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Basic Experiments on Paralle Wireless Optical Communication for ITS

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Abstract— **In this paper, we propose Parallel Wireless Optical Communication with an LED traffic light as a transmitter and a high-speed camera as a receiver. Today, it is proposed to use visible light communication for road-to-vehicle communication, which assists drivers by providing various information. It is also proposed to use LED traffic light as its transmitter. Thus in this paper, we propose a road-to-vehicle communication system using a high-speed camera. In our proposing system, we receive data by capturing the transmitter with the high-speed camera, making it possible to recognize each LED separately. We have examined communication speed and conducted experiment of parallel data transmission under laboratory condition.**

I. INTRODUCTION

The traffic system, the basic facilities of a nation, is now holding problems such as traffic congestion and traffic accidents. Intelligent Transport System, known simply as ITS, is what gives solution to these problems by information communication and control technoloyg[1]. If the traffic system could be optimized by ITS, the consumption of the energy would be saved, the emmision of the CO_2 would be reduced, and it will be possible for the traffic system and environment to coexist. In Japan, ITS technoloyg is being developed in 9 fields: advancement of the navigation system, automatic collection of transit fare, safe-driving assistance, and others. For most of these ITS application, communication system between infrastructure and each vehicle and between vehicles is required. The representative examples of the application using communication system are Electronic Toll Collection System(ETC) and Vehicle Information and Communication System(VICS), which has been already diffused in Japan. There will be more sevices using Road-to-Vehicle and Vehicle-to-Vehicle communication in the near future. A communication method called Dedicated Short Range Communication(DSRC) was developed for ITS communication in Japan and used for ETC.

Most of the DSRC systems use radio wave to communicate, but a system using visible light is also considered. This is because the shortage of radio frequency band is concerned for the recent development of radio technology and it is required to save radio resource. In those researchs, it was proposed to use LED traffic light as transmitter[2][3]. We also have been working to realize the DSRC system by visible light[4]. In our proposing system, we use traffic light as a transmitter to apply the existing infrastructure, and use high-speed camera on vehicle as a receiver to enable parallel and long-distance communication.

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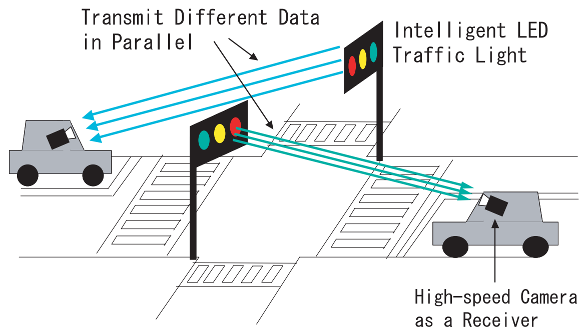

Fig. 1. Communication system at an intersection

In this paper, we examine communication speed and condition and show an experiment result of data transmission.

II. VISIBLE LIGHT COMMUNICATION

In this study, we propose a visible light communication system applied for ITS, but here we give some information of general visible light communication at first.

A. Feature

Visible light communication is a wireless communication using the light we can see and it transfers information by blinking light emitters such as illuminations and displays. The dominant device for transmitter is LED and for receiver a photodiode. There are several advantages in this transmission method. One advantage is that visible light is safe to human body that it is possible to transmit with high power, whereas radio waves are concerned to be dangerous to human body and infra-red light may be harmful to human eyes. Compared to radio waves and infra-red light, there are more features for visible light communication: its use is not limited by law, any existing light source could be used as a transmitter, and it can be used at a place where radio waves cannot be used, for example a hospital or space ship[5].

B. Application

One of the application of the visible light communication is illumination light communication. It is a communication between PCs and illumination light and considered as an alternative to the wireless LAN[6]. Nowadays, light bulbs

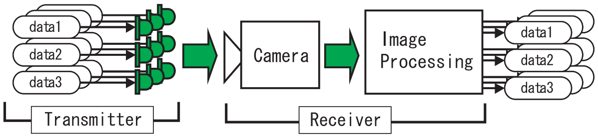

Fig. 2. Paralle Wireless Optical Communication

and fluorescent lights are the dominant room illumination. LEDs, however, are diffusing as an alternative to those. The reasons are that LED is longer-lived, consumes lower power, and is smaller in size. Now, even the emitting efficiency is approaching to that of fluorescent light and thus it will surely replace the bulbs and fluorescents in the future. What is more, LED has been proposed to apply for communication for its features that it responds in high speed and is controlled electrically.

There are many light emitters surrounding us and any of them could become a transmitter of this communication method. Some example devices are PC display[8], TV, electric bulletin board, and cellular phone display. By using those as transmitters, it will be possible to download various information to mobile PC or cellular phone at a station, airport, and anywhere else.

C. *Parallel Wireless Optical Communication*

We use Parallel Wireless Optical Communication, which is one of the visible light communication method.

Light emitters using LED usually contain a number of LEDs, so if we could modulate LEDs individually, the communication speed will dramatically increase. However, a photodiode is generally used as a receiver for the visible light communication and thus it is difficult to recognize each LED individually. Therefore, it is proposed to use a camera as a receiver and receive data by capturing the transmitter to enable a parallel communication between LEDs and the receiver. This means that each LED transmit different information. It will also be possible to recognize and communicate with more than one transmitter simultaneously. This method with a camera is called Parallel Wireless Optical Communication(Fig.2).

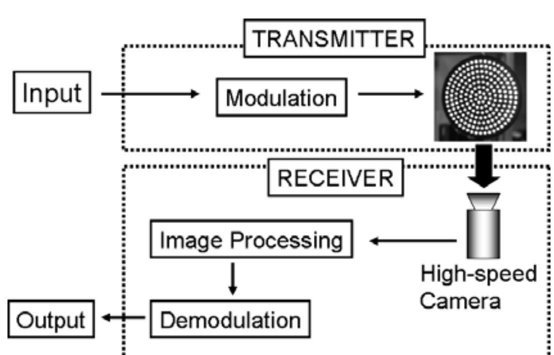

Fig. 3. Communication system

III. Proposed System

Here, we explain the wireless communication system we propose.

A. *Overview of the System*

As we mentioned, we use an LED traffic signal and a high-speed camera in our system. Fig.3 shows steps of the system. At first, we modulate information into the luminance and then transmit the information by blinking each LED. Next, we receive the information by capturing the blinking transmitter. At last, we obtain the luminance of each LED from the captured image by image processing and demodulate.

B. *LED Traffic Light*

LED is suitable to communication for its high speed response and used as a transmitter in most visible light communication system. Traffic light using LED accounts for only 10 percent of all traffic lights at present, but should increase before long.

By using traffic light, we can easily provide information to drivers according to their direction.

C. *High-Speed Camera*

The receiver is a high-speed camera. This is to recognize LEDs individually and enable a parallel communication. General video camera captures at 30frames per second(fps). This frame rate is set as a rate that we feel smooth enough when we appreciate the video. On the other hand, the high-speed camera is able to capture at 100fps to 10,000fps. So we use a high-speed camera to communicate faster. However, as we raise the frame rate, the area it captures becomes smaller and the captured image becomes darker, thus we set the frame rate at 500fps for our experiment at this point. This rate depends on the performance of the high-speed camera we use.

D. *Feature*

The system we proposed has following features:

- light has strong directivity, which makes it possible to provide appropriate information according to the direction of the car
- there is no need to concern wave interference and radio disturbance
- information is recorded as images, thus we can reduce noise by image processing

E. *Communication Distance and Speed*

The communication speed of our system is closely related to the distance between the transmitter and the receiver. This is since the appearance of the transmitter on the image captured by the high-speed camera changes as the communication distance changes.

Fig.4 is a transmitter image captured by a camera placed 4m from the transmitter, Fig.5 at about 30m. As you can see from those two images, we are able to recognize every LED on the transmitter when we capture it from a short distance, but as the distance becomes longer, the images of

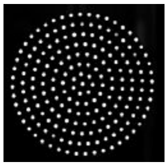

Fig. 4. image of a transmitter captured from short distance

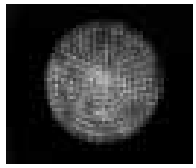

Fig. 5. image of a transmitter captured from long distance

LEDs become distorted and overlap on each other, meaning there is signal interference. Thus, we need a communicaiton method which enables to communicate even when the images of LEDs are overlapped. In this study, we adopted hierarchic encoding[7] which allocate information on spatial frequency.

1) Maximum Communication Speed: The communication speed of this system depends on the following factors:

a) the number of LED
b) signal frequency
c) the number of the amplitude levels of light signal

From these factors, the maximum speed is defined as

$$NF(\log_2 A) \tag{1}$$

Here, N stands for the number of LED, F for the signal frequency, and A for the number of amplitude levels.

The response speed of led is as high as several 10nsec, which means the F can be very high, so the communication speed can be estimated as more than 1Mbps with only one LED. However, the frame rate of the high-speed camera is much lower, 500fps as we mentioned above, and thus the communication speed is estimated to be about 100kbps at present.

2) Hierarchic Encoding: To enable the communication even when the images of LEDs are overlapped, we must think about the character of the images with LEDs not overlapped and the images with LEDs overlapped. Distorted images such as Fig.5 can be considered as an image with its high-frequency component of the spatial frequency taken off from an image such as Fig.4. Thus, by modulating important information to the low-frequency and particular information to high-frequency, the long distance communication becomes possible with lower communication speed. Suchlike methods using spatial frequency characteristic is called hierarchic encoding.

IV. Acquisition of the Data from a Captured Images

The communication system we proposed requires image processing to obtain the transmitted information since it receives by capturing with a high-speed camera. We now show the image processing method for the acquisition of the information. At this point of our study, we use a transmitter with 64 LEDs, arranged in 8×8, instead of an actual traffic.

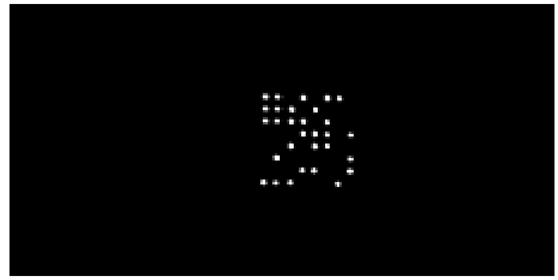

Fig. 6. Captured image of a transmitter

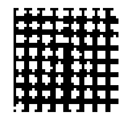

Fig. 7. Template image

A. Detection of the Transmitter

Fig.6 shows one example of a captured image. The lighting pattern changes with time, and we need to detect and track the transmitter from each captured image. To do so, we used template matching between each captued image and a template image. The template image(Fig.7) is obtained from a captured image of the transmitter with all LEDs lighted.

The luminance of a pixel(x, y) on the template image is defined as $L_1(x, y)$, that of a pixel(x', y') on the captured image as $L_2(x', y')$. N_x and N_y stands for the width and height of the template image. If we choose coordinates(X, Y) on the captured image as the origin of the template image, (x', y') can be expressed as $(x + X, y + Y)$. Then, the coordinates(X, Y) that gives the highest value to the following evaluation equation $S(X, Y)$ is where the transmitter is.

$$S(X,Y) = \sum_{x=0}^{N_x} \sum_{y=0}^{N_y} L_1(x, y) \cdot L_2(x + X, y + Y) \tag{2}$$

This means that we have matching as we scan the template image over the captured image, and the area where the sum of all the product of the luminance of the corresponding pixels is the largest is the transmitter.

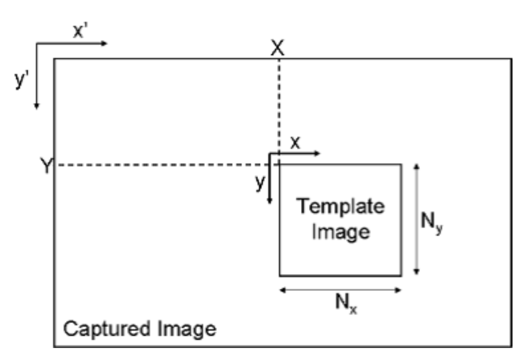

Fig. 8. Template Matching

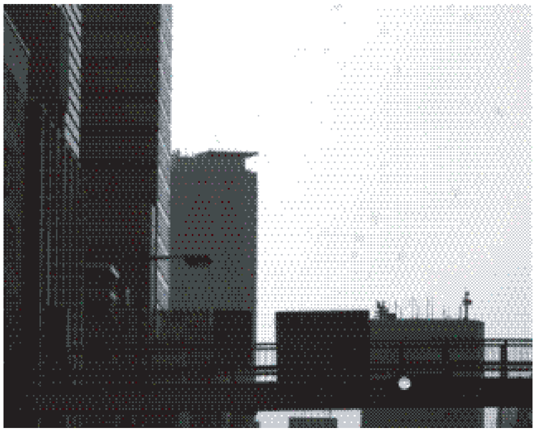

Fig. 9. First frame with traffic light

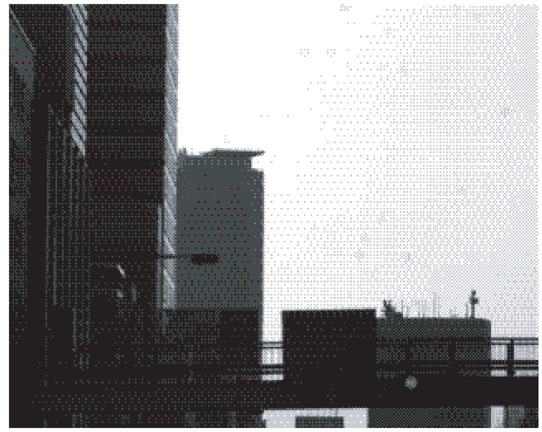

Fig. 10. Second frame with traffic light

B. Acquisition of the Data

Then, we show how to acquire the transmitted data.

Befor we do the template matching, we need to identify the coordinates of every LED on the template image. So, by obtaining the center coordinates of the 4 LEDs at the corners, we estimate other LEDs coordinates.

After the template matching and the transmitter is detected, we convert those coordinates to that on the captured image. When we define $(x_{i,j}, y_{i,j})$ as the coordinates of the LED, i^{th} in x direction and j^{th} in y direction, we choose the highest luminance in the rectangle of $(x_{i,j}-\alpha_{i,j}, y_{i,j}-\beta_{i,j})$, $(x_{i,j}+\alpha_{i,j}, y_{i,j}-\beta_{i,j})$, $(x_{i,j}-\alpha_{i,j}, y_{i,j}+\beta_{i,j})$, $(x_{i,j}+\alpha_{i,j}, y_{i,j}+\beta_{i,j})$ as the luminance of that LED, which should represent the transmitted data. Here, $\alpha_{i,j}$ and $\beta_{i,j}$ are defined as follows:

$$\alpha_{i,j} = \begin{cases} \frac{|x_{i+1,j}-x_{i,j}|}{4} & (i=1) \\ \frac{|x_{i+1,j}-x_{i-1,j}|}{8} & (2 \le i \le 7) \\ \frac{|x_{i,j}-x_{i-i,j}|}{4} & (i=8) \end{cases} \quad (3)$$

$$\beta_{i,j} = \begin{cases} \frac{|y_{i,j+1}-y_{i,j}|}{4} & (j=1) \\ \frac{|y_{i,j+1}-y_{i,j-1}|}{8} & (2 \le j \le 7) \\ \frac{|y_{i,j}-y_{i,j-1}|}{4} & (j=8) \end{cases} \quad (4)$$

V. Basic Experiment

We conducted two types of experiment for this system. One is an experiment to detect the traffic lights in the city. The other is to extract transmitted data as we explained in chapter IV. The former was made at outdoor condition, the latter was at laboratory condition.

A. The Detection and the Tracking of Traffic Lights

In Fig.9 and Fig.10, two consecutive frames captured on a street are shown. By taking the difference of those two images, an image shown in Fig.11 is obtained. As you can see, only the traffic light and edge of buildings are left. This is because the capturing rate is very high that two consecutive images are almost the same except for the area of the traffic light, which is blinking fast enough. Now it is possible to detect the traffic light from this picture by binarization and labeling.

Fig. 11. Difference of two consecutive frames

We made an experiment to detect traffic light by such method. We used 4 sequences captured in Nagoya City, Japan and calculated True Detection Rate and False Detection Rate. These are defined as:

$$TrueDetectionRate = \frac{True\ Detections}{Frames\ with\ traffic\ light} \times 100 \quad (5)$$

$$FalseDetectionRate = \left(1 - \frac{True\ Detections}{Total\ Detections}\right) \times 100 \quad (6)$$

True Detections is the number of detected trafficl light in the frames which do have traffic light. Total Detections is the total number of detection, including objects which are not actually a traffic light.

Traffic lights in Japan blink 120 times every second. Thus the high-speed camera is set to capture them at 250Hz which should be enough. Table I shows the result for 4 sequences.

	True Detection	False Detection
Sequence 1	99.3%	8.64%
Sequence 2	100%	1.3%
Sequence 3	100%	1.17%
Sequence 4	100%	0.6%

TABLE I
RESULT OF TRAFFIC LIGHT DETECTION

Fig. 12. Transmitter with 64 LEDs

This result shows that we were able to detect most of the LED traffic light in the city. However, when we captured many bars lined up, our system recognized them as traffic light since it seems as if they are blinking. Most of the False Detections are due to this reason.

B. Transmission Experiment

We conducted experiment to understand the characteristic of Bit Error Rate (BER) of our system.

We assume that the BER of this system depends on the number of pixels that records one LED. If one LED is captured by many pixels, data is to be transmitted correctly. The space between LEDs on the captured image is also the key factor. If there are more space between two LEDs, that means it is easier to distinguish them. This space changes as we change the distance between transmitter and receiver.

The BER should depend also on the effective diameter of the lens used for the high-speed camera. This is because the image will be more distorted when the effective diameter is enlarged. That is, as the image becomes more distorted, the space between LEDs becomes smaller, and thus the BER rises.

Thus we changed the communication distance while conducted experiment and used two effective diameters to compare. We calculated BER according to the space between LEDs on the captured image.

1) Experiment System Architecture: Fig.13 shows our communication system.

We used a transmitter with 64 LEDs for this experiment(Fig.12). The lighting patterns of LEDs were controlled by FPGA board connected to it.

For the receiver, we used high-speed camera connected to a PC which acquire and decode the data by image processing.

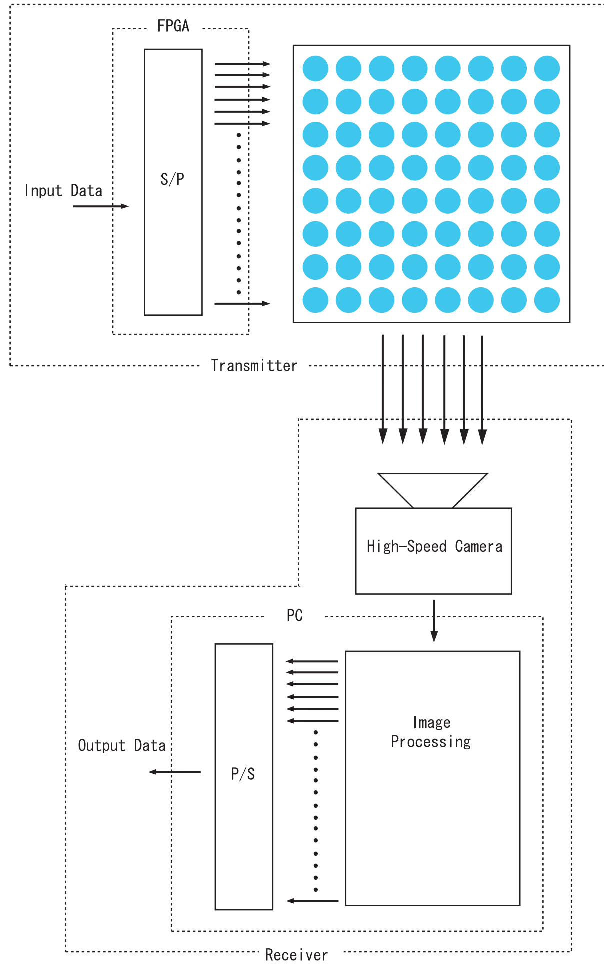

Fig. 13. Communication system

2) Experiment Condition: The experiment was conducted under laboratory condition. The transmitter was fixed at one place. The receiver was moved by hand but was always facing straight to the transmitter. The communication distance was from 22m to 33m. The modulation speed, or the signal frequency, was 250Hz, and frame rate of the high-speed camera was 500Hz.

3) Experimental Result: Fig.14 shows the result of the experiment changing the communication distance by moving the receiver. Fig.15 shows the result of the experiment conducted by two effective diameters.

As we expected, the BER rises as the space between LEDs becomes smaller, or as the receiver moves away from the transmitter. The BER also rises when we enlarged the effective diameter.

VI. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

In this paper, we proposed a Parallel Wireless Optical Communication using a traffic light as a transmitter and a high-speed camera as a receiver. By modulating LEDs of traffic lights individually and using camera, the proposed

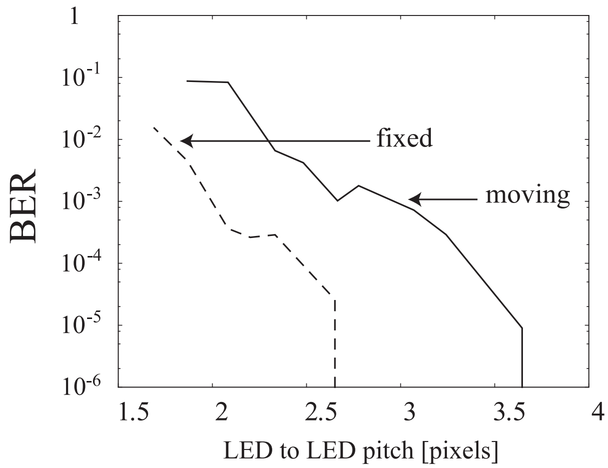

Fig. 14. BER changes by the space between LEDs

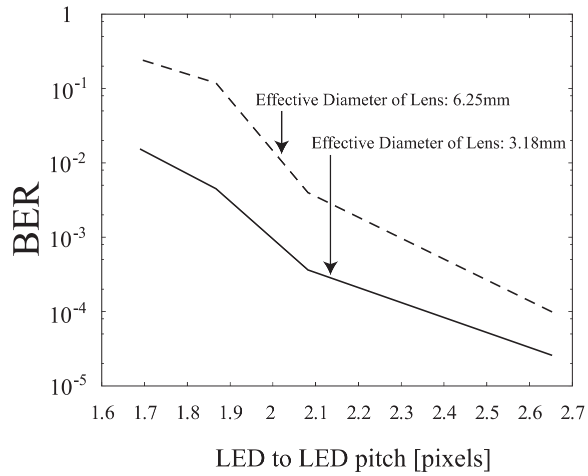

Fig. 15. BER changes by the effective diameter

system is able to have parallel visible light communication. This system can transmit local traffic information for safer driving.

We also proposed to use hierarchic encoding to enable long distance communication. The maximum communication is given as

$$NF(\log_2 A) \tag{7}$$

The communication speed is now limited by the frame rate of the camera, but it has potential of higher than 1 Mbps.

We conducted experiments to understand the BER characteristic of our system. As we have assumed, the BER depends on the communication distance and effective diameter of the lens.

B. Future Works

To realize the communication, we need real-time image processing system. This means that we need to design an image processing hardware since the frame rate is too high and it is not possible for PC to take in the captured images in real-time. Thoug, hardware image processing is much complicated than software. Thus now we are planning to make a hardware/software hybrid system that cut out the small area including the traffic light from the captured image by hardware and do the rest by software.

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