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Analysis on Lane Detection and Departure under IPM

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Abstract

A method of structure lane detection and departure based on inverse perspective mapping (IPM) and effective gradient points is proposed. Firstly, road image is transformed into plan view using inverse perspective transform to eliminate perspective effect. Secondly, "Sobel" operator and morphological image processing are used to detect edge and eliminate noise. According to the actual lane width, effective gradient points are extracted. Finally, lane is fitted using the least square method. Experimental results show that the method can detect both sides lane and analyze departure and lane detection rate is 97.5%. The method can provide reference for lane departure warning system.

Keywords: *structure road; lane; gradient point; least squares method; departure*

1. Introduction

Lane detection is an important research area in intelligent vehicle navigation and driver fatigue warming system. Throughout the foreign and domestic researches, the methods of lane detection include the method based on magnetic guide, the method based on GPS/SNS [1] and the method based on machine vision [2-4]. The first two methods are not influenced by environmental factors, but they have high cost. The method based on machine vision has much more advantages such as large amount of information, low cost, easy to promote, et al, which has become a hot research topic. The method based on machine vision includes two methods: based on road features [5-7] and based on road model [8-11]. The first method is easy to be influenced by illumination and the second method is easy to be influenced by front vehicle, the road damage area, other road signs and shadows. So we propose a method of structure lane detection and departure based on inverse perspective mapping (IPM) and effective gradient points in this paper. Firstly, road image is transformed into plan view using inverse perspective transform to eliminate perspective effect. Secondly, "Sobel" operator and morphological image processing are used to detect edge and eliminate noise. According to the actual lane width, effective gradient points are extracted. Finally, lane is fitted using least squares method.

2. Lane Inverse Perspective Transformation

Inverse perspective transformation of road image is changing image from the image coordinate system to the world coordinate system (z=0). This can remove image perspective effect.

If (x,y,z) represents the coordinate of the world coordinate system and (u,v) represents the coordinate of the image coordinate system, the world coordinate system can be defined as $W = \{(x, y, z)\} \in E^3$, and the image coordinate system can be defined as $I = \{(u, v)\} \in E^2$. The relationship between them is shown in Figure 1. In the experiment, θ is deviation Angle between the camera optical axis and z plan (z=0); γ is the angle between projection of the camera optical axis in the z plane (z=0) and y axis; 2α is the

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camera Angle; R_x is the horizontal resolution of the camera; R_y is the vertical resolution of the camera; the coordinate of camera in the world coordinate system is (d,l,h).

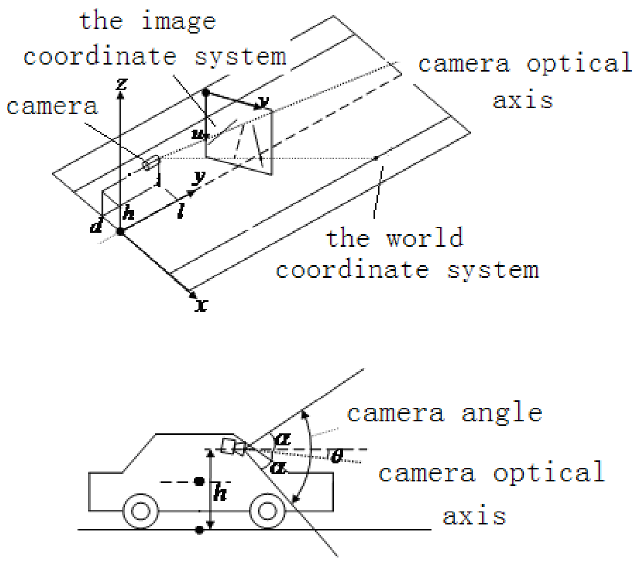


Figure 1. Schematic Diagram of Inverse Perspective Transformation

From Figure 1, we can conclude that the model changed from the image coordinate system to the world coordinate system is:

$$x = h \times c\tan(\frac{2\alpha}{R_y - 1}u - \alpha + \theta) \times \sin(\frac{2\alpha}{R_x - 1}v - \alpha + \gamma) + d \tag{1}$$

$$y = h \times c\tan(\frac{2\alpha}{R_y - 1}u - \alpha + \theta) \times \cos(\frac{2\alpha}{R_x - 1}v - \alpha + \gamma) + l \tag{2}$$

$$z = 0 \tag{3}$$

The result of lane inverse perspective transformation is shown in Figure 2. The result shows that the processed image (Figure 2(b)) has more clear lower part and more obscure upper part.

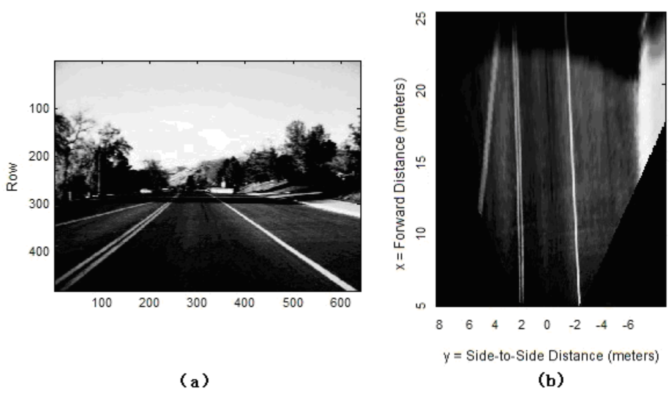


Figure 2. Inverse Perspective Transformation

3. Effective Gradient Points Extraction

After lane inverse perspective transformation, the lane is parallel. Considering that the gradient points usually have the same or opposite direction, we propose a method of using Effective gradient points to detect lane. In the paper, we define the point with horizontal positive gradient value as positive gradient point and the point with horizontal negative gradient value as negative gradient point. Horizontal gradient points of Figure 2 are shown in Figure 3 which has 1402 positive gradient points and 1936 negative gradient points.

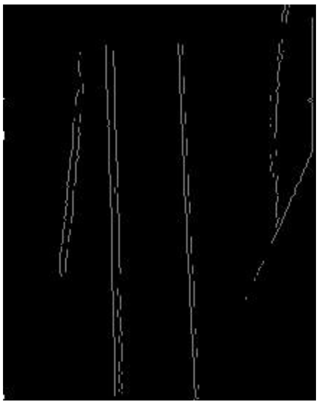


Figure 3. Horizontal Gradient Points

The method of effective gradient points extraction is:

Step 1 Calculating gradient points number of each row in edge image. $G_+ = \{(x_i, y_i) \mid i = 1,2,\cdots,m\}$ represents the set of positive gradient points and $G_- = \{(x_j, y_j) \mid j = 1,2,\cdots,n\}$ represents the set of negative gradient points; m is the total number of positive gradient points; n is the total number of negative gradient points.

Step 2 Matching point between G_+ and G_-. At last we can obtain the $m \times n$ horizontal gradient points.

Step 3 Calculating the distance of horizontal gradient points. If the distance meets a certain threshold, horizontal gradient points are effective gradient points. In the paper, the threshold is 3.6-4.0.

4. Lane Detection and Departure Analysis

4.1 Lane Detection

The methods of lane fitting include Hough transformation and the least square method. Compared with Hough transformation, the least square method has little calculation and high percentage of accuracy. So we use the least square method to realize lane fitting.

Assuming the coordinates of effective gradient points are $(u_{+k}, v_{+k}), (u_{-k}, v_{-k}), k = 1, 2, \cdots, K$. K is the number of effective gradient points. And we define the quadratic curve equation as:

$$f(u_+) = a_1 + a_2 u_+ + a_3 u_+^2 \tag{4}$$

Assume,

$$A=\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix},\ V=\begin{bmatrix} v_{+1} \\ v_{+2} \\ \cdots \\ v_{+K} \end{bmatrix},\ P=\begin{bmatrix} 1 & u_{+1} & u_{+1}^2 \\ 1 & u_{+2} & u_{+2}^2 \\ \cdots & \cdots & \cdots \\ 1 & u_{+K} & u_{+K}^2 \end{bmatrix}$$

Then,

$$P^T P=\begin{bmatrix} K+1 & \sum_{k=1}^{K} u_{+k} & \sum_{k=1}^{K} u_{+k}^2 \\ \sum_{k=1}^{K} u_{+k} & \sum_{k=1}^{K} u_{+k}^2 & \sum_{k=1}^{K} u_{+k}^3 \\ \sum_{k=1}^{K} u_{+k}^2 & \sum_{k=1}^{K} u_{+k}^3 & \sum_{k=1}^{K} u_{+k}^4 \end{bmatrix} \tag{5}$$

$$P^T V=\begin{bmatrix} \sum_{k=1}^{K} v_{+k} \\ \sum_{k=1}^{K} u_{+k} v_{+k} \\ \sum_{k=1}^{K} u_{+k}^2 v_{+k} \end{bmatrix} \tag{6}$$

According to $(P^T P)A = P^T V$, we can conclude:

$$A=(P^T P)^{-1} P^T V \tag{7}$$

The result of lane detection is shown in Figure 4.

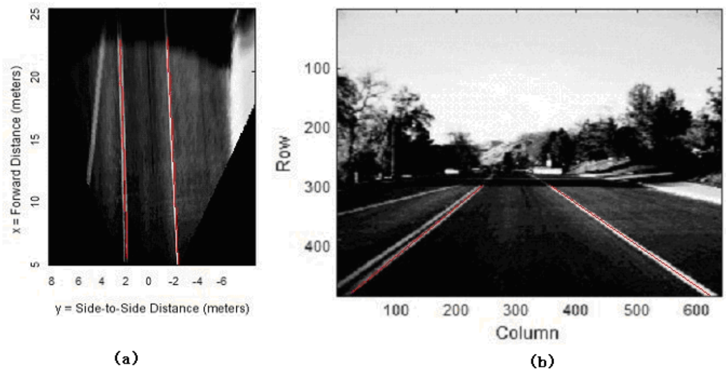


Figure 4. Result of lane detection

4.2 Lane Departure Analysis

It is very necessary to analysize lane departure to ensure vehicle driving safely. The ideal vehicle state is always located in the middle of road and real vehicle safety state is near the midline. If the vehicle deviates from the ideal state for long time, it is easy to cause traffic accidents. After lane inverse perspective transformation, Lane departure can be described as:

$$\xi=\frac{d_l}{d_r} \tag{8}$$

Where, d_l, d_r is defined as in Figure 5.

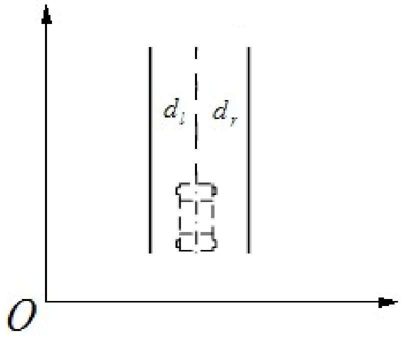


Figure 5. Lane Departure

According to the actual situation, the change of ξ can be divided into: (1) vehicle in the middle, $\xi \approx 1$; (2) vehicle in the left, $0 < \xi < 1$; (3) vehicle in the right, $\xi > 1$. So we can calculate ξ to analysize lane departure.

5. Experimental Results and Analysis

5.1 Lane Detection

In the experiment, the coordinate of camera in the world coordinate system is (0, 0, 1.2); the horizontal resolution of the camera is 640; the vertical resolution of the camera is 480; the camera Angle is 60° ; the deviation Angle between the camera optical axis and z plan (z=0) is 2.472° . Experimental images are some someway and province road. The results are shown in Figure 6, 7. Experimental results show that the method can realize lane detection and be not influenced by road environmental factors such as illumination, shadows and front vehicles.

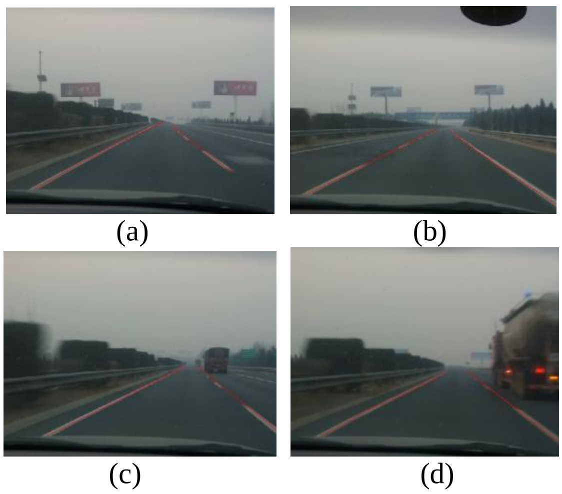


Figure 6. Lane Detection of Highway

(a) (b)

(c) (d)

Figure 7. Lane Detection of Provincial Road

The total results are shown in Table 1.

Table 1. Result of Lane Detection

Road	total/frame	Collect number/frame	Detection rate/%
highway	2458	2396	97.5
Province road	2689	2425	90.2

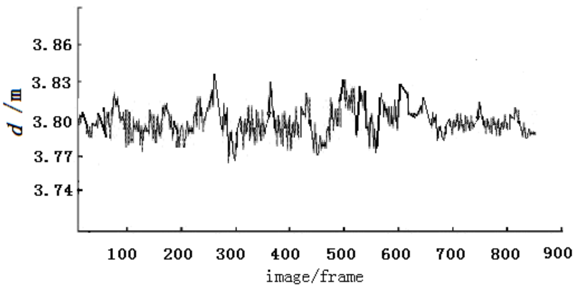
5.2 Lane Departure Analysis

In lane departure experiment, we have done static and dynamic driving. The results of static driving experiment are shown in Table 2. The absolute error between proposed method and actual value is 0.03 which is accepted.

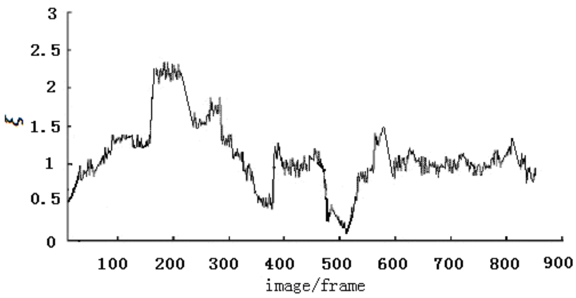
Table 2. Result of Static Lane Departure

Number	d_l /m			d_r /m		
	Proposed method	Actual value	Absolute error	Proposed method	Actual value	Absolute error
1	1.732	1.749	0.017	2.021	2.051	0.03
2	1.971	1.962	-0.009	1.856	1.838	-0.018
3	1.586	1.556	-0.03	2.227	2.244	0.017
4	2.165	2.180	0.015	1.623	1.620	-0.003
5	1.983	1.995	0.012	1.776	1.805	0.029
6	2.213	2.202	-0.011	1.624	1.598	-0.026

The results of dynamic driving experiment are shown in Figure 8. The absolute error between proposed method and actual value also is 0.03. From Figure 8, we can conclude the position of vehicle is right, left and middle.



(a) Lane width



(b) Lane departure

Figure 8. Departure Analysis

6. Conclusions

We proposed a method of structure lane detection and departure based on inverse perspective mapping (IPM) and effective gradient points. Firstly, road image is transformed into plan view using inverse perspective transform to eliminate perspective effect. Secondly, "Sobel" operator and morphological image processing are used to detect edge and eliminate noise. According to the actual lane width, effective gradient points are extracted. Finally, lane is fitted using the least square method. Experimental results show that the method can detect both sides lane and analyze departure and lane detection rate is 97.5%. The method can provide reference for lane departure warning system.

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