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비가시거리 광학 카메라 통신시스템 성능평가

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Performance Evaluation of Non-Line-of-Sight Optical Camera Communication System

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요 약

본 논문에서는 CMOS 카메라를 사용하여 비가시거리 가시광 통신(VLC: Visible Light Communication) 시스템의 성능에 영향을 미치는 다양한 성능파라미터에 대해 분석하고자 한다. 비가시거리 가시광 통신시스템에서 카메라는 LED의 데이터를 직접 수신하는 대신 반사 표면 (벽)으로부터 수신하게 된다. 이로 인하여 통신 가능거리는 NLOS 시스템이 LOS 시스템보다 길어지게 되는데, 이는 반사면의 크기가 LED의 크기보다 훨씬 크기 때문이다. 실험을 통해 카메라와 반사면 사이의 거리가 60cm이고 데이터가 4.5kH로 변조되어 전송된 경우 NLOS VLC 시스템이 3.1x10^{-5} 의 BER 성능을 보임을 확인하였다.

Key Words : LED, camera, reflective surface, NLOS communication, BER

ABSTRACT

In this paper, we investigate the impact of various parameters on the performance of a none-line-of-sight visible light communication (VLC) system using a CMOS camera. In this system, the camera does not record data from LEDs directly but data is recorded from the reflective surface (the wall). By this method, the communication distance of NLOS system is longer than that of LOS system because the size of the reflective surface is much bigger than size of LEDs. Through experiments, we demonstrate that the performance of NLOS VLC system can be achieved 3.1x10^{-5} BER when the distance between the camera and the reflective surface is 60 cm and the data is modulated at 4.5 kHz.

Ⅰ. Introduction

In the last few years, thanks to the development of technology, LED has become an indispensable device in everyday life with superior features over other types of lights, including longer usage time, quick response to change of electric current, and stronger lighting. In addition, LEDs can also be controlled easily through the controller. Therefore, the combination of LED lighting and signal transmission will be a trend in the future communication.

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In the VLC system using a CMOS camera, there are three ways to record data. Firstly, the camera records the signals from LEDs directly. In this method, we can get the highest data rate but the communication distance is very short and the camera needs to be in the right position[1]. The second method is to use LED panels such as televisions and advertising panels[2]. Since these are large screens, the distance between the camera and LED panels is longer. However, to get good performance, the camera is required to be in the right position and not every place has a big screen to operate on. Therefore, this method is not applicable in many situations. The final method is based on light reflection[3]. The camera does not receive signals directly from the LEDs, but it receives signals from the surface that reflects light from the LEDs. The disadvantage of this method is the lower data rate but its advantages are longer communication distance and flexible camera position. Therefore, the camera that captures images from the reflective surface has the highest practical applicability.

In this paper, we investigate the impact of various parameters on the performance of the non-line-of-sight (NLOS) VLC system using CMOS camera. We consider the performance parameters such as illuminance of environment, communication distance between camera and reflective surface and frequency of the signal. The third-order polynomial thresholding is considered as a demodulation method at the receiver. We obtained 3.1×10^{-5} BER when the transmitted data rate is 4.5 KHz, and the communication distance is 60 cm and the illuminance of the reflective surface is 164 lux.

Ⅱ. Experimental setup

Figure 1 shows the block diagram of the non-line-of-sight optical camera communication system. The data modulated by On-Off Keying (OOK) are generated from the computer, then is transferred to the Arduino. The LED driver controls the brightness of LEDs by controlling the current drive. Light of LEDs is projected onto the reflective surface and a CMOS camera is used to capture the reflected light at the receiver. Then, the captured image files is transferred into a computer to demodulate the original signal using Matlab.

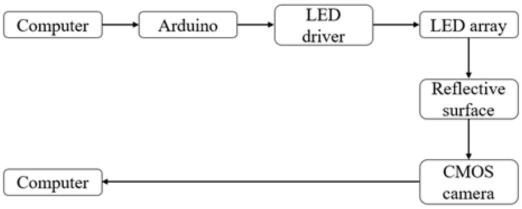

Fig. 1. Block diagram of NLOS optical camera communication system

Figure 2 shows experimental setup of NLOS VLC system. For LED array, we used 10 LEDs whose the power is 3 W, electric current of 600 mA ~700 mA, the voltage of 2 V~3.4 V. In our experiment, each packet consists of an 8-bit header (in Manchester coding format) and 40 bits payload (in on-off keying format). LEDs are projected onto the reflective surface which is the wall and camera captures the light reflected from the wall. We use a CMOS camera (Sony Cyber-shot DSC-RX100) with a resolution of 1080x1920 and a speed of 60 frames/second. However, camera always has the gap-time between frames due to rolling shutter effect. To avoid the data loss during gap-time, each message has to broadcast three times.

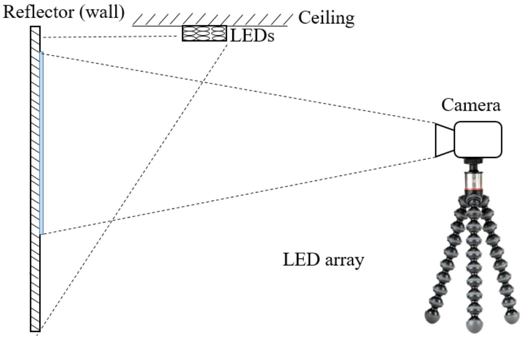

Fig. 2. Experimental setup

Ⅲ. Signal Processing Algorithm

The signal processing is performed by Matlab according to the steps in Fig. 3. Every frame from the video is extracted to the jpg image file. The

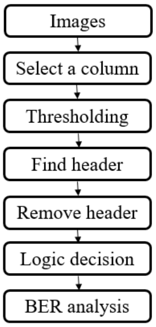

Fig. 3. system processing diagram

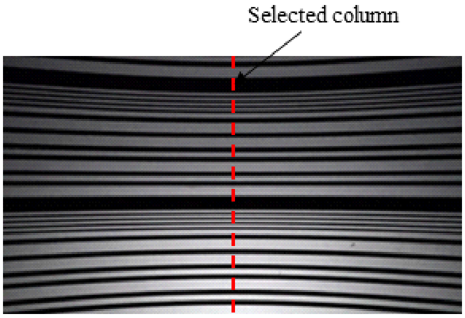

Fig. 4. Received image

received image in a frame is shown in Fig. 4. Then, the image file is converted into a image in grayscale. The 256 levels of grayscale represent the brightness ranging from completely black to completely white. A center column of each image is chosen for demodulation.

In demodulation step, the grayscale value of each pixel is compared with its corresponding threshold value. These threshold values are obtained using a curve fitting technique as below:

Let y_i denote the grayscale value at row i where i=1, 2, ..., 1080. The threshold T_i at row i is obtained by the third-order polynomial fitting curve given as:

$$T_i = a_0 + a_1 y_i + a_2 y_i^2 + a_3 y_3^2, \tag{1}$$

where a_0, a_1, a_2, a_3 are coefficients which can be determined by solving the following equation:

$$\frac{\delta E}{\delta a_0} = \frac{\delta E}{\delta a_1} = \frac{\delta E}{\delta a_2} = \frac{\delta E}{\delta a_3}, \tag{2}$$

where E is the total square deviation between y_i and T_i given as:

$$E = \sum_{i=1}^{1080} (y_i - T_i)^2 \tag{3}$$

Each element in the grayscale series is compared to its corresponding threshold to determine the logic level of that element in Fig. 5. If the value of the grayscale is lower than the threshold, the logic level corresponding to that grayscale is determined as 0. Otherwise, the logic level is determined as 1. The consecutive elements in the logical value series which have the same logical value are grouped. Let A denote the grouped logical value series and A_i (i = 1, 2, ..., n) denote the i-th group of series A. Next, we define the regional value series B in which the value of each element B_i equals to the number of elements of A_i.

The purpose of the header detection step is to find the payload of the message. The payload is determined as the sub-series of logical levels between two headers. Since a payload is transmitted three times, there should be two headers with same bit pattern in a single image frame. In order to find two headers, denote the series of header detection by C. The value of each element C_k can be determined as:

$$C_k = \sum_{i=k}^{k+7} B_i \tag{4}$$

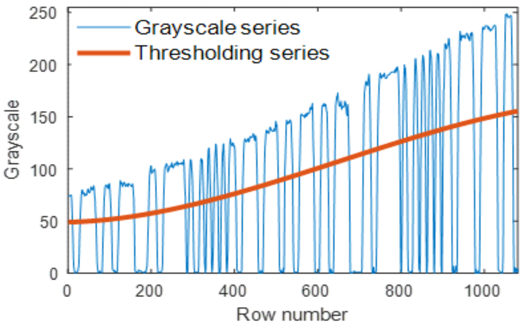

Fig. 5. Third-order polynomial thresholding

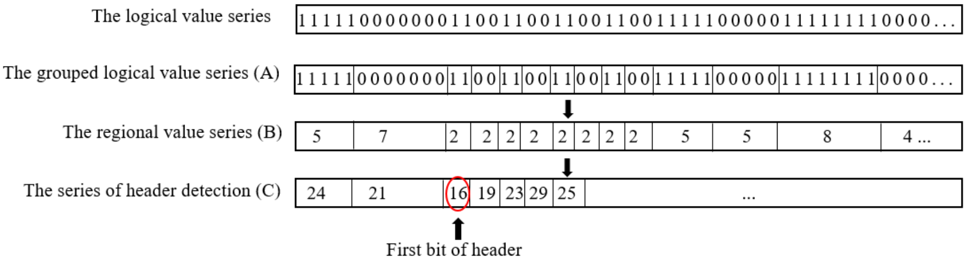

Fig. 6. Header detection

Because the 8 bits of the header are encoded by Manchester coding, the number of elements representing for one bit in header is smaller than the number of elements representing for one bit in the payload. The positions of the first bit of the two headers in series B are the corresponding positions of two smallest values in series C, so that the payload can be extracted from the series B. For the payload obtained, we calculate the sampling rate with the ratio of the total number of elements of payload to the number of bits of the payload.

In the logic decision step, each element of the payload is divided by sampling rate. The result of this division is rounded to the nearest integer. The rounded number represents the number of bits in a specific grouped logical value series, A_i. A bit value is set to the logic value of an element in corresponding A_i.

Ⅳ. Results and Discussion

In this paper, we investigate the performance of the non-line-of-sight VLC system on three different parameters which are the communication distance, environment illuminance, and frequency of the transmitted signal.

4.1 Effect of distance on BER

First, the impact of distance between camera and the wall on BER of the system is investigated when the illuminance of the wall is 164 lux, and the frequency of LEDs is 4.5 kHz. Figure 7 shows that the BER increases with the communication distance. As the distance from the camera to the reflective surface increases, the number of pixels representing a bit decreases, which makes bit detection more difficult.

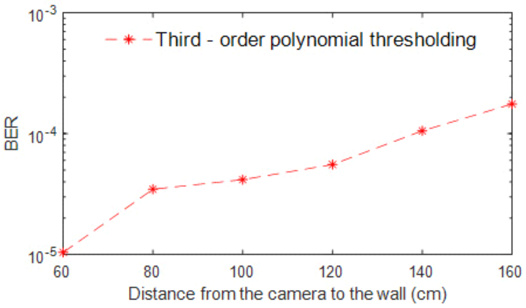

Fig. 7. Effect of distance between camera and the wall on BER

4.2 Effect of environment illuminance on BER

In this experiment, the effect of the illuminance of reflective surface on BER is investigated. The distance between camera and the wall is 60 cm, the frequency of the transmitted signal is 4.5 kHz. The illuminance of the environment of the reflective surface was measured by a mini lightmeter. Figure 8 shows that the BER of the system gets worse when the illuminance of the environment increases. Because as the illuminance of environment is increasing, the difference in grayscale of bright and dark bands gets smaller. This causes more false bit detection.

4.3 Effect of frequency on BER

In this experiment, the effect of frequency on BER is investigated when the distance from the camera to the wall is 60 cm and the illuminance of the reflective surface is 164 lux. As the signal frequency increases, the pulse width representing an element decreases, which is on/off duration of LED.

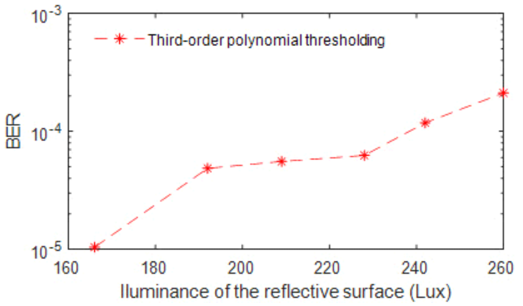

Fig. 8. Effect of the illuminance of reflective surface on BER

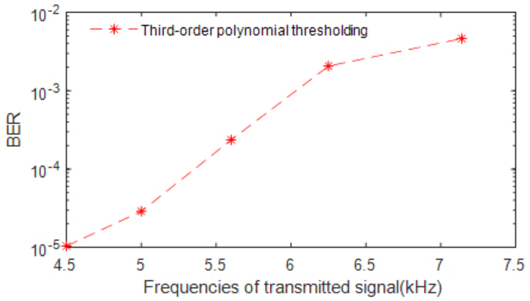

Fig. 9. Effect of frequency of transmitted signal on BER

This makes bit detection more difficult. Therefore, the BER of the system gets worse as the signal frequency increases.

V. Conclusion

In this paper, we investigated the effect of three parameters on the performance of non-line-of-sight VLC system using CMOS camera. The parameters are frequency of the transmitted signal, environment illuminance, and communication distance between camera and the wall. The experimental results show that the frequency of transmitted signals is the biggest impact on BER, while communication distance is the smallest impact.

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