

Vehicle Warning System for Lane Departure and Collision Avoidance: Using Fuzzy Decision Making

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Abstract—This paper focuses on vehicle warning system based on fuzzy decision making for lane departure and forward collision avoidance for dealing with driver assistant system. The proposed system is composed of vision-based preprocessing and a fuzzy decision making. The objective of vision-based preprocessing part is lane tracking and forward vehicle detection, and provides the necessary information for fuzzy decision making to trigger the warning device. The fuzzy decision making unit can adjust the fuzzy decision rule base follow the driving behavior to increase the warning strength for lane departure and/ or forward collision.

Keywords: lane departure, forward collision avoidance, vehicle warning system, fuzzy decision making.

I. INTRODUCTION

Traffic accident happens throughout the world in nearly every single second, the issue should be considered with high priority to deal with. A traffic environment is complicated and most sudden situations are hardly predicted. Driver-assistance systems that monitor driver intent, warn drivers of lane departures, or assist in vehicle guidance are all being actively considered [1]. Although lane position determination is an important component in driver-assistance systems, it is noticed that either lane departure assist or dynamic control assist alone is inadequate to construct a reliable driving assistant system. For drowsy or unawareness drivers, it is hazardous for both himself and other road users as the host vehicle may not be on the track of lane and keeping safety distance with the forwarding vehicles to avoid collision accident[2].

In this paper, we combine the two into a combo driving-assistant system. The concept is to create a fuzzy decision making for driver warning based on lane departure detection and forward vehicle collision detection. Therefore, this paper focuses on vehicle warning system based on fuzzy decision making for lane departure and forward collision avoidance for dealing with driver assistant system. The proposed system is composed of vision-based preprocessing and fuzzy decision making. The objective of vision-based preprocessing part is lane tracking and forward vehicle detection, and provides the necessary information for fuzzy decision making to trigger the warning device, while the increasing possibility for lane departure and/ or forward collision. The proposed system always supervises the vehicle driver on track in safe and stable velocity incorporated with collision avoidance to aid vehicle to keep safety distance apart.

In this paper, the vision-based preprocessing is composed of lane-marking tracking and vehicle detection. In the preliminary studies, we have proposed a new detection and tracking algorithm by means of Kalman Filter for lane detection [3], [4] and implemented the algorithm in a Multi-core DSP embedded system [5]. The proposed lane tracking system can reduce the operations of image data and increase the operating speed. Following the result of lane-making tracking, the region of interest (ROI) for detection forward vehicle and lane departure information can be obtained. Based on the preliminary study on collision-avoidance [6], an effective method for detecting forward vehicle was proposed in this paper.

This paper contains six sections. Section I is the Introduction. Section II describes the overview architecture of the proposed system. Section III introduces the two parts of preprocessing unit algorithm based on a moving object trajectory tracking. Section IV describes the proposed fuzzy decision making unit. The experimental results describe in Section V and conclusions in section VI.

II. SYSTEM ARCHITECTURE OVERVIEW

The proposed system, which architecture depicted as Fig. 1, consists of preprocessing unit and fuzzy making unit. The preprocessing unit is composed of lane-marking tracking (LMT) part and forward vehicle detection (FVD) part. It receives the image frames from the video camera to obtain the lane-marking area (LMA) in the image plane and lane-departure degree (LDD) follow the result of LMT. The LMA is regards as the region of interest (ROI) for FVD part to detect and compute information of the forwarding vehicle effectively. The output of FVD is velocity (V) of host vehicle, and relative distance between (D) the forward and host vehicle can be derived if a forward vehicle is detected in the ROI.

Fuzzy decision making (FDM) unit receives the outputs of preprocessing unit to identify the situations for warning decision of land-departure and/ or forward vehicle collision. When a forward vehicle is detected, the collision inference part receives V and D from FVD. Then, a predefined safety distance (SD) infers the measured D with current V to estimate time-to-collision (TTC) using a fuzzy inference. TTC is a measure for evaluating the emergent collision situation. The warning decision generates different types of alarm message based on the situations of the TTC and LDD. The proposed AFDM consists of collision inference and warning decision.

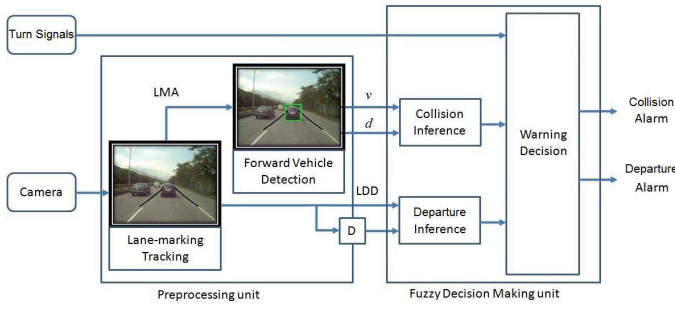


Fig. 1. Architecture of the proposed system

III. PREPROCESSING UNIT

The vision-based preprocessing unit is composed of lane-marking tracking (LMT) and forward vehicle detection (FVD).

A. Lane-marking Tracking

This subsection describes the lane-marking Tracking (LMT) in detail. As shown in Fig. 2, the proposed algorithm consists of four steps.

Step 1. to convert input frame to a grayscale “R+G-B”. This special intensity information can enhance the character of the lane-marking.

Step 2. to decide that an initial point is found out by lane-marking detection for initialization or updated by Nearest Neighbor Peak (NNP).

Step 3. to track the lane-marking trend. Kalman filter and NNP is used to track the trend of lane-markings in each frame. The flowchart is shown as Fig. 3. First, the tracking system is set the initial $x(0)$ which is found out from the Step 2. The predicting part is used to predict the next row of lane-marking location by NNP. If the successful measure is obtained, the predicted value will be updated by the predicting part and to next iteration. However, if the lane-marking is not a continuous type, the measure could not be found out. Therefore, Kalman filter uses the predicted location to present the trend of lane. Finally, if the iteration number k is to meet conditions which is tracking length. Then the tracking step will be stopped.

Step 4. to utilize the result of current tracking initiation to predict the tracking initiation of the next frame.

The proposed LMT algorithm needs only partial region to detect lane-marking location in each frame. The tracking results of LMT are lane-marking area (LMA) in the image plane shown as Fig. 4. The results show that it can reduce the complexity of vision data processing and meet the real-time requirements.

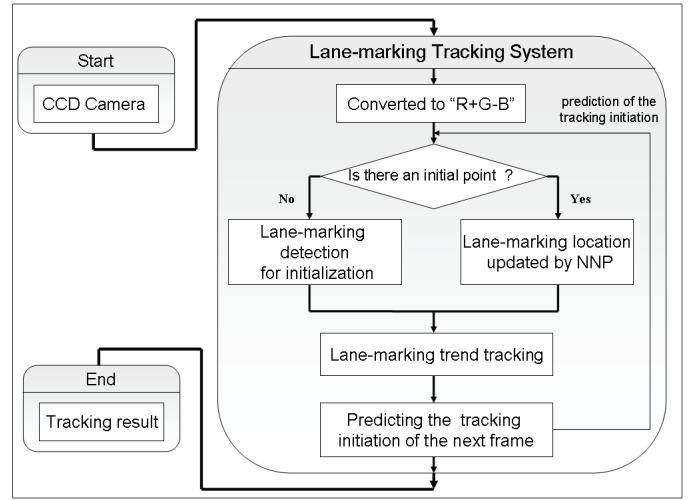


Fig. 2 Flowchart of Lane-marking tracking (LMT)

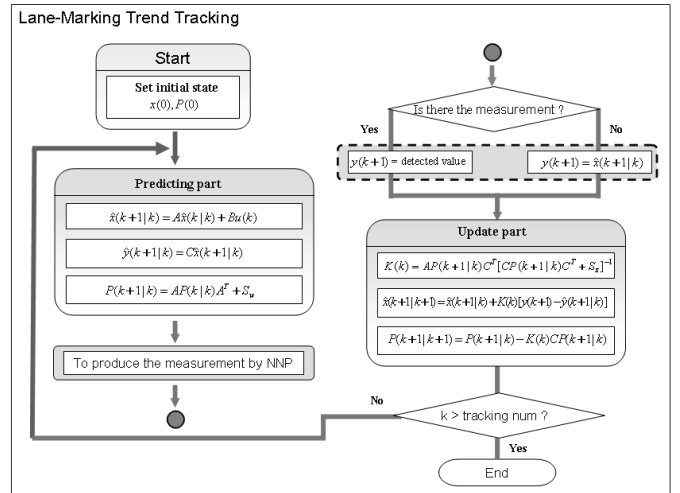


Fig. 3 Flowchart of Lane-marking trend tracking (LMTT)

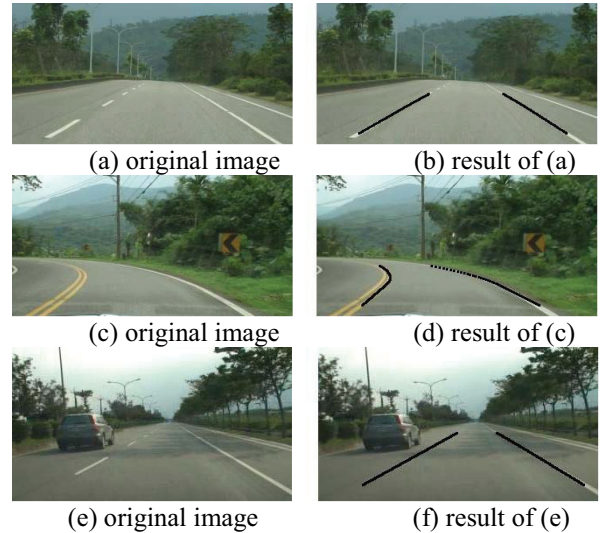


Fig. 4 LMA Results of LMT

B. Forward Vehicle Detection

This subsection describes the forward vehicle detection (FVD) in detail. As shown in Fig. 5, the proposed algorithm consists of four steps. The LMA, the tracking result from LMT, is the ROI for detecting forward vehicle in each image frames. There are three objectives of FVD. The first one is to derive the velocity of host vehicle (V) from global positioning system (GPS) module and the temporal-spatial measure between image frames. The second one is to detect the forward vehicle and calculate the relative distance (D) between forward and host vehicles. The third objective is to measure the lane-departure degree (LDD) of host vehicle for the triggering condition of the warning system.

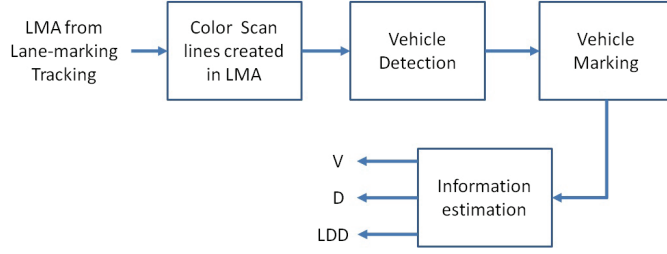


Fig. 5 Flowchart of Forward Vehicle Detection (FVD)

A set of color scan lines are created follow the obtained LMA, and convert into YCbCr color model. A threshold, L , could be decided using (1), where N denotes the total amount of scan line pixels. The set of shadowed pixels of the forward vehicle, E , is derived from (2). Following (3), the forward vehicle could be detected as V_p at the last pixel. The demonstrated examples are shown as Fig. 6. The red line is scan line. The row of detected V_p is sketched by yellow line.

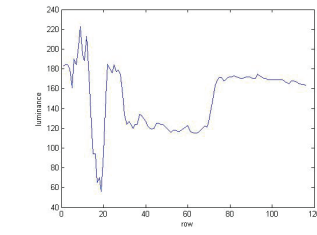
$$L = \frac{\sum_{k=1}^N Y(k)}{N} \times \frac{3}{4} \quad (1)$$

$$E = \{e_i = e(k) \mid i=1,2,\dots,n \text{ and } e(k)=k, \forall Y(k) < L\} \quad (2)$$

$$V_p = e(\text{end}), \text{ end : the last pixel} \quad (3)$$



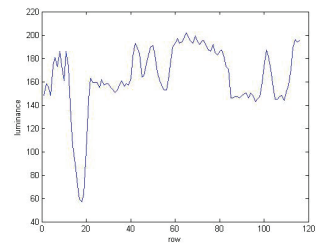
(a) shadowed road



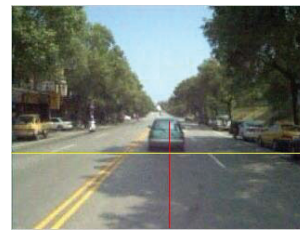
(b) Y values of scan line



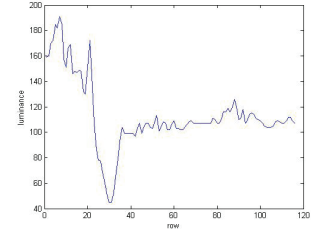
(c) marking in road



(d) Y values of scan line



(e) vehicle in shadowed road



(f) Y values of scan line
Fig. 6 Vehicle detection under different road conditions

When V_p is detected, coordinate mapping relationship (CMR) performs the distance measurement. CMR is the transformation between 2-D and 3-D coordinates systems [4]. If the information of one of coordinates is given, the other is obtained by mapping procedure. The proposed CMR not only derive the distance between image frame and forward vehicle but also the height and width of forward vehicle could be measured.

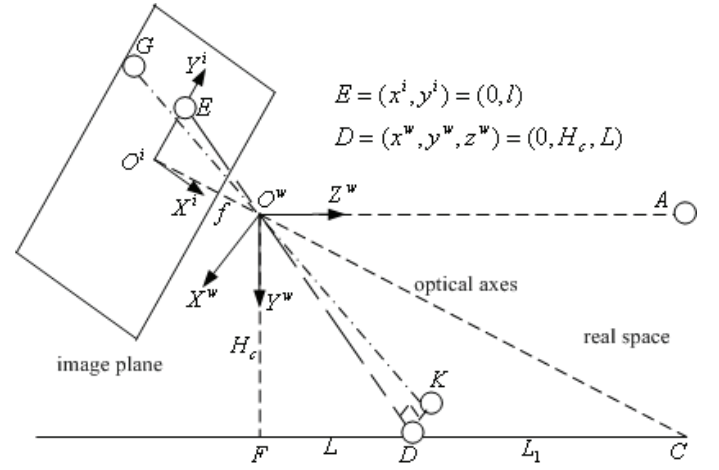


Fig. 7. The geometric relationship

The geometric relationship between 2-D image plane and 3-D real-world illustrated as Fig.7. (X^i, Y^i) and (X^w, Y^w, Z^w) present the coordinate of image plane and real world respectively. O^i and O^w denote the geometric center of image plane and CCD lens respectively. H_c denote the height from O^w to ground. The focal length of CCD lens denote as f . Line $\overline{O^i O^w}$ is the focal axis of CCD and intersects to ground at point C . D and F present the shadow location of the bottom of forward vehicle and the location of CCD lens installed at host vehicle respectively. Therefore, point D is mapping to point E in image plane. Let L denotes the distance between D and F . If H_c and f are fixed, then L can be calculated by (4). In (4), $\theta_1 = \angle A O^w C$ is the depression angle of CCD which is calibrated by (5). c is half of vertical resolution of image plane (example for $c=120$ when image plane is 320×240). y_1 denote the location of image plane which is mapping the vanish point of road. Δp_l is according to the resolution specification of image plane. It can be calculated by (6), where S is the diagonal length of CCD. In (4), $\theta_2 = \angle C O^w D$ is derived by (7),

where $l = \overline{O^i E}$ presents the distance in image plane which is calculated by (8).

$$L = \frac{H_c}{\tan(\theta_1 + \theta_2)} \quad (4)$$

$$\theta_1 = \tan^{-1}\left(\frac{H_c}{L_1}\right) = \tan^{-1}\left(\frac{\Delta p_l \times (c - y_1)}{f}\right) \quad (5)$$

$$\Delta p_l = S \times \frac{p_y}{\sqrt{p_x^2 + p_y^2}} \times \frac{1}{p_y} \quad (6)$$

$$\theta_2 = \tan^{-1}\left(\frac{l}{f}\right) \quad (7)$$

$$l = p_l \times \Delta p_l \quad (8)$$

In Fig. 8, the size of the length of detection window l_{dw} could be calculated via (9) while the distance of the detected forward vehicle L is obtained by (4). In (9), c is half of vertical resolution of image plane (example for $c=120$ when image plane is 320×240), m is the vertical coordinate value of image plane which presents the bottom location of the detected forward vehicle. p_l' can be obtained from (10), where H_v and H_c denote the height and width of vehicle respectively. In (10), L_p denote the depth of 3-D space mapped to m , different L_p could derive different l_{dw} . Therefore, we require (11) to obtain L_p under different m , where θ_1 is the depression angle of CCD.

$$l_{dw} = C + p_l' - m \quad (9)$$

$$p_l' = \begin{cases} \frac{f}{\Delta p_l} \times \tan(\theta_1 - \tan^{-1}(\frac{H_c - H_v}{L_p})) & , \text{if } H_v \leq H_c \\ \frac{f}{\Delta p_l} \times \tan(\theta_1 + \tan^{-1}(\frac{H_v - H_c}{L_p})) & , \text{if } H_v > H_c \end{cases} \quad (10)$$

$$L_p = \begin{cases} \frac{H_c}{\tan(\theta_1 + \theta_2)} & , \text{if } m \in [1, c] \\ \frac{H_c}{\tan(\theta_1 - \theta_2)} & , \text{if } m \in [c^+, 240] \end{cases} \quad (11)$$

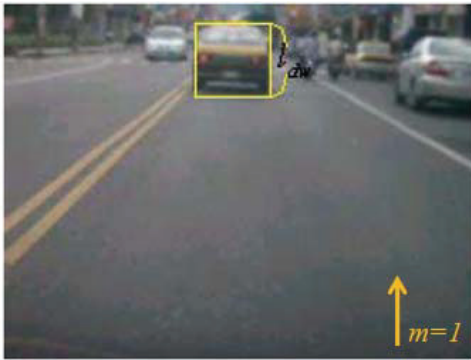
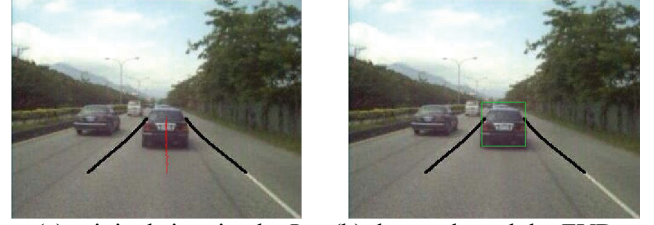


Fig. 8. The detection window of forward vehicle

Following the two stages of preprocessing unit, Fig. 9(a) presents original situation of a red scan line created by LMT part. In Fig. 9(b), a forward vehicle can be detected by FVD

part and completely marked by a precise green box. The distance between the forward and host vehicles measured by CMR is 18.14 m.



(a) original situation by L (b) detected result by FVD

Fig. 9 The result of preprocessing unit.

IV. FUZZY DECISION MAKING

FDM unit receives the outcomes of preprocessing unit. The objective is to identify different triggering situations under different conditions for warning decision of lane-departure and/or forward vehicle collision. When there are no detected forward vehicles, the LDD is calculated by FVD to check the departure situation of the host vehicle for lane-departure warning. When there are any forward vehicles detected by FVD, the collision inference part receives V and D from FVD. Then, a predefined safety distance (SD) infers the measured D with related V_r which is difference between V and velocity of forward vehicle, to estimate TTC for evaluating the emergent collision situation using a fuzzy inference; the departure index (DI) is estimated by departure inference simultaneously. Therefore, the warning decision generates different types of alarm message based on the situations of the TTC and LDD.

Collision inference is used to estimate dangerous level with forward vehicle, and departure inference is used to estimate host vehicle is inside the area of departure lane or not. Then, the warning decision is consider the dangerous level and alert driver. For collision inference, first, related velocity V_r between host vehicle and forward vehicle is calculated by FVD. Then, two input, D and V_r are considered to infer TTC, as Fig. 10. The domain of collision inference is defined by SD and V . It should note that boundary of domain is varied because SD and V are re-calculated in each sampling. The rule of collision inference is described as TABLE I. If D is less than SD and V_r is negative, then the TTC become small (C^+ become larger) that it represents host vehicle is near the forward vehicle. The smaller value the TTC is, the more dangerous vehicle will be.

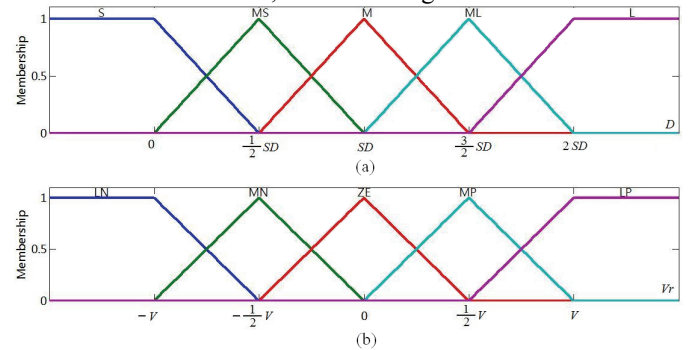


Fig. 10. The membership function of collision inference: (a) distance and (b) velocity membership function.

TABLE I. RULE TABLE FOR COLLISION INFERENCE

$V_r \backslash D$	S	MS	M	ML	L
LM	C^+	C^+	C	C^-	N
MN	C^+	C	C^-	N	S^-
ZE	C	C^-	N	S^-	S
MP	C^-	N	S^-	S	S^+
LP	N	S^-	S	S^+	S^+

*C is collision index, N is normal index and S is safe index.

For departure inference, first, lane vanish point is set in center of video camera that it is ensure the vehicle locating the center of lane at initial setup. In other word, if the lane center is the center column of video frame C_{im} . Then, the right lane y_r and left lane y_l can be gotten by LMT, the lane center C_L is calculated as follows:

$$C_L = \frac{y_l + y_r}{2} \quad (12)$$

and the departure pixel P_{offset} is calculated as follows:

$$P_{offset} = C_L - C_{im} \quad (13)$$

The P_{offset} and ΔP_{offset} are consider to be input in departure inference and their membership function are designed as Fig 11. Values of both membership domains represent the departure pixel in video frame. By experiment result, it is normal driver with departure pixel form 30 to 40 on the way, and the larger ΔP_{offset} is, the more unusual driver is. The rule of departure inference is described as TABLE II, if P_{offset} is large negative and the ΔP_{offset} is negative, then the LDD left alarm is large; if if P_{offset} is large negative and the ΔP_{offset} is positive, then the LDD alarm is zero. Right alarm is similar to left rules.

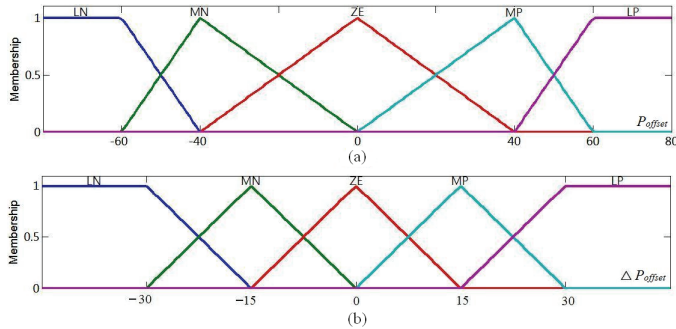


Fig. 11. The membership function of departure inference: (a) distance and (b) velocity membership function.

TABLE II. RULE TABLE FOR DEPARTURE INFERENCE

$V_r \backslash D$	LM	MN	ZE	MP	LP
LM	L^+	L	L^-	N	N
MN	L^+	L	L^-	N	N
ZE	L^-	L^-	N	R^-	R^-
MP	N	N	R^-	R	R
LP	N	N	R^-	R	R^+

*L is left departure index, N is normal index and R is right departure index.

The warning decision is used to warn the dangerous situation. When the TTC and DI are estimated by collision inference and departure inference, the warning decision is active to alarm that it is alert driver that this situation will be dangerous. For FVD, if the collision index is larger than safe index, the collision alarm is alerted which has several alarm level; if the departure index are larger than normal index, the departure alarm is alerted.

V. EXPERIMENTAL RESULTS

Now, it is consider the real driver behavior in the road. Experiment has two parts to show the performance of proposed system: A. Lane marking and forward vehicle detection, then the FVD is estimated. B. Lane marking, then LDD is estimated. the frame rate is 30 frame/sec in all of experiments.

A. FVD experiment

In this experiment, host vehicle accelerated to close the forward vehicle during 50 sec, the situation is shown as Fig. 12. The LMT and LDD results are shown in right column.

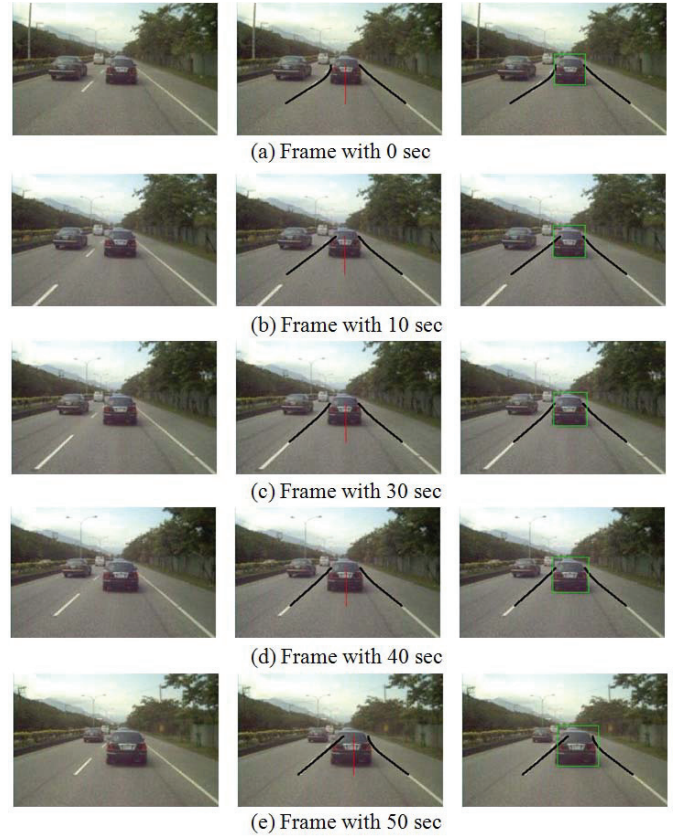


Fig. 12. Lane marking and FVD results

The result of collision inference is shown in Fig. 13, the host vehicle is safe at 20 sec ago. At 30 sec, the host vehicle approaches safety distance, however, it is alarm at 20 sec because the host vehicle accelerated to close the forward vehicle and forward vehicle braked at the same time. After 30 sec, the host vehicle accelerated still to close the forward vehicle lead alarm to be critical by the collision inference.

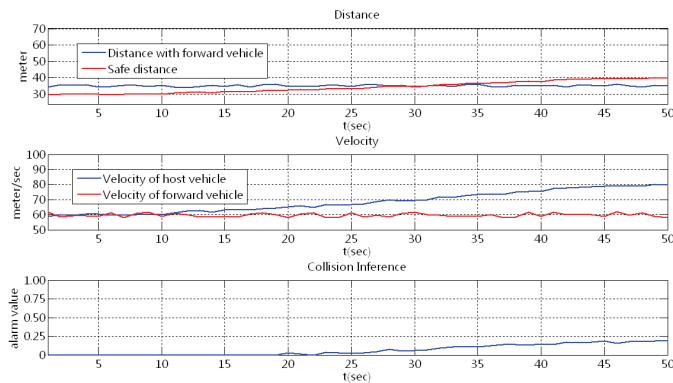


Fig. 13. The distance, velocity, and collision alarm value

B. LDD experiment

In this experiment, vehicle change from left lane to right lane, as Fig. 14. During total of 120 frames with 4 second, the host vehicle changes from left lane to right lane in frame 60 to 75, as Fig. 14 (g) to (h). In departure inference, the negative and positive alarm indicates that the host vehicle is departed to right side and left side respectively. In frame 68, the vehicle just enters the right lane lead inference value has a peak to indicate the left side departure from the lane center.

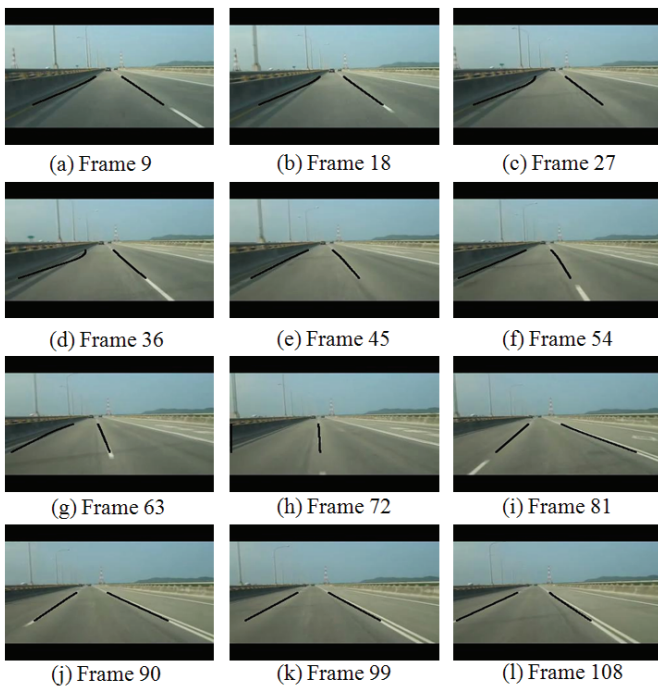


Fig. 14. Situation of change lane during 120 frames

In fact, vehicle always has departure values because video detection error and the behavioral of human driver. So the

alarm has a threshold to restrain small departure value. By experiment, the threshold is set ± 0.3 .

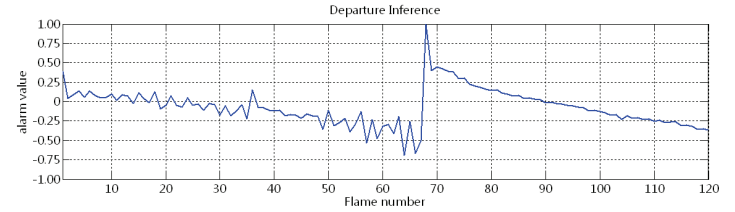


Fig. 15. The departure alarm value in departure inference

VI. CONCLUSION

This paper presents a fast lane-marking tracking, forward vehicle detection, and fuzzy inference to complete a driver assistance system for warning the situations of lane departure and the forward vehicle detection. Following the experiment results, the LMT has better preference and accuracy. Although the detection precision is influenced by the detection area and accuracy of LMT, the FVD also presents high grade. The designed fuzzy inferences are reliable to alert driver no matter departure lane or close the forward vehicle.

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