# Pedestrian Collision Warning of Advanced Driver Assistance Systems

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***Abstract*— Pedestrian collision warning system is one of the major functions of Advanced Driver Assistance Systems. The proposal uses single camera and a cascade detection algorithm to develop the pedestrian collision warning system. Harris corner detection algorithm is applied for getting the features of pedestrian's contour. The modified Lucas-Kanade optical flow algorithm is used to estimate motion vector of pedestrian. Grey theory is used to predict the future driving path of vehicle. And the proposed collision warning system is based on the motion vector of pedestrian and the future driving path of vehicle.**

***Keywords*— Collision warning, Pedestrian detection, Optical flow, Grey theory**

## I. INTRODUCTION

In recent studies, computer vision technologies have been widely used for object detection, especially in the applications of Advanced Driver Assistance System (ADAS). Y.C. Lin et al. [1] used the methods of image morphologies, corner detection, and inverse perspective mapping to detect objects for parking assistance system. These methods have the properties of low computational complexities. Nevertheless, these methods can only detect still objects in the parking assistance application. C.G. Keller et al. [2] proposed an active safety system for pedestrians, the system can validate the brake automatically to avoid collision in specific driving scenarios. For detecting objects and predicting the movements of objects, use sequential stereo images to reconstruct 3-D road scenes and 3-D movement fields, which called 6-D vision. This system can acquire and track the position of object. But the computing of the proposed algorithm is huge and hence it is hard to be implemented. C.T. Hong et al.[3] installed four cameras around a vehicle to set up the bird's eye view, and applied the optical flow algorithm with the inverse perspective mapping method to detect objects around the vehicle. This method aims to improve the non-consistent of optical flows between the inner and outer sides of vehicle when the vehicle makes turns. Furthermore, the proposed method is restricted to applied to vehicles designed based on Ackermann Steering Geometry.

Pedestrian detection is one of the major functions of ADAS. Considering the computational complexity of object detection algorithm and the hardware cost of stereo vision, our proposal uses only single camera and a cascade detection algorithm to develop the pedestrian collision warning system. The cascade detection algorithm focuses on the region of interest (ROI) to measure the motion vector of the pedestrian. Since the applications of cascade structure of detection algorithm and ROI were adopted, the proposal eliminates the time exhausting computation of stereo vision.

## II. THE PEDESTRIAN COLLISION WARNING SYSTEM

The proposal includes three parts, as shown in Fig. 1. The first part is pedestrian detection. It finds the position of pedestrian on the image. The second part is to obtain the motion vector of pedestrians. And the third part is to predict the future path of movement of pedestrians, calculate the collision time, and to determine the possibility of a collision.

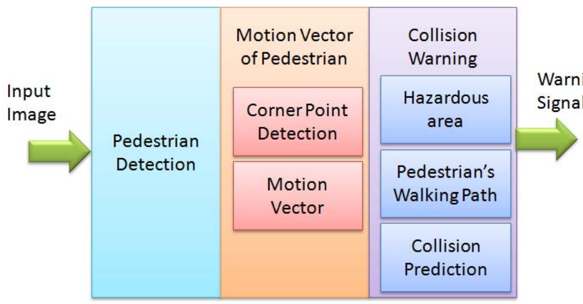


Fig. 1 Pedestrian collision warning system

### A. *Pedestrian Detection*

In our previous work [4], a novel pedestrian detection system that uses Harr-like extraction and a covariance matrix descriptor to identify the distinctions of pedestrians has been presented. The detection procedure is accelerated using a two-layer cascade of classifiers. The front end, constructed based on Harr-like features, can select candidate regions quickly wherever pedestrians may be present. Moreover, the back end, constructed based on the covariance matrix descriptor, can determine accurately whether pedestrians are positioned in candidate regions. If a region tests positive through the two-

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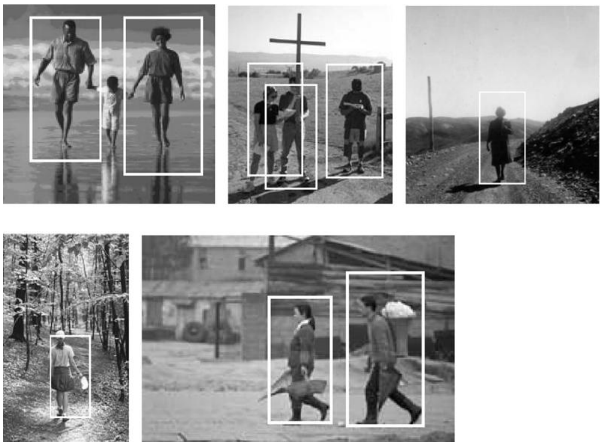


Fig. 2 Detection results of photos of the USC pedestrian test set [5]

layer cascade classifiers, pedestrian images are likely captured and marked by oblongs, show in Fig. 2.

### *B. Motion Vector of Pedestrian*

After the position of pedestrian on the image has been marked, the movement of pedestrian is the major judgment for collision warning system. And for the consideration of computing efficiency, the following procedures are executed only in the marked oblong area which also called region of interest (ROI).

*1) Features of pedistrian's contour:* For estimating the motion vector of pedestrian, Harris corner detection algorithm [6], as shown in equation (1), is applied for getting the features of pedestrian's contour first.

$$G(x,y) = \sum_u \sum_v w(u,v) \cdot \left[ \left[ I_x(u,v)\, I_y(u,v) \right] \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \right]^2 = [\Delta x \quad \Delta y]\, A \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}, \tag{1}$$

$$\text{where } A = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$$

G(x,y) equals the squared sum of the differential errors in 0˚,45˚, 90˚,135˚,180˚,225˚,270˚, and 315˚ totally 8 directions; $(u,v)$ is the range of calculation, usually is a 3x3 square area; $\Delta x$ and $\Delta y$ are the displacement in x and y directions in the range of calculation, respectively; $w$ is a Gaussian window; I represents the gray level value at (x,y) coordinate on the image, $I_x$ and $I_y$ are the differential values of I in x and y directions, respectively.

The matrix A includes the properties of gradients in 8 directions. From observing the eigenvalues $\lambda_i$ of matrix A, (x,y) will be defined as an corner point if the eigenvalues of matrix A have similar values. The motion vector of the corner point found on the image represents the future walking path of the pedestrian.

*2) Estimation of motion vector:* The motion vector of pedestrian represents the future walking path of pedestrian. The modified Lucas-Kanade (LK) optical flow method [7] is used to estimate motion vector. Based on constant brightness phenomenon, two sequential image frames at time *t* and *t+1* have similar brightness, as shown in equation (2).

$$I(x,y,t) = I(x+u, y+v, t+1) \tag{2}$$

After taking Taylor expansion from equation (2), we have equation (3), where $I_t$ is the derivatives of I by time.

$$[I_x \quad I_y] \cdot [u \quad v]^T + I_t = 0 \tag{3}$$

Suppose LK optical flow method has the property of spatial coherence, it means that the $n \times n$ neighborhoods around (x,y) will move in the same direction and same speed. $d = [u \quad v]^T$ denoted in equation (4) represents the solution of

$$d = \left( \begin{bmatrix} \sum I_x I_x & \sum I_x I_y \\ \sum I_x I_y & \sum I_y I_y \end{bmatrix} \right)^{-1} \cdot \begin{bmatrix} -\sum I_x I_t \\ -\sum I_y I_t \end{bmatrix} \tag{4}$$

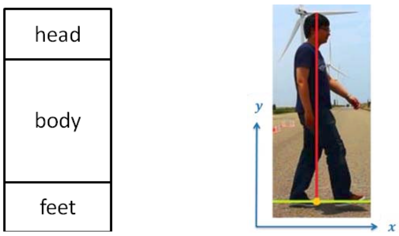
equation (3). It represents the motion vectors in 8 different directions.

### *C. Prediction of Collision:*

*1) Calculate the position of pedestrian:* For precisely estimating the motion vector of pedestrian, the marked oblong of the pedestrian detection result is divided into three regions, includes head, body and feet regions, as shows in Fig. 3(a). When pedestrians are in moving status, the variations in hands or feet are quite obvious. So it is not suitable for estimating the motion vector of pedestrians. In this study, use the variations of head in sequential image frames to estimate the motion vector. And calculate the feet position on the image to represent the position of the pedestrian (Fig. 3(b)). The procedures are as follows：(1) The marked oblong is divided into three regions, includes head, body, and feet. Next, apply optical flow method to calculate the motion vectors of the corner points in head and feet regions; (2) Some corner points are belong to pedestrian, but some are belong to background. Based on the optical flows of corner points, corner points of background can be distinguished and removed; (3) After background is removed, the position of the pedestrian m(x,y) is measured using equation (5).

$$m(x,y) = \left( \frac{\sum_{i=1}^{n_h} head_i(x)}{n_h}, \frac{\sum_{i=1}^{n_f} foot_i(y)}{n_f} \right) \tag{5}$$

$n_h$ is the number of corner points in head region; $n_f$ is the number of corner points in feet region; $head_i(x)$ is the x coordinate of the i-th corner point in head region, $foot_i(y)$ is the y coordinate of the i-th corner point in feet region. In Fig.




(a) (b)

Fig. 3 Position of pedestrian


Fig. 4 hazardous zone

3(b), the yellow-colored line indicates the pedestrian position m (x, y).

*1) Definition of hazardous zone:* A hazardous zone is defined as the travel route of vehicle will soon drive into. The danger occurred in following cases (1) Pedestrian will appear in the hazardous zone; (2) Pedestrian stays in the hazardous zone. In this paper, with reference to general urban roads and general dimensions of vehicle, the camera is mounted in the center of the windshield. The hazardous zone is set in the range shown in Fig. 4. The left of the 1.5-meter line is denoted as $D_L$, the right of the 1.5-meter line is denoted as $D_R$.

*2) Prediction of pedestrian's walking path:* In this paper, grey theory [8] was applied to predict the future walking path of pedestrian. Grey theory has the priority of new information and minimum message explore uncertainty, this property will make our work more sensitive to predict the subsequent pedestrian path. Grey prediction uses the optical flow calculated in previous sub-session to predict the future walking path of pedestrians. It is the information for determining whether a collision with the vehicle will happen or not.

Grey prediction models are usually represented by $\mathrm{GM(h, N)}$, where h is the differential order and N is the number of variables. Grey prediction is used to predict the changes in the future by analysing the past data. The GM(1,1) model of the Grey differential equation is:

$$\frac{\mathrm{dx}^{(1)}}{\mathrm{dt}} + \mathrm{ax}^{(1)} = \mathrm{b} \tag{6}$$

Where a is the representative of the development function; b is a control variable; x represented as a sequence of variables. Grey theory uses the motion vector $\mathrm{d} = [\mathrm{u} \quad \mathrm{v}]^{\mathrm{T}}$ of pedestrian estimated by optical flow algorithms to predict the next location of the pedestrian. If the current location of the pedestrian is $(\mathrm{P_u}, \mathrm{P_v})$, the next location of pedestrian in the future time $f \cdot \Delta T$ can be expressed as equation (7). Where $\Delta u_i$ and $\Delta v_i$ denotes as the differences of the motion vectors between time $i \cdot \Delta T$ and time $(i\text{-}1) \cdot \Delta T$

$$\begin{aligned}(\mathrm{P_{u+f}}, \mathrm{P_{v+f}}) = (&\mathrm{P_u} + \Delta \mathrm{u_1} + \cdots \Delta \mathrm{u_f} \\ &, \mathrm{P_v} + \Delta \mathrm{v_1} + \cdots \Delta \mathrm{v_f})\end{aligned} \tag{7}$$

*3) Calculation of collision point:* The collision point will be estimated if the pedestrian will walk through the range of hazardous zone. $(\mathrm{P_u}, \mathrm{P_v})$ is the current location of pedestrian, then calculates the future location $(\mathrm{P_{u+f}}, \mathrm{P_{v+f}})$ at $\mathrm{f} \cdot \Delta\mathrm{T}$ later. The last two locations can be used to establish a linear equation. Cramer's rule [9] is used to find the intersections of the linear line and the hazardous zone. According to the location and the motion vector of pedestrian, the proposal defines 6 types of the future movements as shown in Fig. 5. Green point denotes the location of the pedestrian, blue vector denotes the moving direction of the pedestrian. Cramer formula is used to estimate the crossing point $(\mathrm{x_b}, \mathrm{y_b})$, the results are shown in Fig. 6.

## III. Experiment Results

The experiments were tested on the roads in urban area during daytime. A camera installed in the center of the front windshield of the car. The specification of the camera is shown in Table 1. Figure 7 shows the detection results of corner points. Figure 8 shows the detection results of motion vectors. Experimental results in real test are concluded in Fig. 9. The estimations of our proposal are consistent with the accurate measurements.

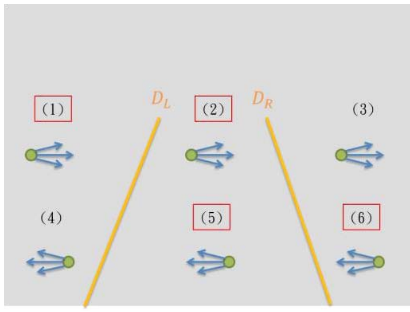



Fig. 5 Classifications of moving directions


Fig. 6 Prediction of collision point

TABLE 1.
SPECIFICATIONS OF CAMERA

| | |
|---|---|
| **SENSOR** | CMOS |
| **FOCAL LENGTH** | 29 MM |
| **RESOLUTION** | 640×360 |
| **ERECTION HEIGHT** | 120CM |
| **TILT ANGLE** | 1° |

Fig. 7 Results of corner detection

Fig. 8 Results of motion vector

| INPUT IMAGE | |
|---|---|
|  | |
| RESULTS | |
|   | |
| ESTIMATE DISTANCE OF PEDESTRIAN | ACTUAL DISTANCE OF PEDESTRIAN |
| (1.42M,4.37M) | (1.55M,4.52M) |
| ESTIMATE DISTANCE OF POINT OF COLLISION | ACTUAL DISTANCE OF POINT OF COLLISION |
| (-1.91M,6.04M) | (-2.03M,6.08M) |
| ESTIMATE TIME THAT PEDESTRIAN TO REACH THE POINT OF COLLISION | ACTUAL TIME THAT PEDESTRIAN TO REACH THE POINT OF COLLISION |
| 5.32(S) | 5.58(S) |
| ESTIMATE TIME THAT VEHICLE TO REACH THE POINT OF COLLISION | ACTUAL TIME THAT VEHICLE TO REACH THE POINT OF COLLISION |
| 0.78(S) | 0.78(S) |

Fig. 9 Real test results of the proposal

## IV. CONCLUSION

The proposal uses single camera and a cascade detection algorithm to develop the pedestrian collision warning system. Based on the image processing technologies, Collisions can be predicted from using the information of motion vector and the future driving route. It can remind the driver to caution pedestrians and decrease the rate of traffic accidents. The results of experiments show that this system can simultaneously handle multiple pedestrians and correctly calculate the possibility of collision.

Since this system is built based on the parallel architecture, it is efficient to process the three functions, as shown in Fig. 1, in parallel. And this will enable the system to achieve real-time processing application.

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