Development of a Vision-Based Driver Assistance System with Lane Departure Warning and Forward Collision Warning Functions

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Abstract

The objective of this research is to develop an advanced driver assistance system with lane departure warning and forward collision warning functions. The main input of this system is a CMOS camera, which is used to acquire roadway image in front of vehicle. In order to extract lane markings and vehicles from roadway image, the image processing methods such as coordinate systems transformation, object detection and object tracking are applied to recognize the lane boundaries and the preceding vehicles. In lane marking recognition, gray scale statistics, dynamic range of interesting (ROI) and featured-based approaches are used to detect lane boundaries successfully. For vehicle recognition, a Sobel edge-enhancement filter and optical flow algorithm are used to implement vehicle detection and tracking. Besides, by means of the roadway and headway physical estimation models, the circumstances of lane departure and forward collision can be detected. The experimental results indicate that the hardware and the implemented algorithm used in this research are able to recognize the lane markings and headway distance precisely, and meet the requirements of real-time computing and high reliability.

1. Introduction

Within the last few years, due to the increasing awareness of automobile safety and the progress in technology, the main international automobile manufactures focus on developing Intelligent Transportation System (ITS) and Advanced Safety Vehicle (ASV). One of these important achievements is the vehicle safety integration system with image processing technology and it has been proved to reduce accidents significantly. Especially in the applications of CCD/CMOS camera used for driver assistance system is the most popular such as lane departure warning system and forward collision warning system. In these two applications, the most important works are lane boundary and preceding vehicle detection.

There have been many methods for lane markings and preceding vehicle recognition. As described in [1][2], the inverse perspective mapping (IPM) approach is adopted to generate the bird's eye image of the road plane so as to remove the perspective effect and extract lane markings through some constraints of road geometry. Other researches [3][4] combine Hough Transformation and road model to estimate the initial lane boundary and improve the availability of lane detection.

For the ways of vehicle recognition, some researches applied feature-based approaches to detect the preceding vehicle [5]. By using particular vehicle features appeared in roadway image such as texture, edge, symmetry and bottom part shadow to distinguish preceding vehicle from the roadway image data. Some studies used template-matching method to detect [6] by means of numerous vehicle templates (such as edges, wavelet characteristics etc.) built-in the system. The main disadvantage of these approaches is the change of environment would affect the recognition rate and cause misjudgment easily. Moreover, most of methods [7] using learning algorithms are too complicated to implement the image processing in real-time.

The proposed vision-based driver assistance system in this research can detect lane markings and preceding vehicles through a CMOS camera and an image-processing unit simultaneously. By meanings of adopting road geometry model and headway distance estimation model, both of the deviation to lane boundary and the headway distance to preceding vehicle will be calculated. The proposed image recognition method not only can reduce the noise interference from the roadway image but also can utilize the settings of dynamic region of interest (ROI)

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to enhance real time processing. When the vehicle begins to drift towards an unintentional lane change or too close to the preceding vehicle, the system will issue early warnings with sound and light, warning the driver to correct driving direction or slow the vehicle down to prevent the driver from potential traffic accidents.

2. System overview

2.1. System structure

The hardware structure of this system is shown in Figure 1, the major input is a CMOS camera, which was installed between the front windscreen and the rear-view mirror. Therefore, roadway image in front of host vehicle can be acquired via the CMOS camera and transmitted to a Digital Signal Processor (DSP) after the decoding process from NTSC analog format to ITUR-656 digital format. Hereby, the DSP with high computing performance will execute the recognition and estimation algorithm for the functions of lane departure warning and forward collision warning. The major processing flowchart is shown in Figure 2, it can estimate vehicle position with respect to its lane and headway distance to preceding vehicle simultaneously. With these hardware and software structure used in this research, we can achieve a vision-based forward safety system for driver as shown in Figure 3.

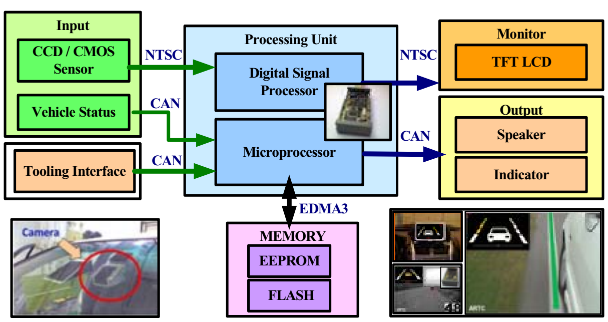

Fig. 1 Hardware structure

2.2. Coordinates system transformation

The relation between the world coordinates and the camera image coordinates is shown in Figure 4. Since the system has to locate lane markings and the preceding vehicle in the image coordinates, the processed 2D image should be transformed into 3D space information through the inverse perspective mapping in order to obtain the lane positions in the real space. Parameters and their definitions in this transformation are shown in Table 1. In such circumstance, we can convert the objects in 2D image into the world coordinates by equations (1), (2) and (3).

According to these x, y and z position data, a quadratic road geometry model can be approximated by meanings of recursive least squares processing and then the physical position of lane boundaries with respect to the host vehicle would be estimated.

$$x = \frac{uH}{e_v m_\theta - v} \cdot \frac{e_v}{e_u} \quad (1)$$

$$y = \frac{e_v H}{e_v m_\theta - v} \quad (2)$$

$$z = \frac{e_v m_\theta H}{e_v m_\theta - v} \quad (3)$$

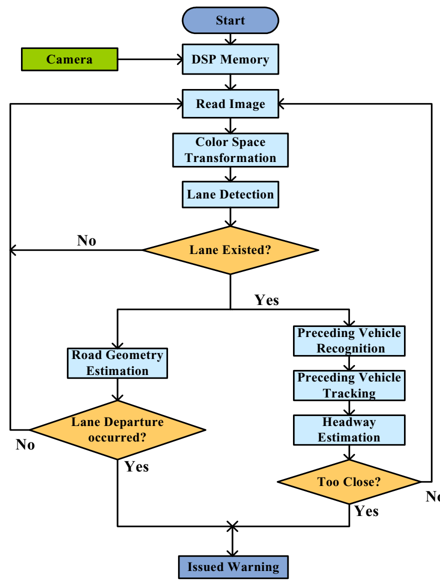

Fig. 2 Flowchart of the driver assistance system

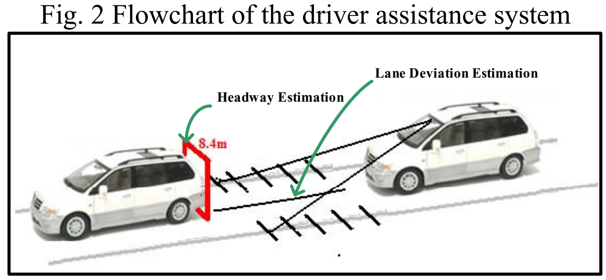

Fig. 3 Lane recognition and headway estimation

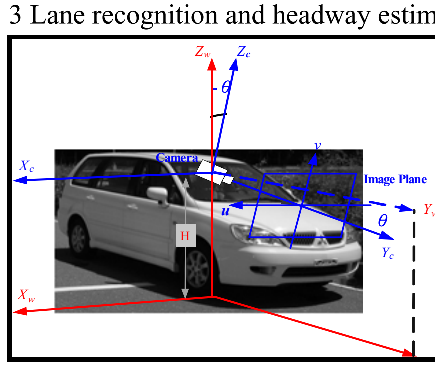

Fig. 4 Image plane and world coordinates definition

Tab.1 Parameters definition

Name	Definition
u	x axis in Image plane
v	y axis in Image plane
H	Height of camera from ground
k, m, b	Coefficient of road geometry
m_θ	Tilt angle of camera
W	Actual lane width
X_w, Y_w, Z_w	World coordinates
e_u	Pixel width of CMOS Sensor
e_v	Pixel height of CMOS Sensor

3. Lane departure detection

3.1. Lane markings recognition

In order to detect whether the host vehicle is departing from its lane through the image processing, the primary work need to be done is to determine positions of lane markings in the image plane. Detecting lane markings use a series of featured-base approaches to do lane markings recognition. Its processing flowchart is shown in Figure 5, and it mainly uses the following features for lane marking extraction.

A. High gray value

Regardless of white, yellow or other lane markings appeared in the roadway image, all of them have higher gray value than road surface. Therefore, we can utilize the statistics of gray scale shown in Figure 3 to identify the threshold value of lane marks and differentiate the lane marks and road surface. In this study, the Sobel's horizontal edge-based technology was used to detect the edge of every lane markings in the image.

$$E(\mathrm{u},\mathrm{v})=\begin{cases} S*[I(u,v)] & if\ \ I(u,v)>0 \\ 0 & otherwise \end{cases} \qquad (4)$$

In the equation, *I(u,v)* is the original image; *E(u,v)* is the edge image. *S*[ ]* represents the Sobel's operation, and its horizontal mask is *[-1 –2 –1; 0 0 0; 1 2 1]*.

B. Range of lane marking width

The actual lane marking width will be shown in the image plane through a constant ratio conversion, the equation (5) shows that even on a road of obscure lane markings, we still can use a determined distance to describe weather the received image can be treated as lane markings or not.

$$\Delta u=\Delta X_w\cdot\frac{e_v m_\theta - v}{H}\frac{e_u}{e_v} \qquad (5)$$

In the equation, Δu is the width of lane marking in the image; ΔX_w is the actual lane marking width.

C. Continuity

Lane markings usually form a lane boundary as segment by segment closed to their neighboring ones. It is an important cue to identify weather it is a lane marking or not.

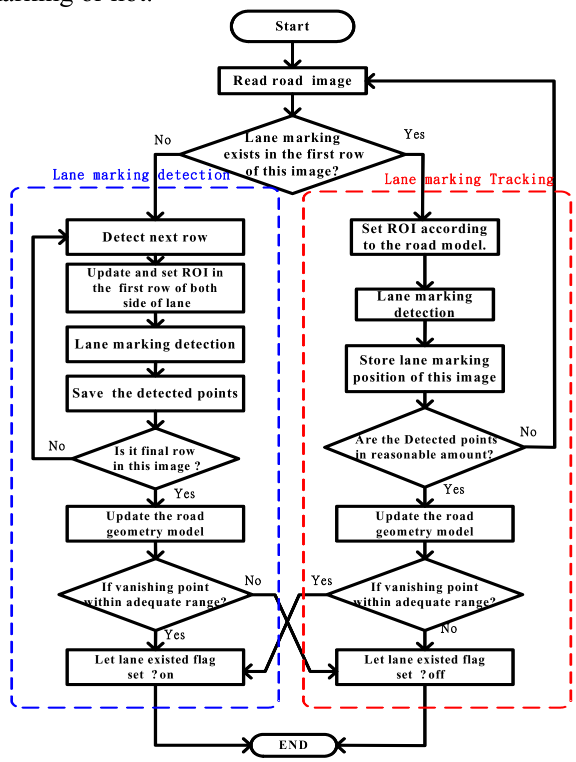

Fig.5 Road modeling flowchart

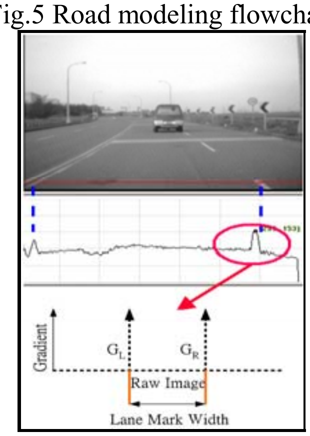

Fig.6 Gray Scale Statistics on roadway image

3.2 Road geometry estimation

In order to enhance the searching speed for lane marking, we used the road geometry model to limit the basic detecting zone within detectable range as shown in Figure 7. In this fundamental detecting zone, we started from the bottom to the top; divide this zone into several equivalent parts and using horizontal method to scan for lane marks; then using equations (6) and (7) to define the range of interesting (ROI).

$$ROI_{n} = [u_{i-1} - \lambda_{n} \cdot \mathrm{Mark}_{l}, u_{i-1} + \lambda_{n} \cdot \mathrm{Mark}_{l}] \qquad (6)$$

$$ROI_{d} = [u_{i-1} - \lambda_{d} \cdot \mathrm{Mark}_{l}, u_{i-1} + \lambda_{d} \cdot \mathrm{Mark}_{l}] \qquad (7)$$

And detect whether lane markings are existed until the last block of the image was processed. The searching result of ROI as shown in Figure 8, under the situation of utilizing image processing to recognize lane markings, an adequate ROI setting not only can reduce noisy signals for finding land marking accurately but also can reduce the processing time by the image processor, to achieve the instant processing result. Figure 9 shows the result after processing the image of lane mark, the left line and the right line are results of detection, and the middle line is the estimated center line of car lane according to both sides of lane marks, this center line can be used to estimate the amount of lane departing off by this vehicle and road curvature.

Once the lane markings were recognized in the image plane, the road modeling for lane markings can be done using coordinates conversion equations (1)~(3) and recursive method to compute an equation as (8) shown for road-modeling simulation equation. In which, the constant value (b), is the deviation value of camera's look-ahead point, the curvature of road (ρ) as shown in equation (9) is used to estimate deviation value when driving in the curve road.

$$x = k \cdot y^{2} + m \cdot y + b \qquad (8)$$

$$\rho = \frac{2 \cdot k}{\left(1 + (2 \cdot k \cdot y + m)^{2}\right)^{3/2}} \qquad (9)$$

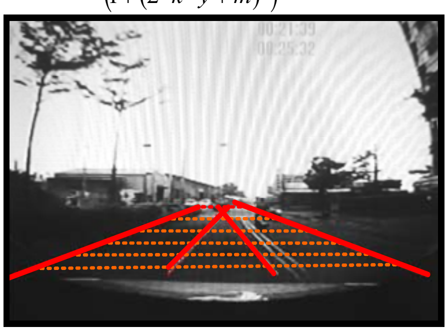

Fig.7 Detection block in roadway image

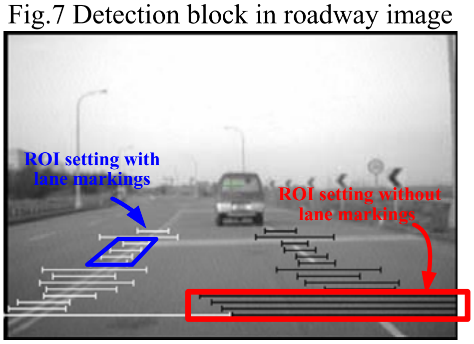

Fig 8. ROI setting in roadway image

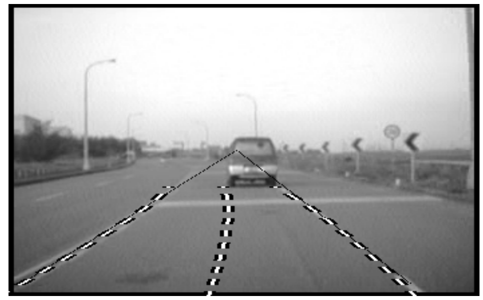

Fig.9 Results of lane modeling

4. Forward collision detection

In order to obtain the distance between the host-vehicle and preceding vehicle, the process of headway estimation is composed of three stages. The first stage is preceding vehicles detection, the second stage is vehicle tracking and the final stage is distance estimation.

4.1 Vehicle detection

The primary work for preceding vehicle detection is to analyze the symmetry of potential vehicle in the image plane by Sobel vertical edge filter and its mask is $[-1\ -2\ -1;\ 0\ 0\ 0;\ 1\ 2\ 1]^{T}$. Afterward a Sobel horizontal edge filter is adopted to detect the continuous horizontal edge and the shape of potential preceding vehicle. After marking the vehicle position in the image plane, the height of preceding vehicle can be estimated by equation (10).

$$CarHi = \frac{(v_{0} - v_{b})(CarHw - H)}{H} \qquad (10)$$

Where $CarHi$ **:** Height of preceding vehicle;

$CarHw$**:** Height of host vehicle;

V_{0}**:**Center position of image plane;

V_{b}**:**Position of preceding vehicle in image plane;

If it is similar to the general vehicle height, the distance between vehicles can be estimated through the image of geometrical relation. After focusing vehicles on the host lane in the ROI, then conducting vehicle recognition, measuring headway and estimating time of close in to preceding vehicle, can effectively reduce range for analysis. Focusing the ROI in the host lane can significantly improve processing speed of detection and accuracy, and avoid system making wrong warnings simultaneously.

Fig. 10 Result of preceding vehicle detection

4.2 Vehicle tacking

Using the above method to detect a previous image frame of the interested vehicle and make it to be a template image, which is $T(X)$, and its $X=[u\ ,\ v]^T$, and let $T(X)$ correspond to a same size of $I(X)$ taken from the current image of the inside lane, the $I(X)$ is used to detect the current vehicle position. When $I(W(X,P+\triangle P))=T(X)$, $\triangle P$ is the Optical Flow, the change of vehicle position between two images. $W(X,P)$ represents the deformation of original image position after Affine Transform, which will lead to image rotation, shrinking or enlarging, tilted or horizontal moving. Its image can be represented in the following equation:

$$I(W(X,P))=\begin{bmatrix} p_1 & p_2 \\ p_4 & p_5 \end{bmatrix} I(X)+\begin{bmatrix} p_3 \\ p_4 \end{bmatrix} \tag{11}$$

In the equation, $\boldsymbol{p_n}$ are the parameters of image deformation. During the process of preceding vehicle tracking, it only has the horizontal moving, so shrinking, enlarging or tilted deformations can be ignored. Therefore, the equation (11) can be rewritten into

$$I(W(X,P))=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} I(X)+\begin{bmatrix} p_3 \\ p_4 \end{bmatrix} \tag{12}$$

Thus, vehicle tracking can be achieved by the moving quantity p_3 、 p_4 calculated from optical flow in this study, the Lucas-Kanade Algorithm [9] was used for tracking optical flow. The result of recognition was shown in figure 10 and the major equation is shown in the following:

$$I(W(X,P+\Delta P))=I(W(X,P))+\Delta I(X)\frac{\partial W(X,P)}{\partial P} \tag{13}$$

In the equation, $\nabla I(X)=\begin{bmatrix} \frac{\partial I(X)}{\partial u} & \frac{\partial I(X)}{\partial v} \end{bmatrix}$ is the gradient of the image and $\frac{\partial W(X,P)}{\partial P}=\begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$, because the horizontal moving change was considered in this paper.

4.3 Headway distance estimation

The headway distance estimation model as shown in Figure 11 mainly bases on the image of preceding vehicle in the image plane and the relation of equivalent triangle equation (14) to calculate the distance between the host and preceding vehicle.

$$d_2=\frac{H\times f_c}{P_r\times(Y_{HV}-\frac{\Delta R}{2})}-d_1 \tag{14}$$

where H is the height of mounted camera from the ground, f_C is the focus length of camera, d_1 is the distance from the camera to the front tip of host vehicle, P_r is the size of every pixel in row direction of the monitor, $\triangle R$ is the size of image in row direction, few parameters as listed below need to be obtained through calculating the collecting data from images, D is the distance between the host camera and the tail of preceding vehicle, d_2 is the headway between two cars, and Y_{HV} is the coordinate of image in row direction of the preceding vehicle bottom end point.

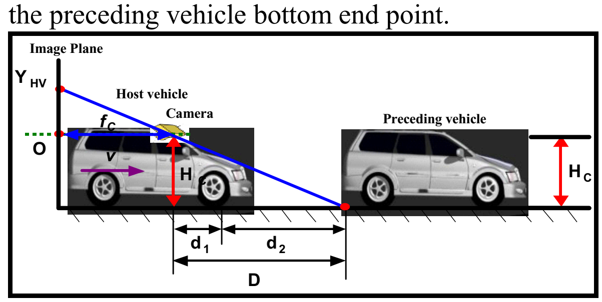

Fig.11 Headway estimation model

5. Experimental Results

This system has been tested on real vehicles under various roads such as highway, speedway, urban roads and ARTC's (Automotive Research and Testing Center) proving ground. These test conditions include various lane markings, front vehicles and road curvature in different weather conditions (e.g. daytime, nighttime, sunny and rainy days). The required visibility of roadway image has to be more than 120m, and the records of accuracy statistics were made during the specific test procedures of lane departure and headway control. The test results of system availability are listed in Table 2. The average availability of the lane departure warning is above 96.3%, and the average availability of forward collision warning is more than 93.5% in sunny day. After carrying out all of the testing, we obtain the average false alarm rate of our system is less than 1.5 times for per hour's driving and the important results of the image processing are shown in Figure 12.

According to the experimental results with the proposed methods in the research, we can summarize the following points:

(1) This system can be used under most of environments in the daylight, nighttime, sunny and raining day.

(2) This system can be used under various lane-markings and vehicles for lane boundary recognition and preceding vehicle detection.

(3) In various environments, the system can provide high availability, reliability and accuracy in lane deviation and headway distance estimation.

(4) The image-processing rate of the system is more than 20 fps (frame per second), and it meets the requirements of real-time computing in an embedded system.

Fig.12 On-vehicle testing results

6. Conclusion

This research has successfully developed a vision-based driver assistance system in a DSP-based (TI 6437) embedded system. Based on a single CMOS camera mounted on the windscreen, the system can recognize lane boundary and preceding vehicle by means of image processing and provide the lane departure warning and forward collision warning functions. In lane departure detection, we applied gray scale statistics, dynamic range of interesting (ROI) and featured-based approaches to recognize the lane boundaries and used road geometry model to detect the lane departure. In forward collision detection, we applied Sobel edge-enhancement filters and optical flow analysis to detect the preceding vehicle and used headway distance estimation model to detect the potential forward collision.

In addition, the driver assistance system has taken convenience installation into consideration. By simplified the installation steps, system can be adaptive to most of vehicles. The system will further advanced to an automatically parameter calibration in the near future, such as parameters of the altitude or view angle of the camera, and add on a self-diagnosis function, to conform with the needs of reliability, real time computing and convenience for advanced driver assistance system.

Tab. 2 System availability

Testing Conditions	LDW (Sunny day) Availability	FCW (Sunny day) Availability	LDW (Rainy day) Availability	FCW (Rainy day) Availability
Speedway	98.2%	95.2%	92.4%	90.2%
Highway	98.6%	95.8%	91%	87.8%
Urban Road1 (Well-Marked)	95.6%	92.2%	86.2%	83.4%
Urban Road2 (Poorly Marked)	94.2%	91.6%	80.6%	81.8%
ARTC High Speed Circuit Curvature=(1/250m)	92%	90.6%	88%	81.2%
ARTC Coast Down Track (1.5km)	99.6%	96%	93.2%	92%
Remark: LDW: Lane Departure Warning; FCW: Forward Collision Warning				

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