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Pedestrian-Vehicular Collision Avoidance Based on Vision System

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***Abstract*--Vehicle-pedestrian collision avoidance is an important issue on intelligent vehicles research field. Although pedestrian detection and collision avoidance were concentrated by previously many studies, there are many problems about the collision prediction and warning. Based on pedestrian detection, the trajectory prediction and time to collision (TTC) still needs to be further studied to prevent vehicle-pedestrian collision. In this study, a monocular camera with low cost was utilized. The well performance of pedestrian detection was shown. Based on this detection system, a model of pedestrian trajectory prediction was proposed. Then, the extended Kalman filter was used to predict motion of pedestrian. Based on trajectory prediction, time to collision range (TTCR) was proposed identify three levels risks, including safe, potential collision and collision. In this study, the on-road experiments were conducted to validate the proposed method. The experimental result shows that the TTCR is more reasonable and safe to apply in vehicle-pedestrian collision avoidance.**
Keywords-- Pedestrian detection, pedestrian safety, time to collision range (TTCR), extended Kalman filter

I. INTRODUCTION

At present, pedestrian-to-vehicle accident is the main cause in the death of pedestrian. Therefore, pedestrian vehicular collision is an important issue for traffic safety. In recent years, there is not reduction for the number of vehicle-pedestrian collision [1]. According to the National Highway Traffic Safety Administration 2014 report, the number of pedestrians injured and fatal was 76,000 and 4,743 in 2012, respectively [2]. It was reported by road safety 2013 form the World Health Organization that 0.62 million victims were pedestrians, motorcyclists and cyclists in traffic accident [3].

Pedestrian detection and collision prediction algorithm are the most important technologies to prevent pedestrian-vehicular collision. Therefore, researchers from universities, government agencies, and companies have being focused on these technologies [4]-[10].

To detect pedestrian, many features and algorithms are proposed in previous studies. Template matching algorithms were applied by Gavrila [11]. About 1000 pedestrian shapes were used to build a database. Then, the method for detecting pedestrian was proposed based on Distance Transforms. In recent years, the features such as Haar-like feature, CENsus Transform hISTogram (CENTRIST) feature, and Histogram of Oriented Gradient (HOG) feature were used to detect pedestrian [12]-[14]. For example, an algorithm based on C^4 feature was proposed by Wu et al. [14] to detect pedestrian. A cascade classifier and CENTRIST were used by this algorithm based on contour information. Harr wavelte-based cascade framework was proposed by Viola [15]. By the algorithm, the walking pedestrian can be detected well. The CENTRIST descriptor was designed by Wu et al. [16]. The contour was considered as important feature in this study. Similarly, in another study by Dalal et al. [17], HOG features that are appearance and shape of pedestrian are described by the distribution of intensity gradients were used to detect pedestrian. As another example, detection of vehicle and pedestrian based on wireless sensors was proposed by Shoma and Shunsuke [18]. The dedicated on-board sensors were used to estimate positions and motions of pedestrians and vehicles.

The collision prediction and avoidance algorithm is another important technology to pedestrian-vehicular collision avoidance. The position of pedestrian was obtained with stereo vision by Llorca [19]. The time to collision (TTC) between the vehicle and pedestrian was calculated to predict collision. An abstract model was proposed by Castro [20]. The location of pedestrian was obtained by a camera. Based on this information, the future trajectory and speed of pedestrian were estimated. Then, a fuzzy rule was defined to estimate collision. Chen proposes a method for predicting collision that can learn and predict pedestrian motion. Motion Patterns (MP) was used to learn pedestrian trajectory [21]. The time difference to collision (TDTC) was proposed by Zhang et al. [22] to analyze and estimate the behavior between vehicle and pedestrian. The results of this study were shown that the safe case is represented by larger value of TDTC. When the value of TDTC is close to zero, the case is more dangerous.

In this study, pedestrian detection is carried out using a single optical camera that the position and relative motion of pedestrians can be provided. The pedestrian motion is considered as liner motion in many previous studies. However, the motion of pedestrian is curve in some case. In this study, the model of pedestrian motion is established. And the extended Kalman filter is used to accurately estimate the motion of pedestrian. And the motion of vehicle is collected with inertial navigation system. Therefore, the curve motion of pedestrian should be considered in collision analysis. The TTC is an instant time in the previous studies. And the TTC is warning the driver when the collision will happen. And the potential collision is not estimated by TTC. However, the potential collision may be danger for pedestrian. Therefore,

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the potential collision is also considered in collision analysis. Based on the above analysis, the time to collision range (TTCR) is proposed to predict and prevent pedestrian-vehicular collision.

This paper is organized as the following: the next section provides methodology including experimental vehicle construction, pedestrian detection, and pedestrian trajectory prediction. Then, experiments are described, followed by the results. Conclusions and future work of this study are provided in the last section.

II. METHODOLOGY

A. Experimental Vehicle

The experimental vehicle used in this study is ALSVIN, which was made in China. It is equipped with video cameras, inertial navigation system, control module and industrial computers (see Fig.1). The brake system of vehicle was refitted by Electronic Vacuum Booster (EVB). The signals of EVB and result for detecting pedestrian are read through the controller area network (CAN) bus. When the collision signal is transferred, the vehicle will stoped by EVB. The inertial navigation, RT 2500, is used to collect vehicle motion data including yaw rate, vehicle speed, lateral acceleration, etc. The sampling rate of inertial navigation system is 100 Hz. The signals of inertial navigation are read through an RS232 serial port.

Figure1. The experimental vehicle

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B. Pedestrian detection

In this study, a single optical camera (see Fig.2) is used to detect pedestrian. The C^4 algorithm is applied to detect pedestrian. In this algorithm, the texture memory is used to compute Sobel images. The resizing process is also implemented by texture. In an image, a 36*108 sliding window is moved. Every window, the CENTRIST descriptors are calculated. The CENTRIST descriptor is computed using Census transform (CT) images. The value is computed between a pixel in a Sobel image and its eight neighbouring pixels by CT. The CENTRIST descriptor is constituted by histogram of these CT values. In a window, a feature vector is extracted. The pedestrian is considered, if the value of a window is larger than the defined threshold.


Figure2. The experimental camera

C. Pedestrian trajectory

A new position estimation model of pedestrian is proposed in this study. The current position of pedestrian is defined as (x_{cur}, y_{cur}). And the prediction position of pedestrian is (x_{pre}, y_{pre}). The velocity of pedestrian is v. The angle between x axis and direction of v is φ. The model of pedestrian is as follow:

$$f = (x_{pre}, y_{pre}) = \begin{cases} x_{cur} & (v = 0, a = 0) \\ x_{cur} + v \cdot t \cdot \cos\varphi & (v \neq 0, a = 0) \\ x_{cur} + v \cdot t \cdot \cos\varphi + a \cdot t^2 \cdot \cos\varphi / 2 & (v \neq 0, a \neq 0) \\ y_{cur} & (v = 0, a = 0) \\ y_{cur} + v \cdot t \cdot \sin\varphi & (v \neq 0, a = 0) \\ y_{cur} + v \cdot t \cdot \sin\varphi + a \cdot t^2 \cdot \sin\varphi / 2 & (v \neq 0, a \neq 0) \end{cases}$$

There are different coordinate systems between camera and ground (see Fig.3). In order to analyze the collision, the coordinate system is needed to be transformed. The coordinate of vehicle based on ground is (x, y). And the coordinate of pedestrian based on camera is (x', y'). Therefore, the pedestrian coordinate based on ground is (x'', y'').

$$\begin{aligned} Pedestrian_{(x,y)/ground} &= (x``, y``) \\ &= (\sqrt{x`^2 + y`^2} \cdot \cos\alpha + \sqrt{x^2 + y^2} \cdot \cos\beta, \\ &\quad \sqrt{x`^2 + y`^2} \cdot \sin\alpha + \sqrt{x^2 + y^2} \cdot \sin\beta) \end{aligned}$$

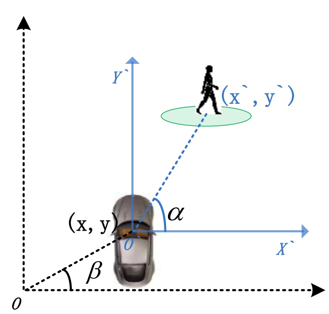


Figure3. The coordinate system

In this study, the flat and horizontal of road is assumed. It is necessary to assess the location of pedestrian accurately to analyze the collision. The extended Kalman filter is widely used to estimate the location. It can accurately estimate location of object if the motion information is obtained.

Therefore, the extended Kalman filter is applied to estimate location of pedestrian.

The state vector of Kalamn filter is defined by location and speed of pedestrian:

$$Q(t) = \begin{bmatrix} x_p & y_p & v_x & v_y \end{bmatrix}^T$$

The process equation is

$$Q(t) = AQ(t-1) + \sigma(t)$$

where

$$A = \begin{bmatrix} 1 & 0 & t & 0 \\ 0 & 1 & 0 & t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The vector $\sigma(t)$ represents process noise, which is modeled as a zero-mean white-noise. The state vector and the observation vector are described by measurement equation. The measurement equation can be obtained.

$$U(k) = \begin{bmatrix} m(k) \\ n(k) \end{bmatrix} + \zeta(k) = \begin{bmatrix} \sqrt{x_p^2 + y_p^2} \\ \arctan(x/y) \end{bmatrix} + \zeta(k)$$

The vector $\zeta(k)$ represents measurement noise, which is modeled as a zero-mean white-noise. The equation of measurement is a non-linear equation, so the EKF can be used.

D. Collision Prediction Algorithm

The time-to-collision has been widely considered as a safety indicator in the collision analyses. The value of TTC was defined as an instant time [23].

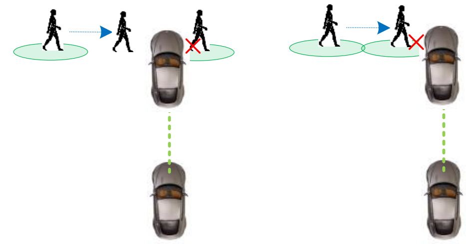
$$TTC = \frac{L_1 - L_2 - l}{|V_1 - V_2|}$$

Where, L1 is the distance between host vehicle and the place of collision. L2 is the distance between other vehicle and the place of collision. V1 is the velocity of host vehicle. V2 is velocity of the other vehicle or obstacle. L is the length of host vehicle.

The driver is warned by TTC when the collision will happen. But the potential collision is not estimated by TTC. And the potential collision may be danger for pedestrian. For example, the potential collision may not happen if vehicle is slowed down by driver. However, the potential collision must be happen if the vehicle is speeded up to leave the pedestrian's own lane. In this case, the driver is warned about the potential collision before the vehicle is speeded up. The collision will be prevented. Therefore, in order to insure the pedestrian safety, the TTCR is established. TTCR is divided into three levels including safe, potential collision and collision. Although pedestrian is detected, the trajectories of vehicle and pedestrian are not intersection in a certain time (η) . This case is defined as safety level.

If vehicle keep the motion, the trajectories of vehicle and pedestrian could be intersection. This case is defined as potential collision level. Two scenarios were considered in potential collision level. One scenario is that the pedestrian is just cross the intersection of collision (see Fig.4 (a)). The other scenario is that the vehicle is just cross the intersection of collision (see Fig. 4(b)). In this case, the value of TTCR has the threshold (ψ, ξ) .

$$\psi < TTCR < \xi$$



(a) (b)

Fig. 4 Potential collision level

If vehicle keep the motion, the trajectories of vehicle and pedestrian must be intersection. This case is defined as collision level (see Fig.5). The value of TTCR is zero.

$$TTCR = \frac{L_1}{V_1} - \frac{L_2}{V_2} = 0$$

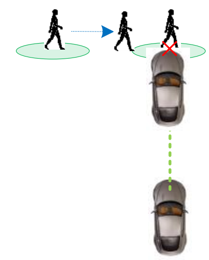


Fig.5 Collision level

III. EXPERIMENT RESULTS

A. Pedestrian detection

In this study, the C^4 algorithm was used to detect pedestrian based on a PC with Intel Core i7-2600 CPU, 8G memory. The 1000 images were used to test the correct rate of detection system. About 90% pedestrian can be detected per image. According to error analysis, the mainly reason is caused by the trees which are like pedestrian.

The postion of pedestrian can be predicted by EKF. In this study, the test distance between pedestrian and vehicle is less 40 meter. The values of X-axis and Y-axis are calculated. The average errors of X-axis and Y-axis are 0.41 meter and 1.39 meter, respectively. It is found that the error became smaller as the distance between pedestrian and vehicle became smaller.

B. Safety assessment

The safety assessment is obtained from 20 individual observers based on the video from camera. Three levels including safety, potential collision and collision are built. The X-shaped intersection is conducted in this experiment. 71 cases are analyzed by observers. The results are described in Table 1. According to the safety assessment, the different distances of three levels can be obtained. Based on the distance and vehicle speed, the time threshold of TTCR is defined in Table 2. Safety assessment from TTC and TTCR was compared and shown in Table 3. To warn the potential collision, the voice and flashing icons are represented in the warning system (see Fig.6) when the potential collision is predicted. The vehicle will brake if the serious collision is assessed. According to Table 3, the potential collision cases could be considered as safety by TTC. Therefore, there are not warning and braking by the collision avoidance system, and the collision accident may be happened. However, the potential collision cases can be detected by TTCR. Thus, the driver will be warned, and the collision accident could be prevented. Another example in table 3, the potential collision cases could be considered as collision risk by TTC according to the data in table 3, and the vehicle will be braked. However, the brake may be redundant because the driver can take measure to prevent the collision under the warning. The TTCR algorithm can avoid this situation well. Therefore, frequent or deficient warning can be represented by warning system with TTC, and warning system with TTCR can warn and control vehicles more reasonable.

Table 1 Safety assessment of observers

Vehicle speed (km/h)	Safety assessment (Number of cases)		
	Safety	Danger	
		Potential collision	Collision
10	7/21	9/21	5/21
20	9/25	10/25	6/25
30	16/25	6/25	3/25

Table 2 Time threshold of TTCR

Vehicle speed (km/h)	Time Threshold (s)		
	Safety (η)	Danger	
		Potential collision (ξ)	Collision (ψ)
10	3.8	3.2	3
20	2.7	2.2	1.9
30	2.3	2.1	1.8

Table 3 Compared between TTCR and TTC

Vehicle speed (km/h)	Safety assessment (Number of cases)					
	safe		Potential collision		Collision	
	TTC	TTCR	TTC	TTCR	TTC	TTCR
10	11/21	6/21	0/21	10/21	10/21	5/21
20	13/25	11/25	0/25	7/25	12/25	7/25
30	19/25	12/25	0/25	8/25	6/25	5/25

Fig.6 Interface of warning system

IV. CONCLUSION

In this study, the C4 algorithm is applied for detecting pedestrian. The Soble image, CT image and histogram are computed by this detection system. The detection result shows that the correct rate is about 90%. The pedestrian model is proposed by this study. Based on the pedestrian model, the extended Kalman filter is used to predict the location of pedestrian. In order to insure the safety of pedestrian, the tradition TTC is improved as TTCR. The potential collision is considered in TTCR model. The experiment result shows the TTCR is more reasonable and safe for pedestrian. The proposed pedestrian-vehicular collision avoidance system can be combined with other avoidance systems such as the Cooperative Vehicle Infrastructure System (CVIS) to enhance the performance of collision avoidance. The proposed method can be further enhanced. First of all, the variously environments, such as light, rain and snow, are impact on accuracy of detection pedestrian based on video. The challenge is to develop an accuracy method to detect vehicle. Furthermore, when a group of pedestrian is ahead of a vehicle, a decision algorithm, to choose the most dangerous condition, is needed to add in the TTCR to accuracy warning or braking.

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