A Lane Departure Warning System based on Machine Vision

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Abstract

Lane departure warning system based on machine vision is a human decision-make like solution to avoid lane departure fatalities with low cost and high reliability. In this paper, the model of vision-based lane departure warning system and the realization is described at first. Then the method of lane detection is illustrated, which is composed of three steps: image preprocessing, binary processing and dynamical threshold choosing, and linear-parabolic model fitting. After that, the solution of how to perform the departure decision-making is proposed and demonstrated. Unlike the usual TLC [1] and CCP [2] methods, the angles between lanes and the horizontal axis in captured image coordinate are used as the criterion for lane departure decision-making. At last the experiments are implemented by use of all the steps; the results indicate the efficiency and feasibility of the solution.

1. Introduction

Leaving the lane causes about 30% of all accidents in the high way, and most of these are resulted from the inattentiveness and fatigue of the driver. The U.S. Department of Transportation has reported 42,643 fatalities in the year of 2003, 59% among which were caused by lane departure [3]. Therefore, it's necessary to investigate a driver assistant system which can remind the driver when needed. Actually, the technologies of intelligent vehicle have been researched widely, such as the intelligent transportation system (ITS).

Lane Departure Warning (LDW) system is a typical application in the field of ITS, which is an active safety system to prevent inattentive lane departure. Compared with other technologies, lane departure warning system based on machine vision is a human decision-make like solution to avoid lane departure fatalities with low cost and high reliability.

There are some machine vision based LDW systems have been reported. The Mobil eye's Lane Departure Warning System uses monocular image processing to detect the lanes and measure the position of the vehicle relative to the lanes. Carnegie Mellon University's AURORA [4] employs a wide-angle lens camera and a portable Sun Sparc workstation. The system use TLC method to make the departure decision. The Michigan University's CAPC [5] uses a camera scene of roadway and a suite of transducers provide vehicle motion and driver steering commands information. These are used to anticipate unintended road departures and warn the driver.

This paper is organized into 5 sections. In section 1, a brief description of lane departure warning and its research status quo is introduced. The construction of a LDW system is described in section 2, which is composed of lane detection module and lane departure decision-making module, and the hardware design is also introduced. In section 3, the lane detection method is illustrated. First a Gauss filter is employed to remove small noises in the incoming picture in the image preprocessing. Then a dynamic threshold value judged by Histogram statistics is utilized for binary processing of image. And the linear-parabolic model fitting is conducted to detect the lane. In section 4, a simple solution of lane departure decision-making is proposed, which is based on angles between lanes and the horizontal axis in captured

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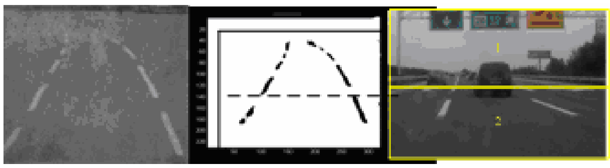
image coordinate. In the final section, experimental results and conclusions are given.

2. Lane departure warning system overview

Lane Departure warning system is composed of two key modules: lane detection module and lane departure decision making module.



(a) Normal lane picture (b) Lane model (c) Image dividing

Figure 1 The lane model and interest region of image

The primary work of LDW system is how to detect the lane correctly. Figure 1(a) shows a typical lane picture. And each lane after picking up is illustrated in Figure 1(b). The model of lanes can be considered as Equation (1) [6], where x_m represents the border between near and far fields.

$$\begin{cases} y = kx + d; x \geq x_m \\ y = ax^2 + bx + c; x < x_m \end{cases} \tag{1}$$

For a captured image, as shown in Figure 1(c), the region 1 contains the stuffs we may not pay attention to; while the region 2 includes the lane information we are interested in. By choosing a proper x_m, the image is split as shown in Figure 1(b). Thus we can adopt the linear-parabolic method to locate the lanes of region 2.

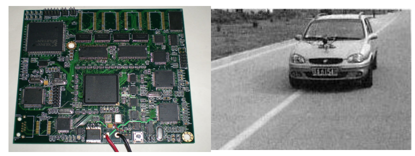
The other necessary part is lane departure making decision module. The departure model can be represent as equation(2), where d is the distance of vehicle from the middle of lane, D is the width between two lanes, h represents the height of the CCD, f stands for focus of the CCD, and P is the incoming picture. There are also other parameters which are not listed in the Equation (2).

$$d = f(D, h, f, P...) \tag{2}$$

The research of the lane departure decision-making is to find the essential relationship between d and the parameters of Equation (2). The proposed departure decision-making model will be discussed later in this paper.

A Lane Departure warning system should be built on a hardware platform, which is composed of a monocular CCD camera, an image acquisition cell, an image process unit, a departure decision-making unit, and an alarm unit.

In our evaluation system, shown as Figure 2(a), the image acquisition cell is made from NXP video decoder; the image process platform and system management are acted by TI DM642, which takes the responsibility of lane detection and departure decision-making; and the alarm unit is a beep controlled by DM642. A sail car equipped with monocular CCD camera, as shown in Figure 2(b), is the evaluation platform.



(a) Main process board (b) Evaluation car

Figure 2 Main process board and evaluation system

3. Lane Detection

The lane detection is the first step of a lane departure warning system. We firstly divide the picture and take the low half regard as Figure 1(c). Secondly we filter the image to remove some black and white noises. Then we make use of the Histogram of the image to gain a proper threshold to perform a binary processing of image. At last we pick up the lane through linear-parabolic way and work out the k, d parameters of Equation (1).

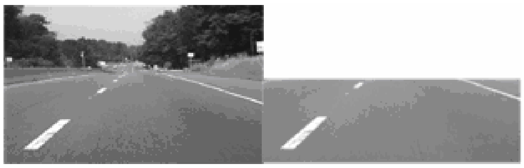
3.1 Image preprocessing

In many cases, the road might be dirtied by cars, rains, etc. In order to remove the spots in the image, we employ a Gaussian template as Equation (3).Given a part image data as Equation (4), we use the Equation (5) to get the result of a′(m, n) .

$$\frac{1}{16}\begin{pmatrix} 1 & 2 & 1 \\ 2 & 4. & 2 \\ 1 & 2 & 1 \end{pmatrix} \tag{3}$$

$$A = \begin{pmatrix} a(m-1,n-1) & a(m,n-1) & a(m+1,n-1) \\ a(m-1,n) & a(m,n) & a(m+1,n) \\ a(m-1,n+1) & a(m,n+1) & a(m+1,n+1) \end{pmatrix} \quad (4)$$

$$a'(m,n) = \frac{1}{4}(1 \quad 2 \quad 1) * A * \frac{1}{4}(1 \quad 2 \quad 1)^T \quad (5)$$



(a) Original image **(b) Image after smoothing**

Figure 3 Original image and image after smoothing

Figure 3 shows the original image and the image after smoothing. After smoothing the image becomes clean and is in a better contrast.

3.2 Binary processing and dynamical threshold choosing

Binary processing of the image is the precondition of a linear-parabolic lane model. Thus we should choose a proper gray value as the threshold [7] for binary processing. In various lamination or weather conditions, the captured image might be in different contrast. It's obviously not proper to choose a constant value as the threshold. In this paper we propose a method to determine the fitting threshold value dynamically based on histogram statistics.

As shown in Figure 4(b), the method is described as the following steps. First, draw a line according to the maximum brightness value point(Hmax) of the histogram and the highest gray value point(Gmax) in the image. Then resolve the point in the histogram curve which has maximum distance(Dmax) to the line, and pick up the value Tm in the X axis. Use Tm as the threshold value for binary processing.

The Figure 4(a) illustrates a bad contrast image; the gray values of other area are close to the gray value of the lane. According to the method of Figure 4(b), use this threshold to perform the binary processing and the result is shown as Figure 4(c).

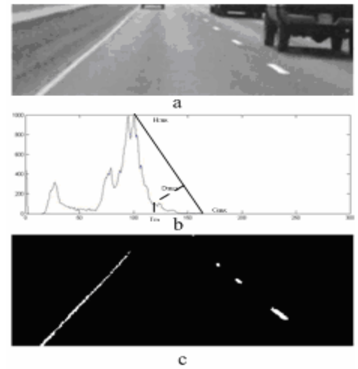


Figure 4 Histogram and image binary

3.3 Linear-parabolic model fitting

According to former discussion, lanes can be treated as the beeline. Hough transform is an efficient way to detect the beeline, but it is too complex to implement in an embedded system. In our design, the least square method is utilized as a simpler solution.

The precondition of implementing the least square method is picking up the point sets of the lanes. Our method is illustrated as follows. To begin with, the image is divided into two parts from the middle line. Then, for the left half, we take a search from left to right. The first white point of each line will be located to establish the point sets. That is, once we find a white point, we put the point into the point sets and jump to the next line; or we should keep searching till we reach the end of this line. In the similar way we can build the point sets of the right part.

4. Lane departure decision-making

TLC and CCP are usual methods for lane departure decision-making [1], which need too many parameters to work out the result however. In order to make the system easier to realize and be adopted by various vehicles, a method which uses as least parameters as possible should be proposed. In our design, the proposed solution for lane departure decision-making is based on angles between lanes and horizontal axis in captured image coordinate, which is discussed as follows.

Above all, the relationship between road view and the captured image through CCD should be analyzed. Present the focus of the CCD as f and the height of the CCD mounted as h. The perspective transfer form the vehicle coordinates to the captured image coordinates can be represented as Equation (6) [8].

$$\begin{cases} x_i = \dfrac{fy}{x} \\ y_i = \dfrac{fh}{x} \end{cases} \Rightarrow \begin{cases} x = \dfrac{fh}{y_i} \\ y = \dfrac{x_i h}{y_i} \end{cases} \tag{6}$$

Furthermore, the relationship between the road and the vehicle coordinate should be worked out. Figure 5 illustrates the straight lane condition. Given the width of the road is D, the departure of the vehicle to the lane is d, and the angle between the Xc axis in vehicle coordinate and the lane is α. After transform from road coordinate to vehicle coordinate is performed, the function of each lane in the vehicle coordinate can be solved.

The Equation (7) represents the function of the left lane in the vehicle coordinate and Equation (8) stands for the function of the right lane in the vehicle coordinate [9].

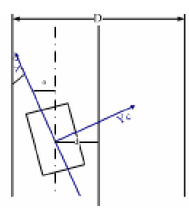


Figure 5 The relationship between the car and lanes in straight lane condition

$$y = \tan\alpha\left(x - \frac{D/2-d}{\sin\alpha}\right) \tag{7}$$

$$y = -x\tan\alpha + \frac{D/2+d}{\cos\alpha} \tag{8}$$

Then, depending on the result of Equation (6) and Equation (7), the angle between the left lane and the horizontal axis in the captured image coordinate can be represented as Equation (9).

$$\theta_1 = \arctan\left(\frac{D/2+d}{\cos\alpha}\right) \tag{9}$$

According to Equation (6) and Equation (8), the angle between the horizontal axis and left lane is represented as Equation (10).

$$\theta_2 = \arctan\left(\frac{D/2-d}{\cos\alpha}\right) \tag{10}$$

Let us consider the sum of the $\theta1$ and $\theta2$ as θ. For a given the value of D is 4, the relationship of θ-α-d is shown as Figure 6.

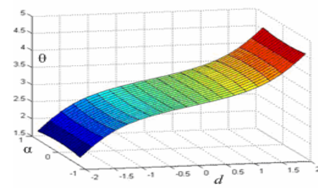


Figure 6 The θ-α-d relationship

From Figure 6 we can see that the value of θ varies mainly according to the value change of d. So a departure decision-making rule can be drawn: If θ is higher than a proper threshold value, the vehicle is in the left departure state; and if θ is lower than a proper threshold value, the vehicle is in the right departure state. In our system we choose the up threshold as 3.6, and down threshold as 2.8.

With the value of θ as the criterion of the lane departure decision-making, we only need to know the value of D to realize the solution.

5. Experiments results

Our preliminary results indicate that the lane departure warning system can effectively predict lane crossings. For example, let us consider the video sequence related to Figure 7. In this sequence, the vehicle starts on the right lane, shifts to the left and returns to its original lane. Figure 8 illustrates the curve of the θ values for the process and shows when the vehicle starts to depart, where n is the sequence number of the images in Figure 7.

The θ value of each image is also provided in Figure 7. With our driving experience, we can judge that the vehicle starts left departure from the third image of Figure 7, and recovers at the 8th one, which matches the result of Figure 8.

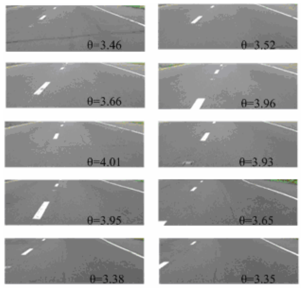


Figure 7 The image sequence of the left departure

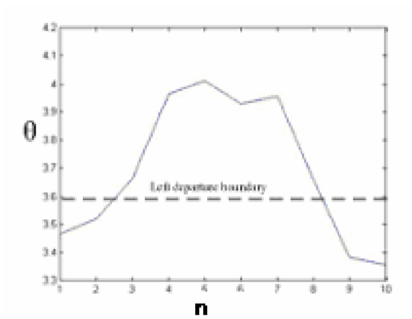


Figure 8 The θ values in the above Image Sequence

6. Conclusions

LDW system acts as a reminder when the vehicle is in danger of departing the road. In this paper, the process of lane departure detection approach was presented. The adopted lane detection method was consisted of image preprocessing, binary processing and dynamical threshold choosing, and linear-parabolic model fitting. The lane detection performance was improved by making use of linear-parabolic model fitting, compared to the usual method of using Hough transform. The lane departure decision-making based on angles between lanes and the horizontal axis in captured image coordinate was proposed, which needed less parameters than the usual TLC or CCP way. The experimental results indicated the efficiency and feasibility of the solution.

Future research of this project will focus on how to detect the lanes correctly when the situations on the road are more complex.

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