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Development of pedestrian ITS: Application of Traffic Signals for Wireless Visible Light Communication System

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Traffic signals based on light emitting diode (LED) are planning to install our community on a trial basis. Those provide the communication device as well as the traffic control device. Recently, we have investigated the possibility of the wireless visible light communication (WVLC) by using LED-type pedestrian traffic lights. The information, such as a time required for a pedestrian to safely cross the street, a route, a city and so on, will be available by a portable small optical detector with a pedestrian. Our initial investigation reveals that LED-type traffic lights are considered to be a success both in terms of their effectiveness in public safety and communication tools for public support through the WVLC technology.

Keywords: *LED-type pedestrian traffic lights, visible light communication, Field experiments, Optical signal/noise ratio (OSNR),*

1. Introduction

In the advanced information communication society in recent years, the Intelligent Transport Systems (ITS) has been studied as a new road transportation system. ITS is expected to integrate people, roads, and vehicles with an information network, and to solve various issues in road traffic through the latest information communication technologies for a comfortable and safe transportation environment [1]. For this purpose, it is required to develop technologies to enable transmission and reception of any information with a simple personal digital assistant. In order to realize mobile communications, the research and development of high-speed transmission and high-speed mobile communication technology are indispensable [2]. So far, the research and development of wireless communication system using radio waves or infrared radiation have been mainly conducted. Under such a background, the authors consider the wireless visible light communication (WVLC) system which employs light emitting diode (LED) type signal lights (including those for vehicles) as one of the effective solutions. The addition of extra value of information transmission function as well as the objective of traffic lights as a conventional traffic control means locates a LED type traffic light as new "communications infrastructure for a road." It is supposed that the proposed system is very promising since the conventional infrastructure can be used.

The WVLC is resistant to electromagnetic noise to assure high security (secrecy). Moreover, the property of light suggests that the WVLC can realize economically a high speed and high band transmission medium, and has the outstanding characteristic not to interfere with an adjoining radio network (interference-proof). Although the WVLC is a kind of wireless communications, the restriction of the Radio Law does not apply since the transmission medium is in a visible light wave region, so that no license is required and it is free to use at present. Since no malfunction in such as aircraft equipment and medical instruments is anticipated, it enables wireless data communication in airports and hospitals where radio communication cannot be used according to electromagnetic wave interference. It is regarded in office as the realization means of a computer network, and at home as the realization means of a multimedia network. Furthermore it is observed as the means of outdoor short distance communication. So far, theoretical discussion on the office illumination light communication using the white LED is reported by Tanaka *et al.* [3]. On the other hand, the WVLC has drawbacks such as hit by a moving body interrupting an optical path, and the tendency to be affected by weather conditions such as fog, snow and heavy rain which hurt visibility in outdoor optical space communication.

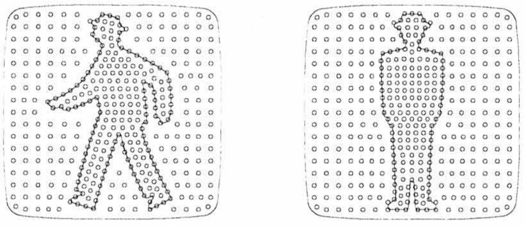

Figure 1. Layout of LED type pedestrians signal lights (blue and red).

In the past, the low cost infrared LED currently used for a low-speed wireless light communication instrument has left issues with respect to eye safety. On the other hand, in spite of low signal rate, the visible light LED assures high eye safety. Moreover, the super luminescent diode (SLD), which has begun to spread lately, is a device having the advantage of the LED and the laser diode (LD). It is a low coherent light source compared with the LD so that it secures high eye safety, and high-speed transmission can be expected.

In this research, the WVLC using a LED type pedestrian traffic light is investigated as information transmission for the pedestrian (the healthy and disabled) assistance in the ITS. About the transportation information service system using a LED type traffic light for vehicles, theoretical discussion with computational approach is carried out by Akanegawa, Maehara, *et al.* [4, 5, 6]. Until now, although discussion on the WVLC using a signal light has been made, there is no deeply studied example due to poor response speed with an electric bulb type light source. Therefore, no result of field experiments has been reported so far. The authors first reported the research using a LED type pedestrian signal light of low power (1/10 of the conventional), long life (maintenance free), high-speed response, and excellent in visibility (no false lighting) [7].

2. Outline of field testing device, measurement system, and evaluation method

In the United States, the LED type signal light has spread rapidly in a lot of states. Also in Asia, it has been introduced in Singapore and Hong Kong. On the other hand in Japan, the specification of the light equipment is discussed for the introduction of the LED type signal light, and field tests have been carried out. The standard specifications of signal lights for vehicles have already been determined, and they are being installed in some places, the number is still small though. The National Police Agency of Japan determined to replace signal lights for pedestrians all over the country from the present electric bulb type to the LED type which is visible at the crossing where under afternoon sunny, on June 6, 2002. It was announced that the specifications including design would be determined by the summer of 2002, and the practical installation would begin after the following spring [8]. Accordingly a variety of design and specification are being proposed from each production company. In this research, LED type signal lights in which both red and blue bulbs were replaced to LEDs were made as an experiment using a pedestrian signal light (by Nippon Signal Co., Ltd.), and a field experiment was conducted.

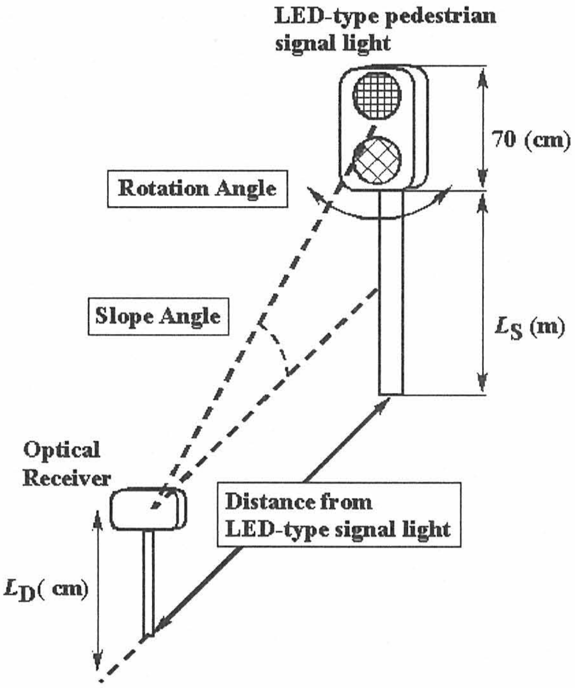

Figure 2. Schematic drawing of field experiment.

2.1. Outline of signal light and receiver

Red and Blue LEDs were placed outside the figure in the pedestrian light. The numbers of red and blue LEDs were 224 and 180, respectively, as shown in Fig. 1, and the light intensity was controlled by the driver circuit. The variation in the brightness among LEDs was not adjusted. When the forward current (I_f) of the red LED (peak wavelength: 639 nm) and the blue LED (peak wavelength: 495 nm) was 20 mA, the voltages were 2.2 V and 3.6 V, respectively.

An APD (avalanche photodiode) module C5460 by Hamamatsu Photonics was used, in which reverse bias was impressed to a *p/n* junction so that an avalanche-breakdown phenomenon was employed for the optical signal detection. The sensitivity wavelength range is 400 - 1000 nm, and the maximum spectral sensitivity is observed at 800 nm. Visible light condensed with a lens was detected by the APD (1.5 mm ϕ of the detection area), converted into an electrical signal, amplified in a process circuit, and finally its wave was observed with an oscilloscope.

2.2 Modulation method

It is necessary not only to modulate data but also to have the role of primary traffic control in the WVLC using a signal light. In this experiment, intensity modulation was employed as the light modulation method. In intensity modulation, information is transferred by modulating the light intensity of red and blue lights. Since the modulation rate is high, no flicker is detected by pedestrians' eyes. The transmitted light pulse in this manner is received by a portable receiver with a pedestrian.

A square wave of 50 % of duty ratio was used as a modulating signal, which frequency was varied between 9.6 kHz - 500 kHz by the driver circuit of the LED.

2.3 Field experiment and evaluation method

In the field experiment, a signal light with the installation height L_S = 1.2 m (standard: road clearance of 2.6 m) and about 0.7 m of the height of the main part of the light equipment, and a receiver at the installation height L_D were used as indicated in Fig. 2. The experiment evaluated the receiving quality of a light signal using the optical signal/noise ratio (OSNR). The OSNR is expressed in the following equation.

$$OSNR(dB) = 20 \times Log\left(\frac{IS_0}{IS_D}\right), \qquad (1)$$

where IS_0 indicates the electrical signal intensity (output voltage from the APD) converted from the photodetector of the receiver measured at the position of a signal light, while IS_D indicates the electrical signal intensity in each measurement place.

3. Result of field experiment and discussion

First, in the WVLC experiment on inside-house shading conditions, the red and blue lights were observed with a optical signal intensity over OSNR = 50 - 60 dB at 20 m from the signal lights. However, when measured on outdoor sunny weather conditions, irrespective of the distance from the signal lights, due to disturbance light, the perverted signal was observed by the saturation of the APD, or no square wave signal was observed. Therefore in this experiment, a band pass filter of 30 % or more of permeability was employed at the peak wavelengths of the red and blue LED. Moreover a secondary light penetration cut filter for the red LED was also employed. It was confirmed that the saturation phenomenon of the APD was suppressed and that the S/N ratio was improved by filter insertion. The effect of the disturbance light which is closely related to a weather condition was quantified by measuring the illuminance measured with an illuminometer at the time of measurement.

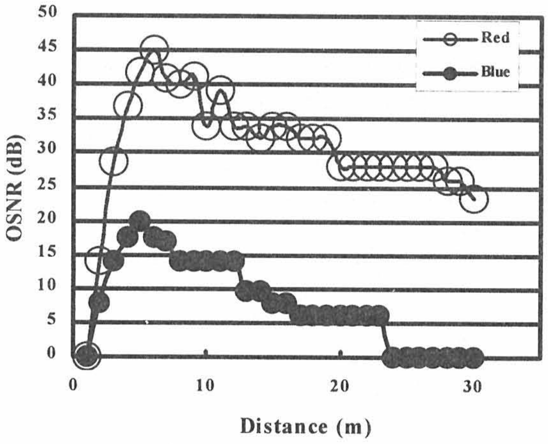

Figure 3. The effect of distance from signal light on the OSNR property.

3.1 Transmission distance property

The length of a pedestrian crossing varies with the number of lanes on the road. In the WVLC using a signal light, it is important to evaluate the transmission distance property of a light signal precisely. The measurement was carried out for 15 - 20 m distance, assuming a road width of 3.75 m per lane and four or more lanes, and on L_D = 10 cm condition. The L_D = 10 cm condition is equivalent to the height relationship between a real signal light and a pedestrian (the receiver).

Figure 3 shows the result measured on sunny condition (illuminance 33000 [lx]). It turns out that the OSNR property is more excellent at red lighting compared with at blue lighting. Since loss by dispersion generally decreases with longer wavelength, in a long wavelength area, i.e., red, the loss is less and long-distance transmission is attained. It is supposed that the difference in the transmission distance property from a red and blue signal light is due to the free-space transmission loss by the difference in wavelength. The measurement result proves that 5dB or better of the attenuation of red and blue light from the signal light is guaranteed in 20 m of measurement distance, and especially for red light, which requires long distance space communication, 30 dB or better in more than 20 m. This suggests that the WVLC in the distance of four or more lanes is sufficiently practical.

The elevation angle (see Fig. 2) from the receiver to the signal light computed from the transmission distance property shown in Fig. 3 proved that a high OSNR value is obtained for both red and blue in 10 - 15 degrees. This result indicates that moving the detection face of the receiver slightly improves the S/N ratio.

3.2 Relationship between transmission distance and rotation angle (receiver position)

Change of the light receiving property is anticipated by the visible light radiation pattern emitted from a signal light and the position of a pedestrian. This corresponds to the condition that the relative position (angle) between a pedestrian under crossing and the signal light always varies with the position of the pedestrian waiting for a green signal.

The measurement was carried out with the receiver position fixed and rotating a signal light for the simplicity of the experiment. The measurement was carried out at every 5 m distance from the signal light up to 20 - 30 m with the receiver on $L_D = 10$ cm condition.

The results measured on the sunny condition (red lighting: illuminance 26000 [lx] and blue lighting: illuminance 30000 [lx]) are shown in Figs. 4 and 5, respectively. 5 dB of OSNR was obtained at +/-15 degrees for both red and blue lighting. The S/N ratio of the received signal is better for blue lighting than red lighting. An OSNR characteristic curve varies from the inverse parabolic type centering at zero degree to a trapezoid type with the increase in measurement distance. This shows that the effect of the orientation of the receiver detection surface on the input signal decreases due to the increase in the distance (10 m or more) from the signal light.

Figures 6 and 7 indicate the measurement result in rainy sometimes cloudy condition (red and blue lighting: illuminance 5000 [lx]), respectively. Since the illuminance was about 1/6 of a sunny day, the light space transmission characteristic by the difference in a weather condition was investigated. As compared with a sunny day, little difference was observed in the OSNR property at both red and blue lighting. This is considered because a space transmission characteristic equivalent to a sunny day is obtained if an optical-axis blockage does not take place by the light absorption and diffusion by rain waterdrops and fog, although the illuminance lowered by the weather condition. The result measured on sunny daytime and nighttime conditions (at red lighting: illuminance 25000 [lx]) is shown in Fig. 8. In this measurement, the receiver was fixed at 10 m and 20 m distance from the signal light, and at the height of $L_D = 70$ cm.

It turns out that the OSNR value at daytime lowers to about half of nighttime. The OSNR property tends to depend on distance in daytime, while it does not vary with distance from the signal light less than 20 m at night. The reason why the OSNR value at night is bigger than that in daytime is considered that there is no effect of the disturbance light at night. However, if a signal light is installed in a shopping quarter where there are night lighting and neon signs, it is anticipated that the OSNR property (S/N ratio) lowers by disturbance light. The OSNR angle dependency proves that an inverse parabolic OSNR curve was obtained from 0 to +/-30 degrees, while a smooth damping property of OSNR was obtained over +/-30 degrees. In measurement in daytime, no such smooth damping property over +/-30 degrees was observed as at night. This result indicates that the S/N ratio of a received signal improves all day and night, by moving a receiver in +/-30 degrees both while a pedestrians waiting or moving.

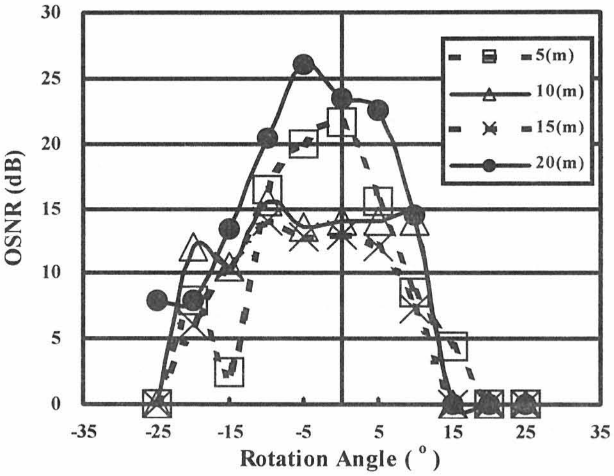

Figure 4. The OSNR property on red lighting (sunny, illuminance 26000 [lx]).

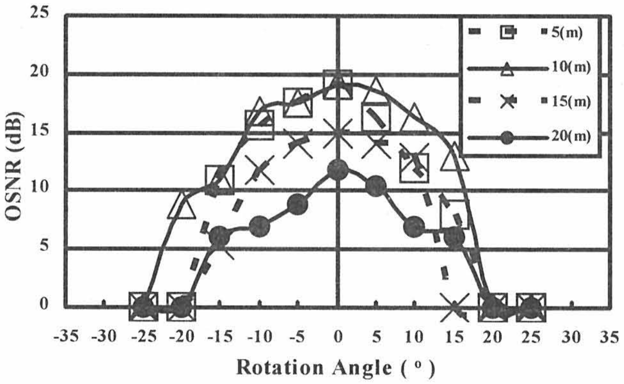

Figure 5. The OSNR property on blue lighting (sunny, illuminance 30000 [lx]).

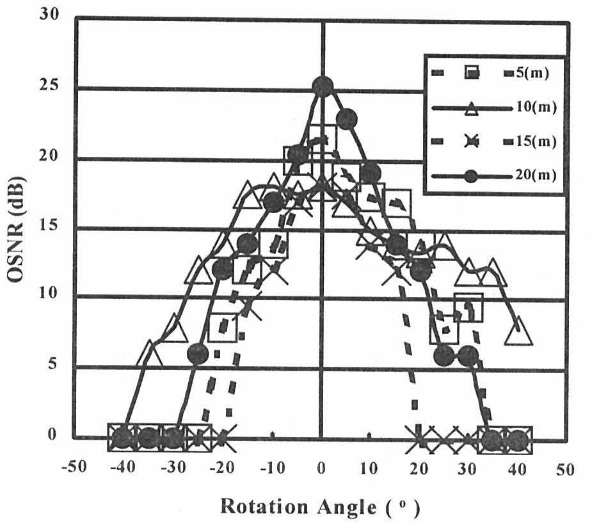

Figure 6. The OSNR property on red lighting (cloudy sometimes rainy, illuminance 5000 [lx]).

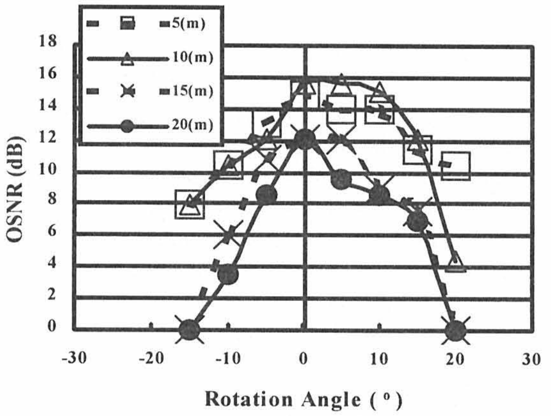

Figure 7. The OSNR property on blue lighting (cloudy sometimes rainy, illuminance 5000 [lx]).

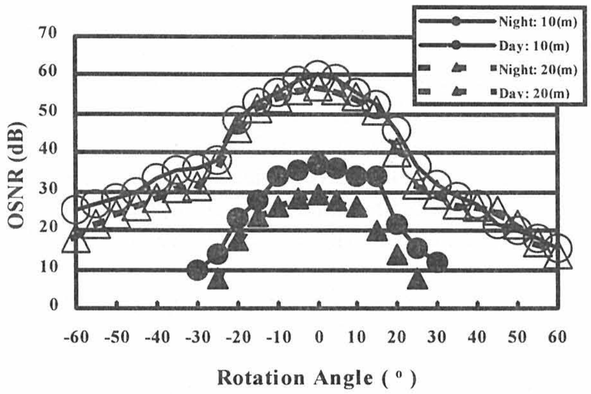

Figure 8. The OSNR property on red lighting (comparison between daytime (illuminance 25000 [lx]) and night.)

3.3 Relationships between transmission distance, transmission frequency, and rotation angle (receiver position)

The amount of information transmitted from a signal light depends on the modulation frequency of LEDs. In this experiment the modulation frequency of red LEDs was modulated up to a maximum of 500 kHz by the computer control, and the relationship between transmission distance and rotation angle was evaluated. A maximum modulating frequency depends on the own frequency characteristic of the LED. High modulation frequency has been realized in a red LED in previous research.

There are few data available, on the other hand, concerning the frequency characteristic of a blue LED. Therefore, this experiment was focused on red lighting. In this measurement, the receiver was fixed at 10 m and 20 m distance from the signal light, and at the height of L_D = 70 cm. In the previous experiment, L_D = 10 cm (the relationship between a real signal light and a pedestrian). However, it is anticipated that a receiver must always follow a signal light at a high frequency. Therefore, the experiment was carried out at L_D = 70 cm with the assumption that the receiver was turned to the signal light.

Figures 9 and 10 show the result measured at distances of 10 m and 20 m distance from the signal light on cloudy condition, respectively. The OSNR value tends to decrease with the increase in modulation frequency. The OSNR over 20 dB was obtained at the transmitted frequency under 200 kHz in the case of 10 m distance, and at under 100 kHz in the case of 20 m. The frequency dependency of the OSNR is greater as the distance from a signal light is larger. On the frequency at 500 kHz or more, the received wave form was distorted and was not accurately measured. The property of the OSNR function of each frequency is an inverse parabolic type, and the distance from a signal light makes no difference. At a high frequency, when the distance from a signal light becomes large, the OSNR property deteriorates rapidly. This is considered due to the degradation of the S/N ratio by the attenuation of a light signal. Moreover, the frequency characteristic of the LED itself is closely related. Thus a field experiment using a LED of a RF specification is needed.

4. Conclusion

A LED type pedestrian signal light was made as an experiment, and the WVLC in red and blue lighting was evaluated by the OSNR property of electrical signal obtained by converting light detected with an APD in this study. The result of the dependency of the transmission distance, rotation angle (receiver position), and transmitted frequency in various weather conditions (sunny, cloudy sometimes sunny and cloudy) in daytime

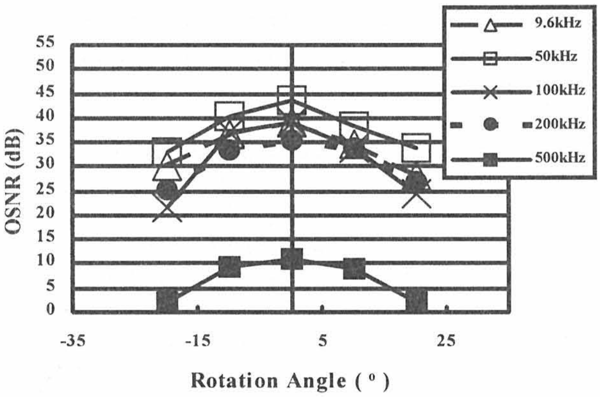

Figure 9. The OSNR frequency property on red lighting (cloudy, 10 m from signal light).

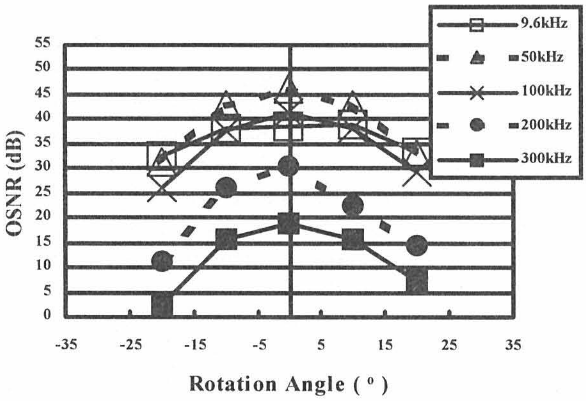

Figure 10. The OSNR frequency property on red lighting (cloudy, 20 m from signal light).

and nighttime obtained in the field experiment is summarized below.

1) When light-electrical signal conversion by an APD is employed, it is necessary to insert a band pass filter which passes only the major wavelength of a LED to a photoreceptor. Disturbance light is suppressed by filter insertion and the S/N ratio improves.

2) The transmission distance property proves that the WVLC is possible in the distance of 20 m or more (equivalent to a pedestrian crossing on a four or more lane wide road) from a signal light. The OSNR value at red lighting is twice or more than that of blue lighting.

3) In case a pedestrian receives a light signal from a signal light, the S/N ratio of a receiving signal can be raised by moving the detection surface in ±30 degrees.

4) The OSNR value obtained in sunny daytime is about twice the value obtained at night. In ±30 degrees, no difference in the angle dependency of the OSNR between daytime and nighttime is not observed.

In a high frequency region, as the distance from a signal light becomes larger the OSNR property deteriorates rapidly. It is supposed that a red signal transmitted at a frequency of about 200 kHz is practically possible in 20 m of the transmission distance (equivalent to a pedestrian crossing on a four or more lane wide road).

Thus from the above result, it is concluded that the establishment of a WVLC system for the purpose of pedestrian (the healthy and disabled) assistance is possible, with a LED type pedestrian signal light as a means of the Pedestrian ITS. The remarkable improvement of the performance of a LED (frequency, brightness, etc.) suggests that it is practical to provide various information with a WVLC system (using red light) to pedestrians waiting for a green signal.

The pedestrian ITS which we propose as new "communication infrastructure for a road" is considered quite different from the required methods (usage of infrared and radio wave) in the infrastructure development proposed so far in the point that the conventional infrastructure can be used, as described in Chapter 1.

5. Future subject

It is supposed future subjects that the investigation of the following WVLC issues for the realization of the WVLC using a LED type pedestrian signal light.

1) The permeability of light falls by the absorption and diffusion (dispersion) of visible light, and optical-axis blockage by waterdrops due to moisture in air, such as rain, snow, and fog, so that the transmission distance shortens. The information deficiency and the deterioration of quality in the WVLC in such weather conditions that the light attenuation from the light equipment is significant should be well studied.

2) When light attenuation is remarkable, a modulation method which complements the information suffered a loss intermittently and improves information quality needs to be investigated. It is important that hit by a moving body interrupting an optical path not be trouble for a user by the improvement of the method of data transfer.

3) The effect of light interference from other pedestrian signal lights on the WVLC needs to be revealed. Furthermore, the effect of street lights and neon signs on the WVLC at night also needs to be studied.

4) The spread of LED type signal lights requires cost reduction for the manufacturing of light equipment. Although the cost reduction can be realized by reducing the number of LEDs, it is essential that the number of LEDs and a light equipment layout be optimized so that the substantial role of signal lights is not spoiled and the communication quality in the WVLC is maintained.

5) It should be investigated whether mutual (two-way) information exchange is possible with simultaneous two-way communication (one to n communication) between a signal light and portable receivers. Moreover, it is

necessary to establish an upward communication method in order to carry out two-way communication.

Acknowledgment

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http://www.mlit.go.jp/road/ITS/j-html/index.html
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