N-type semiconductors. Both elements placed in direct contact, part of the region called the P-N junction. The LED or IRED has a transparent package, allowing visible or IR energy to pass through it. Also, LEDs or IRED have large PN-junction areas whose shapes adapted to the application [9]. In this study, we use super-bright white LEDs with a power of 10W and a wavelength of around 450nm.
2.3. Phototransistor
A phototransistor is a transistor that can convert light energy into electricity, and it has an internal amplifier. The internal amplifier makes phototransistor sensitivity to light much better than other light detection components such as photodiode or photoresistor. The received light generates a current in the base region and produces a current gain of up to hundreds of times even several thousand times. A phototransistor is also an electronic component that classified as a transducer [10].

2.4. Electrocardiography
Electrocardiography is a medical device that able to display recordings electrical signals of the heart is in the form of graphs [11–14]. The signal then displayed through a monitor or printed on paper. The record called an electrocardiogram (ECG), as Goldman said: “the electrocardiogram (ECG) is a graph of the results of the electrical potential generated by the electrical activity of the heart muscle” [15].

The retrieving ECG signal method used in this research is the vectorcardiogram method based on Einthoven Triangle. This method is modelling the body’s potential as a three-dimensional vector using bipolar leads through three specific points on the body. Electrodes placed on three points of the body are right arm, left arm, and right leg as reference [16].

3. System Design
The system model implemented in this research designed for a line-of-sight indoor area. VLC is intended to replace lighting construction in the room to connect directly with the ECG machine. Then the clinician can monitor through the application while in the room area. The system model is shown in Figure 1.
The general system consists of two main subsystems that are the transmitter and receiver. The transmitter component consists of an ECG module which connected to the VLC transmitter prototype. Whereas in the receiver of the VLC prototype is equipped with a device to display the received ECG signal. The diagram design of the transmitter and receiver shown in Figure 2.

**Table 1** Experiment in 0 lux condition

| Distance (cm) | Transmitted Signal | Received Signal |
|--------------|--------------------|-----------------|
|              | Point R (V)        | Point S (V)     | Point R (V) | Point S (V) |
| 50           | 2.772              | 1.3898          | 2.58        | 2.4         |
| 100          | 2.64               | 1.464           | 2.39        | 1.44        |
| 150          | 2.73               | 1.416           | 1.9         | 0.9         |
| 200          | 2.624              | 1.386           | 1.02        | 0.46        |
| 250          | 2.71               | 1.39            | 0.73        | 0.33        |
| 300          | 2.68               | 1.24            | 0.51        | 0.08        |
| 350          | 2.73               | 1.36            | 0.38        | 0.03        |
| 400          | 2.66               | 1.31            | 0.31        | 0.074       |
| 450          | 2.68               | 1.26            | 0.215       | 0.082       |
The Transmitter subsystem serves to send electrocardiograph signals acquired by the analog front end ECG. The captured signal is an analog signal with an amplitude value that changes with time. This amplitude change affects the intensity of the LED linearly. Due to ECG signals having a

| Table 2 | Experiment in 15 lux condition |
|---------|-----------------------------|
| Distance (cm) | Transmitted Signal | Received Signal |
| | Point R (V) | Point S (V) | Point R (V) | Point S (V) |
| 50 | 2.828 | 1.404 | 0.68 | 0.38 |
| 100 | 2.792 | 1.42 | 0.71 | 0.32 |
| 150 | 2.47 | 1.39 | 0.64 | 0.374 |
| 200 | 2.624 | 1.366 | 0.49 | 0.234 |
| 250 | 2.77 | 1.36 | 0.6 | 0.37 |
| 300 | 2.54 | 1.31 | 0.62 | 0.47 |
| 350 | 2.772 | 1.398 | 0.53 | 0.41 |
| 360 | 2.64 | 1.424 | 0.244 | 0.23 |

| Table 3 | Experiment in 30 lux condition |
|---------|-----------------------------|
| Distance (cm) | Transmitted Signal | Received Signal |
| | Point R (V) | Point S (V) | Point R (V) | Point S (V) |
| 50 | 2.772 | 1.398 | - | - |
| 100 | 2.64 | 1.424 | 1.802 | 0.62 |
| 150 | 2.73 | 1.416 | 0.95 | 0.322 |
| 200 | 2.624 | 1.386 | 0.7 | 0.314 |
| 250 | 2.94 | 1.45 | 0.542 | 0.306 |
| 300 | 2.772 | 1.45 | 0.428 | 0.304 |
| 310 | 2.79 | 1.36 | 0.412 | 0.296 |
| 320 | 2.66 | 1.31 | 0.404 | 0.3 |
| 330 | 2.68 | 1.26 | 0.39 | 0.294 |

| Table 4 | Experiment in 100 lux condition |
|---------|-----------------------------|
| Distance (cm) | Transmitted Signal | Received Signal |
| | Point R (V) | Point S (V) | Point R (V) | Point S (V) |
| 50 | 2.921 | 1.283 | 1.894 | 0.97 |
| 100 | 2.624 | 1.37 | 1.25 | 0.526 |
| 150 | 2.47 | 1.39 | 0.924 | 0.286 |
| 200 | 2.624 | 1.386 | 0.924 | 0.286 |
| 250 | 2.94 | 1.45 | 0.39 | 0.174 |
| 260 | 2.772 | 1.45 | 0.302 | 0.168 |
| 270 | 2.79 | 1.36 | 0.2 | 0.166 |

| Table 5 | Experiment in 200 lux condition |
|---------|-----------------------------|
| Distance (cm) | Transmitted Signal | Received Signal |
| | Point R (V) | Point S (V) | Point R (V) | Point S (V) |
| 50 | 2.79 | 1.36 | 2.43 | 2.28 |
| 100 | 2.64 | 1.31 | 1.68 | 1.238 |
| 150 | 2.68 | 1.26 | 1.18 | 0.95 |
| 200 | 2.644 | 1.386 | 1.02 | 0.916 |
| 210 | 2.94 | 1.45 | 0.96 | 0.916 |
relatively small amplitude (mV), we use transistors as LED drivers that connected to the primary power source of 9V. LEDs are arranged in an array to increase the intensity of the beam. This method is expected to be able to extend the range between the transmitter and the receiver. In the receiver subsystem, light received by Phototransistor which arranged in parallel arrays. The array design in a phototransistor circuit is useful for amplifying currents that are relatively low due to distortion. As in the transmitter subsystem, the output signal has a change in the voltage value that represents the analog ECG waveform. This analog signal then forwarded to the digital component for the processing and display. Both circuits and prototype that implemented in this work shown in Figure 3 and 4.

4. Result and Discussion
The system performance tests that we proposed with ideal angle conditions (0°) without obstacle (LOS) between the transmitter and receiver. An example of an ECG wave on the transmitter and receiver side shown in Figure 5. The performance measurement of the proposed system was carried out by evaluating the distance to the light intensity measured using lux meters. In certain light intensity conditions, we conducted several experiments by changing the distance between the transmitter and receiver. During the experiment, we measured the maximum and minimum voltage values for the received ECG waves. Where the maximum voltage is the R wave, and the minimum voltage is the S wave of the ECG signal.

The voltage value obtained by converting the ADC value on the graph, with an increase in each decimal value in the graph is 4.488 mV. This test was conducted to analyze the effect of distance to the voltage level received at the light intensity of 0 lux, 15 lux, 30 lux, 100 lux, and 200 lux. From this test, it obtained that the distance is inversely proportional to the ECG wave voltage level in the receiver. This condition occurs because the photodiode only receives less light. The difference of the signal form as shown in Figure 5 can also be caused by the distortion of the light environment, and there is a possibility due to the limited response time of the transistor. If this system applied under real conditions, a description of the maximum distance specification is required by considering the primary form of the ECG signal that can still be analyzed. In the real application, amplifier and filter components are also needed on the receiver to maintain the ECG waveform. The results of testing this scenario shown in Table I, II, III, IV, and V.

The variation in light intensity also affects the achieved maximum transmission distance. In conditions of no light or intensity of 0 lux, we obtain the maximum distance between the transmitter and receiver from this prototype reaching 450 cm. In conditions of 15 lux prototypes working up to a distance of 350 cm, conditions of 30 lux up to 320 cm, and conditions of 100 lux to 260 cm. Moreover, in the brightest condition of 200 lux, the prototype can work effectively up to a distance of 200 cm. The effect of variations in light intensity on transmission distance shown in Figure 6.
5. Conclusion

This research has successfully implemented a VLC prototype as an ECG signal transmission medium for important parameter monitoring applications. This proposed system is capable of sending ECG signals in real-time. The sent and received signals do not lose important points in the ECG signal data, so the signal received has the same meaning as the signal produced by the ECG module, even though the receiving side of the voltage obtained is lower than the sending side. In conditions without light or intensity of 0 lux, this prototype is capable of sending signals up to 450 cm. Whereas in the brightest conditions during experiments with an intensity of 200 lux, the prototype can work optimally up to a distance of 200 cm. The higher the intensity value in a room, will reduce the maximum distance performance and the higher the intensity of the light causes the received signal voltage level to be smaller. This condition can overcome by adding a low noise amplifier circuit to the receiver with the note that the QRS complex form of the ECG signal was not damaged or in another meaning, the basic signal of ECG’s form can still be analyzed.

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