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2차원 코딩을 이용한 광학카메라 통신시스템의 성능평가

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Performance Evaluation of Optical Camera Communication System Using Two-Dimensional Coding

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요 약

본 논문에서는 2 차원 코딩을 이용한 광학 카메라 통신 시스템 (OCC)의 성능을 평가한다. 이 코딩 방법은 LED 어레이가 한 번에 하나의 신호 만 전송하는 기존의 코딩과 비교하여 광학카메라 통신시스템의 데이터 전송 속도를 향상시킨다. 수신단의 신호처리 방법 중 두 가지 다른 임계 값 방법을 비교하였고, 3 차 다항식 임계 값 방법이 성능측면에서 더 우수함을 보였다. 실험을 통해 2차원 코딩을 이용한 경우 데이터 속도가 최대 60 kbps임을 보였다.

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

ABSTRACT

In this paper, we evaluate the performance of an optical camera communication system (OCC) using two-dimensional coding. This coding method aims to improve the data rate as compared with traditional coding in which the LED array transmits only one signal at a time. We examine two different thresholding methods of signal processing at the receiver, and show that the third-order polynomial thresholding method achieves better performance. Through experiments, it is shown that the data rate on target system can be increased up to 60 kbps

Ⅰ.Introduction

In recent last years, light emitting diode (LED) has been increasingly used widely because of its advantages compared to other types of lighting bulbs. Besides, LEDs have also been used not only for lighting but also for wireless signal transmission over short distances. In visible light communication (VLC) systems, there are two types of receiving signal. The first type of receiver is a photodiode where the optical signal is converted into an electrical signal via an optical sensor. This method allows high-speed signal transmission but it is not suitable for outdoor applications due to the impact of many other light sources such as the sun, advertising panels, car lights, and traffic lights. The

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second type of receiver is complementary metal-oxide-semiconductor (CMOS) camera where the signal is obtained based on the rolling shutter mechanism of CMOS camera. Although CMOS camera does not provide a high transmission speed, it can be used in both indoor and outdoor applications.

In traditional VLC system, LEDs only transmit one signal in time so the data rate is about a few kbps[1-3]. In this paper, we apply two-dimensional coding for the optical camera communication (OCC) system using CMOS camera in [4]. In the OCC system using two-dimensional coding, LED array may have multiple LED columns, and each LED column broadcasts a different signal. Therefore, it is possible to transmit many different signals simultaneously. Thus the data rate of OCC system using two-dimensional coding can be significantly improved as compared to the conventional system with one LED array.

For performance evaluation, we introduce and compare two different thresholding methods for signal processing at the receiver: average thresholding and third-order polynomial thresholding. In addition, the impact of parameters on the system performance is investigated, which includes ambient light, the distance between LED array and camera, and signal frequency (data rate). Experimental results show that OCC system using two-dimensional coding can achieve data rates up to 60 kbps.

Ⅱ. Experimental setup

Figure 1 displays the experimental setup of OCC system using two-dimensional coding with a CMOS camera. The data for transmission is generated on a personal laptop computer, which is then fed to controller circuit. The controller, Arduino UNO board, converts digital control data (on/off) to analog control signal, which is going through the amplification stage to generate enough power to control the LED array. The control signal need to be supplied with 3 W power, 600 mA to 700 mA current, 2-3.4 V voltage. To operate LED array (100 LEDs), the external power of 150W is supplied. 100 LEDs are grouped into 10 columns with 10 LEDS, each of which acts as a transmitter as shown in Fig. 2.

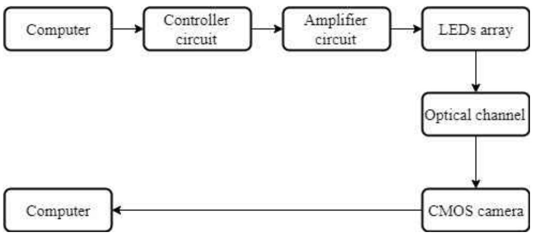

Fig. 1. The experiment system

A CMOS camera (Sony Cyber-shot DSC-RX100) receives the LED signal with 1080 x 1920 resolution and 60 frames/s speed. Each frame is a jpeg image file, where the information is processed in a pixel unit, which represented in a grayscale. We use the grayscale ranging from 0 to 255 brightness, from completely black to completely white.

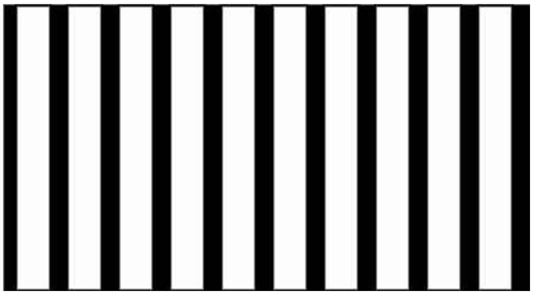

Fig. 2. LED array

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 jpeg image file. The received image in a frame is shown in Fig. 4. Then, the image file is converted into an 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 the demodulation step, the grayscale value of each pixel is compared with its corresponding threshold value. We consider two thresholding

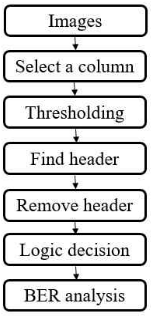

Fig. 3. System processing diagram

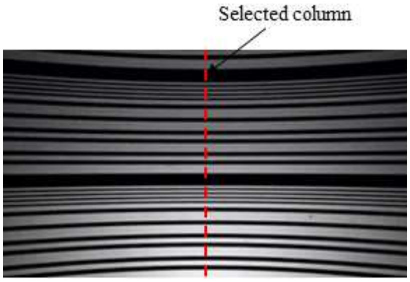

Fig. 4. Received image

methods: average thresholding and third-order polynomial thresholding.

The first method is the average threshold, the most simple method for calculating the threshold sequence. With this process, the threshold is used as the average value of the grayscale sequence. In other words, in the threshold sequence, the threshold is calculated as follow:

$$T(i) = \frac{1}{N}\sum_{i=1}^{N} y_i, \tag{1}$$

where N is the number of pixels in the column and y_i is the grayscale at row i, that's the i^{th} element inside the grayscale series.

The second method is the third order polynomial thresholding, this thresholding is calculated by curve fitting. Assume each element in the column matrix is (x_i,y_i), where x_i is the position of the pixel and y_i is that pixel's grayscale value. The third-order polynomial fitting curve $f(x_i)$ can be represented by:

$$f(x_i; a_0, a_1, a_2, a_3) = a_0 + a_1 x_i + a_2 x_i^2 + a_3 x_i^3. \tag{2}$$

The square deviation can be represented as:

$$\left| y_i - f(x_i) \right|^2, \tag{3}$$

and the total square deviation function E is represented in (4) shown below. Then, we need to find the minimum value of this function:

$$E = \sum_{i=1}^{1080} (y_i - T_i)^2. \tag{4}$$

We can obtain a_0, a_1, a_2, and a_3 by solving the following equation:

$$\frac{\delta E}{\delta a_0} = \frac{\delta E}{\delta a_1} = \frac{\delta E}{\delta a_2} = \frac{\delta E}{\delta a_3}. \tag{5}$$

In the next step, the grayscale value of each pixel is compared with the corresponding thresholding value. If the grayscale value is greater than the threshold, the corresponding pixels will have a logic level of 1. Otherwise, the logic level will be 0. The demodulation data is a series of logic levels having a length equal to the number of pixels in each column of the image.

Ⅳ. Results and Discussion

The performance of OCC system using two-dimensional coding is investigated with three parameters: the distance from the camera to LED array, the illuminance of the environment, and the data rate. The effect of each parameter on bit error rate (BER) is investigated. When investigating each parameter, the value of target parameter changes, while the values of remaining two parameters are fixed. The default fixed values of data rate, communication distance, illuminance of external light are 36 kbps, 14 cm, 37 lux, respectively.

Figure 5 illustrates the effect of data rate on BER. The lowest BER value is obtained when the data rate is set as 36 kbps and the average thresholding is used. It shows that when the data rate increases, BER also becomes higher. The reason

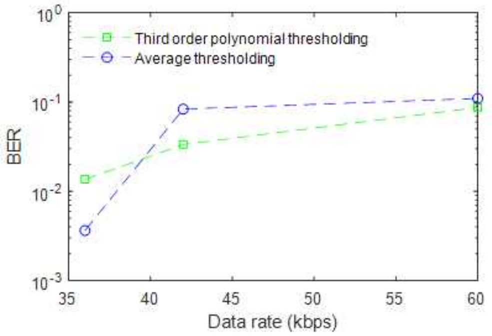

Fig. 5. Effect of data rate on BER

for this variant is because as the on/off duration decreases, the pulse width representing each on/off duration decreases too. Therefore it leads to a high bit detection error.

The effect of the communication distance on BER is shown in Fig. 6. BER is the best when the distance is 14 cm and becomes worse when the distance gets longer. It can be understood that the number of pixels representing a bit decreases when the camera is getting farther away from the LED array, which makes bit detection more difficult.

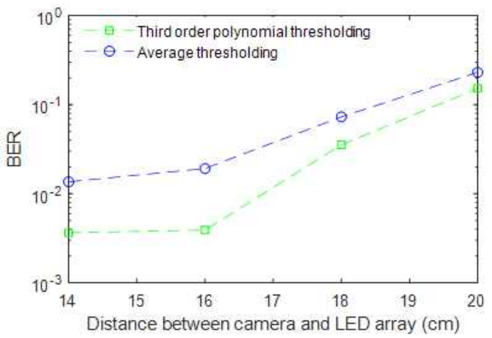

Fig. 6. Effect of communication distance on BER

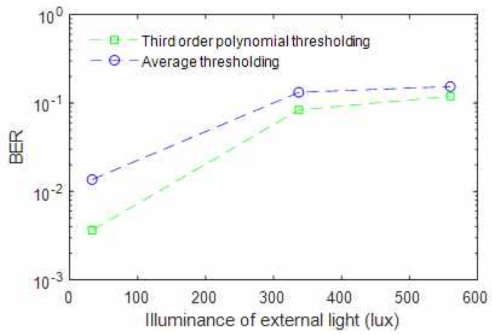

Fig. 7. Effect of illuminance of external light on BER

The effect of environment illuminance on BER is shown in Fig. 7. BER is the lowest in the darkest environment. BER increases with the environment illuminance, which can be explained that when the environment is brighter, the difference in grayscale of bright and dark bands in the signal gets smaller. This increases the number of bits that are falsely detected.

V. Conclusion

The performance of OCC system using two-dimensional coding is evaluated with three parameters: communication distance, data rate, and ambient light. The performance of the system is best when the distance is 14 cm, the data rate is 36 kbps, and the illuminance is measured in the LED surface is 37 lux. Our experiment shows that OCC system using two-dimensional coding can achieve the data rate of 60 kbps when the third order polynomial thresholding is used.

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