A Study on the Simulator Development for Visible Light Communication Using LED and Camera

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***Abstract*—This paper develops a simple simulation program for visible light communication (VLC) systems using LED (Transmitter) and a camera (Receiver). In the simulation, we generate an image of LED array transmitter which consists of LEDs arranged in a square matrix. In addition, effects of optical spatial channel, which is a unique channel in VLC, are constructed by using image processing techniques. We describe a system model of the VLC simulator and carry out the simulation with various parameters of the image processing.**

I. Introduction

Light emitting diode (LED) has the advantage of long life, low power consumption, low heat generation and good visibility as compared to conventional incandescent lights. In recent years, lighting equipments and traffic lights using LED have become more common. Since LED is semiconductor devices, we can control its intensity electrically at a fast rate. Namely, LED can be used not only as lighting devices but also as communications devices. The communication using the light which is visible to the naked eye is called "visible light communications (VLC)" [1]–[5].

VLC using LED traffic light as a transmitter are one of interesting topics in the field of the intelligent transport system (ITS). By using LED traffic lights, it is possible to use as not only the primary task as the traffic light but also the communication system for vehicles and pedestrians. As the VLC receiver, there are two major methods: image sensor such as a camera, and photodiode. The method using the photodiode can perform high-speed communication. However, we require to narrow the view angle of the photodiode for ensuring enough signal-to-noise ratio (SNR). On the other hand, the method using the camera has three advantages. First, the mechanical swing of the camera is not necessary since LED transmitter can be detected and tracked by the image processing after wide-angle photography. Second, the camera can individually recognize a transmitter from plural light sources. Third, the parallel data transmission is possible by individually modulating LEDs of the transmitter due to the camera can recognize each LED luminance from the received image. Thus, we can improve the communication rate of the method using the camera without increasing the shutter speed. Because of these reasons, we apply VLC system using a camera in this study (Fig. 1).

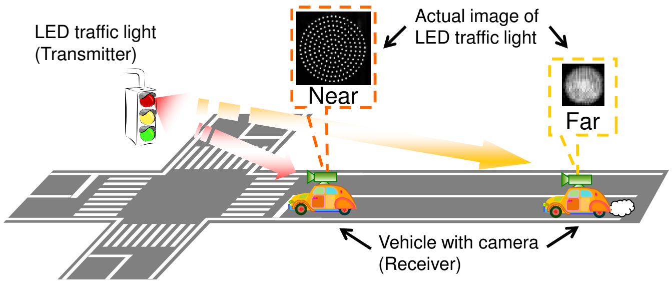

Fig. 1. Example image of visble light communication (VLC) using LED and camera for ITS.

In the system using the camera, the image processing block is very important to correctly recover data. Especially, the quality of the received image degrades with increasing communication distance. For example, the camera captures a blurred image due to long communication distance, as shown in Fig. 1. In addition, the size of LED transmitter in the received image depends on the communication distance. These phenomena influence the recognition of LED luminance in the receiver. Thus, the error rate of data increases due to the phenomena.

As a solution for the problems, we need to carry out computer simulations with various communication environments and to analyze the influence of the transmission channel. Therefore, it is important to develop a simulator of VLC which simulates its specific channel characteristics. In this study, we develop a simple VLC simulator using image processing techniques as the specific channel. Specifically, the blurred image is simulated by using Gaussian filter. Furthermore, the size of LED transmitter depending on the distance is simulated by the image scaling processing. In this paper, we describe a system model of the VLC simulator and carry out the simulation with various parameters of the image processing.

II. System Model of VLC Using LED and Camera

In this section, we introduce the system model of VLC using LED and the camera in Ref. [2]. Figure 2(a) shows a block

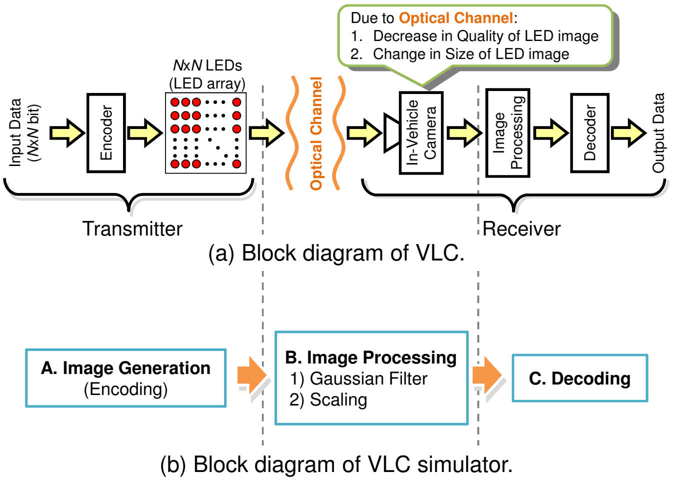

Fig. 2. System model: (a) Block diagram of VLC using LED and camera, (b) Block diagram of VLC simulator.

diagram of the system model.

The transmitter consists of LEDs arranged in $N \times N$ square matrix (i.e. LED array) and a encoder. The transmitter can generate nonnegative pulse and can change a width of pulse. Thus, we can control a LED lighting pattern (i.e. luminance of LED) by changing the width. The transmitter modulates data by controling the luminance. In the case of On-Off Keying (OOK) modulation, the transmitter represents data as On/Off control of the luminance (On='1', Off='0').

The receiver consists of an in-vehicle camera, an image processing unit and a decoder. First, the camera captures the transmitted LED pattern which passes through the optical channel. Second, the image processing unit detects the position of each LED and extracts the luminance. Finaly, the decoder demodulates data using the extracted luminance. In the case of OOK, the decoder determines data by the threshold processing of the extracted luminance.

III. VLC Simulator

In this section, we explain our VLC simulator and its operation. Figure 2(b) shows a block dagram of the VLC simulator based on the system model in Ref. [2]. In addition, Fig. 3 shows a dialog box of the VLC simulator in this study. The simulator consists of three blocks: Image generation (Encoding), Image processing and Decoding. The correspondence relationship between the actual system and the simulator is shown in Fig. 2. The operation of each block is described below.

A. Image Generation (Encoding)

This block generates the image of LED array. We set four parameters of LED array: 1) Interval of the neighboring LED [pixel], 2) Diameter of LED [pixel], 3) N, 4) Lumnance of LED (Max=255). The detail of each parameter is shown in Fig. 4. According to the set parameters, the block can generates two kinds of the lighitng pattern ("All LEDs On" and "Random"). We can meke an either/or choice between these two patterns and can get the image of LED array.

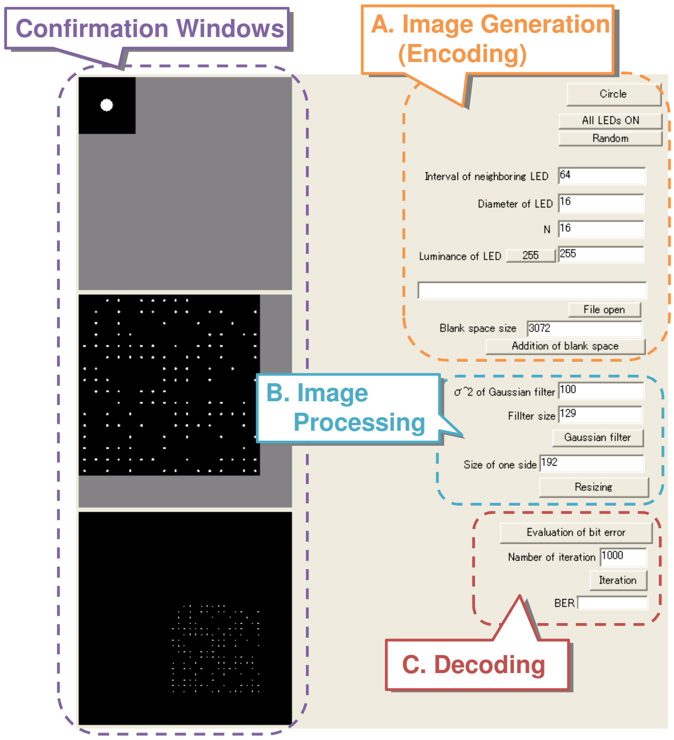

Fig. 3. Dialog box of VLC simulator.

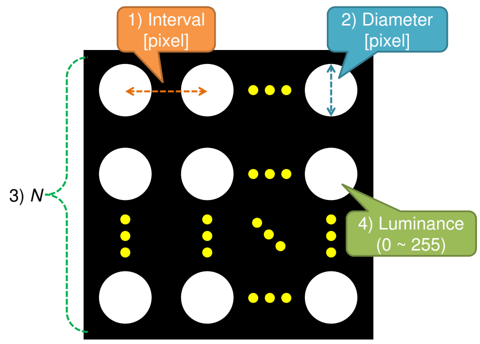

Fig. 4. Parameters of LED array for image generation.

The generated image can be confirmed in the confirmation windows, as shown in Fig. 3. In addition, this block adds a blank space around LED array region, as shown in Fig. 5. The reason for this space is that the next block equally performs the image processing in the whole LED array region. In this study, we use the blank space which is three times larger than the length of the array's side. Also, the color of the blank space is black (i.e. the luminance is zero).

Here, let us focus on the random pattern of LED array. In this case, it is considered that the random pattern is equivalent to the pattern which is encoded by OOK. Namely, we can use the random pattern for the VLC simulation with OOK modulation.

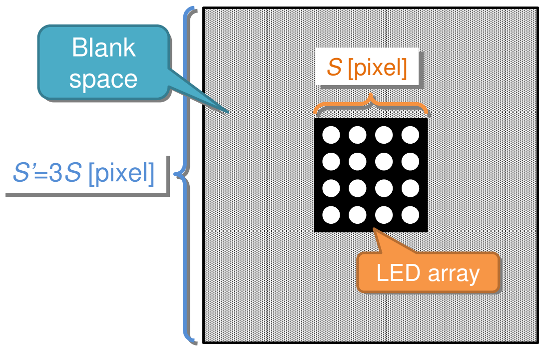

Fig. 5. Blank space of LED array.

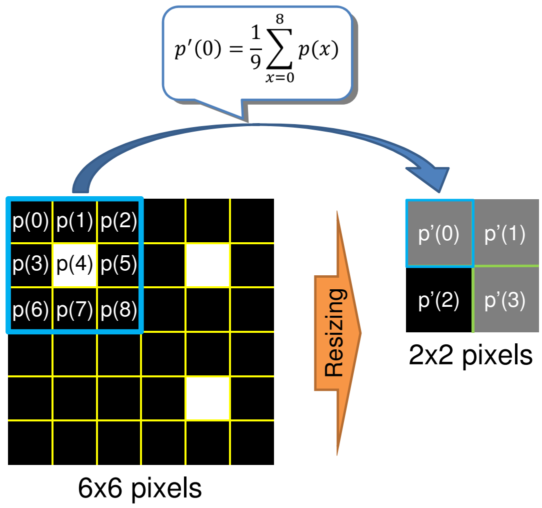

Fig. 6. Resizing of image using area averaging.

B. Image Processing

This block performs the image processing as the optical channel of VLC. As described in Introduction, the camera captures a blurred image due to long communication distance. Moreover, the size of LED array in the received image depends on the communication distance. In this study, we use two kinds of the image processing as the optical channel: 1) Gaussian filter, 2) Image scaling. The detail of each processing is described below.

1) Gaussian Filter: Gaussian filter is used for simulating the blurred image. The filter function is expressed by the following equation;

$$h_g(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right), \tag{1}$$

where σ^2 is the variance of the Gaussian distribution, x and y is the distance from the origin in the hrizontal axis and the vertical axis, respectively. By using the Gaussian function, we perform the filtering for each pixel. In this process, the average of pixel value is calculated by using the focused pixel of the original image and its neighborhood pixels. We allocate the weight of the smoothing depending on the distance from the focused pixel in advance. In this case, the weight decreases with increasing distance from the focused pixel. We calculate the weighted mean according to the allocated weight and perform the smoothing for the original image. Here, the number of the neighborhood pixels and the blur intensity depend on the filter size and the variance σ^2, respectively. We assume this filtered image as the blurred image due to long communication distance.

2) Image Scaling: The size of LED array depending on the distance is simulated by the image scaling processing. In this study, we use the area averaging [6] which is one of the image scaling methods. Here, we explain the reduction method using the area averaging. First we divide the original image (the blurred image) into equally intended image size. Next, the average pixel value is calculated for each divided pixel group. This average value is used as the pixel value of the reduced image. As an example, let us consider the scaling from 6×6 pixels to 2×2 pixels, as shown in Fig. 6. In this case, the reduced image value is calculated as

$$p'(0) = \frac{1}{9}\sum_{k=0}^{8} p(x), \tag{2}$$

where $p(0)$–$p(8)$ denote the divided pixel group of the original image, $p'(0)$ denotes its average value, i.e. the pixel value of the reduced image.

C. Decoding

This block performs a demodulation of data from the processed image and a calculation of bit error rate (BER). Here, we explain an operation of decoding. First, we find positions (i.e. coordinates) of LEDs from the processed image using its size and the number of LEDs. Second, the luminance of each LED is extracted from the coordinates. Third, we calculate an average of the extracted luminance values and use the average value as a threshold for decoding. Fourth, the data is demodulated by a threshold-based decision. We decide the decoded data as 1 (or 0) if the extracted luminance is larger (or smaller) than the threshold. Finally, BER is calculated by comparing the demodulated data and the data pattern on the transmitting side.

IV. Operation Result of VLC Simulator

In this section, we perform our simulation and show the performance of the simulator. This paper shows output images and BER performance as the simulation results

A. Simulation conditions

Table I shows simulation parameters. In this study, N, the interval and the diameter are determined based on Refs. [2]–[5]. Also, the filter size is set to the double of the interval. Moreover, we use four kinds of reduced images: 64^2, 32^2, 16^2 and 8^2 pixels. For calculating BER performance, we iterate the simulation 1,000 times.

TABLE I
SIMULATION PARAMETERS.

Number of LED	16×16
Interval of neighboring [pixel]	64
Diameter of LED [pixel]	16
Modulation method	OOK
Size of original LED array image [pixel]	1024^2
σ^2 of Gaussian filter	10, 100, 1000
Filter size	129×129
Size of reduced image [pixel]	64^2, 32^2,16^2 ,8^2

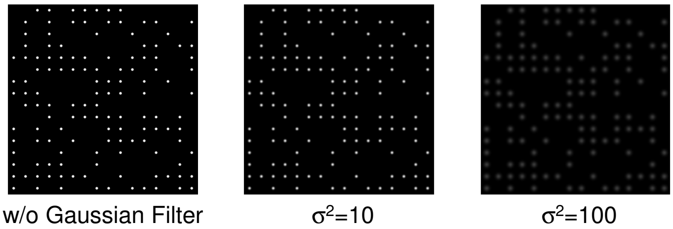

Fig. 7. Output images using Gaussian filter (Filter size = 129×129).

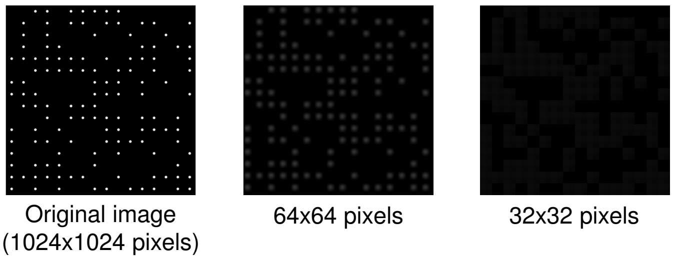

Fig. 8. Resized output images using area averaging.

B. Simulation results

Figures 7 and 8 show output images using the Gaussian filter and resized output images, respectively. From these figures, we can observe that the original image changes according to the simulation parameters. As one can see, our simulator not only calculates BER performance but also outputs its image.

Table II shows BER performance of our simulator. From this table, we can confirm the error-free transmission when the size is 16^2 pixels or more, and σ^2 is 100 or less. However, we can also confirm that the error occurs in the case $\sigma^2 = 1000$, i.e. the strong blur intensity. This result has been reported in previous researches [2]–[5]. Namely, we can say that the phenomenon similar to the previous researches is also obtained in our simulator. Next, we focus on the BER of each σ^2 which is about 5.0×10^{-1} when the size is 8^2 pixels. The reason for this is that the image resolution of LED array area is lower than the number of LED (N^2). In addition, the luminance value of the image decreases due to the area averaging, as shown in Fig. 8. Therefore, we consider that it is difficult to demodulate data because of the very low resolution and luminance. In the actual VLC system, the luminance does not decrease significantly because the sensitivity of camera sensor is high. Thus, it is our important future work that the performance improvement of our simulator with the sensitivity.

TABLE II
BER PERFOMANCE.

	w/o filter	Filter size $= 129 \times 129$		
Size of image	–	$\sigma^2 = 10$	$\sigma^2 = 100$	$\sigma^2 = 1000$
64^2 pixels	0.0	0.0	0.0	7.2×10^{-2}
32^2 pixels	0.0	0.0	0.0	6.6×10^{-2}
16^2 pixels	0.0	0.0	0.0	7.8×10^{-2}
8^2 pixels	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}

V. CONCLUSIONS

This paper has developed the simple VLC simulator using the image processing as the specific channel of VLC. We have used two kinds of the image processing: 1) Gaussian filter for simulating the blurred image, 2) the area averaging for simulating the size of LED array depending on the communication distance. As results of using our simulator, we have obtained output images by the image processing and BER performance.

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