Relation between Warning Error and Vehicle Speed in Vehicle-to-Pedestrian Warning System

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***Abstract*—In order to prevent potential accidents between pedestrians and vehicles, it will be effective to introduce a vehicle-to-pedestrian warning system. The system detects potential accidents between pedestrians and vehicles in advance and sends warning to pedestrians and vehicles ahead of time so that potential accidents can be avoided. The time ahead of the potential accidents is named *prior notification time* and it is set in advance in the system. However, there is a difference between the prior notification time and the actual notification time due to system delay and inaccuracy of GPS localization. This difference is named *warning error*. The location estimation error and the speed of pedestrians and vehicles will affect the appropriate estimation of prior notification time. In this paper, how warning error is changed with vehicle speed is investigated through simulation. The simulation results show that the warning error increases as the vehicle speed increases. The maximum warning error is 2 seconds regardless of the vehicle speed. Thus, notification time delay can be reduced by estimating the maximum value of the warning error and increasing the prior notification time in advance.**

Keywords—road, traffic, vehicle-to-pedestrian, accident, location information, crash, detection, prior notification, warning error

I. INTRODUCTION

The impact of autonomous vehicle technologies on safety is potentially enormous given that human error accounts for an estimated 94% of potential accidents on the road [1]. Unlike human drivers, autonomous vehicles do not suffer from decreased performance due to distraction or fatigue, so they can eventually be expected to perform at high levels of precision. However, while advances in algorithm and sensor technology continue to improve vehicle performance on the road and safe operations around other vehicles, there are still concerns about interaction with high-risk groups, such as pedestrians. In contrast to vehicles, pedestrians' behaviour is not particularly constrained by traffic regulations, which makes them unpredictable much of the time [2]. Pedestrians who run into the road and cross improperly account for around 50% of pedestrians fatalities [3]. Therefore, in order to prevent potential accidents between pedestrians and vehicles, it is important to inform pedestrians and vehicles of their approach in advance. Developers of autonomous vehicle technologies have proposed multiple types of displays, including digital road signs, text, audible chimes and voice instructions to communicate intent to pedestrians [4]-[6]. For smooth communication between pedestrians and vehicles, it will be effective to introduce a vehicle-to-pedestrian warning system. The system detects potential accidents between pedestrians and vehicles in advance and sends warning to pedestrians and vehicles ahead of time so that potential accidents can be avoided. The time ahead of the potential accidents is named *prior notification time* and it is set in advance in the system. However, there is a difference between the prior notification time and the actual notification time due to system delay and inaccuracy of GPS localization. This difference is named *warning error*. The location estimation error and the speed of pedestrians and vehicles will affect the appropriate estimation of prior notification time. In this paper, how warning error is changed with vehicle speed is investigated through simulation. Section II gives an outline of the vehicle-to-pedestrian warning system and system danger judgement conditions. Section III describes a parameter setting and an assumed environment of simulation. Section IV illustrates results of simulation. Conclusion is made in Section V.

II. VEHICLE-TO-PEDESTRIAN WARNING SYSTEM

This section gives an outline of the vehicle-to-pedestrian warning system and system danger judgement conditions. The system outline shows a mechanism in which vehicles and pedestrians set their own areas and warn each other when both areas overlap. The system danger judgement conditions show three conditions required for warning and an example that do not meet conditions.

A. Sysetm Outline

In order to prevent potential accidents between pedestrians and vehicles, it is important to inform pedestrians and vehicles of their approach in advance. In the vehicle-to-pedestrian warning system, there is a mechanism in which vehicles and pedestrians set their own areas and warn each other when both areas overlap. This vehicle area is named *vehicle observation area* and this pedestrian area is named *pedestrian detection area*. Vehicle observation area is created by the prior notification time, speeds and directions of the pedestrian and the vehicle. Pedestrian detection area is created in consideration of sizes of the pedestrian and the vehicle. In order to reduce the warning error, it is necessary to calculate the vehicle area accurately.

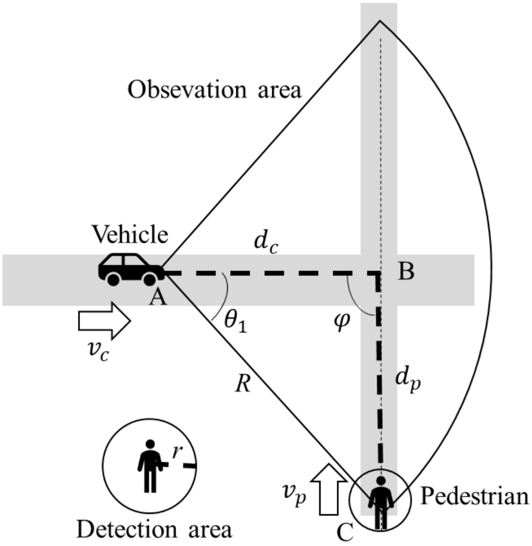

Fig. 1. Positional relation between the vehicle and the pedestrian at the intersection

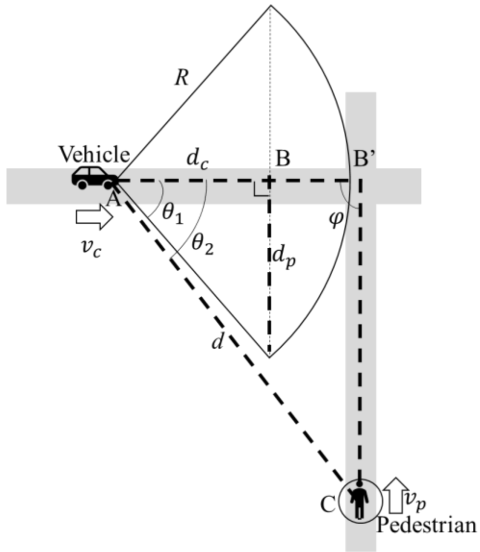

Fig. 2. Positional relation between the vehicle and the pedestrian at the intersection (before notification)

First, to set the appropriate vehicle observation area, the prior notification time is set to α [s], and the situation is considered in which the vehicle and the pedestrian crash at an intersection after α seconds. Fig. 1 shows the positional relation between the vehicle and the pedestrian at the intersection. The position of the vehicle is A, the position where the vehicle has moved in α seconds is B and the position of the pedestrian is C. In the situation, B is the predicted collision position and C is the end point of the vehicle observation area. The vehicle speed is v_c , the pedestrian speed is v_p, the distance that the vehicle moves in α seconds is $d_c(= v_c\, \alpha)$, the distance that the pedestrian moves in α seconds is $d_p(= v_p\, \alpha)$, a half of the central angle of the vehicle observation area is θ_1, the angle formed by both directions is φ, the radius of the vehicle observation area is *R* and the radius of the pedestrian detection area is *r*. φ is equal to the intersection angle of the road and *R* is determined as $\varphi = \pi/2$ [rad] by assuming orthogonal roads. *r* is a constant considering sizes of the pedestrian and the vehicle. The vehicle observation area is created by *R* and θ_1. *R* is calculated from (1). θ_1 is calculated from (2).

$$R = \sqrt{{d_c}^2 + {d_p}^2 - 2d_c d_p \cos\varphi} \tag{1}$$

$$\boldsymbol{\theta_1} = \mathbf{arccos}\left(\frac{R^2 + {d_c}^2 - {d_p}^2}{2Rd_c}\right) \tag{2}$$

Next, the situation is considered before which the pedestrian enters the vehicle observation area. Fig. 2 shows the positional relation between the vehicle and the pedestrian at the intersection. In addition to positions A, B, and C in Fig. 1, the position of the intersection is B', the distance between the vehicle and the pedestrian is *d* and the angle made by the vehicle, the pedestrian and the intersection is $\boldsymbol{\theta_2}$. $\boldsymbol{\theta_2}$ is calculated from (3).

$$\boldsymbol{\theta_2} = \mathbf{arccos}\left(\frac{(AB')^2 + d^2 - (B'C)^2}{2(AB')d}\right) \tag{3}$$

It is assumed that the position of A, B, B', C, and the angle of the intersection $\boldsymbol{\varphi}$ will be acquired by road information or GPS.

B. Sysetm Danger Judgement Conditions

For the vehicle-to-pedestrian warning system to make a danger judgment, the following three conditions must be met.

Condition 1:

$$d \leq R + r \tag{4}$$

The distance between the vehicle and the pedestrian *d* must be less than or equal to sum of the radius of the vehicle observation area, and the radius of the pedestrian detection area.

Condition 2:

Vehicles and pedestrians are close to each other. The system judges from φ.

Condition 3:

$$\theta_1 \geq \theta_2 \tag{5}$$

The pedestrian enters within the angle of the vehicle observation area.

When three conditions are met, the system judges that it is dangerous.

III. Simulation

This section gives a parameter setting and an environment of simulation. The purpose of the simulation is to investigate how warning error is changed with vehicle speed. The simulation parameter setting shows the values of each parameter and their purpose. In the simulation environment, the traffic environment of pedestrians and vehicles, and the acquisition method of warning error are shown.

A. Simulation Parameter Setting

Table 1 shows the simulation parameter setting. The vehicle speed is changed in 5 [km/h] increments from the slow speed to the legal maximum speed. The pedestrian speed is based on the walking speed used when calculating the walking time of real estate. The radius of the pedestrian detection area is set in consideration of sizes of the pedestrian and the vehicle. The prior notification time is set in consideration of the stop time at a vehicle speed of 60 [km/h].

TABLE I. SIMULATION PARAMETER SETTING

Vehicle speed [km/h]	10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60
Pedestrian speed [km/h]	4
Radius of pedestrian area [m]	2
Prior notification time [s]	5
Location accuracy [m]	±1
Update interval of location information [s]	1
Occurrence frequency of vehicles and pedestrians	100
Intersection angle [rad]	$\pi/2$
The size of intersection [m]	1000×1000
The search range [m]	Vehicle speed ＊Prior notification time ＊2
Number of trials	500

Location information accuracy is the difference between the accurate location and the actual location measured by GPS. Fig. 3 shows a mechanism of location error due to location information accuracy. For each step, an error is generated for the *xy* coordinates within the set range by using random numbers. When the error is set, location information error occurs in the vehicle's and the pedestrian's location information used in the calculation of the danger judgement.

The update interval of location information is the time that required for processing per step in the system. Location information is shared at the time interval. This is based on the actual GPS location information acquisition frequency.

The occurrence frequency of vehicles and pedestrians is the frequency that vehicles or pedestrians are occurred. In this simulation, a single road intersection without traffic rights in an urban area is assumed. The value of the occurrence frequency is set in consideration of the traffic volume per twelve hours in urban areas which was reported by the Ministry of Land, Infrastructure, Transport and Tourism in Japan. Random numbers and the time that it takes for a vehicle or pedestrian to occur are used to determine whether to generate vehicles or pedestrians.

The size of the intersection is the vertical and horizontal size of the space in the simulation. The size is set larger than the actual size of the intersection. This is to ensure that objects can move by the set prior notification time.

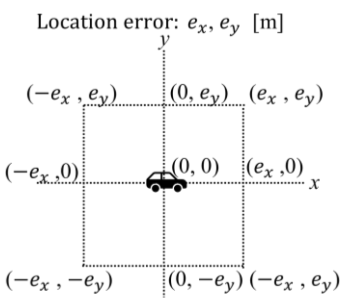

Fig. 3. Mechanism of location error due to location information accuracy

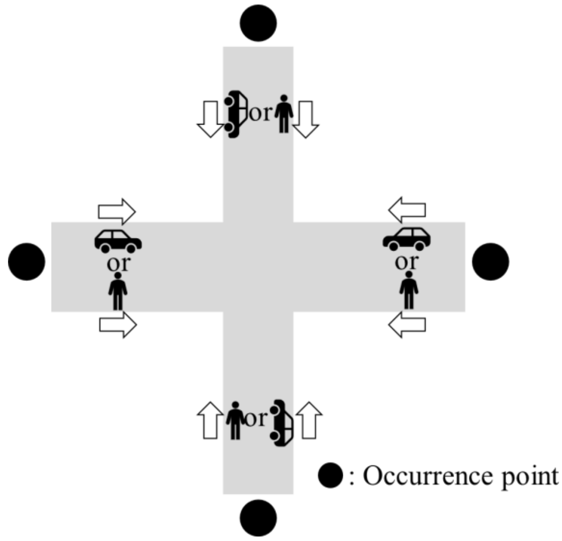

Fig. 4. Simulation environment

The search range is the range in which vehicles search for pedestrians. The search range is a circle whose radius is the distance traveled in twice the prior notification time.

B. Simulation Environment

Fig. 4 shows the environment for the simulation. Vehicles or pedestrians appear randomly from four intersections according to the set occurrence frequency. Vehicles and pedestrians do not turn left or right, the direction is straight toward the centre of the intersection, and the speed is constant. When the vehicle observation area and the pedestrian detection area overlap, the detection is started. When the vehicle is in the pedestrian detection area, it is regarded as a crash, and the detection is ended. Using the above simulation specification and environment, how warning error is changed with vehicle speed is investigated by changing the vehicle speed in 11 patterns.

IV. RESULTS

This section shows simulation results. As a result, the warning error increases as the vehicle speed increases. The maximum warning error is 2 seconds regardless of the vehicle speed. The factors that cause warning errors are the following three problems.

Fig. 5 shows the kurtosis and skewness values at each vehicle speed. Fig. 6 shows the relation between the vehicle speed and danger possibility. Danger possibility is the percentage of the warning error is negative. Fig. 7 and Fig. 8 show histograms of warning error at 10 [km/h] and 60 [km/h]. As shown in Fig. 5, the kurtosis decreases as the vehicle speed increases. This result means that the warning error increases as the vehicle speed increases. It is the same as in Fig. 6. This is because the faster the vehicle speed, the less the number of times the location information is shared before potential accidents between pedestrians and vehicles. As shown in Figs. 7 and 8, this result can also be seen by the fact that the mode values of the histograms are different. On the other hand, regarding the skewness in Fig. 5, there is not much difference in vehicle speed. This is because the following three error problems can occur regardless of vehicle speed.

A. Area Entry Problem

Depending on inaccuracy of GPS localization and the location relation between pedestrians and vehicles, there are cases where the areas do not overlap slightly. As a results, the notification may be sent one step later than the prior notification time.

B. Vehicle Crash Problem

In the simulation, when the vehicle exists in the pedestrian detection area, it is regarded as a crash and the detection is completed. Therefore, it may not be regarded as a crash slightly, and an error may occur in the notification time. In addition, there are three possible patterns for approaching the vehicle to the pedestrian: (a) the vehicle approaches from behind, (b) the vehicle approaches from the front, and (c) the vehicle meets the vehicle at an intersection. In the simulation, in (a) and (b), $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2} = 0$ are obtained from (2) and (3). Thus, the actual judgment conditions are reduced. However, in pattern (c), condition 3 in crash detection is applied, so there is possibility that the judgment is satisfied with a delay of one step depending on the GPS error that occurs randomly.

C. Simulation Spatial Setting Problem

In the simulation, pedestrians and vehicles appear randomly from four occurrence points. Therefore, there are cases where vehicles and pedestrians appear at short distances and the warning may be started without securing a sufficient distance. The problem is more likely to occur as the vehicle speed increases.

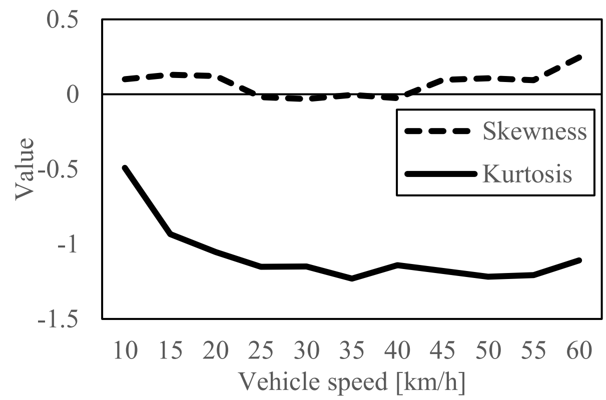

Fig. 5. Relation between vehicle speed and kurtosis/ skewness

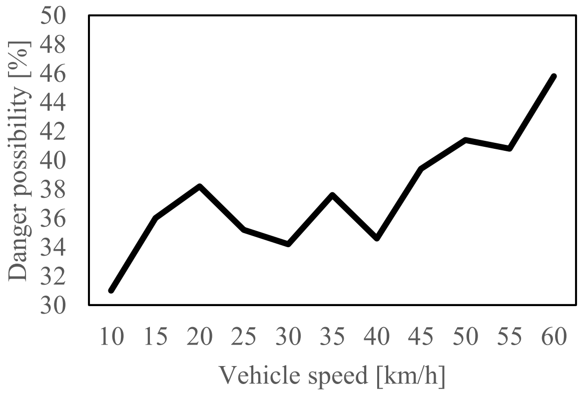

Fig. 6. Danger possibility in each vehicle speed

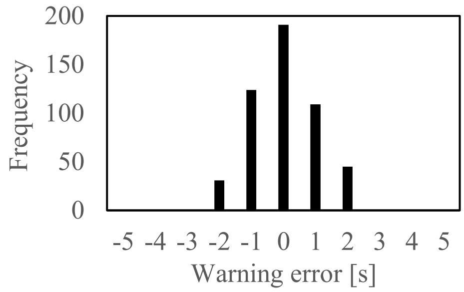

Fig. 7. Histogram of notification time (10 [km/h])

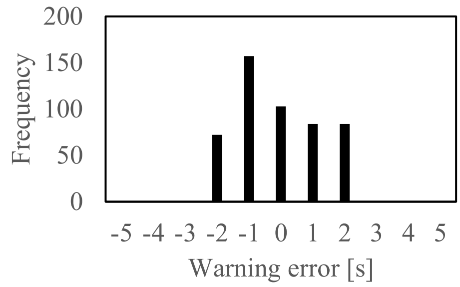

Fig. 8. Histogram of notification time (60 [km/h])

V. Conclusion

In this paper, the effect on the warning error in the danger notification system under various conditions is clarified by the simulation. The main contributions are as follows:

1) The warning error increases as the vehicle speed increases. The maximum warning error is 2 seconds regardless of the vehicle speed.

2) The positive and negative skewness of the notification error does not depend on the vehicle speed. It depends on whether the above three problems occur.

The results show that notification delay can be reduced by estimating the maximum value of the warning error and increasing the prior notification time in advance. It is left for further study to make more realistic models such as speed changes of vehicles and pedestrians, turning left and right, etc.

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