RESEARCH ON V2X COMMUNICATION SYSTEM TO REDUCE PEDESTRIAN ACCIDENTS

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ABSTRACT
Everyone deserves to feel safe on the road. The goal is to strive for zero traffic collision fatalities involving motorcycles and automobiles globally by 2050. Many traffic fatalities are categorized as vulnerable road users such as pedestrians and cyclists. In particular, pedestrian fatalities account for the largest portion. Pedestrian accidents have occurred not only through drivers' errors but through pedestrians' errors. Thus, in addition to advanced driver-assistance systems, safety behavior by pedestrians is effective for reducing pedestrian accidents. Research was therefore conducted on the vehicle-to-everything (V2X) communication system connecting vehicles and pedestrians to assist both drivers and pedestrians.

The system used 5G standalone mobile communication system and a cellular-V2X communication system. With an in-vehicle camera, the system detected a pedestrian walking across a street ahead and in an area that is in a blind spot for the driver. Then, the total time required for the pedestrian to receive notification after detection by the in-vehicle camera was estimated. Also, the reactions of pedestrians were observed, and the time required for pedestrians to react to notification was measured as well.

The result in the assumed use case was that the system promoted safety behavior by supporting drivers and pedestrians before collision occurred.

However, considering the reaction time of pedestrians, assisting system users before collision is a challenge if the time to the collision is extremely short. Therefore, the system is required to notify the users in plenty of time before the collision. In order to utilize the system, it is desired to promote widespread adoption by installing the system on smartphones rather than on dedicated equipment. Also, the accuracy of location ascertained using smartphone needs to be improved to establish acceptability.

The safe use of communication technologies was considered as one of the one-step-ahead integrated vehicle safety technologies. This report details the structure, results, and issues of the V2X communication system.

RESEARCH QUESTION/OBJECTIVE

According to traffic statistics from the National Public Safety Commission and the National Police Agency [1], 2839 people died in traffic accidents in Japan in 2020. The number of fatalities from traffic accidents has decreased greatly over the past decade or more, but in the past several years, that decrease has tended to slow down. In particular, a comparison of the annual incidence of accident fatalities among people riding in motor vehicles and accident fatalities among people walking shows that their levels have been about equal in recent years, which means that countermeasures against pedestrian accidents are important for reducing the number of fatal accidents. Functions that help prevent accident include, for example, advanced emergency braking systems (AEBS) and forward collision warning (FCW). As these suggest, safety technology development has been focused on the vehicle side. These functions have shown results in preventing accidents due to human error, such as inattention to the road ahead and operating errors by vehicle drivers. These are considered to have contributed to a reduction of fatal accidents among vehicle occupants. However, risks hidden in blind spots cannot readily be handled solely using information from autonomous sensors. Looking further at the number of fatalities due to traffic accidents by type of traffic violation among fatal pedestrian accidents, it can be seen that 582 out of 970 pedestrian fatalities, or 60%, involved pedestrian violations such as ignoring traffic signals or crossing violations. From this it is apparent that accidents occur not only because of human error by vehicle drivers, but also because of dangerous behavior by pedestrians. Steps to reduce accidents resulting in pedestrian fatalities will be taken, therefore, by assistance that prompts safe behavior by pedestrians before accidents occur and by assistance to notify drivers to the presence of pedestrians in blind spots.

The present research created systems using communication technology to notify pedestrians of risks and to notify drivers of risks in places that are blind spots from their vehicles, to function linked to conventional assistance functions for vehicles such as AEBS and FCW. In addition, changes in behavior by pedestrians who received assistance were verified, more effective means of notifying pedestrians of danger were explored, and a study of the acceptance of assistance while walking was conducted.

METHOD

A system was created to connect pedestrians and vehicles for the purpose of sharing their risk information. This system is an assistance system that features an in-vehicle camera and communications coordinated in an event-driven system. In the event-driven system, the occurrence of risk is a trigger that executes assistance by means of communication. Pedestrians posing a danger and blind spot areas are detected by an in-vehicle camera and the system uses communication to provide assistance to the party at risk. This method coexists with conventional support systems and provides more reliable support when risks between vehicles and pedestrians increase. This system is not only a human–machine interface (HMI) to provide the required assistance to the vehicle driver, but also a HMI directed at pedestrians. Smartphones were therefore used as the device for providing assistance to pedestrians. The reason for this is that according to a survey of smartphone ownership in recent years [2], 80% or more of the world population has a smartphone, and so it is likely that pedestrians will be holding one. As smartphones are equipment for individuals, it is also possible to provide assistance only to the party at risk. Notification by smartphone informs recipients about circumstances in their surroundings without interfering with their walking, and prompts pedestrians to take action themselves to avoid danger.

Verification of V2X System in Actual Vehicles

For the verification of V2X system in actual vehicles, cellular V2X (C-V2X) was adopted as the method of communication [3]. Figure 1 shows the C-V2X communication interfaces. In direct communication among V2X-special user equipment by means of the C-V2X PC5 interface, assistance information is broadcast from the vehicle, and traffic participants in the surrounding area that have communications equipment receive the information. Communication via base station (BS)/core network (NW) by means of the Uu interface uses the cellular network to conduct communication through the server. In communication via BS/core NW, information from the vehicle is used by the server to identify the party targeted to receive assistance. For this reason, it is necessary for the MEC server to have a grasp of traffic participant location information. The cellular network was implemented by means of 5G standalone (5GSA). In 5GSA, the use of 5G core equipment achieves ultra-high speed and high capacity. It is a communication service that enables ultra-low delay and high reliability by means of network slicing technology and multi-access edge computing (MEC), which suits it for use in vehicle automated driving and safety [4].

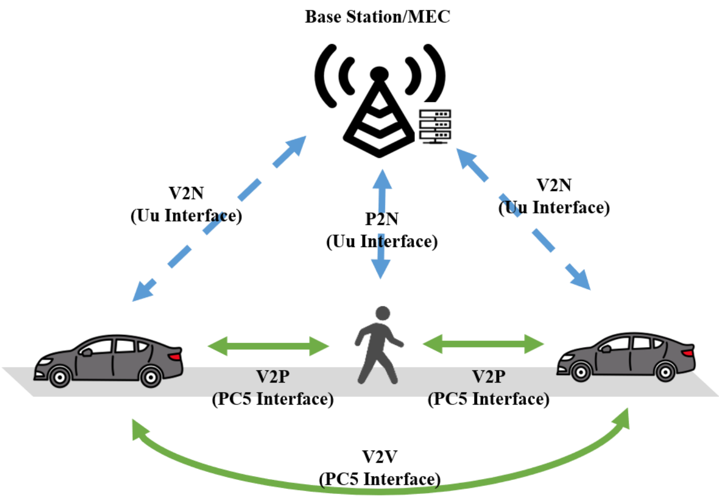


Figure 1. C-V2X Interfaces

Figure 2 shows an overall view of the actual vehicle system that was created. This system comprises three elements: the vehicle, the pedestrian, and the MEC server. The vehicle system is made up of global navigation satellite system (GNSS) equipment for acquiring location information, a radio for conducting communications, a recognition processing unit that performs object recognition using the in-vehicle camera, and an in-vehicle unit that, based on recognition results, manages calculation and communication regarding the possibility of collision with pedestrians and areas with blind spots due to occluding objects. The pedestrian system is made up of a portable terminal that acquires location information and a pedestrian unit that processes communications by radio. The MEC server manages location information regarding traffic participants and manages transmission and reception of information to and from parties that require assistance.

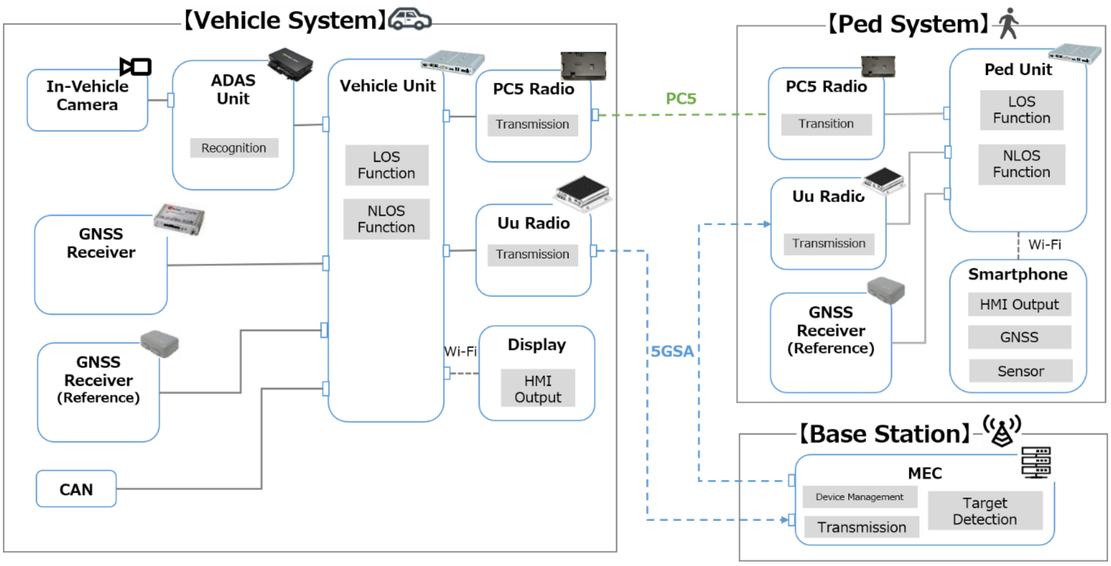


Figure 2.V2X System for Pedestrians

For verification in actual vehicles, two use cases were prepared and verified. Testing of verification in actual vehicles was conducted in open sky with GNSS receivable, with the number of server connections with units limited to the traffic participants appearing in the particular use case and with dedicated communication circuits. Figure 3 shows the first line-of-sight (LOS) use case. The LOS use case was implemented in an environment where there were no occluding objects between the vehicle and pedestrian. The case recreated a scene in which a vehicle was moving straight ahead, and pedestrians crossed ahead of it.

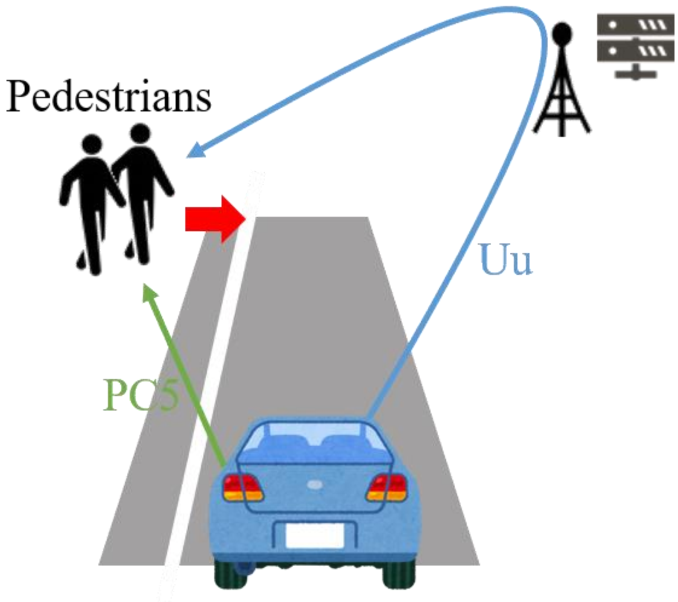


Figure 3. LOS Use Case

Figure 4 shows the processing sequence in verification of the LOS use case. The vehicle system uses the in-vehicle camera to detect the pedestrian crossing the road ahead, judges the possibility of collision with the subject vehicle, and calculates the time to collision. When this time to collision is at or lower than a certain threshold value, assistance information is transmitted from the vehicle. For this verification, this threshold value was set to 2 seconds and verification was carried out uniformly with that setting. Assistance information was transmitted simultaneously by direct communication and by communication via BS/core NW. In the case of communication via BS/core NW, processing by the MEC server is added to the time until the party targeted to receive assistance is notified. In this verification, the arrival rate of the transmitted information at the party targeted to receive assistance, the vehicle system processing time, the server processing time, and the communication time were calculated to obtain the total time the system took to provide assistance.

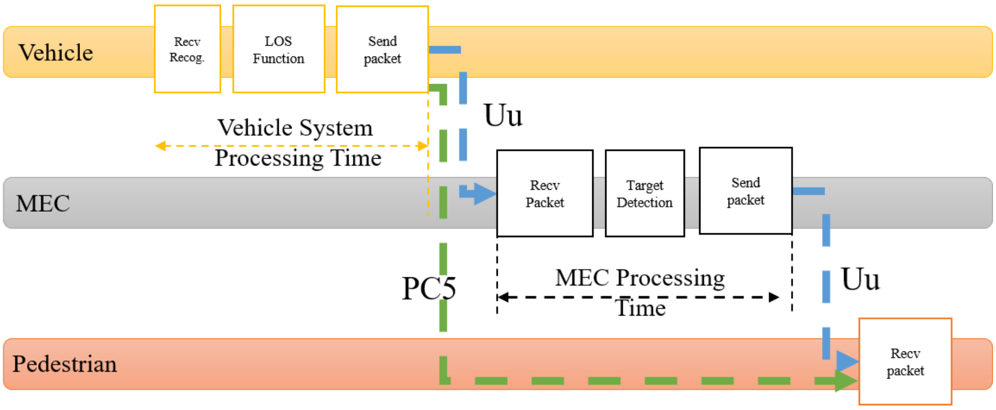


Figure 4. LOS Use Case Sequence

Next, the second non-line-of-sight (NLOS) use case is shown in Fig. 5. In this use case, a vehicle with high vehicle height was prepared to function as an occluding object between the subject vehicle and the crossing pedestrian such that the subject vehicle driver and the pedestrian were unable to see each other. With the present system, communication is used to check whether or not a pedestrian is present in a blind spot from the vehicle, and when a pedestrian is present, assistance is provided to the vehicle driver and the pedestrian.

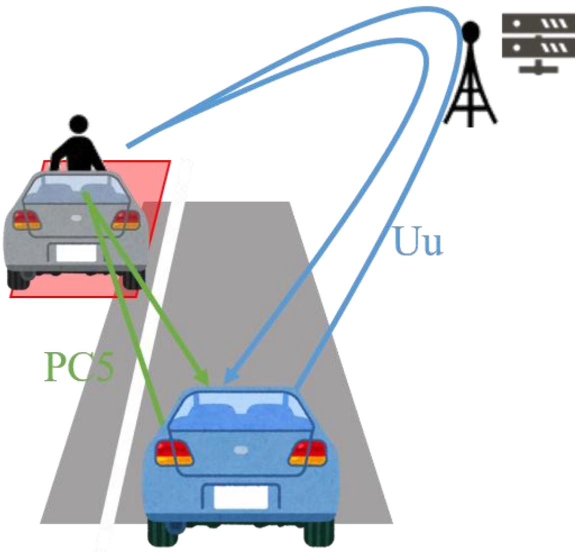


Figure 5. NLOS Use Case

In the NLOS use case, the in-vehicle camera is used for object recognition of an occluding object ahead of the vehicle, and the system calculates the risk area that includes the blind spot as viewed by the vehicle driver. Figure

6 shows an example of the risk area that is calculated. With this system, the risk area is a quadrangle, and each side is calculated as parallel or perpendicular to the subject car's direction of movement. The purpose of this is to reduce the calculation cost, as the area that is a blind spot is by its nature polygonal. In the present verification, when the time headway to the calculated area became 2.5 seconds or less, the area up to the point that would be arrived at in 3.8 seconds was taken to be the risk area, and a request for information about the area was made using communications.

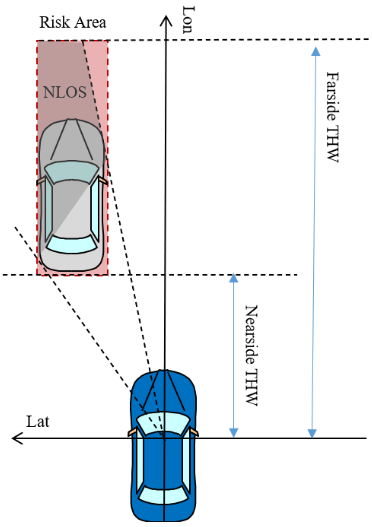


Figure 6. NLOS Risk Area Detection

Next, the processing sequence in verification of the NLOS use case is shown in Fig. 7. In the case of direct communication, the risk area information broadcast from the vehicle is received directly by the pedestrian. At this time, the pedestrian judges on the basis of their own location information whether or not they are in a risk area, and they send back that result. In the case of communication via BS/core NW, the received risk area information was used by the MEC server as the basis for identifying pedestrians in the surrounding area and distributing that area information by multicasting. Pedestrians who receive the information would judge whether they are in that area and send back their reply. The MEC server would then notify the vehicle that made the information query whether or not there are pedestrians in the area. For the verification conducted here, measurements were made of the communication time taken from when the query information was transmitted from the vehicle to when the reply was received and of the processing time.

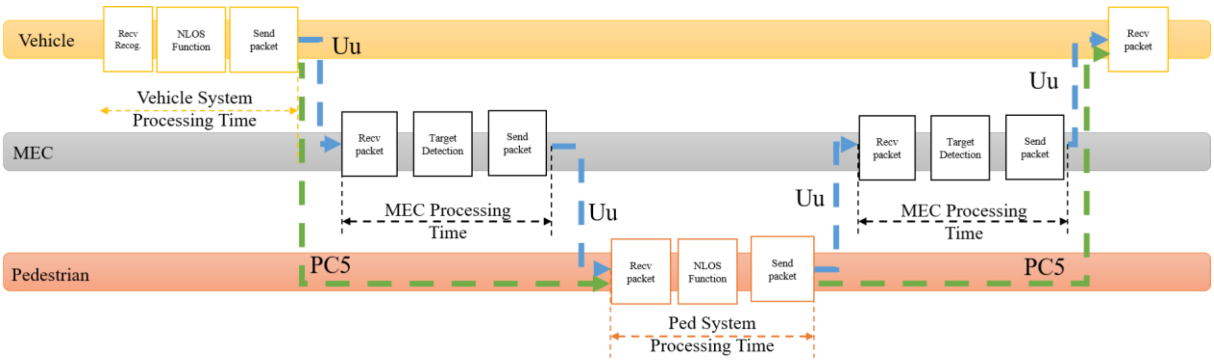


Figure 7. NLOS Use Case Sequence

Verification of Pedestrian-Oriented HMI

With this system, the subject pedestrians themselves are prompted to avoid danger. When the lines of movement of pedestrians and vehicles overlap so that the risk of collision is heightened, the smartphones that pedestrians possess are used to convey that “a vehicle is approaching, and caution is necessary” by sound, vibration, and display. The effectiveness and acceptance of this HMI were confirmed by verification using the below procedure.

As testing with actual vehicles is dangerous, a simulator using the head-mounted display (HMD) shown in Fig. 8 was created and used. The simulator uses the HMD and motion trackers in an arrangement that coordinates the test subject’s actual actions with actions within the virtual space. The test subjects were instructed to cross a street. At that time, a vehicle approaches, recreating a scene of increasing risk. The results of these actions are analyzed together with questionnaires of subjective evaluations collected after completion. Test subjects were selected from among employees who responded to an in-house call for applications and who were not aware of the content of the research. Prior to the start of the experiment, all participants received an explanation of the contents and risks of the experiment as well as their rights and voluntarily signed a participation agreement. This study was approved by the Ethical Committee of the Honda Motor Co., Ltd.

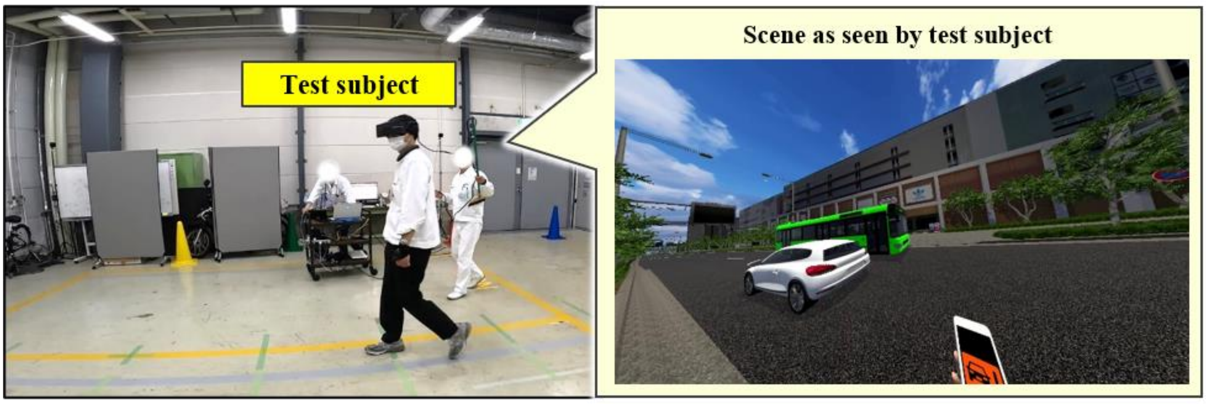


Figure 8. Simulator Using HMD

An overview of the test scenario is shown in Fig. 9. The test subject would repeatedly cross the street, and some of those times, the subject vehicle would approach from the right side. When the risk from this vehicle rises, a warning is issued by means of the HMI. In addition, a sub-task was assigned that would tend to draw attention toward the left side in order to induce subject vehicle recognition error. Test subjects would cross the street a total of nine times. If they learn when doing this that a vehicle will approach from the right each time, it will not be possible to confirm the aimed-for effect. Therefore, the number of times that a vehicle would approach was limited to three out of that total number of times. To check whether or not the behavior of test subjects would change according to whether or not they understood the purpose of this in advance, the test was conducted so that during the first vehicle approach and up to the time the alarm was issued, the test subjects were not told of the aim of the HMI.

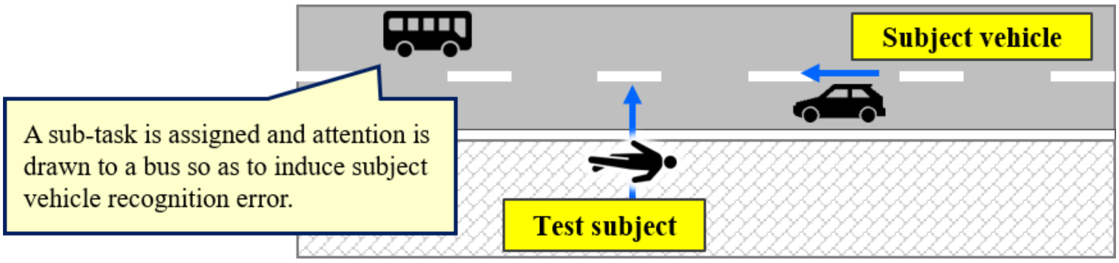
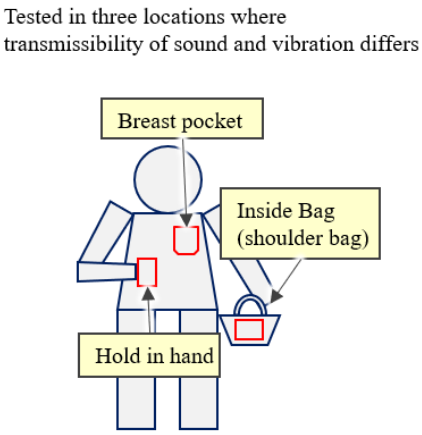


Figure 9. Overview of Test Scenario

The testing was conducted with three patterns each of where the pedestrian kept the smartphone and what notification sound was made by the HMI. The specifics are shown in Fig. 10.



Sound	Notification from three types below • Vehicle tire squealing sound • Artificial (1): Repeated monotone blowing sound that rises gradually • Artificial (2): Repeated monotone blowing sound at maximum volume from the start
Vibration and display	In preparatory testing, notification was made by the one type most recognized as effective

Figure 10. Location Where Smartphone is Kept and HMI Specification

After the testing ended, analysis of the filmed images that had been acquired and of the system log confirmed that behavior change, and reaction time change effects did occur. The subjective questionnaire responses also confirmed awareness, degree of understanding, and acceptance.

RESULT

Results from Verification of Actual Vehicle V2X System

In verification of the LOS use case with direct communication, the assistance information arrival rate was 100% and with communication via BS/core NW, the arrival rate was 95%. In the tests in which assistance information from the vehicle to the pedestrian through communication via BS/core NW did not arrive, the assistance information arrival rate at the MEC server was 100%. However, large discrepancies occurred in the location information used by the server to identify the party targeted to receive assistance, as a result of which the system was not able to identify the target.

Figure 11.1 shows the vehicle system processing time in validation of the LOS use case. The average time from reception of recognition results to transmission of assistance information was 38 ms. Figure 11.2 shows the total time of risk information reception processing at the MEC server, identification of the target, and transmission processing during communication via BS/core NW. The average processing time was 16 ms. Figures 11.3 and 11.4 show the communication time for direct communication and for communication via BS/core NW, respectively. Direct communication took an average of 25 ms, whereas communication via BS/core NW took 39 ms. The results show that the time taken by communication is shorter in direct communication than in communication via BS/core NW, and there was also less variation.

Ave	Min	Max	68%	95%
38ms	2ms	98ms	50ms	91ms

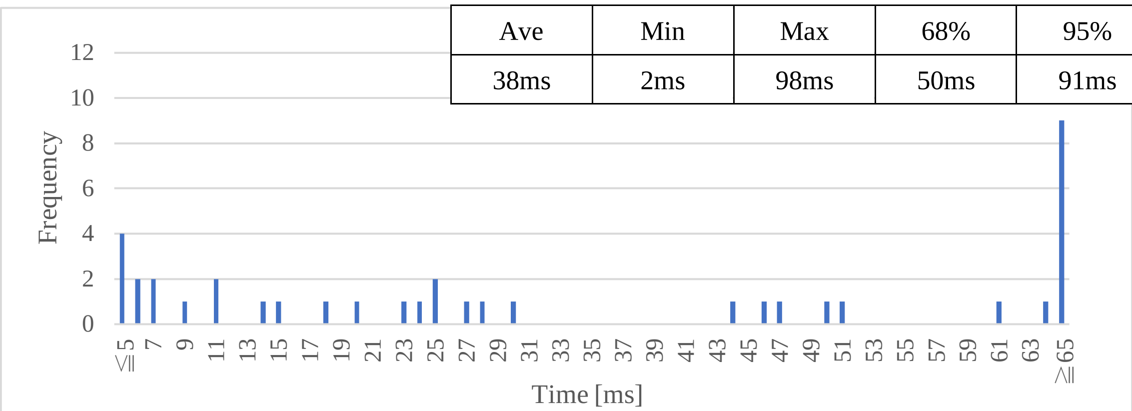


Figure 11.1. Vehicle Processing Time

Ave	Min	Max	68%	95%
16ms	6ms	53ms	13ms	39ms

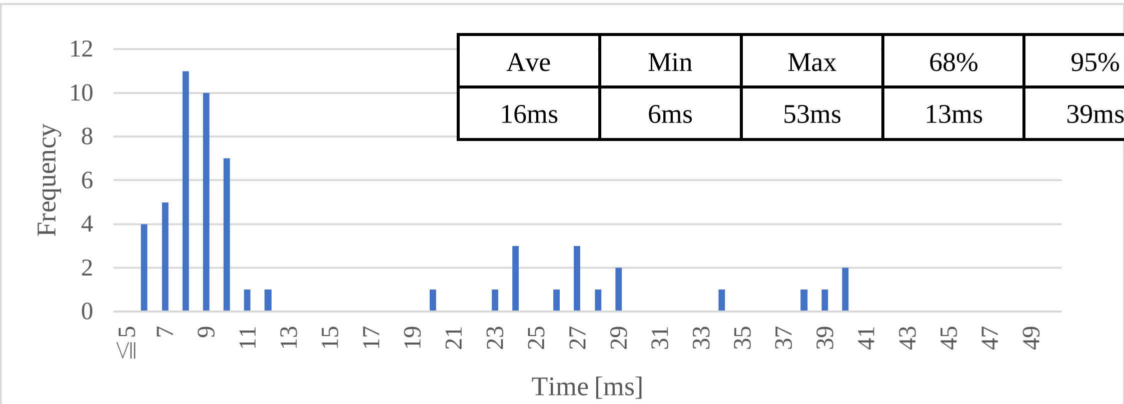


Figure 11.2. MEC Processing Time

Ave	Min	Max	68%	95%
25ms	16ms	34ms	26ms	31ms

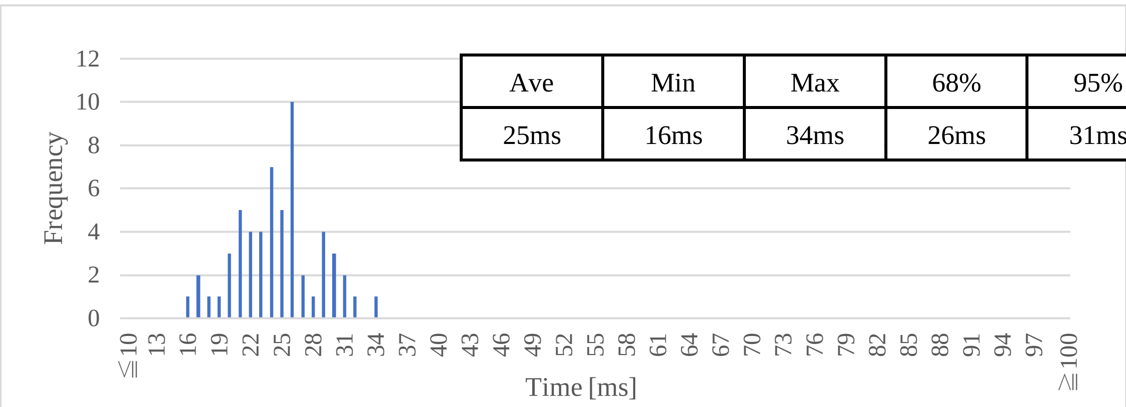
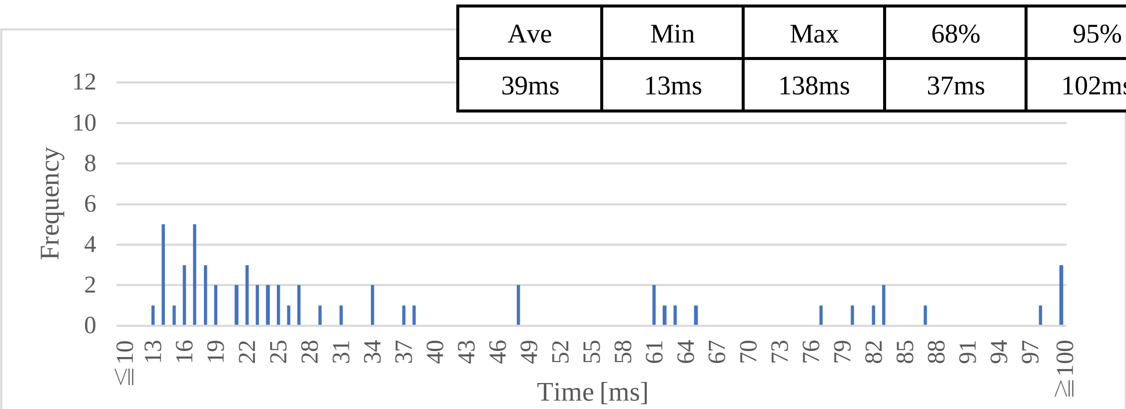


Figure 11.3. PC5 Communication Time



Ave	Min	Max	68%	95%
39ms	13ms	138ms	37ms	102ms

Figure 11.4. Uu Communication Time

In verification of the NLOS use case, in cases when a pedestrian was present in an area that was a blind spot for the vehicle driver, it was possible to convey assistance information to the driver of the vehicle before the vehicle arrived at that area. Table 1 presents the average time taken for the system to provide support during verification. The average time taken for the vehicle driver to receive information by direct communication was 79 ms, and the average time by communication via BS/core NW was 131 ms. In the case of communication via BS/core NW, it is necessary for the MEC server to mediate each communication, and thus it required more time than direct communication.

Table 1 NLOS Use Case Average Required Time

	Total System Required Time	Communication Time	MEC Processing Time
PC5	79ms	26ms	
Uu	131ms	58ms	32ms

Results from Verification of Pedestrian-Oriented HMI

The results regarding whether or not test subjects perceived the notifications are shown in Fig. 12. Note that these are the results immediately after the first tests ended and the test subjects did not understand that they would be notified by HMI from a smartphone. Notification by sound was perceived by all test subjects regardless of where the smartphone was kept. Next, regarding notification by vibration, half of the test subjects did not perceive it when the smartphone was in the breast pocket or a bag, which are not in direct contact with the body. Regarding display, even among test subjects who were holding the smartphone in their hand, only half perceived it. Test subjects who were not holding the smartphone in their hand did not bring the smartphone out when the notification was issued. These results suggest that in order to notify pedestrians of a risk by means of smartphone, it is important to obtain their perception of it by sound.

HMI type	Location where smartphone is kept	N*	Not perceived	Perceived
Sound	Held in hand	11		100%
	In breast pocket	11		100%
	In bag	11		100%
Vibration	Held in hand	11	9%	91%
	In breast pocket	11	45%	55%
	In bag	11	45%	55%
Display	Held in hand	11	45%	55%
	In breast pocket	11	100%	
	In bag	11	100%	

*Total number in test: 33 people (held in the hand: 11 people; breast pocket: 11 people; bag: 11 people)
(Test subjects experienced only one location where smartphone is kept. Notifications by sound, display, and vibration issued simultaneously.)

Figure 12. Perception or Otherwise of Notification by Sound, Vibration, and Display Without Advance Explanation

Next, the results regarding whether the purpose of notification by smartphone was successfully understood, as tested without informing the test subjects of the purpose in advance, are shown in Fig. 13. Of the test subjects who perceived the notification for the first time, 70% or more understood that the purpose was to convey that a vehicle was approaching and that therefore caution was necessary. Also, all of those in the group of test subjects who perceived the display responded that the display was most helpful to their understanding of the purpose. The above suggests that adding use of the display together with sound could heighten the degree of understanding on first notification.

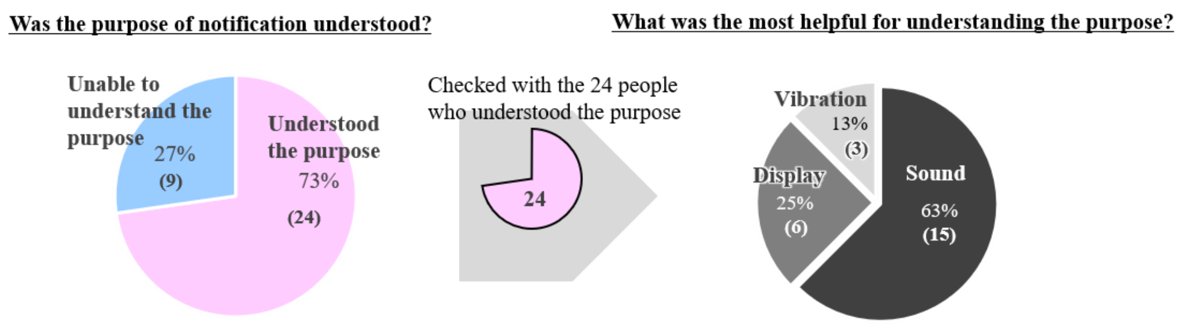


Figure 13. Whether the Purpose of Notification was Understood

Figure 14 shows changes in test subject behavior due to notification. From the images and system logs, we confirmed changes in the subject's behavior before and after the notification. In addition, the subjects who confirmed the right side before the notification and were aware of the approaching vehicle were excluded from the results. As a result, after the notification, 97% of the subjects stopped after checking the surroundings or stopped immediately to avoid accidents. Also, the average time from the notification to the subject's cessation was 1250ms.

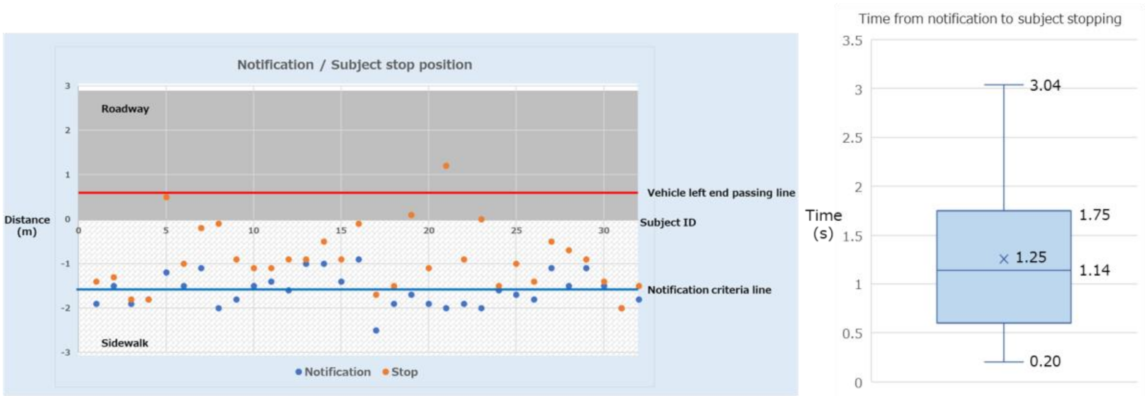


Figure 14. Notification/Subject stop position / Time from notification to subject stop

Finally, Fig. 15 shows the results from checking whether the test subjects' feeling of security would change when they go walking outside, on the assumption that this system would be present on their smartphone. The test subjects who replied that their feeling of security would increase amounted to 84%, and no test subjects replied that their feeling of insecurity would increase. The above confirms that there is acceptance of the use of smartphones to convey to pedestrians that a vehicle is approaching.

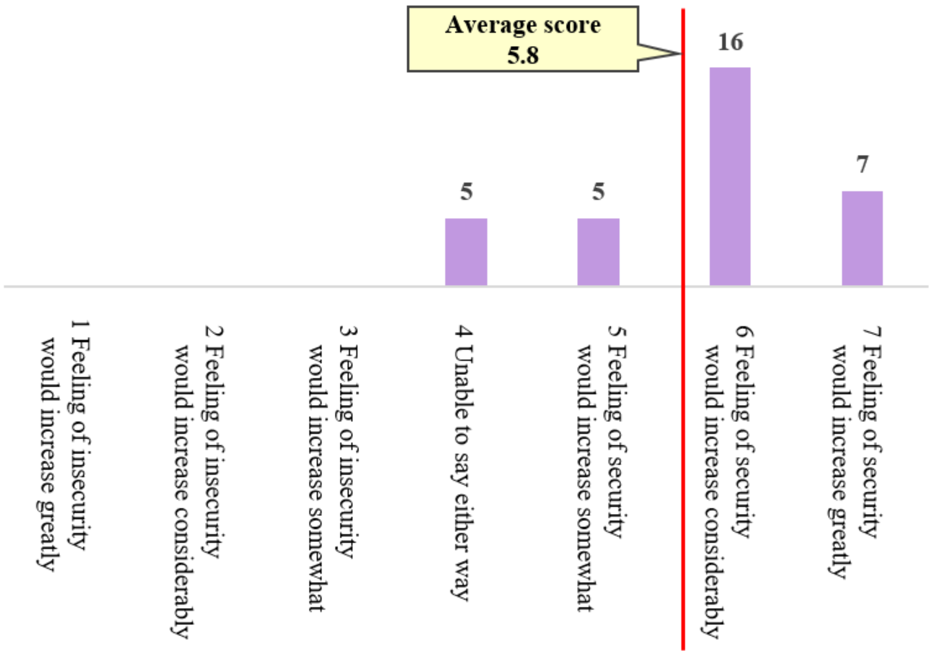
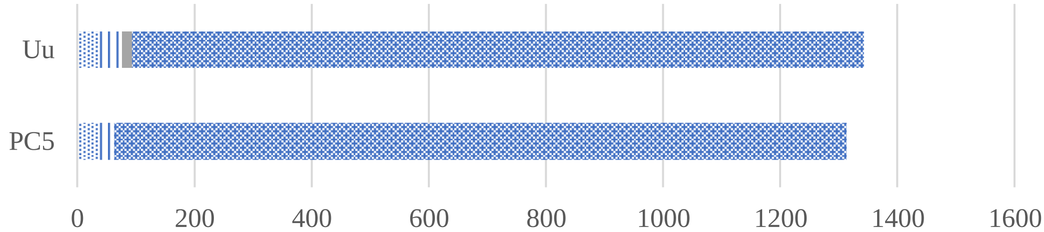


Figure 15. Whether the Sense of Security Would Change
When the HMI Experienced Here is Present While Out Walking

Total Required Time for Pedestrian Assistance

The processing time taken by this system, including the time taken for communication segments, to notify pedestrians of risk and the reaction time taken by pedestrians who received the notification until a behavior change occurred, were learned from the two verifications conducted to this point, that of the V2X system in actual vehicles and that of the pedestrian-oriented HMI. The average times required for assistance in the case of direct communication and the case of communication via BS/core NW, respectively, are presented in organized form in Fig. 16. The result was that the time taken by this system to provide assistance in the case of direct communication was an average of 1313 ms, and in the case of communication via BS/core NW it was an average of 1343 ms. The greatest amount of time taken was the pedestrian reaction time, which took up 90% or more of the total time to provide assistance.



	PC5	Uu
Vehicle System	38	38
Communication	25	39
Server	0	16
Pedestrians	1250	1250

Figure 16. Average Total System Requrired Time [ms]

DISCUSSION and LIMITATIONS

The present research created a system that coordinates between vehicles and pedestrians by means of communication. This yielded findings regarding a number of issues. First, there is a limit to assistance that comes from the time required by the system to provide assistance. An average of 1.3 seconds was required from when a pedestrian crossing the street was detected until assistance resulted in a behavior change by the pedestrian. In an environment where a greater number of units are connected by communication, however, constraints on bandwidth and increasing load on the server are expected to further increase the time taken. In cases where pedestrians dash out into the street very close to the vehicle, it is possible that assistance cannot be provided before collision is avoided. In order to deal with such cases, it will be necessary to predict the behavior of pedestrians and provide assistance before they start to cross the street. Also, GNSS location information is key information for assistance in the present system, but when the influence of multipath or other such factors cause conspicuous degradation of location accuracy, there is a possibility that assistance by the system will no longer be possible. In order to maintain a high level of acceptance and promote widespread adoption of the system even when systems like this one end up with degraded location accuracy, it will be important to clarify the conceptual approaches to providing mistaken assistance and not providing assistance. There is also the fact that the perceptibility of the HMI can differ according to the location where the smartphone is kept. For this reason, it is necessary to use auditory information, which was the most effective means of notification, as the main approach regardless of where the smartphone is kept, and to use tactile information and visual information as supplementary means, so as to convey the risk to the intended subject intuitively.

CONCLUSION

The present research focused on the fact that fatal accidents for pedestrians are caused not only by drivers of vehicles but also by unsafe behavior by pedestrians and created a system to provide assistance both to the drivers of vehicles and to pedestrians. Measurement of the processing time necessary to provide assistance in an actual vehicular environment successfully confirmed the feasibility of assistance systems that make use of communication. Also, verification of the pedestrian-oriented HMI through the use of a simulator successfully confirmed the signs change in behavior toward safety as a result of assistance, thereby successfully indicating the usefulness of assistance to pedestrians. Going forward, the aim will be to realize cooperative safety that can enable the coexistence of all traffic participants by the use of communication technology, and to realize a world that is safe and sound, with no risk caused by mobility.

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