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Investigation on Relationship Between Communication Distance and Receiving Characteristic in Visible Light Communication Using LED and High-Speed Camera

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***Abstract*—The present paper considers an optical spatial channel in visible light communication (VLC) using LED and a high-speed camera. In general, the optical spatial channel affects the communication performance. However, the previous studies have not enough discussed the channel for VLC. This study focuses on the communication distance, which is one of channel parameters, and investigates the relationship between the distance and a receiving characteristic in the VLC.**

I. Introduction

This study considers visible light communication system (VLC) using an LED (transmitter) and a high-Speed Camera (receiver) [1]–[6]. The communication performance of this system depends on the recognition of the camera receiver. If the camera receiver cannot enough recognize an intensity of the LED light from the transmitter, its communication performance decreases. We consider that the recognition performance is affected by the optical spatial channel. However, the previous studies have not enough discussed the channel for VLC. This study focuses on the communication distance, which is one of channel parameters, and investigates the relationship between the distance and a receiving characteristic in the VLC.

II. System model and experimental method

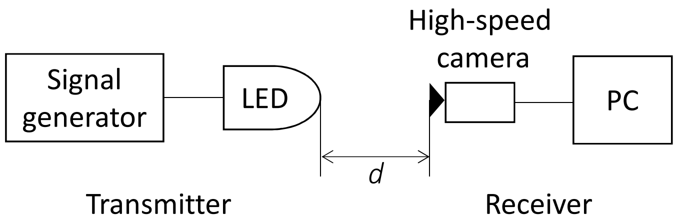

Fig. 1. Experimental system.

Figure 1 shows an experimental system. As a transmitter, we use a simple system consisting of a signal generator and a single LED. This study assumes that the transmitter sends data modulated by On-Off-Keying (OOK). Thus, the signal generator generates a f [Hz] square wave, and LED repeats periodic blinking (ON/OFF) depending on the square wave. The blinking LED light passes through the optical spatial channel and is arrived at a camera receiver. In this study, the camera captures the LED light at the shutter speed of $4f$ [fps]. In other words, we shoot the blinking LED light four times in a row and robustly capture a moment of LED ON or OFF. The received light is converted into an image, and the pixel value of the LED is extracted from the image as a LED luminance value. The actual VLC demodulates data using the extracted luminance values.

In this study, we shoot the LED light by changing the communication distance d [m] and analyze a number of pixels of the LED projected area and these pixel values (i.e., the luminance values) in each distance. Based on the analysis results, we investigate an effect on the demodulation performance in VLC due to the change of d. Specifically, we calculate an average LED luminance value (LED ON or OFF) and a threshold for demodulation of OOK signals by using the number of pixels of the LED area and these luminance values. Here, we explain the definition of the average LED luminance value. First, we choose the highest luminance value within the projected LED area and calculate its half luminance value. Second, we extract several pixels more than the half luminance value within the projected LED area. Finally we use these extracted pixels and calculate these average, i.e., the average LED luminance value. We analyze the threshold depending on d and express the demodulation limit of OOK due to the change of d in the actual VLC.

III. Experimental result

First of all, we explain experimental conditions. In the transmitter, a frequency of the square wave (f) is 500 Hz. We use a single white LED (LA504W3CA2C02) for the transmitter. In addition, we set any current flowing along the single LED due to avoid saturation on the sensor of the camera.

In the receiver, a frame rate of the camera is 2,000 fps, a focal length of the lens is 35 mm, a focus of the lens is infinity, and a lens diaphragm is 16. The transmitter and receiver are put face to face in a straight line, and are fixed on the ground. Based on these conditions, we perform the experiment described in Sec. 2 and analyze the number of pixels of the LED area and these luminance values by changing d. Furthermore, based on the analysis results, we investigate an effect on the demodulation performance in VLC due to the change of d.

Figure 2 shows the average LED luminance values (LED ON and OFF) and the threshold value versus the communication distance (d). First, let us focus on the transition of the average luminance value of LED ON. We can confirm that the average value of LED ON is high and almost constant until $d = 10$ m. However, more than $d = 10$ m, we can also confirm that the average one rapidly decreases with increasing d. The reason for this is that the size of LED on the image becomes smaller than one pixel of the image. To confirm this, we calculate the size of LED on the image geometrically according to a pin-hole camera model [7], as follows.

$$n_p = \frac{1}{\lambda^2}\frac{f^2}{d^2}S. \tag{1}$$

Where λ is the sensor size per one pixel, f is the focal length of the lens and S is the actual physical area of LED. From Eq. (1), we can find that the number of pixels of the LED projected area decreases in proportion to d^{-2} when λ and S are constant. We also plot pixel values calculated from Eq. (1) on Fig. 2. From Fig. 2 , we can find that the number of pixels is 1 when $d = 16$ m. In addition, this distance is near the distance that the average value of LED ON begins decrease. Thus, we consider that there is a close relationship between the LED luminance value and the size of LED on the image. Next, let us focus on the transition of threshold.

When d is near, the width of threshold, which is the difference between the average luminance of LED ON and OFF, is large. Namely, the receiver is easy to determine whether LED is ON or OFF even if the pixel values of the LED projected area are affected by noise. However, the width of threshold narrows with increasing d because the LED luminance value decreases as described the above reason. In this case, it is severe to distinguish LED ON or OFF on the image. In addition, it is difficult to recover data even if the small noise is added to the image. Therefore, we consider that the size of the LED on the image is necessary more than one pixel to ensure the enough width of threshold for OOK in VLC with the camera.

IV. Conclusion

In this study, we have investigated the relationship between the communication distance and the threshold for OOK in VLC with the camera. As a future work, we will investigate the influence of the optical spatial channel for VLC performance using multiple LEDs.

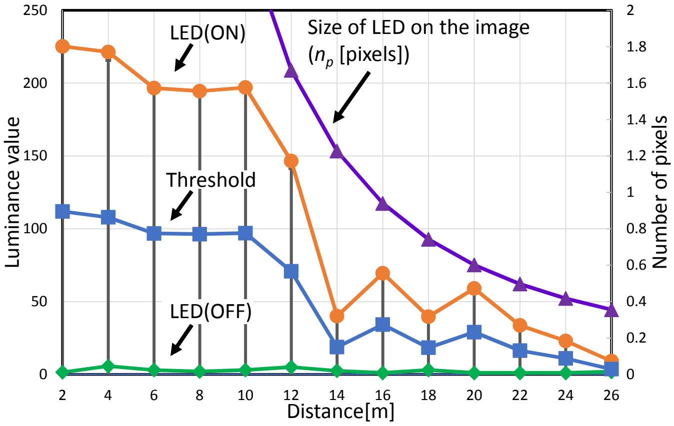

Fig. 2. Experimental result.

Acknowledgment

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