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Research in Video Detection of Lane Curve and Its Application in Speed Alert System

[1, 2]Maliang Song and [1, 2]Xiaoyan Liu
[1]Faculty of Information Engineering and Automation, Kunming University of Science and Technology, Yunnan Province, 650500, China
[2]Yunnan Provincial Key Laboratory of Computer Application Technology, Yunnan Province, 650500, China

Abstract: That vehicles travel on a curve with excessive speed tends to skid or roll over. This study presents research in video recognition technology of lane and its application in traffic early safety alert system, which improves traffic safety. In our study, we use a monocular camera to acquire the image of the road ahead. Techniques such as gray-scale transformation, filtering, edge detection and curve fitting are used for the recognition of the lane line and curve fitting. Then radius of curvature of the road ahead will be extracted and then the maximum safe speed, which is to be compared with the speed of the vehicle in safety alert system. Experiments show that this method can accurately calculate the radius of the curve ahead and timely give alert message when the vehicle's speed exceeds safe speed.

Keywords: Coordinate transform, computer image processing, monocular vision, speed alert

INTRODUCTION

The bend of the road is prone sections of traffic accidents, whose high probability of accidents and severity of the accidents have been the emphasis of relevant foreign agencies Institutes. The number of accidents that occurs around the bend each mile is significantly higher than that of the highway. For example, the number of traffic accidents around curve sections accounted for 41.01% of all in Japan (Wang, 2002). According to China Statistical Yearbook 2005, traffic accident around curve sections accounted for 7.84% of all accidents in China. From the view of the severity of all the accident, the curve sections lead to 16.3% of the total fatalities (Gao and Wang, 2005). Especially when the vehicles skid or roll over, it will lead to serious traffic accidents, which will result in serious casualties and property loss. In this study, we show our research in the vehicle recognition based on monocular vision technology and apply it to the traffic safety alert system.

Recently, main video recognition algorithms of lane are Hough transform algorithm, the road edge search algorithm and wavelet transform algorithm for edge extraction. Axel *et al*. (2002) Gern proposed a road edge search-based algorithm, which can be used for curve detection, but the accuracy is not high in complex road conditions. McCall and Trivedi (2004) proposed a fast lane detection algorithm which is based on Hough transform algorithm. This algorithm has good effectiveness and high accuracy. While it is suitable for straight lane line, it is not ideal for curve recognition. Yang *et al*. (2010) introduced a lane line video detection method based on improved Hough algorithm. It gets a better timeliness by improving Hough transform model. Huang *et al*. (2009) improved edge detection threshold algorithm, which lead to a better accuracy of image processing algorithm.

Based on previous studies, we propose a method that combines the edge search algorithm and Hough transform algorithm, which can be used for lane line detection. Monocular visual sensor is used for the identification of the lane line. Through the conversion of the image coordinate system and the world coordinate system, we can calculate the radius of the curve of the road and the maximum speed of the vehicle in real time, which is necessary for safety alert system.

LANE CURVE RECOGNITION

The basic principle of speed alert system of lane curve is that the image of the road ahead is collected first by a monocular camera mounted on the vehicle. Then the lane line is fitted through image detection technology. The radius of curvature is obtained after the coordinate transform and the maximum speed through the alert speed formulator at the same time. Before the vehicle enters into the corner, the voice will prompt alert to the driver.

The early alert system mainly consists of two parts. The first part is the extraction of the radius of curvature of the curve ahead. A CCD camera is mounted on the

Corresponding Author: Maliang Song, Faculty of Information Engineering and Automation, Kunming University of Science and Technology, Yunnan Province, 650500, China

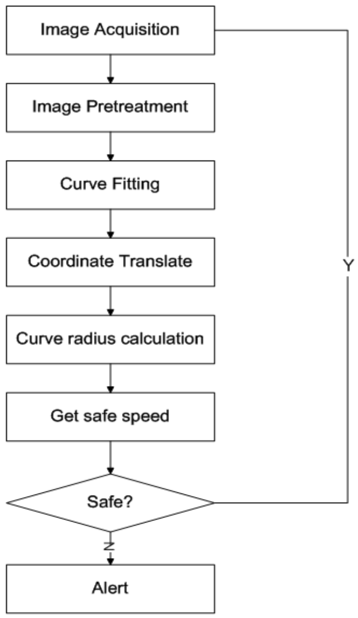


Fig. 1: Workflow

windshield of the vehicle for image acquisition of the road ahead. After pretreatment of the image, the lane curve in the image is extracted through fitting algorithm. Through conversion to restore the actual shape of the lane line, the radius of curvature of the curve ahead is obtained. The other one is the speed alert system. Vehicle dynamics, combined with relevant parameters of the vehicle by the bend radius of curvature, can be used for obtaining the maximum safe speed for the vehicle to prevent rollover slip. Then the maximum is compared with the current speed of the vehicle, if the current speed is larger, the speed alert system will alert the driver through a voice operation as showed in Fig. 1.

To calculate safe speed in the corners of the vehicles, the key point is to determine the radius of curvature of the bend in the speed alert system. The alert system acquires the image through a camera. Then the pretreatment, the lane line is fitted. After that, coordinate transform is performed, to restore the lane curve in the coordinate system of the actual road, thereby calculating the radius.

Gray-scale transformation: The original image is a color image with a CCD camera as an image sensor, which will be converted to gray-scale image and then gray stretched, as formula 1, to select similar gradation with the lane line:

$$\begin{cases} Vg = Vg \times 2.5 - 1.25 (0.9 > Vg > 0.5) \\ Vg = 0; (Vg < 0.5) \\ Vg = 1; (Vg > 0.9) \end{cases} \tag{1}$$

Vg represents the gradation of the pixels in the image.

Image median filter: To deal with the noise in the image, the image needs to be filtered. According to the characteristics of the monocular camera, linear median filter is taken, which can change the contrast of image for later feature extraction, enhancing the robustness of the system at the same time. For median filter, mathematical expression:

$$f(i, j) = median\{S_{f(i,j)}\} \tag{2}$$

$f(i, j)$ represents the gradation of point (i, j)

Road image feature enhancement: The system uses a Sobel operator to enhance the characteristics of the highway lane lines. Sobel operator threshold selection is the key point, which effects edge detection a lot. The category variance threshold method is to introduce the category variance as discrimination, which selects the largest category variance with minimize class variance as the best threshold. In this study, we improved the existing adaptive threshold algorithm according to the characteristics of the lane line.

The specific methods of operation:

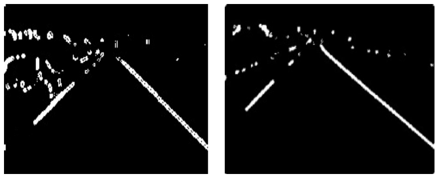
- Select an approximation as image initial threshold Tk
- Use Tk for the image segmentation. The distinction between the lane line and the surrounding pavement color is very obvious. Therefore, the continuous white region large enough is left while the area less than a given value are abandoned.
- Process clustering algorithm to each pixel and get their average value u_1, u_2. w_1. is the probability of the foreground image and u_2 is the probability of the background image, p_i is the probability of pixel with gray gradation i.

$$\begin{cases} u_1 = \sum_{i=Z\min}^{Tk} ip_i / w_1 \\ u_2 = \sum_{Tk+1}^{i=Z\max} ip_i / w_2 \end{cases} \tag{3}$$

Class variance and total variance are as follows:

$$\begin{cases} \sigma_1^2 = \sum_{i=z_{\min}}^{T} (i - u_1)^2 p_i / w_1 \\ \sigma_2^2 = \sum_{i=T+1}^{Z\max T} (i - u_2)^2 p_i / w_2 \\ \sigma = \sigma_1^2 + \sigma_2^2 \end{cases} \tag{4}$$

If $S_{k+1} > S_k$, the algorithm will stop, otherwise it will continue. S_k is the ratio of class variance and total variance.



(a) (b)

Fig. 2: Comparison; (a): with interference; (b): without interference

Morphological processing: In actual situation, the vehicles and other obstructions in the road have a considerable impact on the actual lane line fitting. Therefore, there is a need to use the morphological operations to remove this impact in the image pretreatment process (Zhu *et al*., 2006). Black and dark obstructions in the road of the image, include the car, are extended maximum to integration with the road with a specific transform algorithm. When comes to the light-colored obstacle, their gray threshold is generally higher than the lane mark in the image and the shape of the lane line are finer erased. We can obtain an image with more complete lane line and less interferes through morphological erosion, dilation and obstructions, which help filter the image as shown in Fig. 2.

BEND RADIUS OF CURVATURE CALCULATION

Lane line fittings: The lane line fitting needs to find the center point of two lane lines. Since the lane line of the actual road can be regarded as approximately parallel, the space between the two lanes will reduce according to a certain proportion in the image. This feature can be used to find the center of the lane line accurately.

First, Hough transform fitting process is applied to a straight line in the image (Li *et al*, 2004; Bertozzi and Broggi, 1998), to determine the end point and the point of intersection of the two lane line. Then query two points from the end point of two lane lines upward progressively and the calculated center point of them and then all of the center point for curve fitting. In this study, the least squares fit are used and the fitting function is bellow:

$$x = ay^4 + by^3 + cy^2 + dy + e \tag{5}$$

Figure 3 shows the results, which indicates that the equation of the straight sections and curve sections have a better fitting effect.

Coordinate transformation: To calculate the radius of the lane mark on the actual road surface, the fitting-out lane line will need coordinate transformation to obtain the real information in the world coordinate system (Guo *et al*., 2006). This study references (Guo *et al*., 2006), to calculate of the point of the road line in the world coordinate system and then to process curve fitting.

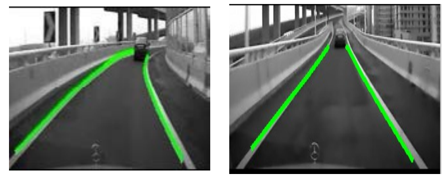


Fig. 3: The effect of fitting algorithm

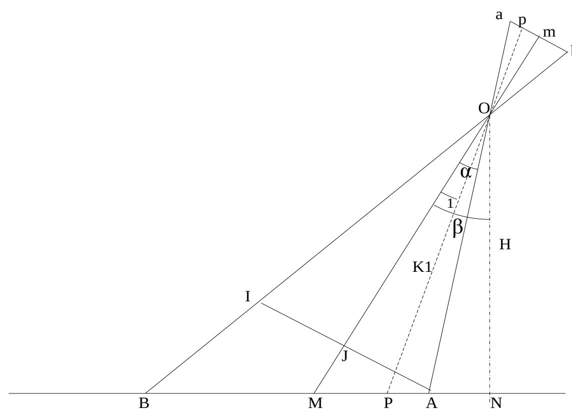


Fig. 4: Ross-sectional view of imaging light path

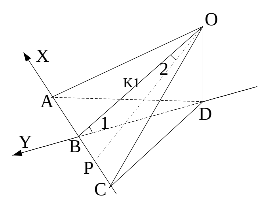


Fig. 5: Side view of imaging light path

Let plane point of the lane line to be p (x, y) and its corresponding point in the world coordinates is P (X, Y). According to the principle of the imaging light path and (Guo *et al*., 2006), we can get the imaging light path cross-sectional view as Fig. 4 and a side view as Fig. 5.

According to Guo *et al*. (2006), we can get the relationship between p (x, y) and P (X, Y) as follows:

$$\begin{cases} X = k1 \times \cos\angle 2 - k1 \times \cos\gamma \\ Y = H \times \tan(\beta - \angle 1) - H \times \tan(\beta - \alpha) \end{cases} \tag{6}$$

$$\begin{cases} k1 = H \times \cot(\beta - \arctan(\tan\alpha \times \dfrac{n}{2x})) \\ \angle 1 = \arctan(\tan\alpha \times \dfrac{n}{2x}) \\ \angle 2 = \arctan(\tan\gamma \times \dfrac{x}{n}) \end{cases} \tag{7}$$

Lane line in the world coordinate system can be obtained by curve fitting equation if (x, y) are replace by (X, Y).

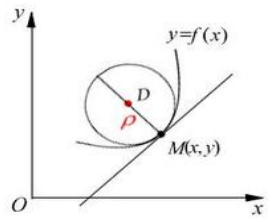


Fig. 6: Solving schematic diagram of curvature

Curvature radiuses calculate: The radius of curvature is used to describe a radius of curvature of a point somewhere curve bending extent of the change in the curve, a curve that is the point of the radius of the circle, namely the radius of the lane line curve. Figure 6 is a solving schematic diagram of the point r M(x, y) on the curve y = f(x). The radius of curvature is calculated as Eq. (6):

$$r = \left| \frac{\left(\sqrt{1+y'^2}\right)^3}{y''} \right| \tag{8}$$

and

$$y' = \frac{dy}{dx}$$
$$y'' = \frac{d^2y}{dx^2}$$

According to the characteristics of the vehicle lane line, a minimum turning radius curve is needed ahead, namely the minimum radius of curvature, which can be calculated as:

$$\min(r_i) = \left| \frac{\left(\sqrt{1+y_i'^2}\right)^3}{y_i''} \right| \tag{9}$$

where, i is 0, 1, 2 ... n, i.e. , which means the line of the road ahead to be divided into n stages, the minimum radius of curvature of the formula is the turning radius, which is also the turning radius for alert.

ALERT SPEED CALCULATION

Vehicles with high center of gravity need to consider both rollover and side slip when considering maximum safe speed.

According to the principle of vehicle dynamics, the maximum speed of the vehicle skidding is:

$$v_{\max}^h = \sqrt{ugr} \tag{10}$$

The speed when rollover occurs:

$$v_{\max}^f = \sqrt{\frac{gbr}{2h}} \tag{11}$$

(a) (b) (c)

Fig. 7: The actual road

$$v_{\max} = \min(v_{\max}^f, v_{\max}^h) \tag{12}$$

where,
b = A tread
h = The center of gravity of the vehicle
r = A turning radius
u = The pavement of mocha coefficient

The vehicle track and the center of gravity and the minimum radius of curvature of the corners through the video detection determined the safe speed, which is to be compared with the current vehicle speed, alert will start if the current vehicle speed is greater than the safe speed.

EXPERIMENTS ANALYSIS

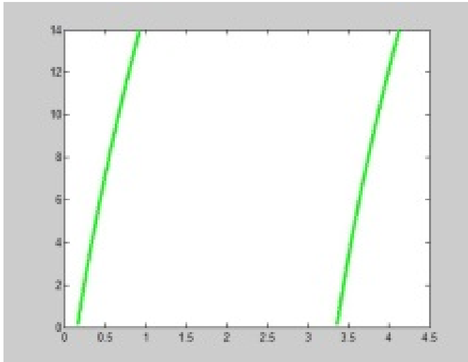
In this study, the real vehicle test platform is used to verify the effectiveness of the proposed method. Real vehicle test platform equipped with laptop-board CCD camera. The CCD camera is mounted on top of the vehicle windshield and MATLAB7.1 is used for real-time processing of CCD camera image. The experiment has two phases. The first phase of experiment is on three different camber corners, comparing the calculated radius and the actual radius to verify the accuracy of the method while in the second stage, different speeds on the same road are test to verify the early alert effect.

Road test: Test the system at three different exit ramp locations respectively, to verify the accuracy of authentication methods. Three corners (Fig. 7) the experiment finally obtained the curve shown in Fig. 8. The curve line in the experiment is as follows:

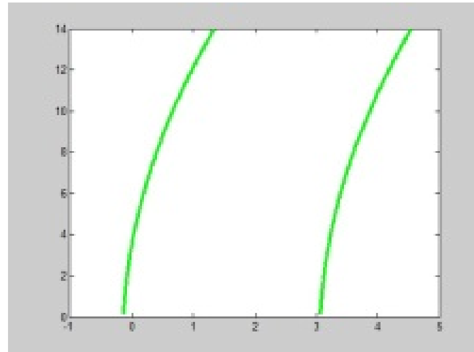
$$y = 0.0013x^2 + 0.0081x + 0.1744$$
$$y = 0.0062x^2 + 0.0194x - 0.1362$$
$$y = 0.0003x^4 - 0.0048x^3 + 0.0297x^2 - 0.0017x - 0.1221$$

Calculate the curvature radiuses every 0.2M and record the maximum.

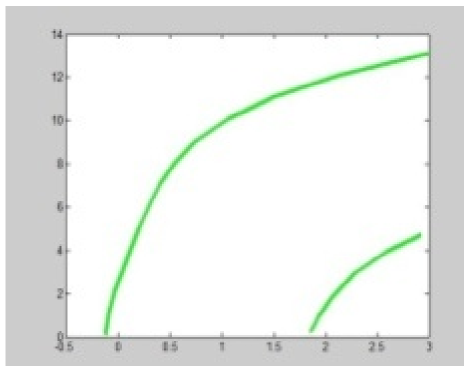
As shown in Table 1, according to the calculation, the calculated maximum radius of curvature are slightly less than the road approximate radius which means the fitting effect is ideal and the data can be used in an early alert system.



(a)



(b)



(c)

Fig. 8: The curve line

Table 1: Curvature radiuses

Calculated radiuses	119.3	84.2	66.0
Actual radiuses	121	88	68

Fig. 9: The alert experiment

Warning effect validation: In order to verify the effect of the methods, a vehicle drives through the corner with a speed of 35, 45, 55 km/h respectively. The alert system starts work at the corner when the speed is between 35 km/h and 45 km/h while it alerts before the corner with a speed higher than 55 km/h, which meets the vehicle security needs (Fig. 9).

CONCLUSION

This study proposes a method that we get the radius of curvature of the curve ahead through computer vision technology. We calculated a safe speed for the vehicle using the radius of curvature ahead for alert judgment and alert system. Experiments show that: this method can accurately provide the radius of curvature of the road ahead with good light conditions and alert safe speed to the driver timely with better robustness.

The key point of this study is about research and implementation of key algorithms, without considering the lane line recognition under different lighting conditions, which will be improved later

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