A Study on Visually Impaired Person's Support System Utilizing Visible Light Communication Technology at Signalized Intersections

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In this paper, we analyzed the issues and needs that visually impaired persons feel on a daily basis at signalized intersections. And then we evaluated a visually impaired persons' support system utilizing the visible light communication (VLC) technology that was developed in order to solve the problems by using the experiment and the questionnaire. As a result, it was shown that the guidance of VLC system enables them to cross safely and comfortably at signalized intersection. Therefore, it can be said that the potential of VLC system to support visually impaired persons' crossing at signalized intersection is sufficiently high.

Keywords: *Visible Light Communication technology, Visually impaired person, Signalized intersection*

1. Introduction

1.1 Background of this study

In Japan, transportation infrastructures for vulnerable road users have been developed in recent years. Various countermeasures for visually impaired persons such as the acoustic signals (hereinafter called "AS") and the tactile tiles on sidewalk have been done up to now. Recently, with the development of information and telecommunication technology, various pedestrian support systems such as "Pedestrian ITS" promoted by the National Institute for Land and Infrastructure Management (NILIM) have been developed. As a representative system, Pedestrian Information and Communication Systems (PICS) have been introduced since 2001 [1]. This system can extend the green time when they cross at intersection and transfer the signal condition information to them with portable devices. And the other systems such as utilizing RFID and Visible Light Communication (hereinafter called "VLC") have been discussed [2]-[4]. Though various systems are developed to date, it is not enough environmental considerations for them at the intersection because the existing systems cannot necessarily meet their needs.

Meanwhile, Light Emitting Diode (LED) traffic signals have spread rapidly, and the utilization of the signals is expected as a next-generation information communication device at signalized intersection. That is, LED traffic signal with VLC technology can fulfill not only traffic control function but also information-communication function as shown in Figure 1. This

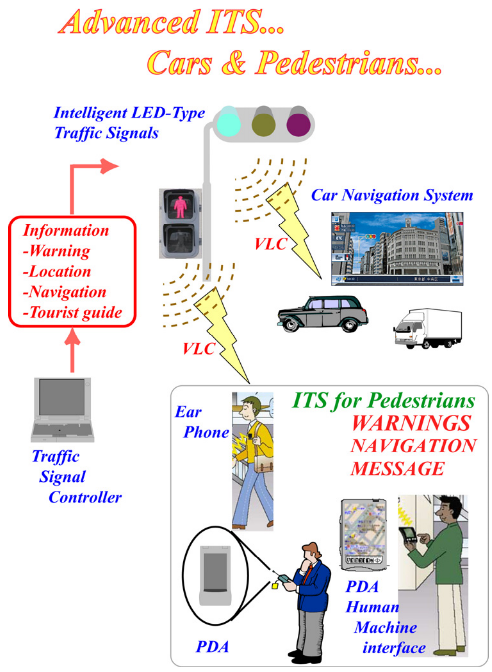

Figure 1 Schematic diagram of VLC system at signalized intersection

system needs less equipment besides the traffic signal in comparison to the existing crossing support system. In addition, for the characteristics of VLC, it is resistant to electromagnetic noise and can ensure a high security. And it is also useful from the viewpoint of economic efficiency because it has a potential to transmit high speed and broadband communication for a property of light without constraints of the Radio Law [5], [6]. Moreover, VLC doesn't interfere in neighboring wireless network. The existing infrared wireless LED, which is used in optical wireless device, has a problem of eye-safe, but VLC can avoid the problem. And it is hoped that this system doesn't cause annoyance to the residents living near the intersection by the noise of traffic signal with AS. Therefore this system can perform an effective information provision system for pedestrians, especially visually impaired persons at signalized intersection without AS.

1.2 Purpose of the study

In this paper, we focus on the pedestrian crossing support system at signalized intersections, especially for the visually impaired persons. Firstly, we try to reveal the issues and needs when they cross at signalized intersection. Secondly, we evaluate the VLC system, which are developed by our research group, through the result of the experiment and the questionnaire at simulated environmental conditions. From these two approaches, we discuss the feasibility of our VLC system that can support for visually impaired persons to cross at signalized intersection safely.

2. Consciousness analysis for visually impaired persons at signalized intersection

2.1 Questionnaire about signalized intersection environment for visually impaired persons

We conducted two types of investigations about signalized intersection environment for visually impaired persons: one is a hearing investigation, another is a questionnaire. The former was carried out for the staffs and users of Nagoya Information and Culture Center for the Blind in January 2006. The number of samples was 18. On the other hand, the latter was done for the people involved in the same center by e-mail in March 2006. The number of distribution was 200, and the collected data was 41 as a result. In this paper, both results are used for the analysis. These investigations covered 59 visually impaired persons in their ages of twenties to seventies, and thirty percent of its respondents were over sixties. And male-female ratio of them was nearly equal. For the other characteristics of respondents, 53 percent of them go out once or more a day, and over 50 percent of them walk by themselves on a daily basis. That is, it can be said that the respondents of these investigations are relatively active persons.

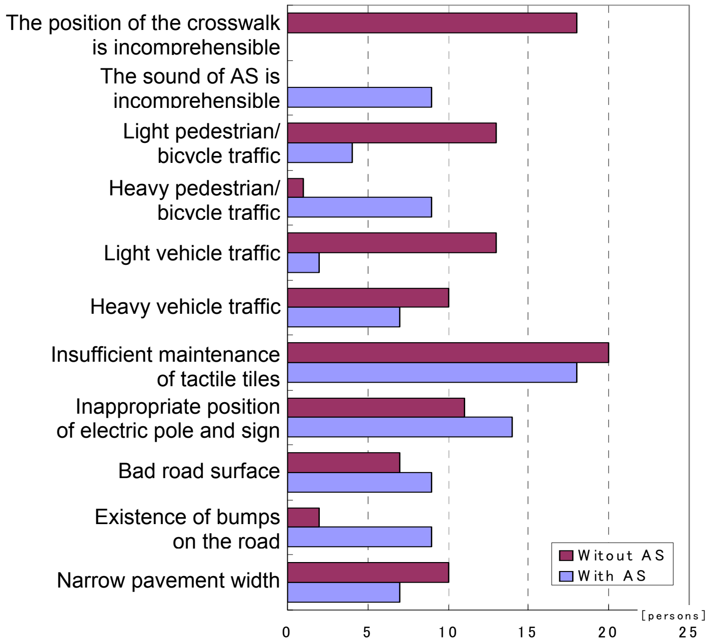

Figure 2 Issues for visually impaired persons at signalized intersection

The contents of both investigations are the same as below, and we analyze the question (iii) and (iv) in this paper.

(i) Attributes: Gender, Age, and Eyesight

(ii) Behavior characteristics as usual:
Trip frequency, Trip purpose, Trip range, With or without of supportive device, Proportion of walking alone

(iii) Issues and needs of signalized intersection environment with AS:
The reason why they cannot cross at signalized intersection easily, Information that they need additionally

(iv) Issues and needs of signalized intersection environment without AS:
The reason why they cannot cross at signalized intersection easily, Direction search behavior when they cross at the intersection, Comprehension of the timing when they start to cross at the intersection, Standards of judgment to recognize green signal, Information that they need additionally when they cross at the signalized intersection

2.2 Issues for visually impaired persons at signalized intersection

The result of the issues for visually impaired persons at signalized intersection with or without AS is shown in Figure 2.

From the figure, it became clear that the maintenance of tactile tiles is insufficient both with and without AS. For the intersections without AS, it is shown that incomprehensible position of crosswalk and low traffic volume have an influence on their evaluation. This means that the sound created by surrounding traffic contributes for visually impaired persons to find out about the adjacent intersection and crosswalk. On the other hand, for the intersection with AS, it is revealed that the inappropriate position of electric pole and sign have a significant impact on their evaluation, however, the surrounding noise disturbing to hear the sound of AS, such as heavy traffic, bothers them.

2.3 Behavior characteristics of visually impaired persons at signalized intersection

Behavior characteristics of visually impaired persons at signalized intersection are analyzed in this section.

The method for searching a signalized intersection is shown in Figure 3. From the figure, it is shown that 40 percent of the respondents depend on the tactile tiles to search a signalized intersection. And the surrounding sound is the second largest proportion. That is, it is important for them to support the situation when they can't use both tactile sense and auditory sense, for example, there is low traffic volume and not lay tactile tiles on sidewalk.

Then, we analyze a criterion to decide to start crossing at signalized intersection without AS. The result is shown in Figure 4. This result means that surrounding vehicles' sound is the most important criterion for them.

2.4 Necessary information for visually impaired persons at signalized intersection

Figure 5 shows the result of necessary information for visually impaired persons at signalized intersection with or without AS. From this figure, it is revealed that with or without of traffic signal and the color of light are needed without AS. Moreover, it is also cleared that 60 percent of respondents need the timing to start crossing. On the other hand, for the intersection with AS, since the traffic signal conditions such as with or without of traffic signal, the color of the light and the timing to start crossing are already understandable, the guidance information, such as to walk straight, is needed instead of these information.

3. Details of VLC system in this study

In this chapter, we describe VLC system that was developed for supporting visually impaired persons at signalized intersection.

VLC system in this study is that when a pedestrian receives visible light from pedestrian traffic signal via a portable receiver, he/she can listen to sound information on earphones or headphones.

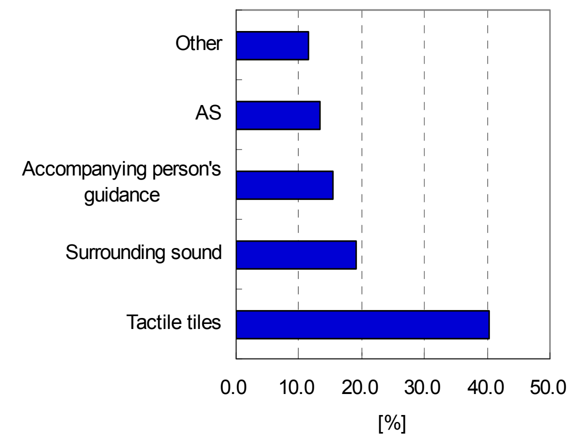

Figure 3 Method for searching signalized intersection (multiple answers allowed, N=52)

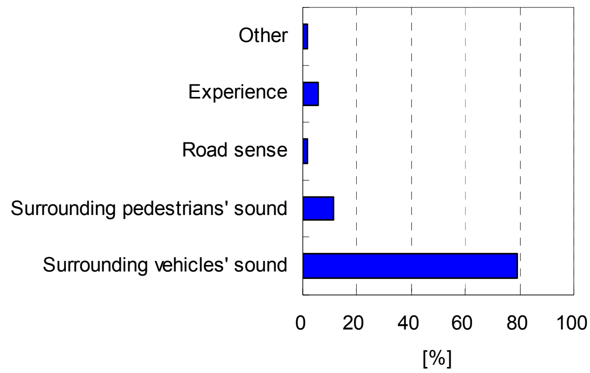

Figure 4 Criteria to decide to start crossing at signalized intersection without AS (multiple answers allowed, N=52)

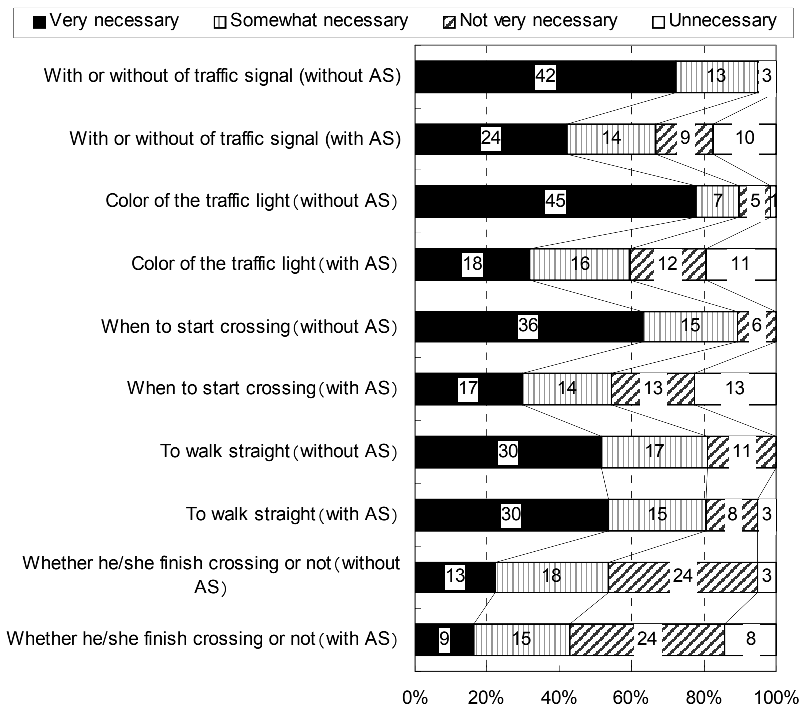

Figure 5 Necessary information for visually impaired persons at signalized intersection

Figure 6 Receivers of VLC system

Table 1 Main specifications of the VLC system

Functions		Specifications
Receivable distance		30m
Receivable light		Red / Green
Audio output		Built-in speaker (bone conduction-type headphone)
Modulation Method		Frequency Modulation
Carrier Wave		190KHz
Receiver	Size	(W)75mm× (D)66mm× (H)14mm
	Mass	80g (include battery)
	Power source	N battery (1.5V)

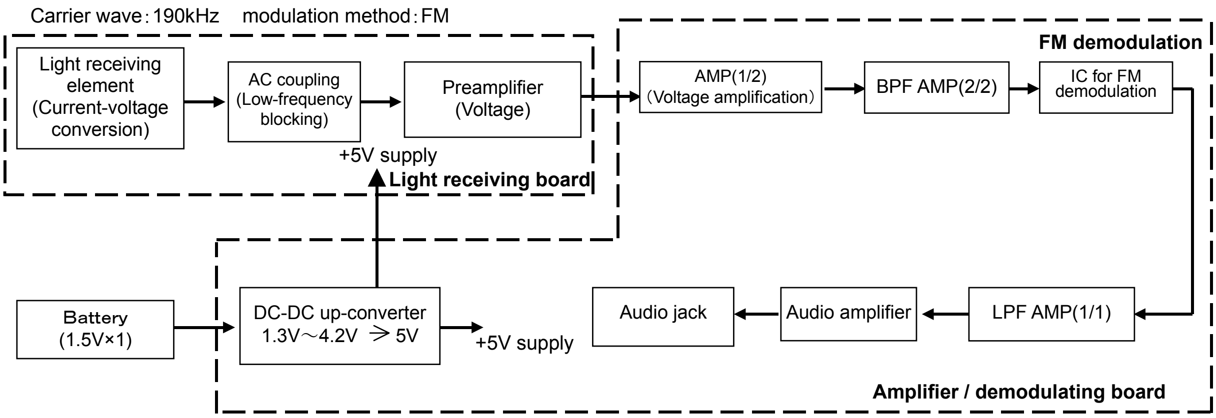

Figure 7 Block diagram of VLC system in this study

This system needs less equipment besides the traffic signal in comparison to the existing crossing support system at signalized intersection. And it doesn't cause annoyance to the residents living near the intersection by the noise of traffic signal with AS. Therefore this system can become an effective information provision system for pedestrians, especially for visually impaired persons crossing at signalized intersection without AS.

In this study, two types of portable receivers, which are shown in Figure 6, were developed: one is a breast pocket type receiver (BR) and another is a handheld-type receiver (HR). And main specifications of these receivers are shown in Table 1. The mechanisms of both receivers are the same that subjects in experiment can hear the phonetical information from the headphone when the lens on a receiver catches the visible light of pedestrian traffic signal. If they don't face the correct direction to pedestrian traffic signal, they receive the burst of noise. So they can understand the correct direction and cross the road with the guidance of VLC. Moreover, Figure 7 is a block diagram of VLC system in this study. From this figure, it is understood that frequency modulation is applied to this VLC system as a method of transmission of sound information.

4. Indoor experiment for testing the performance of VLC system

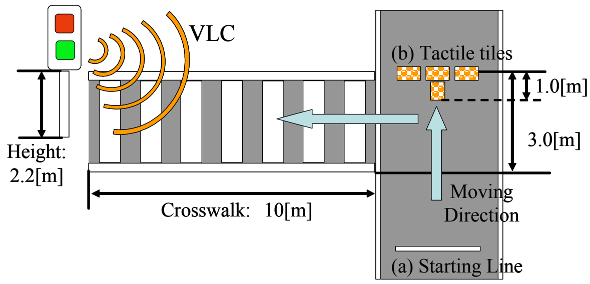

Figure 8 Outline of indoor experiment

The indoor experiment was conducted for three visually impaired persons who are completely blind, and seven able-bodied persons, who assumed completely blind with blindfold, in order to confirm the test model of VLC system in November 2005. In this experiment, we examined the following two points: one is whether visible light from a pedestrian signal can be received or not and another is whether the subjects can walk straight by the guidance or not.

The outline of experiment is shown in Figure 8. A subject starts walking from point (a), and when he/she reaches the tactile tiles (point (b)); he/she turns to the left and searches for the direction of a pedestrian signal. After looking for the correct direction, he/she begins walking toward the signal. And when he/she arrives at the edge of crosswalk, one-trial is completed. All subjects examined the trials two times for two types of

Table 2 Result of mean time for searching the signal and mean walking velocity

Receiver type of VLC	Mean time for searching the signal [sec]		Mean walking velocity [km/hr]	
	VIP*	ABP**	VIP*	ABP**
BR	2.95	1.08	1.79	1.28
HR	5.14	2.58	1.12	1.20

* Visually Impaired Persons

** Able-Bodied Persons

receivers. In each trial, the search time of direction to signal, the crossing time and the distance from the crosswalk entrance were measured by the image of digital video camera recorders. After the experiment, the questionnaire about the usability of each receiver and the integrated evaluation for the VLC system were conducted for each person. In this experiment, subjects can obtain guide information only during green signal, and listen to the typical sound of AS in Japan, "To-ryanse" in Japanese, as guide information.

Table 2 illustrates both the mean search time for the direction to signal and the mean walking velocity in each receiver. From this table, it is found that the BR is easier to search the direction to signal than the HR for both subject groups. In addition, according to the result of the questionnaire, there was no answer that finding the direction to signal was difficult with the BR.

The result of walking trajectories for HR is illustrated in Figure 9, and those of BR are also shown in Figure 10. In these figures, the horizontal axis means the distance from the crosswalk entrance and the vertical axis means the lateral transition to the traveling direction (Y=0 means crosswalk center. Positive value of Y means right side of crosswalk center in his/her traveling direction and negative value is left side of crosswalk center).

From Figure 9, it is found that the traveling direction is modified at the periphery of 6 meter point by the guidance of VLC system and the walking trajectories gradually come close to the crosswalk center. On the other hand, from the Figure 10, a similar tendency was seen for the BR as well. From these results, though subjects' trajectories fluctuated between 150 centimeters and -100 centimeters, all subjects could walk within the crosswalk. For that, it would be shown that the guidance of VLC system enables visually impaired persons to cross safely at signalized intersection with keeping them in a width of crosswalk.

Moreover, the questionnaire analyzed the pedestrians' comfort when they cross with the guidance of AS only and with a combination of AS and VLC system.

As a result, it is shown that pedestrian comes to be able to cross at ease by using not only the guidance of AS but also the guidance of VLC system, though the number of subjects is very limited. And from the result of free-answer question, it became clear that visually impaired persons need the information of remaining time before turning the signal red as the guidance of VLC system. And they prefer the receipt of a message at one ear rather than by both ears because it becomes difficult to catch the other surrounding sound.

5. Outdoor experiment for testing the performance of VLC system

5.1 Outline of outdoor experiment

An additional outdoor experiment as shown in Figure 11 was conducted in August 5 and 6, 2006 on the basis of the knowledge obtained by analysis of chapter3 and chapter4. In this experiment, the method was almost same as the indoor experiment as above-mentioned. The differences of these experiments are mainly three points as follows: the crossing distance of outdoor experiment is twice as long as the one of indoor experiment in order

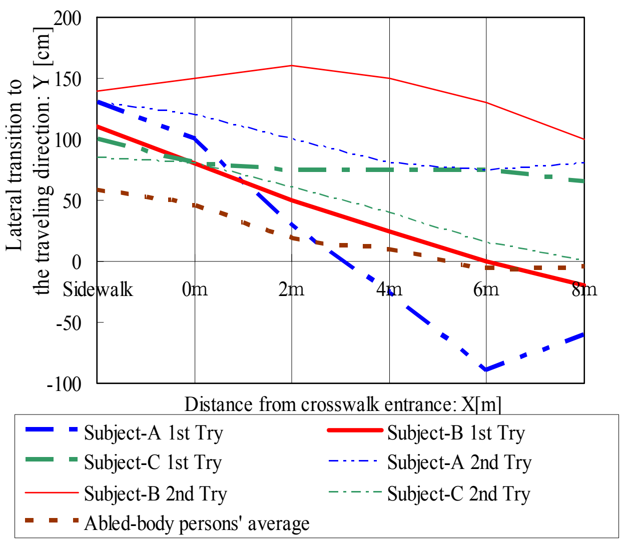

Figure 9 Result of walking trajectories for HR

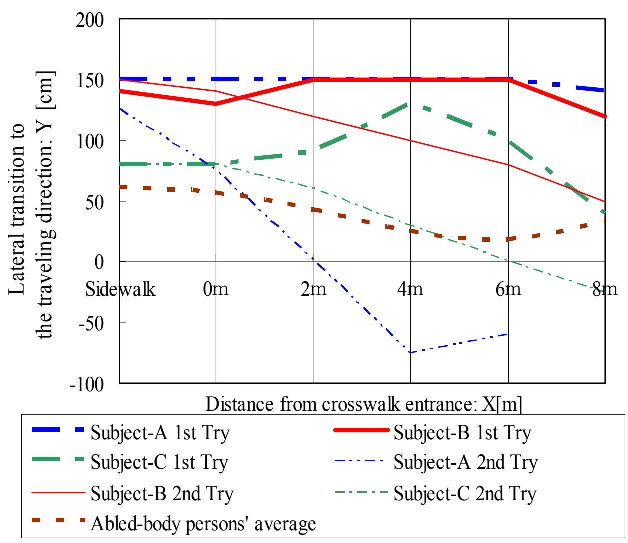

Figure 10 Result of walking trajectories for BR

to evaluate it under a more realistic situation, the receivers of outdoor experiment are not handheld-type but wearable-types (Peaked cap type receiver (hereinafter "PCR") and Belt attachment type receiver (hereinafter "BAR")) and they can obtain multiple detail guide information not only during green signal but also during red signal. Outline of the experiment is shown in Table 3.

In addition, subjects on the first day didn't pre-train how to use the VLC system, meanwhile those on the second day pre-trained. And we adjusted the position of speaker of PCR in order to reflect the views of experiment until the midmorning of second day. Therefore, only the data of the afternoon of the second day is analyzed in this paper in consideration of the change in these experiment situations.

5.2 Performance analysis of VLC system for lengthwise direction

Firstly, we analyze the performance of VLC system for lengthwise direction. For the result of outdoor experiment, we measured the distance from the other side of crosswalk to the point where a subject couldn't receive the visible light from pedestrian traffic signal and stopped to search for the direction to the signal. The distributions of the distance from the edge of crosswalk for each receiver are shown in Figure 12.

It is found that the distance of PCR is shorter than that of BAR. This is because the operability of PCR is higher than those of BAR. For over 70 percent users of PCR, the distance was less than or equal to one meter. Since this distance is about the same length of blind person's cane, it can be said that their crossing are all but completed. For the BAR, it is shown that almost 70 percent users were less than or equal to two meters.

On the other hand, the average time required to cross for each receiver is shown in Figure 13. From the figure, it is shown that the time required of PCR is shorter than that of BAR for almost all subjects. This means that finding the direction of traffic signal with PCR is easier than that of BAR.

5.3 Performance analysis of VLC system for crosswise direction

Secondly, we analyze for the performance of VLC system for crosswise direction. Walking trajectories for each receiver are shown in Figure 14 and Figure 15. The absolute value of gap from the crosswalk center was measured 5 meters apart and averaged out per four trials.

From these figures, it is understood that the gaps of BAR are smaller than those of PCR. It is considered that the settings of PCR are unstable though BAR doesn't move easily when the direction is decided once. Moreover, it is also found that both receivers can support them without departing from the width of crosswalk because the absolute values of gap stay within two meters (generally, the width of crosswalk is about 4 meters in Japan). In addition, it was seen that some trials

Figure 11 Scene of the outdoor experiment

Table 3 Outline of outdoor experiment

Survey date (Time period)	August 5 and 6, 2006 (8:30-10:30, 15:30-17:30)
Weather	Shine
Number of subjects	Total: 22 (completely blind: 13) 8/6 pm : 6 (completely blind: 3, blindness of one eye:2, perception of light: 1)
Crossing distance	20 [m]
Receiver-type	PCR (set in front of the cap) BAR (waist mounted)
Communication media	Sound information from a speaker
Information substances	During red signal: Color of the light, Name of the signalized intersection, Direction that subject is heading in, Road width During green signal: Color of the light, Remaining green time (ten second bit), continuous sound from general AS (To-ryanse)
Number of trials a subject	8 (4 times per each receiver)
Examination method	Same as the indoor experiment noted above
Data obtained by this survey	(i)Usability of VLC system, (ii) Applicability evaluation of VLC system (Both (i) and (ii) obtained by questionnaire) (iii)Walking characteristics, such as trajectory, velocity, and so on (Obtained via digital video camera recorders)

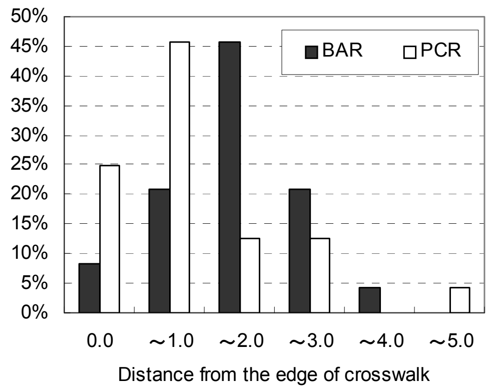

Figure 12 Distributions of the distance from the other side of crosswalk to the point where a subject couldn't receive visible light and stopped to search for the direction to signal (N=24)

in PCR exceeded the threshold value of gap at 15 meters point. Stopping short of the other side of crosswalk has the possibility of causing the conflict with the vehicles, so the improvement of VLC system is needed.

From the result of 5.2 and 5.3, it can be said that this VLC system has a sufficient performance to support their safety crossing though there will be room for a further improvement in the future.

5.4 Evaluation for the usability of the VLC system

Thirdly, we evaluate the usability of the VLC system based on questionnaire. The result of the ease of crossing with VLC system is shown in Figure 16, and the comprehension of direction to cross with VLC receiver is shown in Figure 17.

From the figure 16, the evaluation of PCR is higher than that of BAR. It can be considered that it is not easier for subjects with BAR than for subjects with PCR when they search the direction to signal by moving their receiver back and forth and around. However, from the evaluation of both easy and fairly easy in the figure, it is found that the subjects of 90 percent or more have a high evaluation in both receivers.

From the Figure 17, both types of VLC receiver receive a high evaluation for the comprehension of direction to cross.

5.5 Analysis on the applicability evaluation of the VLC system

Finally, we discuss the applicability evaluation of VLC system based on questionnaire. Here, it is analyzed for three points;

(i) Comprehensive evaluations of VLC system and AS
(ii) Intersection where we should introduce the VLC system
(iii) When the interruption of guidance information occurs, whether subjects want to use this system or not

For point (i), it is shown in Figure 18. From the figure, it is understood that the assessment of VLC system is nearly equal to that of AS as the existing visually impaired persons' support system.

Then for point (ii), it is shown in Figure 19. From the figure, almost 30 percent of respondents need the system at nighttime. And it is also found that the ratio of the case of low vehicle traffic volume and that of low pedestrian traffic volume are about 20 percent, and both cases are equally needed for them.

One of the limitations of this VLC system, the communication could be interrupted when the visible light from traffic signal cannot be received by a surrounding traffic condition, such as the existence of heavy vehicle ahead. Therefore, we confirm for point (iii). This result is shown in Figure 20. From the figure,

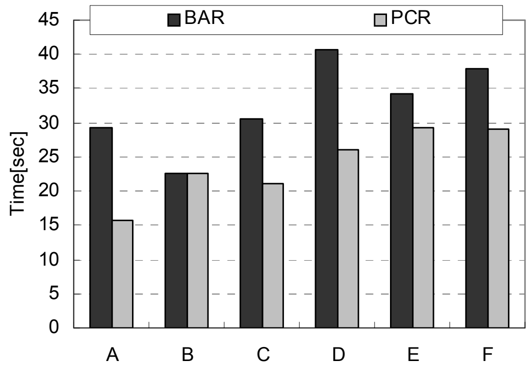

Figure 13 Average crossing time for each receiver

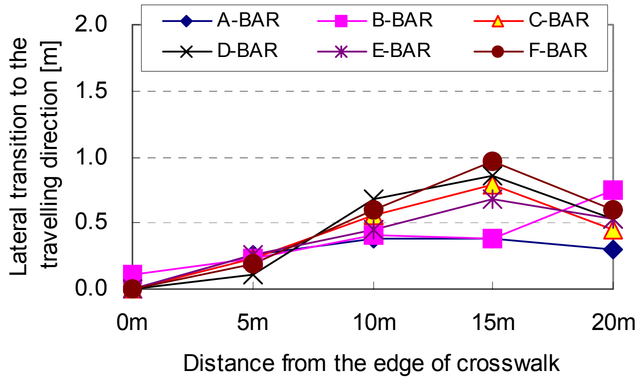

Figure 14 Walking trajectories for BAR

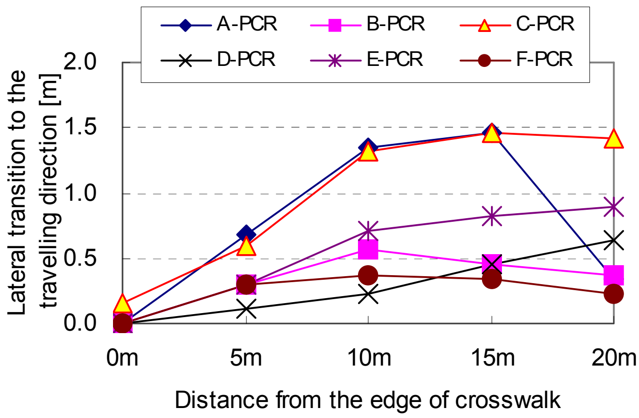

Figure 15 Walking trajectories for PCR

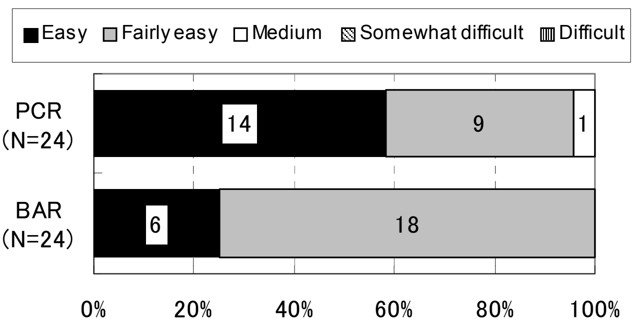

Figure 16 Evaluation of the usability of VLC system

it is understood that if we install both AS and VLC system simultaneously, over 90 percent respondents have intent to use this VLC system even if the interruption of guidance information occurs. On the other hand, for only VLC system installed, about 30 percent respondents will not use this system. This means VLC system in this study has the potential as assistance for the existing support system.

As a result, though there is an issue of introducing it independently, it can be considered that the potential of VLC system to support visually impaired persons' crossing at signalized intersection is sufficiently high.

6. Conclusion

In this paper, in order to discuss the supporting system for visually impaired persons to cross safely at signalized intersection, we tried to reveal the issues and needs when they cross at signalized intersection, firstly. And then, we evaluated the VLC system, which are developed by our research group in order to support the handicapped persons' safety crossing, through the result of the experiment and the questionnaire survey at simulated environmental conditions.

The conclusions of this paper can be summarized as below:

- It became clear that the maintenance of tactile tiles is insufficient both with and without AS. For the intersections without AS, it was shown that incomprehensible position of crosswalk and low traffic volume have an influence on their evaluation. On the other hand, for the intersection with AS, it is cleared that inappropriate position of electric pole and sign have a significant impact on their evaluation.
- It is important for visually impaired persons to support the situation when they can't use both tactile sense and auditory sense, for example, there is low traffic volume and not lay tactile tiles on sidewalk. And it is found that the surrounding vehicles' sound is the most important criterion for them to understand the existence of intersection.
- It is revealed that with or without of traffic signal and the color of the light are needed at the signalized intersection without AS. On the other hand, for the intersection with AS, the guidance information, such as to walk straight, is needed.
- It was shown that the guidance of VLC system enables visually impaired persons to cross safely at signalized intersection with keeping them in a width of crosswalk. And, it is understood that the assessment of VLC system is nearly equal to that of AS from the viewpoint of users' behaviors and consciousness.
- It was shown that the wearable-type receiver has a high evaluation from the viewpoint of the ease of

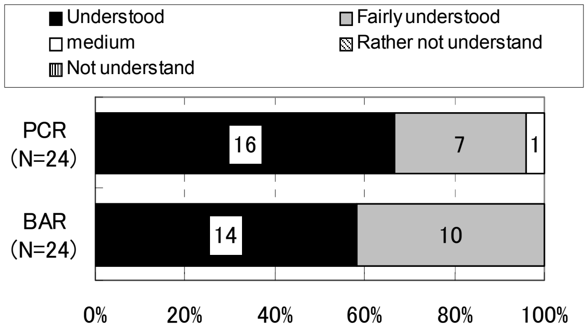

Figure 17 Evaluation of the comprehension of direction to cross with VLC receiver

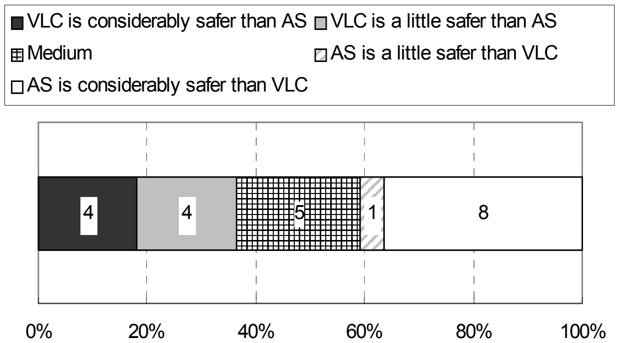

Figure 18 Comprehensive evaluations of VLC system and AS

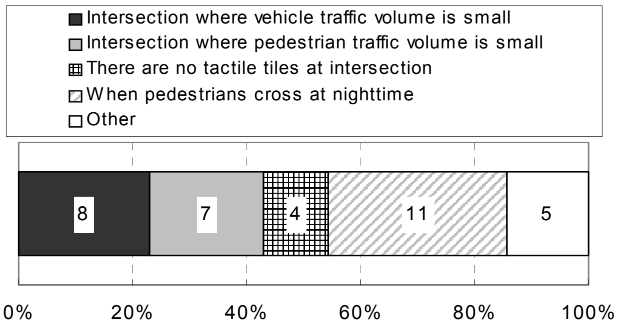

Figure 19 Intersection where we should introduce the VLC system

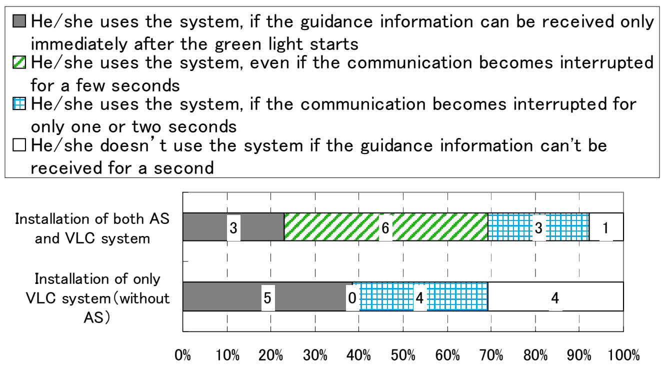

Figure 20 Applicability evaluation of VLC system for the occurrence of temporary communication interruption

crossing and the comprehension of direction to cross.
- VLC system is needed at nighttime and the situation of low traffic volume. And it is revealed that if we install both AS and VLC system simultaneously, almost all users have intent to use this VLC system even if the temporary interruption of guidance information occurs.

The future issues are listed below to realize our system:
- An additional investigation that increases the number of test subjects is executed for the reliability improvement of the result of this study.
- Further testing under the more realistic surrounding circumstances, such as the existence of pedestrians, cyclists and vehicles at signalized intersection. And the reliability of our VLC system should be proved by comparing our system and other wireless network system under same experimental condition.
- Though another communication interruption of our system as shown in chapter 5.5 affected by the ambient light from non-traffic signal, is existed, it can be considered that this problem could be technically-improved.

7. Acknowledgments

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