On-Vehicle Receiver for Distant Visible Light Road-to-Vehicle Communication

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*Abstract***— In this paper, we propose a road-to-vehicle visible communication system for ITS. In this system, a LED traffic light is used as transmitter and a photodiode is used as receiver. There are several problems associated with applying visible light communication to the field of ITS. It is necessary to receive information from long distance. And tracking the transmitter for a certain moving distance of the vehicle is also important. We applied an imaging optics to receive information over long distance, and two cameras are used to solve the relationship between the transmitter and the receiver position changes with time, and vibrational correction technique is also fixed to the system to minimize vibrational affections. We developed algorithms to track the transmitter. The experiments were conducted to confirm the proposals.**

I. Introduction

TRAFFIC system has been holding problems such as congestion and traffic accidents from its beginning. Intelligent Transport System, known simply as ITS, is what gives solution to these unfortunately lasting problems with information communication and control technology. If the traffic system could be optimized by ITS, it will surely be safer and more ecological for our environment. 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 be applied to lighting, vehicles' headlights and tail lamps in the future. 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][3][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 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's body

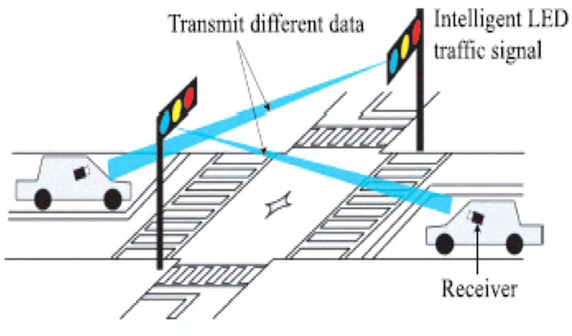

Figure 1: Visible light communication in ITS

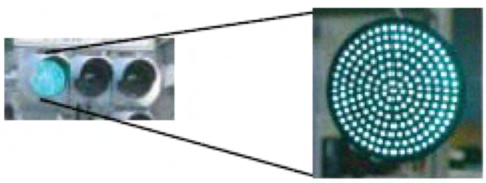

Figure 2: LED traffic signal

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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 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

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 about visible light communication in next section and the proposed system is explain in Section III. We explain the experiments in section IV, and Section V presents our conclusion and future work.

II. Visible Light Communication

In this study, we propose a visible light communication system applied to ITS. Here we introduce basic characteristics of general visible light communication.

A. Features

Visible light communication is one of wireless communication methods using light we can see. It transfers data by emitting light source and receives by light sensor. The dominant device for transmitter is LED and for receiver photo diode. There are several advantages in this communication method. One is that visible light is safe to human body, which makes it 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, it has more advantages: its use is not limited by law, any existing light source, such as room illuminations and displays, could be used as transmitters, and it can be used at a place where radio waves cannot be used, for example hospitals or area around precision machine.

B. Method for Finding Transmitter

One of the applications of 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. At present, light bulbs 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. Even the emitting efficiency is approaching to that of fluorescent light and thus it will surely replace the bulbs and fluorescents in the near future.

There are many light emitters surrounding us and any of them could become a transmitter of this communication. Some examples are PC display, 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 e.g. stations, airports.

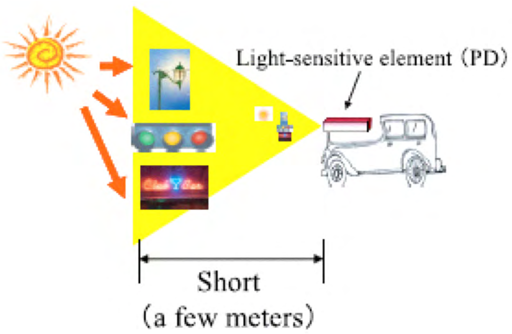

Figure 3: Photodiode as a light-sensitive element

III. Proposed System

In the previous work, a receiver is constructed with a photodiode and an optical filter [8]. However it doesn't satisfy our demand (high-speed and long-distance transmission, dynamic condition) with the current receiver. So, we propose a new receiving system to be able to solve 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 light, neon lighting and sunlight and so on) are present in front of a photodiode, the photodiode receives all of these lights (Fig.3). 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 achieved 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 communication. The photodiode problem that we state above is solved by using imaging optics and a tracking mechanism. This is explained in detail below.

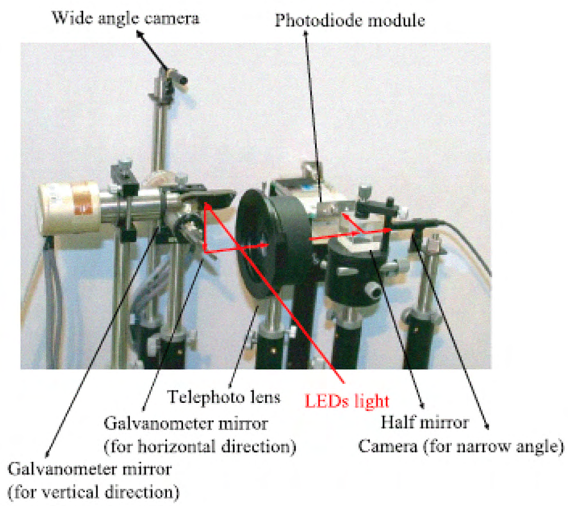

Figure 4: Intelligent receiving system

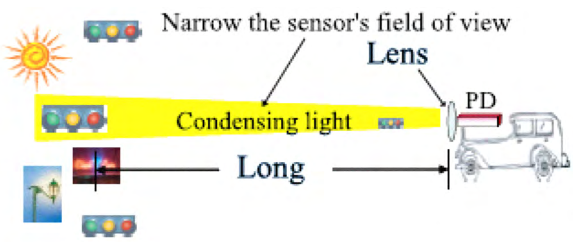

Figure 5: Photodiode and lens

B. *Solution for the problems*

Here, we tried to solve the three problems outlined above. 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, we can cut the background noise (the optical noise) and achieve a long-distance transmission. 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.

Figure 6: Galvanometer mirror

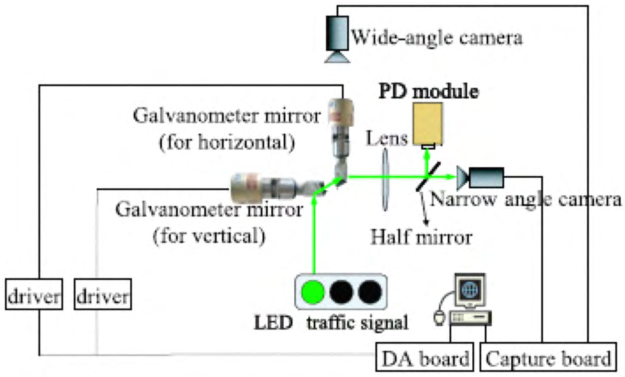

Figure 7: Proposed system

C. *Implementation of the proposed system*

The proposed system consists of devices below.

- Two cameras
- A photodiode module
- An achromatic lens
- A half mirror,
- Two galvanometer mirrors.

Figure 7 shows the structure of the proposed method.

The transmitter (an LED traffic light) sends the information to the receiver as an LED light. This LED light goes through an achromatic lens and the light 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.6). 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 high-speed direction control. In addition, we use a wide-angle camera to detect the LED traffic signal as a first step.Operation of the system is as following.

[Step1]: Wide-angle camera detect the transmitter

[Step2]: Control two galvanometer mirrors

[Step3]: Narrow-angle camera detect the transmitter

[Step4]: Repeat [step2] and [step3] and return to [Step1] if transmitter disappeared from the narrow-angle camera

D. *Vibrational correction*

While experiment being conducted, we found that the vibration of the vehicle affect system, and the response from the system was not good. To solve this, vibration correction technique was applied to the system.

In this paper, we fixed a gyro sensor to the system. The gyro sensor is a kind of vehicle's vibration sensor having features of high-speed response and it is able to sense angular speed as well. When we track transmitter in long-distance, angle is important.

Here, fist the gyro sensor senses angular speed. Then the vibrated angle of the camera is calculated using angular speed and the galvanometer mirrors are controlled depending on calculated angle.Fig.8 shows the operation flow of the system.

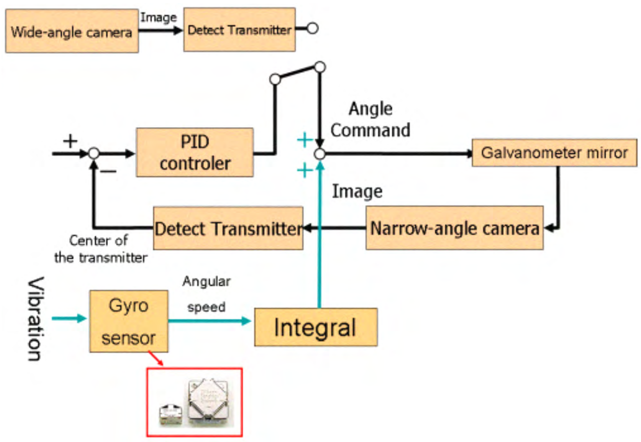

Figure 8: The operation of the system

IV. EXPERIMENT

The experiments were conducted for tracking traffic light on dynamic conditions and measuring BER on static conditions.

A. *The experiment of the tracking system*

There are two experiments were conducted to confirm tracking the transmitter. One experiment was conducted without vibration correction technique and another on was conducted with vibration correction technique. The experimental conditions were as below.

Condition and Description:

We made two experiments on the following condition.

- Data/Time: 2008/8/31,11:00-13:00
- Place: Outdoor, in Chubu Nippon Driver School
- Vehicle Speed: 35km/h
- Initial Distance Between Vehicle and Transmitter: 100m
- Frame Rate: 30fps
- Number of LEDs: 192
- Angle of narrow-angle camera: 1.2deg x 0.9deg

We recorded the video from the narrow-angle camera in each experiment and checked the tracking system and vibrational correction. Photodiode'field is 0.4deg. So we must track the transmitter correctly to communicate with transmitter. In this experiment, we detected the transmitter manually without the wide-angle camera.

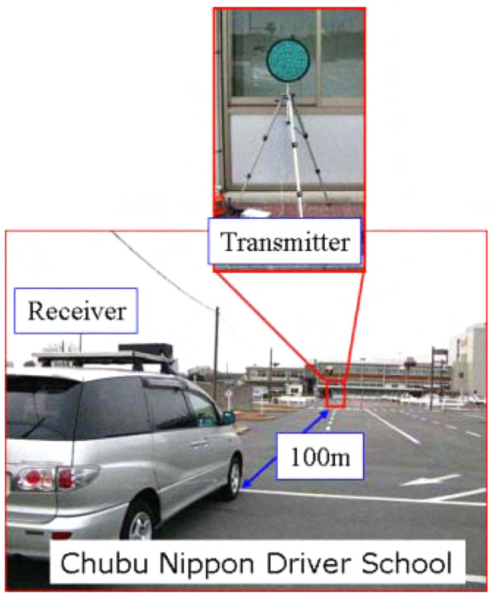

Figure 9: Environment of experiment1

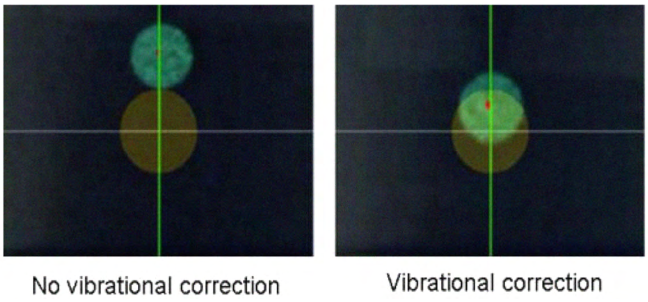

Figure 10: The image of the narrow-angel camera

Result:

Figure 10 is the image from narrow-angle camera. Yellow circle in Fig.10 is photodiode's field. The tracking results are shown on Fig.11. In Fig.11, left and right graphs show results of without and with vibration correction technique respectively. The horizontal axis of the graph is frame and the vertical axis is difference between center point of Image and center point of transmitter. These graphs show the narrow-angle camera could capture the transmitter in each frame, but transmitter was't always existed in the center of the image. We can conduct communication when the center point difference is existed inside the blue curves. The result showed that the communication can be conducted with vibration correction technique.

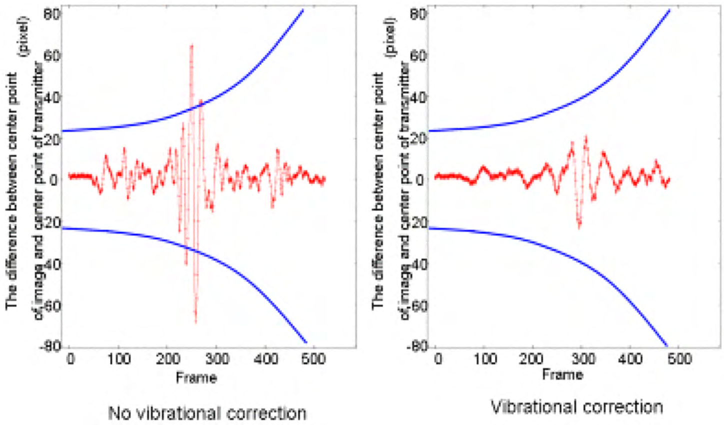

Figure 11: Result of tracking

B. The experiment of the measuring BER on the static condition

Condition and Description:

We made the experiment on the following condition.

- Data/Time: 2008/01/16,14:00-16:00
- Place: Outdoor, in Nagoya University
- Communication Distance: 20-100m
- Number of LEDs: 192
- Photodiode field: 0.4deg
- Data: pn9 Random Data
- Data Rate: 1Mbps(QPSK), 2Mbps(16QAM)
- Error Correction: Turbo Code

In this experiment, we controlled the galvanometer mirrors manually without tracking the traffic light. In the case of center of transmitter is nearly similar to the center of image from the narrow-angle camera, we measured BER. As the distance between transmitter and receiver is changed, the light intensity of the photodiode is also changed. As a result of this, output voltage of photodiode is also varied according to the position movement of the receiver. So, it is needed to control gain of the receiver to achieve better communication.

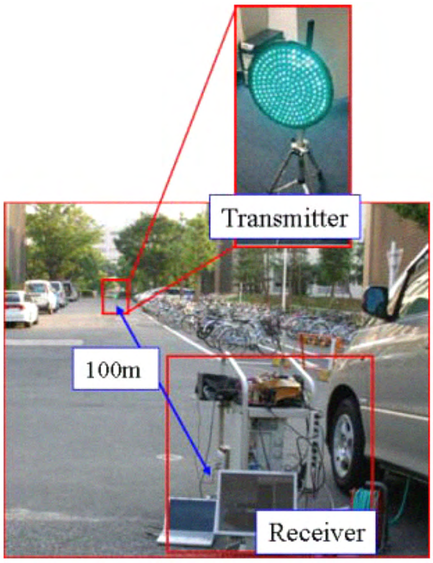

Figure 12: Environment of experiment2

Result:

Figure 13 shows the results of the experiment. This results showed that it is possible to communicate, if the receiver is maximum 40m far from the transmitter since (BER< 10^{-6}).

Generally, movies can be sent, if BER< 10^{-6}. However, as the receiver getting more than 60m far from the transmitter, BER is getting high value, decreasing the communication accuracy. The system has to be modified to obtain the long distance communication.

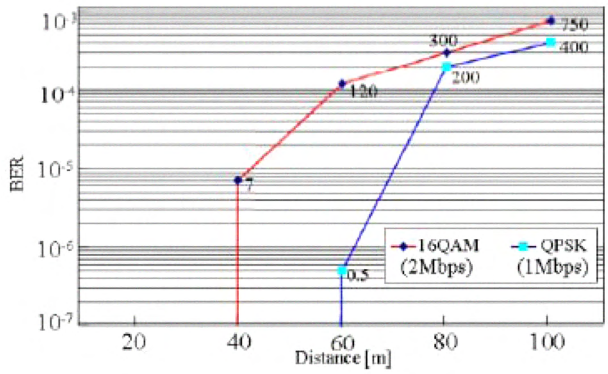

Figure 13: BER feature

V. CONCLUSION AND FUTURE WORK

We proposed a new receiving system for road-to-vehicle communication as an ITS technology using visible light. Algorithms were developed for tracking the transmitter using wide-angle camera and narrow-angle camera. We fixed vibrational correction technique to the receiver to solve vibrational problems on dynamic condition. Two kinds of experiments were conducted to confirm the tracking system and to measure BER on the static condition. In the first experiment, we obtained favorable results after fixing vibrational correction technique. The results of second experiment showed that, some modifications of the system are necessary to conduct communication from long distance(from more than 60m).

As the future work, we must improve the receiver to communicate correctly from long distance and fix Auto Gain Control(AGC) to the receiver to measure BER on dynamic condition. An algorithm has to be developed to track transmitter automatically by wide-angle camera.

VI. ACKNOWLEDGEMENT

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