Research into Evaluation Method for Pedestrian Pre-collision System

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ABSTRACT

Researchers in Japan, Europe, and the United States of America are investigating ways to help reduce pedestrian accidents. Methods of how to evaluate the pre-collision systems (PCS) for pedestrians are being considered with the goal of global dissemination and enhancement of the performance. This paper analyzes accident and near-miss incident data and proposes evaluation conditions for a pedestrian PCS. The development of a test apparatus for assessing the performance of the pedestrian PCS under the proposed evaluation conditions is also described.

First, accident data was analyzed to determine the evaluation scenario. The frequency of each combination of vehicle and pedestrian behavior in pedestrian accidents was investigated. According to the analysis results, the most frequent accident scenario was a pedestrian crossing a road while a vehicle goes straight ahead. This scenario was selected for the evaluation. After collating the accident data in terms of pedestrian age, the research focused on two accident patterns: one involving elderly pedestrians and one involving children. The accident scenario evaluation conditions include the position lateral to the vehicle at which the pedestrian appears, the walking direction, vehicle speed, and the like. These specific conditions were set by analyzing pedestrian accident data and near-miss incident data. For accidents involving elderly pedestrians, two evaluation conditions were set: crossing from the left during daytime and crossing from the right at night. For children, the evaluation conditions featured a child emerging suddenly from behind a parked vehicle.

Next, a pedestrian dummy capable of evaluating the PCS based on these conditions were developed. The pedestrian dummy must be compatible with the use of automotive millimeter wave radar or cameras by the PCS under the evaluation conditions. For a PCS that uses millimeter wave radar, a pedestrian dummy will be required to have low reflection intensity, a capability to reflect radar waves from the entire body, and a walking motion. For a PCS that uses cameras, a dummy must be capable of simulating a human body with both arm and leg movement. To achieve these requirements, the skeletons of the pedestrian dummy were manufactured from vinyl chloride pipes. The reflection intensity was adjusted by winding a metal tape around the entire body of the dummy. A walking mechanism which moves both the arms and the legs was provided from above the pedestrian dummy.

The developed dummy successfully simulated a pedestrian by achieving a reflection intensity which is virtually identical to an actual pedestrian, and a highly realistic walking motion. Furthermore, the test apparatus was developed to assess the PCS under the proposed evaluation conditions.

INTRODUCTION

Nearly half of global traffic accident fatalities are vulnerable road users [1]. In Japan, although the number of traffic accident fatalities has continued to decline, this trend is slower for pedestrians. Consequently, the proportion of pedestrians within the total number of traffic accident fatalities is increasing. Since 2008, the proportion of fatal accidents involving pedestrians has risen to approximately 30%, which is the highest proportion of the various crash types [2].

For this reason, pre-collision systems (PCS) capable of detecting pedestrians are being researched and developed as a type of active safety system. One such PCS for pedestrian detection that is already in use helps to alleviate pedestrian injury or helps to avoid a collision by warning the driver when a collision is imminent and then providing braking assistance or even automatically braking the vehicle if the driver does not brake after the warning.

With the goal of facilitating more widespread use and enhancing the functions of this type of PCS for pedestrian detection, methods of evaluating the performance of these systems are currently being researched, including standards and assessments [3]. In this research, standard test methods and ways of estimating system effectiveness is considered. For example, Ando et al. used a lateral-facing static pedestrian dummy to calculate the collision avoidance rate at various vehicle speeds [4]. This data was then analyzed to calculate the fatality reduction effect based on the vehicle speed in accident data. Although this effect was proposed as a method to evaluate system performance, this research has issues that remain to be resolved. To implement this evaluation method, the evaluation conditions based on the accident data must be defined. However, the research does not discuss the relationship between the tests and actual accidents. Furthermore, the dummy used in the evaluation was not capable of sufficiently simulating the characteristics of a pedestrian.

Consequently, this paper describes evaluation conditions based on pedestrian accident analysis using pedestrian accident data and near-miss incident data. It also summarizes the requirements and the development of pedestrian dummy and a test apparatus for use in this research.

DEFINITION OF EVALUATION CONDITIONS

Pedestrian Accident Analysis

The pedestrian accident evaluation pattern was defined based on the pedestrian accident data. The data source was traffic accidents in 2009 compiled by the Institute of Traffic Accident Research and Data Analysis (ITARDA) in Japan. The relevant data was extracted based on two requirements: the first party in the accident must be a vehicle, and the second party must be a pedestrian.

Accident pattern analysis First, to extract the accident patterns for evaluation, the frequency of each combination of vehicles and pedestrian behavior was investigated. Figure 1 shows the percentage of fatalities caused by each combination. Accident scenarios involving the vehicle going straight ahead while a pedestrian crosses the road account for approximately 60% of all pedestrian fatalities. This was selected as the accident pattern to be evaluated.

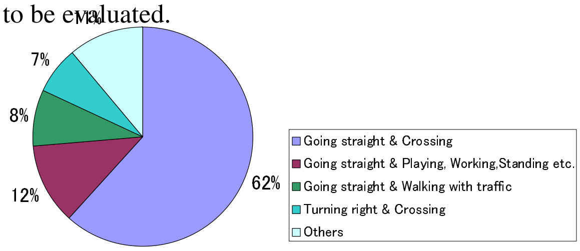


Fig1. Percentage of fatalities for each combination of driver and pedestrian behavior.

(Source :compiled by ITARDA)

Age-based analysis of pedestrian accidents Since the behavior of how to cross the road differs according to age, the age of the relevant pedestrians in the accident data was analyzed. Figures 2 and 3 show the number of traffic accident fatalities and casualties per 100,000 pedestrians in each age group. This data indicates that pedestrians aged 65 or older accounted for approximately 70% of fatalities. In contrast, children aged 12 or under accounted for approximately 30% of casualties. It was concluded that elderly pedestrians and children are more susceptible to involvement in traffic accidents. Therefore, the characteristics of these accidents and the road-crossing behavior of these age groups were analyzed more in detail to identify the test conditions.

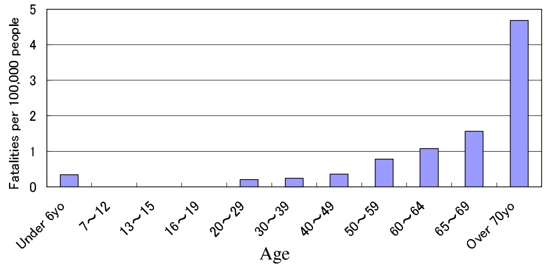


Fig.2 Fatalities according to age

(Source :compiled by ITARDA)

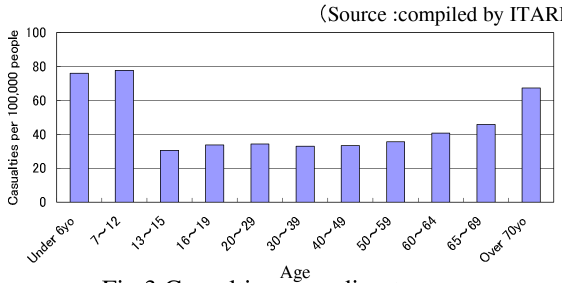


Fig.3 Casualties according to age

(Source :compiled by ITARDA)

Definition of Evaluation Conditions

Within the process from pedestrian detection to system operation, the evaluation conditions were considered based on an accident pattern in which a vehicle goes straight ahead while a pedestrian crosses the road. The following five parameters were set to examine the pedestrian recognition performance of the system and the time from pedestrian detection to collision: (1) the walking direction of the pedestrian and the time of day the accident occurred, (2) the position lateral to the vehicle at which the pedestrian appears (lateral appearance position), (3) the walking speed, (4) the position of the impact at the front of the vehicle, and (5) the vehicle speed. These conditions were investigated for both elderly pedestrians and children.

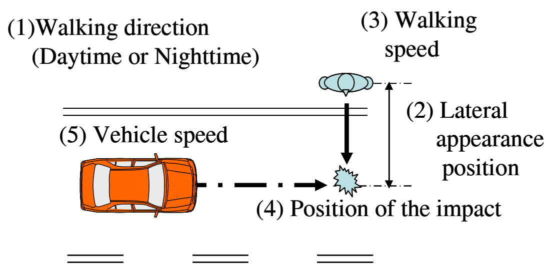


Fig.4 Pedestrian accident parameters

Walking direction of pedestrian and time of day the accident occurred The time accidents occurred has been described in previous research [5]. Elderly pedestrians are more likely to be involved in an accident between 10 and 11 o'clock in the morning (daytime) and between 5 and 7 o'clock in the evening (nighttime). Accidents involving children are more likely to occur between 7 and 8 o'clock in the morning and between 4 and 5 o'clock in the afternoon. The relationship between the time of the accident and the walking direction shows a virtually equal proportion between left and right during the daytime. However, at night, 70% of accidents occur when the pedestrian crosses the road from the right. This is because drivers are slower to see objects further away on the right at night than objects on the left.

Lateral appearance position The major factor affecting the pedestrian lateral appearance position is whether the driver's view of the pedestrian is blocked by a parked vehicle or other objects (this is referred as visual influence). Matsuura investigated the visual influence of parked vehicles and other objects for various age groups [6]. This research found that the visual influence was low in the case of accidents involving elderly pedestrians. However, it also found that approximately half of accidents involving children aged 12 or under involved congestion, stepping out of a vehicle, or a similar condition. Therefore, the research described below evaluated accidents without another object for elderly pedestrians, and accidents with children appearing from behind a parked vehicle.

The pedestrian lateral appearance position can only be defined by examining the situation before the accident risk occurs. However, since accident data is only recorded after the risk occurs, it is not adequate to define the lateral appearance position [7]. Actual images or similar data are the best way of examining the situation before the accident risk occurs. Consequently, this research used the near-miss incident database created by The Society of Automotive Engineers of Japan to analyze the pedestrian lateral appearance position and behavior. The pedestrian data was extracted from the database with the near-miss level set to high. The database identified 58 accident cases that could be grouped into the following categories of pedestrian appearance. The lateral appearance position was examined for each category.

Pedestrian appearing from left:
- Appearance from road shoulder or sidewalk
- Appearance from behind parked vehicle

Pedestrian appearing from right:
- Appearance from median strip or from the right on a single-lane road
- Appearance from behind oncoming vehicle
- Appearance from outside of oncoming lane

Fig.5 Drive recorder data of pedestrian lateral appearance positions

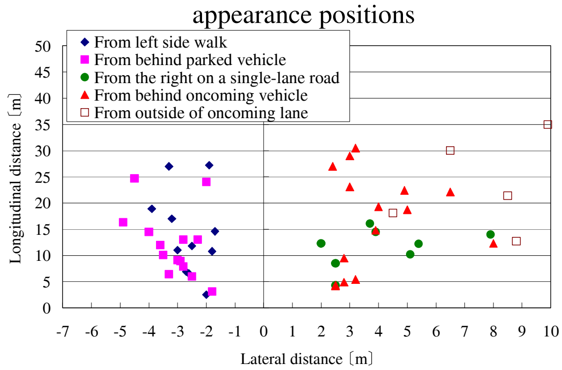


Fig.6 Distribution of pedestrian lateral appearance positions (near-miss data).

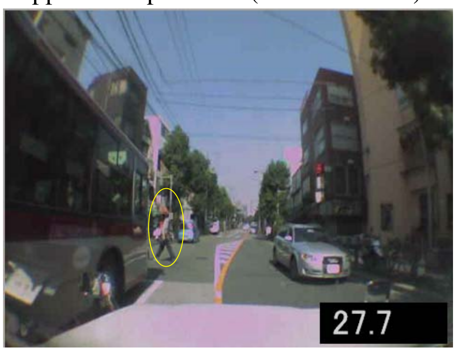


Fig.7 Drive recorder data of pedestrian appearance behind parked vehicles.

Figure 5 shows one of the near-miss incidents. The lateral appearance position is defined as the lateral distance from the position at which the whole body of the pedestrian is visible to the center of the vehicle. Figure 6 shows the pedestrian lateral appearance positions identified from the image analysis. The lateral appearance position distribution of pedestrians coming from the road shoulder on the left or from a sidewalk is between 1.9 and 4 meters. The lateral appearance position distribution of pedestrians emerging from behind a parked vehicle on the left is between 2 and 5 meters. The near-miss incident images indicated that pedestrians can be seen further away from the parked vehicles. As a result, the pedestrians were visible further away than the parked vehicle in lateral distance (Figure 7). The positional relationship between the parked vehicle and the pedestrian must be identified to define the evaluation conditions when a parked vehicle is present. Therefore, two distances were examined using the data of pedestrians emerging from behind a parked vehicle: the longitudinal distance from the pedestrian to the parked vehicle, and the lateral distance between the driver's vehicle and the parked vehicle. Figure 8 shows the distance from the pedestrian to the parked vehicle and Figure 9 shows the lateral distance between the driver's vehicle and the parked vehicle. Figure 8 shows that most pedestrians leave a gap of between 1 and 2 meters. Therefore, the median value of 1.5 meters was set as the distance between the pedestrian and the parked vehicle in this research. In the same way, Figure 9 also shows a lateral distance of between 1 and 2 meters between the parked car and the driver's car. The median value of 1.8 meters was set as the evaluation distance in this research.

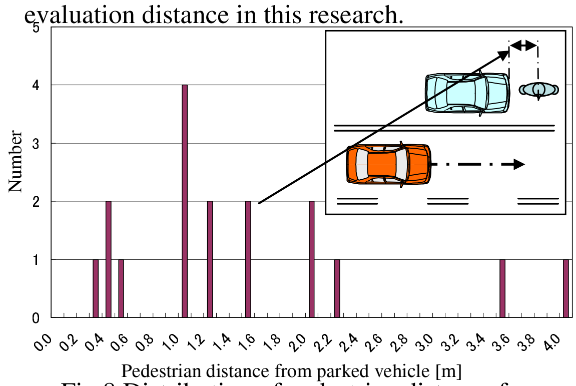


Fig.8 Distribution of pedestrian distance from parked vehicle

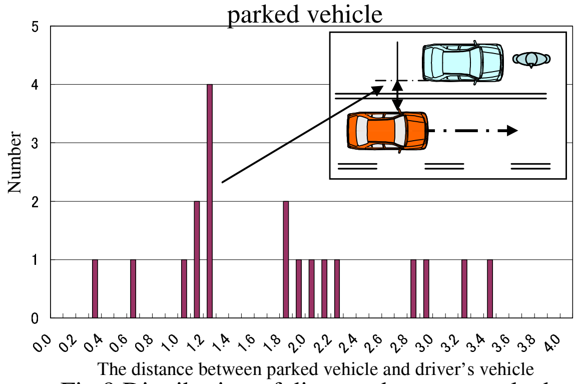


Fig.9 Distribution of distance between parked vehicle and driver's vehicle

Using these results, the lateral appearance position of pedestrians crossing from the road shoulder or sidewalk on the left was set to 3 meters (the median value in the distribution shown in Figure 6). In the case of pedestrians emerging from behind a parked vehicle, the lateral distance between the driver's vehicle and the parked vehicle was set to 1.8 meters, and the distance between the pedestrian and the parked vehicle was set to 1.5 meters.

The lateral appearance position of pedestrians coming from the right was considered separately. Although the lateral appearance position of pedestrians from the median strip or the right of a single-lane road is shorter than other conditions, it was still at least 2 meters. For this reason, the lateral appearance position in these cases is the same or longer than scenarios involving pedestrians coming from the left. Many cases of pedestrians emerging from behind an oncoming vehicle had a lateral appearance position of between 3 and 5 meters. This scenario has a wide distribution because the pedestrian lateral appearance position changes depending on the intersection timing with the oncoming vehicle. Finally, the lateral appearance position of pedestrians coming from the outside of the oncoming lane was between 4.5 and 10 meters. These results indicate that the lateral appearance position of pedestrians crossing from the right is further outward from the driver's vehicle compared to pedestrians crossing from the left. For this reason, it should be possible to evaluate a PCS using pedestrians crossing from the left only. However, an evaluation from the right is required because drivers are slower to see objects further away on the right in accidents at night. After examining the lateral appearance positions of pedestrians coming from the outside of the oncoming lane or emerging from behind an oncoming vehicle, 6 meters was selected as the lateral appearance position for pedestrians crossing from the right (the median value of the distribution of 2 to 10 meters).

Walking speed Walking speed is another factor affecting road crossing behavior. This behavior was investigated for each age group. A comparison between accidents involving adults and children found that most adults were walking normally, but a large proportion of children were running [8]. Consequently, this research used a normal walking speed for elderly pedestrians and running speed for children.

Various research has already investigated walking speed. This research adopted 4 km/h as the normal walking speed for elderly pedestrians, which is the median value defined by Hino et al. [9]. The running speed of children varies greatly according to age. This research set the running speed assuming a 6-year old child. After investigating the running speed of 6-year old children, Sato et al. found that the speed of children increased more slowly than adults and that it requires 3 meters for children in this age group to accelerate to approximately 9 km/h [10]. This value was set as the child running speed.

Impact position at vehicle front Accident data cannot be used to determine the impact position since it includes cases in which the driver braked or steered the vehicle immediately before the collision. This makes it difficult to identify the estimated position of impact prior to the collision. Therefore, published ITARDA reports were examined [11] and the impact position was estimated based on the relationship between the position of the pedestrian when the accident risk occurred and the vehicle speed. Figures 10 and 11 show the impact position frequency in accidents involving pedestrians crossing from the left and right, respectively. The lateral position from the left side of the vehicle is shown as a negative value and the lateral position from the right side of the vehicle is shown as a positive value. The vehicle width was assumed to be 1.8 meters. For both directions, the most frequent impact position was toward the center of the vehicle. However, some impacts occurred further from the center and the overall distribution is wide. Consequently, the center of the vehicle was set as the impact position in this research.

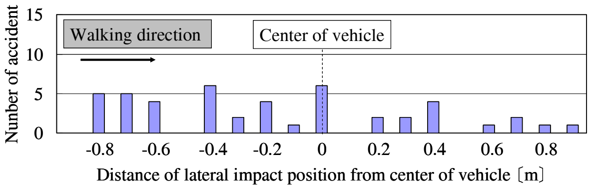


Fig.10 Lateral impact position from left side

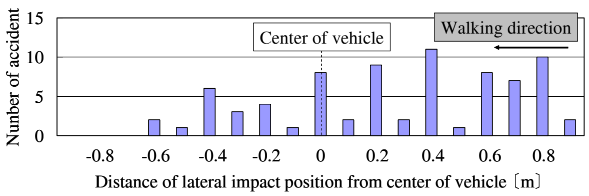


Fig.11 Lateral impact position from right side

Vehicle speed Vehicle speed is an important condition because a vehicle travelling at higher speed will take longer time to slow down, which requires technology to detect pedestrians from further away. In addition, although the time to collision is comparatively longer when the vehicle speed is lower, pedestrians must be detected within a wide angle since the speed difference between the pedestrians and the vehicle is smaller. As a result, PCS evaluation must be carried out at both lower and higher speed conditions.

The accident data from ITARDA were used to investigate the fatality rate and the serious and slight injury rates at each vehicle speed in pedestrian accidents. Figure 12 shows the results.

The rate of fatal accidents increases when the vehicle speed exceeds 30 km/h. The rate of slight injuries falls to 10% or less at 60 km/h as the rate of fatalities and serious injuries increases. For this reason, a speed of between 30 and 60 km/h was selected as the evaluation conditions in this research.

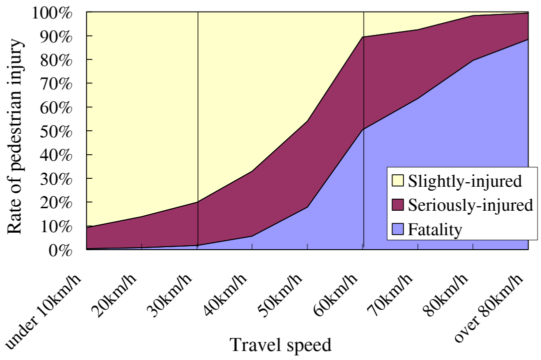
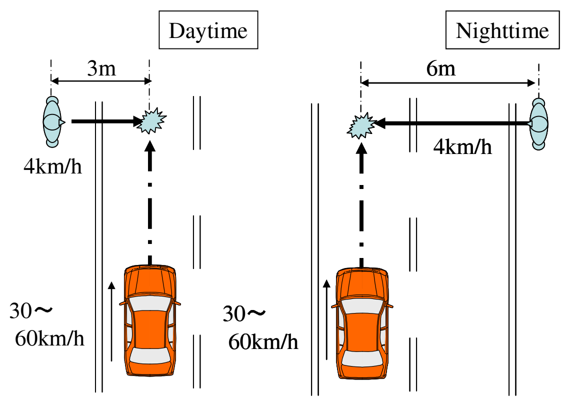


Fig.12 Rate of injury level at each travel speed

（Source :compiled by ITARDA）

Definition of evaluation conditions Figures 13 and 14 show an outline of the evaluation conditions set based on the results described above. Two test patterns were set for elderly pedestrians: crossing the road from the left at daytime and from the right at nighttime. One test pattern was set for children: suddenly emerging from behind a parked vehicle at nighttime. A test pattern involving a child crossing the road from the right was omitted.



(a) From left side (b) From right side

Fig.13 Test patterns for elderly pedestrians

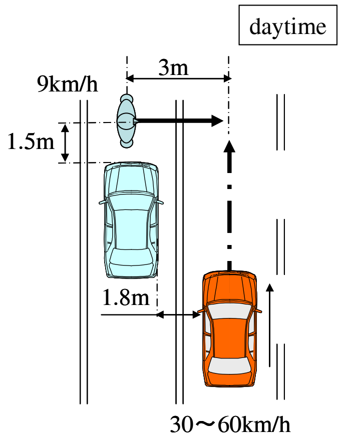


Fig.14 Test pattern for child pedestrians

RESEARCH OF PEDESTRIAN PCS TEST APPARATUS

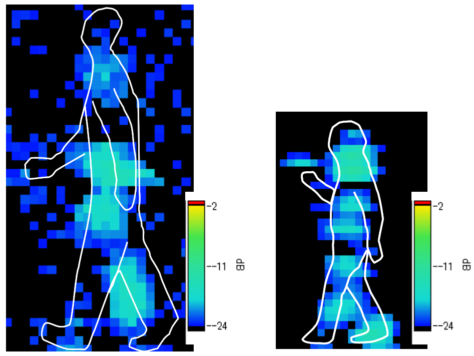
Development of Pedestrian Dummies

As described above, the evaluation conditions were defined by analyzing pedestrian accident data. A pedestrian dummy for a test is required to evaluate the deceleration performance of a PCS under the defined conditions. Since the dummy used will affect the pedestrian recognition performance of the system, the dummy must closely resemble actual pedestrians as viewed by the on-board detection sensors.

Currently, vehicles equipped with a PCS for pedestrian detection use three types of detection method: a stereo camera, a combination of millimeter wave radar and a monocular camera, and a combination of millimeter wave radar and a stereo camera. This section discusses the requirements of pedestrian dummies compatible with millimeter wave radar and cameras, and describes dummies capable of satisfying these requirements. For a preliminary study, an AM50 dummy and a 6-year old pedestrian dummy with precisely defined dimensions were prepared.

Requirements and example dummies compatible with millimeter wave radar detection The reflective characteristics of millimeter wave radar have already been identified in the case of a static human body. A person is approximately 1/100 as reflective as a vehicle [12]. A pedestrian dummy must be capable of simulating the reflective characteristics of a person in terms of how each part of the body reflects millimeter waves and in terms of a human walking motion. First, the sideways reflective characteristics of a midsize adult (AM50) and a 6-year old child were measured to investigate how each part of the body reflects millimeter waves. A 77 GHz millimeter wave radar (the RI76G-01 manufactured by KEYCOM Corporation) was used to measure the radar cross section (RCS) from the side of the human subjects. The height of the millimeter wave radar was set to 650 mm, assuming installation in a vehicle. Figures 15(a) and (b) show the measured results for the AM50 and 6-year old child. The subjects only who agreed with informed consent were attended to the experiment.

Figure 15 shows that radar waves were reflected mainly from the pelvis, torso, knees, and shoulders. This indicates that more radar waves are likely to be reflected from surfaces directly facing the millimeter wave radar. In other words, a dummy must simulate a human physique and be capable of reflecting waves from the entire body to achieve the same reflection distribution.



(a)AM50 (b) 6 years old

Fig.15 Human RCS distribution

Next, two types of reflective characteristics were investigated to examine the effects of walking: a static state with the arms and legs spread out to simulate a walking posture, and the same posture in a moving state. The same 77 GHz millimeter wave radar was used. Figures 16 to 19 show the results (Figures 16 and 17: AM50, Figures 18 and 19: six-year old child). A comparison of the results shows that the reflection intensity in the moving state has a much finer cycle of fluctuation. Previous research also indicated that the reflection intensity fluctuates in accordance with extremely small movements of the body [12]. This is because the radar waves reflected from each part of the body overlap, becoming more intense or canceling each other out. These extremely small movements of the body are not constant and differ from person to person. In Figures 17 and 19, the timing of the drop in the radar wave reflection has a constant cycle. This is due to the interconnected motion of arms and legs during walking, creating a fine fluctuation cycle. These results indicate that walking changes the reflective characteristics. Therefore, a dummy must have movable arms and legs to simulate the millimeter wave radar reflective characteristics of a pedestrian.

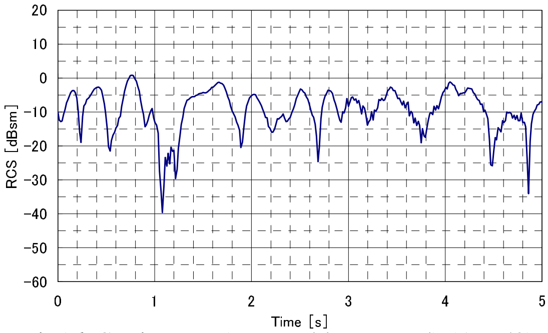


Fig16. Static state (arm and leg spread) (AM50)

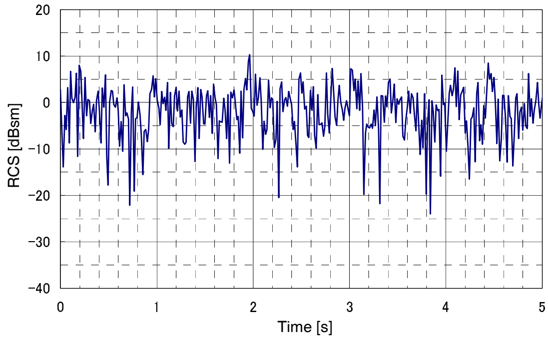


Fig17. Walking state (AM50)

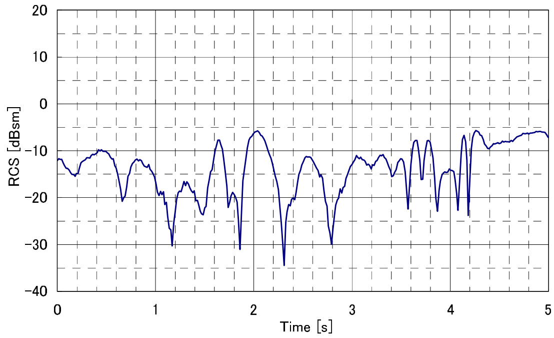


Fig18. Static state (arms and legs spread) (6-year old child).

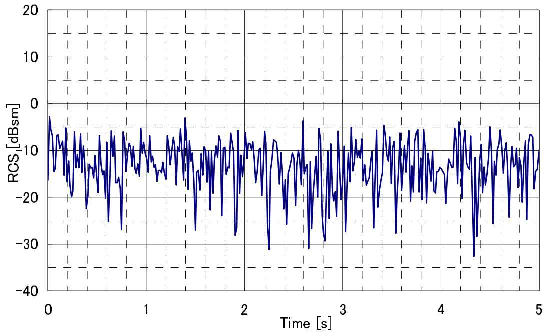


Fig19. Walking state (6-year old child).

In addition, the following requirements for a pedestrian dummy were identified in previous research.

(1) Low reflection intensity

(2)Capability to reflect radar waves from the entire body

(3) Capable of making walking motion

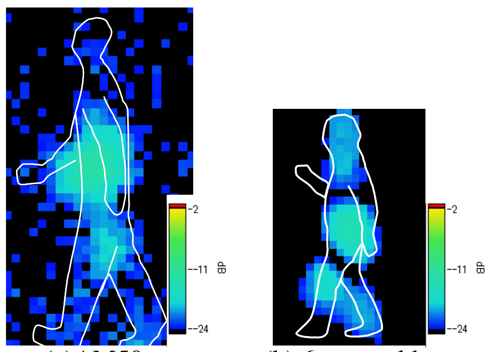
To satisfy these three requirements, the dummy was developed as follows.

- Use vinyl chloride pipes for the dummy skeleton to achieve low reflection, and adjust the position and amount of reflective material on the dummy surface to simulate the reflection intensity to a human.

- Achieve full-body reflection by placing reflective material over the whole of the dummy body.

- Provide a mechanism above the pedestrian dummy (to reduce the effect of the mechanism on the reflection intensity) to simulate arm and leg movement.

Pedestrian dummies that satisfy these requirements were developed specifically as follows. A lifelike sponge body was created that allows reflective material to be attached to the whole body. The reflection intensity was adjusted by winding metallic mesh tape around the surface of the sponge. The same 77 GHz millimeter wave radar measurement apparatus as described above was used to measure the reflection intensity. In the same way as with the measurement with human subjects, two types of evaluation were carried out: an investigation into the RCS distribution from the side, and the fluctuation in reflection in a walking state. Figures 20(a) and (b) show the reflection distribution results for the AM50 dummy and 6-year old child dummy, respectively. Replicating the results with the human subjects, radar waves reflected mainly from the pelvis, torso, knees, and around the shoulders. Figure 21 shows the reflection intensity with a walking AM50 dummy and Figure 22 shows the results for the 6-year old child dummy. The average reflection intensity also replicated the fine fluctuation cycle of the human subjects.



(a)AM50 (b) 6 years old

Fig.20 RCS distribution of pedestrian dummy

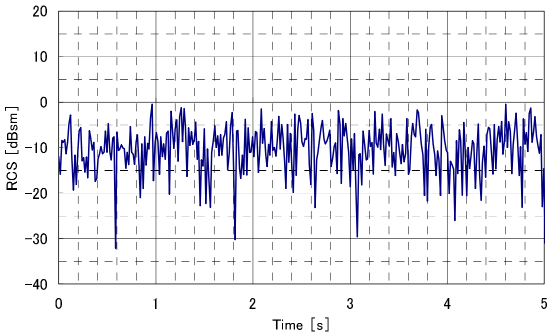


Fig21. Walking state (AM50 dummy)

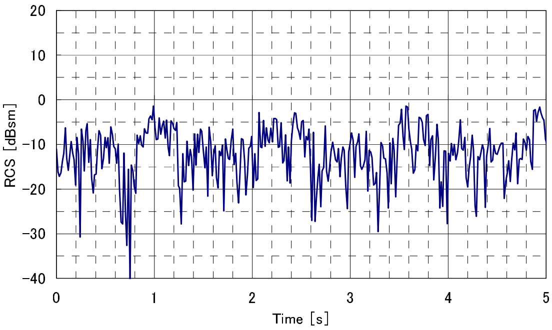


Fig22. Walking state (6-year old child).

Requirements and example dummies compatible with camera detection Since body types and shapes differ due to body size and posture, pedestrian detection by camera uses statistical pattern recognition [13]. Recent research has focused on methods using image features which express the spatial distribution of edges on the image, such as histograms of oriented gradients. Applied methods of these histograms have also been proposed [14-15]. Pedestrian detection also uses edges on images as features, but defining the edges of which part of the body differs to each system. Since the movement of the arms and legs is an important aspect of a dummy simulating a pedestrian crossing a road, the following requirements were identified to develop dummies compatible with camera detection.

(1) Simulation of a realistic human shape (dimensions)

(2) Simulation of arm and leg movement

To satisfy these two requirements, the dummies were developed as follows.

- Reproduce an AM50 physique and walking motion (arm and leg dimensions, and the like)
- Provide the mechanism above the pedestrian dummy (to reduce the effect of the mechanism on the reflection intensity as described above to simulate arm and leg movement.

SAE J2782 (Performance Specifications for a Midsize Male Pedestrian Research Dummy) was referenced to determine the dimensions of the AM50 dummy. The dimensions of the 6-year old child dummy were also determined based on physical data. The walking motion was set to correspond to the stride length defined in pedestrian data. Although walking has been studied in various research, the results differ in accordance with age and body shape. This research used the stride length results obtained by Yamazaki et al. [16]. From these results, the dummy height was set to 175 cm or more, the walking speed was set to 4 km/h, and the average stride length was set to 70 cm.

Figure 14 shows several frames from the walking motion of the AM50 pedestrian dummy that adopted these requirements.

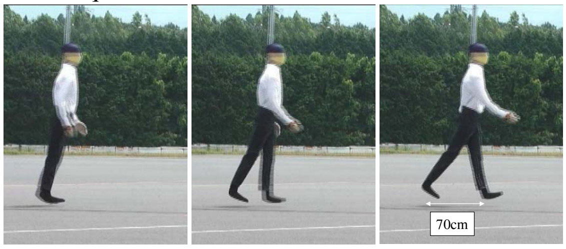


Fig.14 walking motion of pedestrian dummy

Development of Test Apparatus for Evaluation

Based on the details described above, the following requirements were identified for the test apparatus to be attached to the pedestrian dummies.

- Compatibility of a child's walking speed of up to 9 km/h and a maximum lateral appearance position of 6 meters
- No interference with detection of the pedestrian dummies by millimeter wave radar and cameras

Figure 15 shows the developed test apparatus compatible with these requirements. An aluminum truss frame was created to attach the walking mechanism above the dummy. Considering the millimeter wave reflective characteristics of the truss, the width and height were set to 15 meters and 3.6 meters, respectively. A clear pipe was used to connect the walking mechanism and the pedestrian dummy to minimize the effect on the camera.

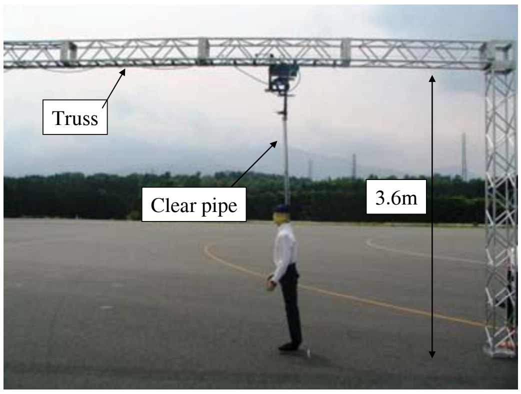


Fig.15 Test apparatus for Pedestrian PCS evaluation

CONCLUSIONS

This paper has described the research results of the method of evaluating PCS for pedestrian detection. The evaluation condition was determined by analyzing the pedestrian accident data. Requirements of the pedestrian detection sensor for a test apparatus were identified. Finally, the test apparatus was developed. The results of the research can be summarized as follows.

(1) Accident scenario of a vehicle going straight ahead while a pedestrian crosses the road account for approximately 60% of all pedestrian fatalities in Japan. Furthermore, a large proportion of accidents involve either elderly pedestrians or children. Consequently, the research focused on accident scenarios involving elderly pedestrians and children crossing a road.

(2) The evaluation conditions of accidents involving elderly pedestrians and children crossing a road were defined based on analysis of pedestrian accident data and near-miss incident data in Japan. Two evaluation conditions were set for accidents involving elderly pedestrians: crossing from the left during daytime and crossing from the right at night. The evaluation conditions for children featured a child emerging suddenly from behind a parked vehicle.

(3) Pedestrian dummies and test apparatus to carry out these evaluations were developed to be compatible with pedestrian detection sensors.

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