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# A New Receiving System of Visible Light Communication for ITS

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*Abstract*— **This paper discusses a new receiving system for visible light communication applied to intelligent transport systems (ITS). We use a light emitting diode (LED) traffic signal as a transmitter that sends information to vehicles that feature a receiver. There are, however, several problems associated with applying visible light communication to the field of ITS. First, we have to transmit information over long distances; second, the relationship between the transmitter and the receiver position changes with time; and third, the communication is affected by a lot of optical noise. Here, we propose a new receiving system to solve these problems and construct a prototype. Evaluation experiments on the system demonstrate its validity.**

## I. INTRODUCTION

The study of LEDs, which are the next-generation of long-lived luminous sources, is progressing rapidly. LEDs have various positive attributes such as longevity, compact size, and low power consumption. Consequently, they have already been applied to some traffic signals, displays, and message boards and we believe that LEDs will in future be applied to lighting, vehicles' headlights and tail lamps.

LEDs also have another feature, their high-speed response, making it possible to control them electronically. This means LEDs can be used for communication purposes. Thus, some researchers have proposed communication system using LEDs indoors, for roadway lighting, or at traffic signals [1][2][4][5][6].

In this paper, we focus on visible light communication in ITS (Intelligent Transport Systems). Traffic signals are gradually changing from electric light bulbs to LED lights, and these new lights have the potential to be used as transmitters of information, with signals detected by receivers mounted in vehicles. LED y traffic signal can transmit location information, safe driving support information, and other information from the road. Since light goes straight on, high directional communication is possible. So, transmitting different information for every lane of a road is possible (Fig.1). This system has other advantageous characteristics.

1) No radio interference
2) Saving radio resources
3) Utilization of the existing infrastructure
4) Safe for human üs body

Next, we compare visible light communication in ITS with other types. Visible light communication using indoor lighting, electric bulletin boards or sign lights are conventionally applied in fixed environments (the positional relationship between the transmitter and the receiver is fixed) and done

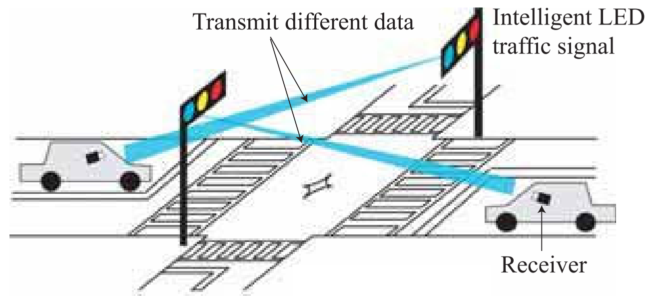


Fig. 1. Visible light communication in ITS

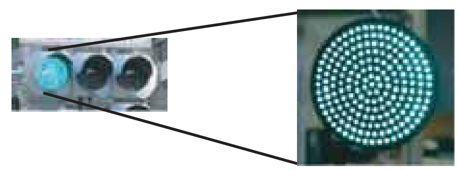

Fig. 2. LED traffic signal

over a short distance. Such communication is relatively simple. On the other hand, visible light communication using an LED traffic signals and an in-vehicle receiver features several problems such as:

1) the necessity of long-distance transmission;
2) the influence of a lot of optical noise (i.e., background lights) outdoors; and
3) changes in the positional relationship between the transmitter and the receiver.

Akanegawa and Maehara in [3] and [7] conducted experiments on visible light communication using an LED traffic signal, but these experiments were only theoretical tests. Hayashi [8], on the other hand, undertook field experiments on visible light communication using a pedestrian LED traffic signal, but this experiment was performed over a comparatively short distance (about 30 m) and did not consider the communication speed. Thus, to the best of our knowledge nobody has ever achieved or conducted experiments on high-speed and long-distance communication in a dynamic environment using LED traffic signals. We propose a new receiving system that makes high-speed and long-distance visible light communication possible, and construct a prototype based on this proposal. By using this system, the vehicles themselves can find and track an LED traffic signal, and then they can obtain information from its signal. The remainder of this paper is as follows. We describe the proposed system in Section II, where we also segment the proposed system into two groups. Then, we explain the

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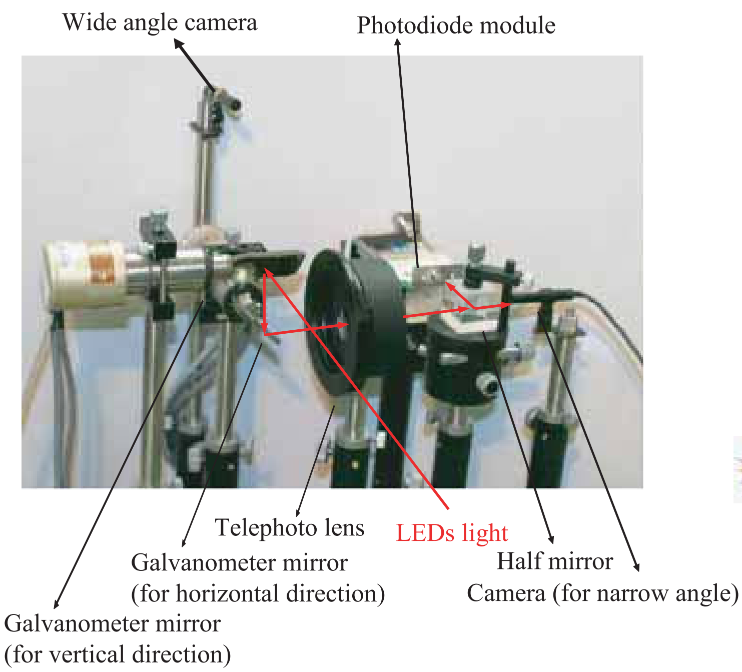


Fig. 3. Intelligent receiving system

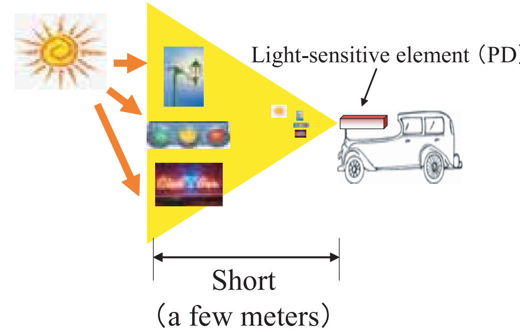


Fig. 4. Photodiode as a light-sensitive element

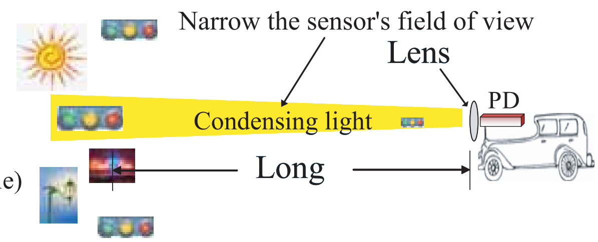


Fig. 5. Photodiode and lens

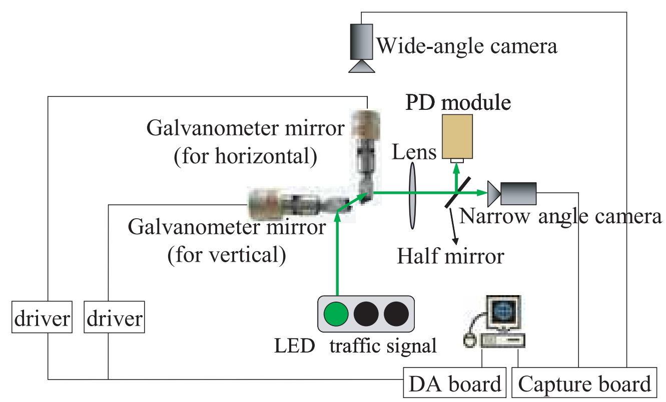


Fig. 6. Proposed system (Figure)

experiment on each system in Sections III and IV. Section V explains an experiment on a simple sound transmission, and Section VI presents our conclusion and future work.

## II. The Proposed System

In the previous work, a receiver is constructed with a photodiode and an optical filter [8]. However it doesn üt satisfy our demand (high-speed and long-distance transmission, dynamic environment) with the current receiver. So, we propose a new receiving system that solves the three problems outlined above.

### A. Light-sensitive element

A photodiode is generally applied as a light sensor in the field of visible light communication. It is capable of high-speed communication because of its quick response to the signal. But photodiode is also sensitive to optical noise. When light sources (ex. LED traffic signals, neon lighting and sunlight and so on) are present in front of a photodiode, the photodiode receives all of these lights (Fig.4). By applying a device from a modulation method or using an optical filter though, we can reduce the influence of noise and achieve short-distance communication. In the previous work, they actually use the optical filter and the photodiode as a light-sensitive element [8]. And then, they acieved the short distance communication. However, the signal-to-noise ratio fundamentally decreases as communication distance grow. Therefore, as transmission distance increases, the communication speed slows down, soon becoming too slow for any practical applications. So, it doesn't satisfy our demand with the current receiver.

On the other hand, an image sensor, in other words a camera, can also be applied as a light sensor. The camera can perceive light from a long distance and it is not affected by optical noise because the lens condenses light and segments any optical sources spatially. However, the communication speed is low because the camera frame rate is low, acting as a bottleneck to communication speed.

In this work, we apply the photodiode as a light-sensitive element because our target is high-speed and long-distance communication. The photodiode problem that we state above is solved by using imaging optics and a tracking mechanism. This is explained in detail below.

### B. Answers to the three problems

Here, we answer to the three problems outlined above. First, the first and the second problems are solved by applying an imaging optics to the receiver. Using these optics enables us to narrow the light sensor's field of view and condense the LED light (Fig.5). Consequently, can cut the background noise (the optical noise) and achieve

Fig. 7. Galvanometer mirror

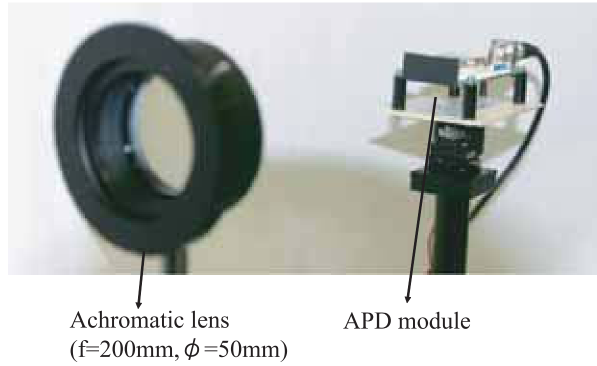


Fig. 8. The imaging optics' receiving sensor system

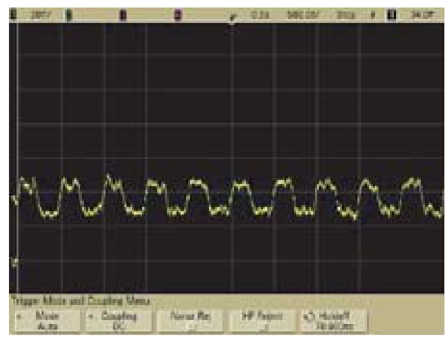

Fig. 9. Signal waveform (abscissa axis: 500 nsec/div)

a long-distance transmission. Second, by fitting a tracking mechanism to the receiver, we solve the third problem. This process also operates advantageously in narrowing the field of view. In addition, we employ a photodiode as a light sensor to make high-speed communication possible.

### C. Implementation of the proposed system

The proposed system consists of

- two cameras,
- a photodiode module,
- an achromatic lens,
- a half mirror,
- and two galvanometer mirrors.

The following explains the operation of the proposed system. The transmitter (an LED traffic signal) sends the information to the receiver as an LED light. This LED light goes through an achromatic lens and is separated into two optical paths by a half mirror. The two optical paths enter the photodiode and camera, which is applied to a narrow-angle camera. In addition, there are two galvanometer mirrors in front of an achromatic lens, one of them for horizontal scanning and the other for vertical scanning. The galvanometer mirror is a device that can rotate a mirror rapidly (Fig.7). Thus, by controlling the galvanometer mirror system, we can track the LED traffic signal. Furthermore, by using the captured image obtained from the narrow-angle camera, we control the galvanometer mirror. The galvanometer mirrors enable us to achieve hight-speed direction control. In addition, we use a wide-angle camera to detect the LED traffic signal as a first step. The tracking method is explained in more detail in Section IV.

To realize the proposed system, we segmented the system into two groups and investigated each one separately. One is the receiving sensor system for the imaging optics and the other is the tracking system for a dynamic environment. Section III includes an experiment on this receiving sensor system, and Section IV features an experiment on the tracking system for a dynamic environment.

## III. Experiment on the imaging optics' receiving sensor system

In this experiment, we used the C5460 avalanche photodiode module produced by HAMAMATSU HOTONIKUSU for photon detection. The wavelength range to which it is sensitive is 400ô 800 nm, and the light-sensitive element diameter is 1.5 mm.

To lengthen the transmission distance, we set an achromatic lens (focal length: 200 mm; aperture: 50mm) in front of an avalanche photodiode module and used it as a receiving sensor (Fig.8). The receiver sensor's field of view was 0.4 degree due to the relationship between the focal length and the light-sensitive element area.

The outline of this experiment is as follows.

We conducted a basic experiment with a $4 \times 4$ LED array (16 LEDs) transmitter and a receiver, the imaging optics' receiving sensor system. The transmitter was fixed 30 m from the receiver (in this case, the LED light intensity was equal to that of an LED traffic light (192 LEDs) that was fixed 100 m from the receiver). We modulated the LED light to a rectangular wave (2 MHz) and collected it with the receiver. We then observed the waveform modulated at 2 MHz using an oscilloscope (Fig.9). The experimental results proved that a high-speed (about 2 MHz) and long-distance (about 100 m) communication is possible by using this system.

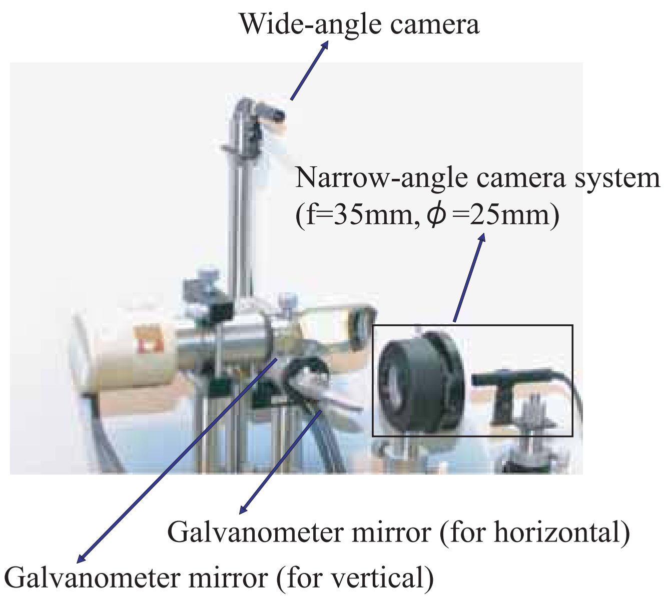


Fig. 10. Tracking system

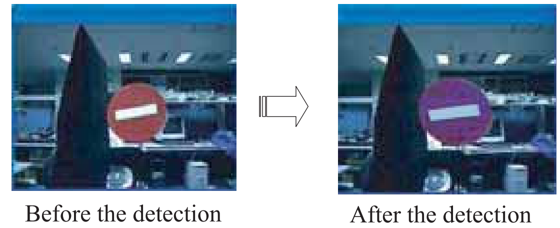


Fig. 11. Sample object (Red)

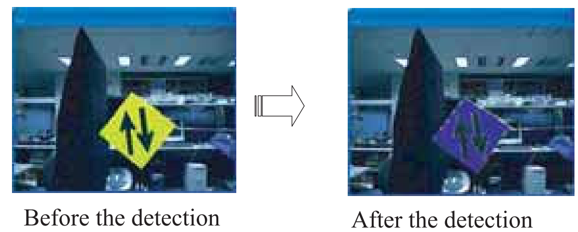


Fig. 12. Sample object (Yellow)

## IV. The Experiment of the Tracking System in a Dynamic Environment

The proposed system has to track the transmitter because the light sensor's field of view is very narrow (about 0.4 deg) and the positional relationship between the receiver and the transmitter changes with time. The method of tracking and the tracking system mechanism are explained as follows.

We used two cameras for the tracking system – a wide-angle camera and a narrow-angle camera – and fitted a view control mechanism to the narrow-angle camera. Later we will give a more precise account of the view control mechanism. The wide-angle camera was applied to find the transmitter in the first step, and the narrow-angle camera for tracking the transmitter and obtaining a high-resolution image. The narrow-angle camera consisted of two parts: One was a camera with its original lens removed; the other was an achromatic lens (focal length: 35 mm; aperture: 25 mm). We set up these parts appropriately and applied them as a narrow-angle camera.

Here we explain the view control mechanism in detail. We prepared two galvanometer mirrors and placed them in front of the narrow-angle camera. One was used for horizontal-view control while the other was for vertical-view control. The mirrors were set up in front of the narrow-angle camera in such a way that their two rotation axes were perpendicular. By controlling the angle of each mirror, we could control the view of the narrow-angle camera.

Next, we explain how to track the transmitter. First, we use the wide-angle camera to obtain the transmitter's position. Second, by using the information gained in the first step, we point the narrow angle camera at the transmitter. After this process, the transmitter is tracked by the narrow-angle camera equipped with the view control mechanism. Additionally, the tracking range of the transmitter is $\pm 24$ degree both horizontal direction and vertical direction. This is a range enough to track the LED traffic signal from 100m away from the traffic signal to an intersection (10m away from the traffic signal).

We experimented with the tracking system as follows:

- Detection of a sample object
- Method of galvanometer mirror control

### *A. Detection of a sample object*

The purpose of this experiment was to determine whether the tracking system operates correctly. In other words, since we did not give priority to recognition, we used a fairly simple recognition scheme. In future, however, we intend to apply a more advanced algorithm for recognition. We prepared two sample objects (Fig.11,12) for this experiment.

First, we found these objects from a captured image using color gamut information. Second, upon detecting these objects, we applied binarization. Finally, we calculated the center of the captured object (the center of mass) and applied it to control the galvanometer mirror. Below we describe the method for controlling the galvanometer mirror.

### *B. Method of controlling the galvanometer mirror*

There are actually three methods for controlling the galvanometer mirror. The first is based on the wide-angle camera. Secondly, the galvanometer mirror control based on the narrow angle camera. Third, the galvanometer mirror control based on the wide angle camera and the narrow angle camera. Each method is explained in the following subsection.

*1) Galvanometer mirror control with the wide-angle camera:* We find the center of the object in question by using the captured image obtained from the wide-angle camera; the captured image from the narrow-angle camera is not used. Then, the angle given to the galvanometer mirror system

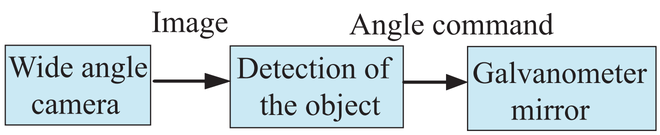


Fig. 13. Galvanometer mirror control with the wide-angle camera

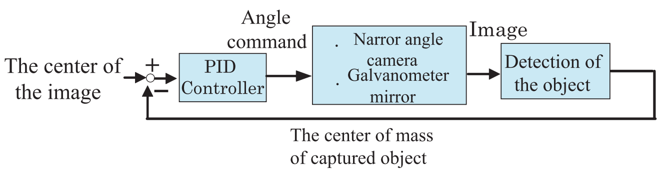


Fig. 14. Galvanometer mirror control with the narrow-angle camera

is calculated from the captured image. By repeating this process, the narrow-angle camera is able to track the object. Figure13 illustrates this process.

Unfortunately, this control method cannot track the object smoothly because the wide-angle camera measures the scene more roughly than does the narrow-angle camera. Furthermore, this method includes error in camera geometry between the narrow-angle camera and the wide-angle one. Thus, the tracking pixel of the narrow-angle camera is not actually in the center of the image. To solve this problem, we apply feedback control to cancel the error, achieved by using the captured image obtained from the narrow-angle camera. We explain the feedback control in the next subsection.

*2) Galvanometer mirror control with the narrow-angle camera:* Here we focus on controlling the galvanometer mirror using only the narrow-angle camera. In this case, it is assumed that the object is captured by the narrow-angle camera.

We apply the PID algorithm to reduce the distance between the center of the image and the center of the region of the detected object. Figure 14 depicts this process. This control method makes it possible to track the object smoothly.

*3) Galvanometer mirror control with both the wide-angle and the narrow-angle camera:* Our proposed method combines the two control methods above. First, we find the object using the wide-angle camera as explained in Section IV-B.1. Second, we track the object using the narrow-angle camera as explained in Section IV-B.2.

Incidentally, the following is worth a mention in passing. The wide-angle camera image is captured regardless of the control method explained in Sections IV-B.1 and IV-B.2. Thus, we can find a new object that should be tracked while one object is already being tracked by the narrow-angle camera. In short, we can switch between control methods according to need, as shown in Fig. 15. This control method makes it possible to both find an object and track it smoothly.

## V. An Experiment on Audio Transmission with the Proposed System

We segmented the proposed system into two parts and conducted an experiment on each part (Sections 3 and 4). Here, we describe an experiment on a simple audio transmission. The aim of this experiment was to check the feasibility of our entire system. Therefore, we conducted the experiment under simple conditions: The distance between the transmitter and the receiver was close (a few meters). Additionally, by using only brightness information, we found the transmitter ($4 \times 4$ LED array) from a captured image. This experiment was conducted indoors under simple conditions, but future work will include testing the system in more realistic environments.

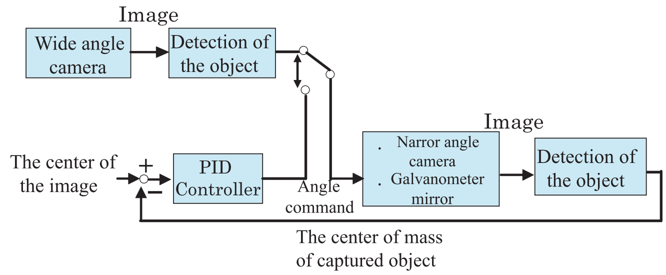


Fig. 15. Galvanometer mirror control with both the wide-angle and the narrow-angle camera

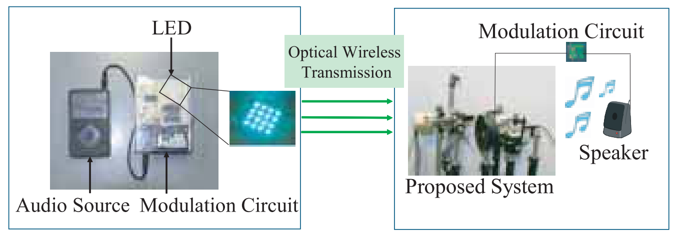


Fig. 16. Experiment on an audio transmission

Figure 16 shows the transmitter, which comprises a $4 \times 4$ LED array, a modulation circuit and an audio source. The aim was to determine whether the audio signal came from the speaker when the transmitter was moving in front of the receiver. In other words, we checked whether the audio data signal was received by our system in a dynamic environment. Additionally, we use an achromatic lens with a focal length of 100 mm.

The results revealed that the audio came out from a speaker when the transmitter was moving within the area where the proposed system could track an object. Additionally, if I block out the light with an obstacle, we can stop the communication. Therefore, we can verify that our system operates correctly.

In terms of signal modulation, we used pulse-width modulation so as to encode the audio source. There are several reasons for doing this. One is that the modem circuit makes modulation easy. Another is that this modulation scheme has no relationship with the optical intensity. That is, for LEDs that have a directional characteristic, the optical intensity received by the photodiode changes during tracking.

## VI. Conclusion and Future Work

The target of our experiment was long-distance (about 100 m) and high-speed (approximately a few Mbit/sec) visible light communication in a dynamic environment. However the current receiver which is constructed with an optical filter and a photodiode achieved only short-distance and slow-speed visible light communication in intelligent transport systems. Thus, we proposed a new receiving system for visible light communication in ITS, and constructed a prototype of it. The proposed system construct with the photodeiode, the imaging optics and the tracking mechanism. The proposed system and experiment were described in detail. The experiment proved the validity of our system.

Future work will involve preparing an in-vehicle experiment. For this purpose, we intend to apply a more advanced algorithm for recognition, and then to miniaturize the proposed system. We also apply more accurate tracking algorithm.

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