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A Method of Lane Detection and Two Dimensional Reconstruction Based on Machine Vision

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Abstract: This paper presents a method of lane detection and reconstruction based on machine vision. Based on the analysis of various lane detection methods, Hough transform technique is used to detect the Lane, establish mathematical model, analysis of the slope curvature model and the adjacent lane two lane line difference algorithm, and two-dimensional reconstruction of the lane to lane, current location, at the same time to lane line location prediction and detection of next time. The experimental results show that, this method can detect lane road accurately, and to identify the important information of the current lane, effective, rapid detection and reconstruction of lanes, and has good robustness, high reliability and accuracy. *Copyright © 2013 IFSA.*

Keywords: Hough transformation, Machine vision, Lane edge, Image processing, Two dimensional rebuilding.

1. Introduction

In recent years, with the economic development and the popularization of cars, urban traffic congestion, frequent traffic accidents and deterioration of traffic environment have become important problems of our country. The study shows that the driver has the worst reliability in the three aspects of, driver, car and road. More than 80 % of traffic accidents are caused by the driver's errors. The driver's subjective factors, such as fatigue, poor concentration, excessive stress and the like are root causes leading to a lot of traffic accidents. About 30 % of these incidents are performed as accidents caused by vehicles deviated from the lane. The study of vehicle lane tracing and holding, as important contents of vehicle auxiliary driving or unmanned driving, obtained high attention from all countries of the world, particularly major developed countries in the West in view of this situation and in order to improve transport efficiency. The study has been developed into important part of these countries to carry out intelligent transport systems. With the development of image processing technology, machine vision is applied in many fields such as industrial condition monitoring, automated testing, quality control and the like due to rapid access to large amounts of information, low-cost and easy automatic processing [1].

2. Lane Line Model

The left and right indicator lines of the lane are usually white. The indicator lines are generally parallel to each other and continuously changed in the real space, and the degree of bend which usually characterized by horizontal curve radius is related with road grade. The road with higher level has large horizontal curve radius. They are in taper complexion which is gradually converged to the middle from top to bottom as shown in Fig. 1.

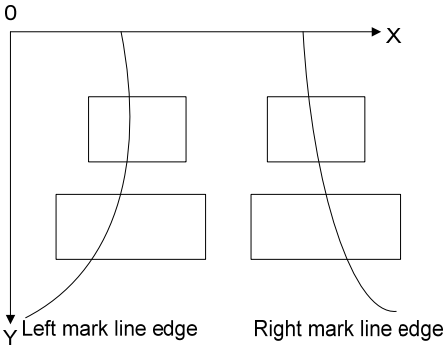

Fig. 1. The image in the lane.

The background of the study is based on monocular vision vehicle lane tracing and holding, and thereby it is assumed that the vehicle is traveling in the lane with larger horizontal curve radius. The left and right indicator lines of the lane, which are originally parallel, are not parallel in the image due to perspective projection [2].

The lane indicator lines can be described as quadratic curves under the condition. The lane left and right indicator lines can be described in the following formula under the icon image coordinate system oxy.

$$x = a + by + cy^2 \tag{1}$$

Wherein, the parameter a, b and c may be obtained through selecting several points on each curve by fitting or interpolation approach, thus the relation between the lane position and the image center can be determined. When the camera is placed in the widthwise center position of the vehicle, the center of the vehicle coincides with the center of the image, and the relative positional relationship of the vehicle and the lane can be inferred.

3. Principle of Hough Transform

Hough transformation is a method for utilizing the global characteristics of images to detect targets. In target detection, if you do not know the location of the target in the image but only know the curve equation of the contours, you can use Hough transformation for detection. Basic idea of Hough transformation is to establish the mapping relation between the image space and parameter space, to transform the study objects from targets in the image space into corresponding reference points in a parameter space [3].

As for the original image space XY, the basic form of linear equations is:

$$y = ux + v, \tag{2}$$

where in u and v are the slope and interception of a beeline respectively. If a parameter space UV is established to u and v, (u, v) represents a point in the parameter space UV, and beelines which are represented by the point and the formula equation (2) are corresponding one by one. On the contrary, the point (u, v) given in the parameter space UV can uniquely identify a beeline in the original image space XY. Similarly, a beeline in the parameter space UV is also corresponding to a point in the original image space XY one by one.

For any three points (x_i, y_i) on a given point beeline $y=u_{0+}v_0$, i=1,2,3, where in two corresponding beelines of the point (x_1, y_1) and the point (x_2, y_2) in the parameter space UV are:

$$\begin{cases} v = -x_1 u + y_1 \\ v = -x_2 u + y_2 \end{cases} \tag{3}$$

The crossing point of the two beelines can be calculated as:

$$\begin{cases} u_1 = \dfrac{y_1 - y_2}{x_1 - x_2} = u_0 \\ v_1 = \dfrac{x_1 y_2 - x_2 y_1}{x_1 - x_2} = v_0 \end{cases} \tag{4}$$

The crossing point of the two beelines is:

$$\begin{cases} u_2 = \dfrac{y_2 - y_3}{x_2 - x_3} = u_0 \\ v_2 = \dfrac{x_2 y_3 - x_3 y_2}{x_2 - x_3} = v_0 \end{cases} \tag{5}$$

There by it can be inferred that: a corresponding point in the parameter space UV corresponding to each beeline on the beeline y=ux+v is shown in Fig. 2 and Fig. 3. Some collinear points in the original image space can be detected through utilizing this important feature [4].

The slope of a beeline may be close to the infinite condition, linear equations are not represented by intercept modes but are represented as polar coordinates as shown in Fig. 4.

The expression of the polar coordinates of the beeline is:

$$\lambda = x\cos\theta + y\sin\theta, \tag{6}$$

wherein (ρ, θ) defines a vector from the origin point to the nearest point on the straight line, and the vector is vertical to the straight line. If the parameter ρ, θ is used to define a two-dimensional space, any straight line on the xy plane corresponds to one point on the space, one straight line on the x and y plane is set to correspond to the point (ρ_0, θ_0) of the space,

and space transform is carried out to every detected point, increment is carried out to all (ρ_i, θ_i) units obtained through calculation, after all detection points obtain the transform operation, the units may have local maximum space, the local maximum space of the space is searched to obtain the straight line parameters formed by the points [5].

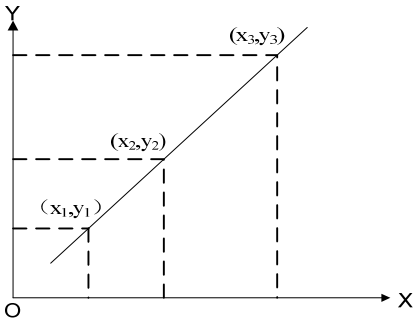

Fig. 2. Image space XY.

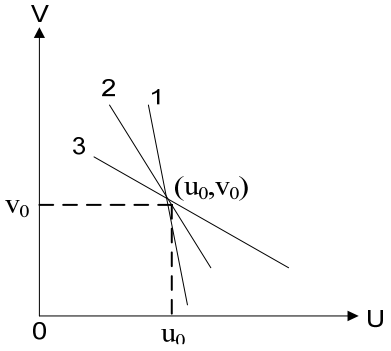

Fig. 3. Parameter space UV.

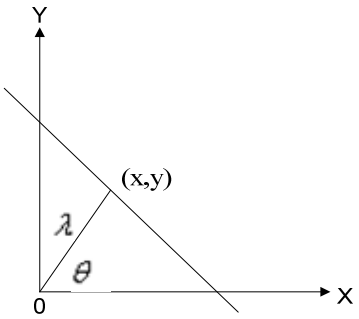

Fig. 4. Line in polar coordinates.

4. Sobel Algorithm Edge Detection

Commonly used edge detection algorithm is mostly based on the original image gray values, and the edges are detected through observing the gray changes in a region of each pixel of the image and utilizing rules of one step of the edge or one step of derivatives [6]. Gradient operator uses one step of derivatives of the edge of the image to detect the edge, in many gradient operators such as Roberts, Sobel, Prewitt, Laplace etc., the most classic gradient operator is the Sobel operator. Gradient is recorded as follows:

$$\nabla f(x,y) = \frac{\partial f}{\partial x} i + \frac{\partial f}{\partial y} j \tag{7}$$

The gradient amplitude is re-recorded e (x, y) as follows:

$$e(x,y) = \sqrt{\Delta f_x^2(x,y) + \Delta f_y^2(x,y)} \tag{8}$$

In order to simplify the calculation, it also can be defined as the absolute value sum of the partial derivative f_x and f_y:

$$e(x,y) = \left|\Delta f_x(x,y)\right| + \left|\Delta f_y(x,y)\right| \tag{9}$$

Firstly, neighborhood averaging or weighted averaging is carried out, then, one step differential treatment is carried out to detect the edge points. Usually convolution kernels h_1 and h_2 in the formula (10) are used to detect horizontal and vertical edges of images respectively: The convolution operator is:

$$h_1 = \begin{vmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{vmatrix}; \; h_2 = \begin{vmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{vmatrix} \tag{10}$$

If the h_1 is response is x, h_2 is response is y, we can get out the amplitude H and the direction angle θ.

$$H = \sqrt{x^2 + y^2} \tag{11}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \tag{12}$$

As the brightness changes near the edge of image are relatively large, so pixel points whose gray exceeds certain value in the region can be used as edge points. The operation result is a marginal amplitude pattern. Using Soble edge detection technology on the road image after image pre-processing edge detection. The Sobel edge detect effect of Fig. 5 is shown as Fig. 6.

5. Analysis of Lane Curvature Model

The lane line can be described with a curvature model in view of the standardized road design and construction standards. Suppose the radius of road curvature is R, the curvature model diagram of lane line is shown in Fig. 7.

Fig. 5. Selecting interested region.

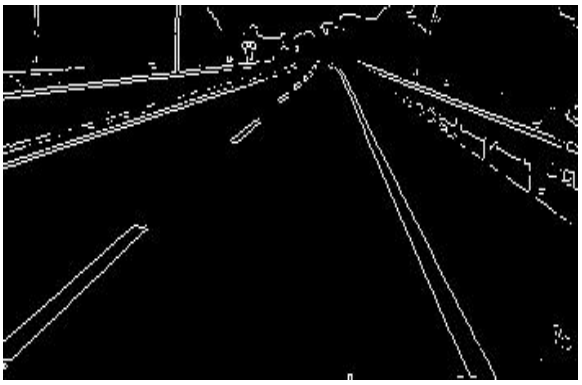

Fig. 6. Sobel edge detect effect.

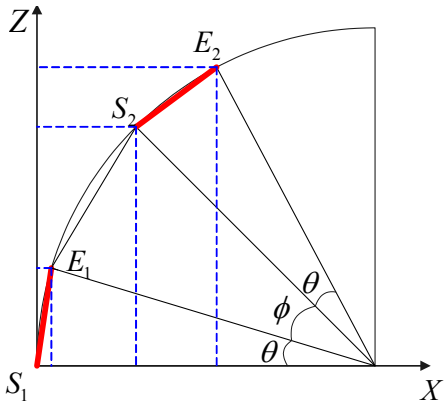

Fig. 7. The sketch map of lane curvature model.

Wherein the line segments S_1E_1 and the line segment S_2E_2 are two neighboring lane lines in the road, the length is 6 meters. The segment E_1S_2 is the interval of two neighboring lane lines. The length is 9 meters. If offset direction of the car is not considered temporarily, the car's direction of travel is the tangent direction of the point S_1. When the road curvature radius R is infinite, the road is straight, namely, the straight line condition of the lane line is a special case of the curvature model. The limit turning radius for vehicle speed of 120 km/h on standardized highway is 650 meters. The general minimum radius is 1,000 meters that R is greater than or equal to 650.

Next, we derive the corresponding relation of each road marking in the image through using the geometric relationship [7].

Coordinates $S_1(S_{X1}, S_{Z1})$, $E_1(E_{X1}, E_{Z1})$, $S_2(S_{X2}, S_{Z2})$ and $E_2(E_{X2}, E_{Z2})$. The geometric relationships in the road curvature model diagram are as follows:

$$\begin{cases} \sin\dfrac{\theta}{2} = \dfrac{|S_1E_1|}{2R} \\ \sin\dfrac{\phi}{2} = \dfrac{|E_1S_2|}{2R} \end{cases} \tag{13}$$

S_1 is coincident with the origin of coordinates, i.e. the coordinate (S_{X1}, S_{Z1}) for S_1 is:

$$S_{X1} = S_{Z1} = 0 \tag{14}$$

E_1's coordinate (E_{X1}, E_{Z1}), S_2's coordinate (S_{X2}, S_{Z2}) and E_2's coordinate (E_{X2}, E_{Z2}) are respectively:

$$E_1 : \begin{cases} E_{X1} = R - R\cos\theta \\ E_{Z1} = R\sin\theta \end{cases} \tag{15}$$

$$S_2 : \begin{cases} S_{X2} = R - R\cos(\theta + \phi) \\ S_{Z2} = R\sin(\theta + \phi) \end{cases} \tag{16}$$

$$E_2 : \begin{cases} E_{X2} = R - R\cos(2\theta + \phi) \\ E_{Z2} = R\sin(2\theta + \phi) \end{cases} \tag{17}$$

The starting point S_t's coordinate (S_tx, S_{tZ}) and ending point E_t's coordinate (E_{tX}, E_{tZ}) of the No. t lane line in front of the car can be obtained as follows according to the induction recursive principle:

$$S_t : \begin{cases} S_{tX} = R(1 - \cos((t-1)\theta + (t-1)\phi)) \\ S_{tZ} = R\sin((t-1)\theta + (t-1)\phi) \end{cases} \tag{18}$$

$$E_t : \begin{cases} E_{tX} = R(1 - \cos(t\theta + (t-1)\phi)) \\ E_{tZ} = R\sin(t\theta + (t-1)\phi) \end{cases} \tag{19}$$

As for the left lane line, the slope of the No. t road marking segment in the image is called left lane white line slope K_{lwt}. K_{lw} is follow according to the slope formula.

$$K_{lwt} = \frac{-H(S_{tZ} - E_{tZ})}{S_{tZ}(E_{tX} - D_L) - E_{tZ}(S_{tX} - D_L)} \tag{20}$$

The slope of the segment between the end of No. t road marking segment to the starting point of No. t+1 road marking segment is called black line slope K_{lbt}. K_{lbt} is follow according to the slope formula.

$$K_{lbt} = \frac{-H(S_{tZ} - E_{(t+1)Z})}{S_{tZ}(E_{(t+1)X} - D_L) - E_{(t+1)Z}(S_{tX} - D_L)} \quad (21)$$

Similarly, the white line slope Krwt and the black line slope Krbt of the right lane line can be calculated as follows respectively:

$$K_{rbt} = \frac{H(\sin(\varphi+\phi) - \sin\varphi)}{(R - D_R)(\sin\varphi - \sin(\varphi+\phi)) + R\sin\phi} \quad (22)$$

$$K_{rwt} = \frac{H(\sin\varphi - \sin(\varphi-\theta))}{(R - D_R)(\sin(\varphi-\theta) - \sin\varphi) + R\sin\theta} \quad (23)$$

Thus, the difference of the white line slope Krwt and the black line slope Krbt in each road marking is:

$$\Delta K_{lt} = K_{lbt} - K_{lwt} \quad (24)$$

$$\Delta K_{rt} = K_{rbt} - K_{rwt} \quad (25)$$

Suppose H=1.5m, D_L=2 m, D_R=1.75 m, R=5000, the slope model road marking slope of the lane undergoes simulation analysis, and the results are shown in Fig. 8 to Fig. 10.

We can get the following conclusions by simulation analysis [8]:

1) When the lane belongs to curve road in accordance with curvature radius, the slope difference of two adjacent road markings is changed in V type with one turning point. When the radius of curvature is 5000 m, the slope difference turning point appears in No. 6 road marking, namely, the position of 90 m within the camera view field range.

2) The slope differences of the left lane line and the right lane line are very close, and the segment distributions in the turning point are very close. The curvature radius R is greater than 1000 meters in standard normalization road. The turning point is in the No. 4 to No. 8 road marking, namely, the position of 60 to 120 meters in the camera view field range.

3) The slope differences of the adjacent road markings are very small, for example, the angle of No. 6 road marking deviated from the car driving direction is 4.5 degrees when the curvature radius R is 1000 m, equivalent to 110 meters in front of the car minimum sight line of the camera is 20 m plus nearest view field of 90 m away from the camera on the No. 6 road marking. Since the deviation angle is very small, the lane line in front of the car within the scope of 100 meters can be approximated as a straight line and can be used as straight line model for fitting.

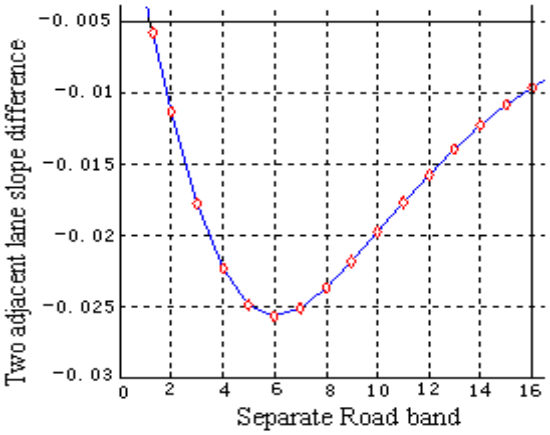

Fig. 8. The analysis of slope difference of the right lane.

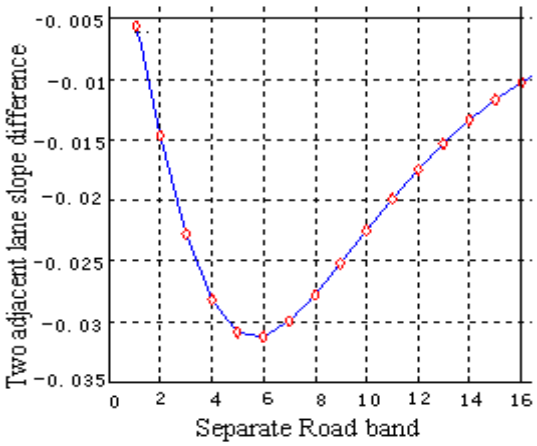

Fig. 9. The analysis of slope difference of the left lane line.

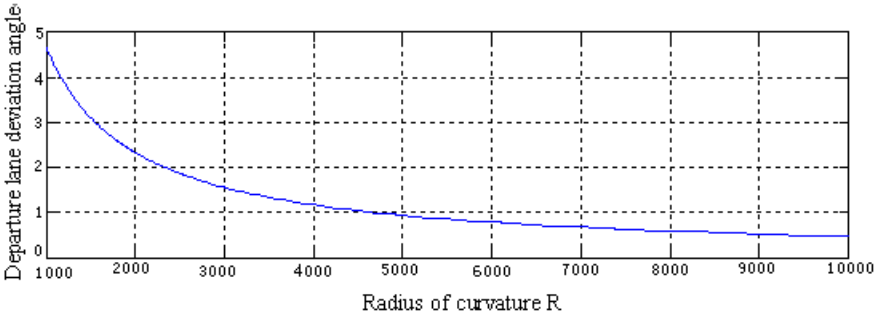

Fig. 10. The analysis of departure lane deviation angle.

6. Lane Line Two-dimensional Reconstruction

Roads within the vehicle front angle can be processed through linear roads, and two-dimensional reconstruction can be carried out through straight-line models in certain range in front of automobiles on roads. Through the road imaging model, we can see that [9]:

$$\begin{cases} x = f\dfrac{x_W\cos\alpha + z_W\sin\alpha}{H\sin\varphi - x_W\sin\alpha\cos\varphi + z_W\cos\alpha\cos\varphi} \\ y = f\dfrac{y_W\cos\varphi - x_W\sin\alpha\sin\varphi + z_W\cos\alpha\sin\varphi}{H\sin\varphi - x_W\sin\alpha\cos\varphi + z_W\cos\alpha\cos\varphi}, \\ \varphi = \arctan(\cos\alpha\tan\beta) \end{cases} \quad (26)$$

wherein, x, y, z are the horizontal, vertical and cutting-edge stretch coordinates, f is the camera focal length, H is the camera lens height, α is automobile yaw angle, β is road gradient. Through the anti-perspective principle to road imaging model, the coordinates in the world coordinate systems can be derived from the image coordinates, and through the formula, we can derive the following:

$$\begin{cases} x_W = \dfrac{a_{22}b_1 - a_{12}b_2}{a_{22}a_{11} - a_{21}a_{12}} \\ z_W = \dfrac{a_{12}b_2 - a_{21}b_1}{a_{22}a_{11} - a_{21}\ a_{12}} \end{cases}, \quad (27)$$

wherein

$a_{11} = -x\sin\alpha\cos\varphi - f\cos\alpha$;

$a_{12} = x\cos\alpha\cos\varphi - f\sin\alpha$;

$a_{21} = -y\sin\alpha\cos\varphi + f\sin\alpha\sin\varphi$; $b_1 = -xH\sin\varphi$;

$b_2 = y_W f\cos\varphi - yH\sin\varphi$. According to the above theory, parameters can be taken: H=1.5 m, Z_w=20 m, f=2680 (pixel), α=2,85°, β=4.29°. Two-dimensional reconstruction to lane lines can be carried out to road images, the results can be represented from Fig. 11 to Fig. 14.

Wherein the abscissa represents auto horizontal coordinates, 0 represents vehicle horizontal center position; vertical coordinates represent the distance from the road surface to the automobile in the world coordinate system [10].

Simulation results show that despite the lane line of two-dimensional reconstruction is not a very smooth straight line, it has been able to basically meet the practical engineering requirements. The reconstructed two-dimensional lane line is not a perfect straight line, the main reason is dispersed error caused when the camera captures digital images. The analysis results on the lane line pixel lane boundary in Fig. 12 road picture 2 are shown in the Fig. 15 to Fig. 16.

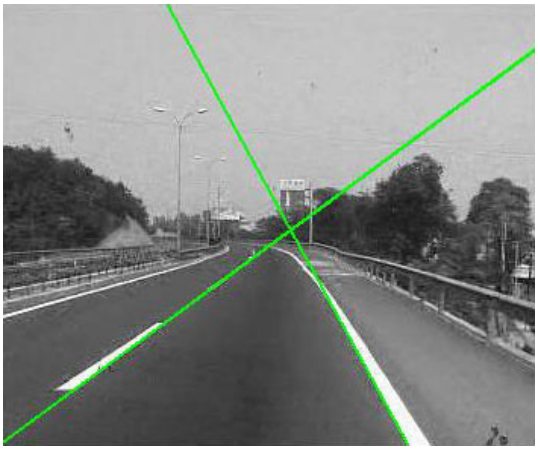

Fig. 11. Road image 1.

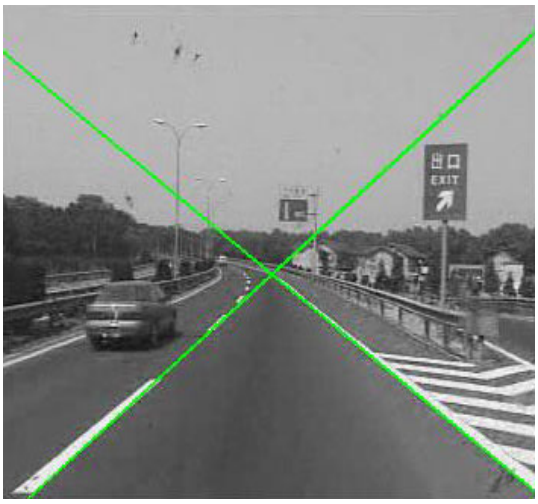

Fig. 12. Road image 2.

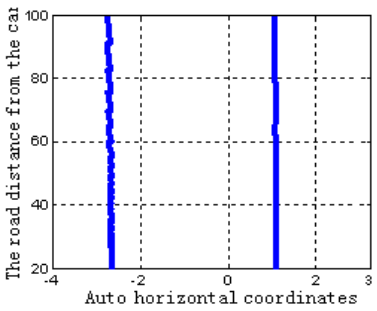

Fig. 13. Two-dimensional Reconstruction of Fig. 11.

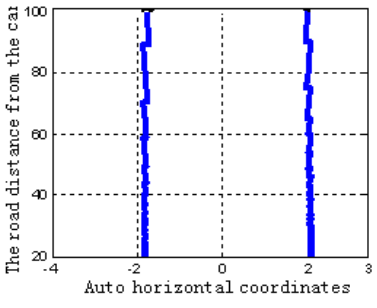

Fig. 14. Two-dimensional Reconstruction of Fig. 12.

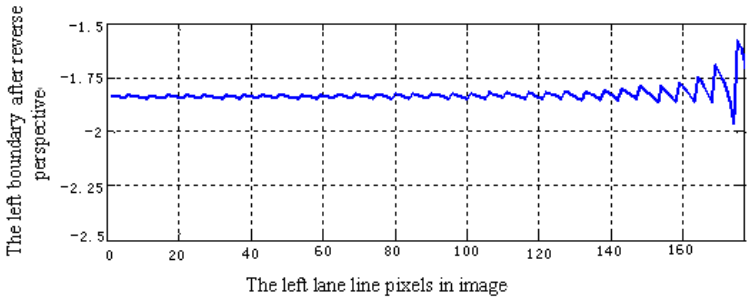

Fig. 15. Analysis of left lane boundary from lane pixels with anti-perspective.

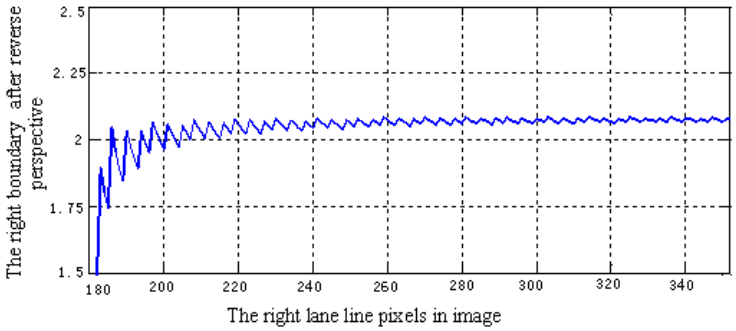

Fig. 16. Analysis of right lane boundary from lane pixels with anti-perspective.

It can be seen in Fig. 15 and Fig. 16 that the distance from the left boundary to the car center position remains unchanged basically within 0-160 pixel, and is about -1.8 m. The maximum error distance is only -0.03 m. The relative error is 1.67 %. The z_w corresponding to 160 pixels is 64.1 m, i.e. the detection error of the right lane line 64.1 meters away from the car is small. The distance from the right boundary to the car center position remains unchanged basically in the 200-352 pixels, and is about 2.1 meters. The maximum error distance is also -0.03 m. The relative error is 1.43 %. z_w corresponding to 200 pixels is 69.4 m by reverse perspective calculation, namely, the detection error of the right lane line 69.4 meters away from the car is small. The lane width is calculated by minus left lane boundary coordinates from the right lane boundary coordinates, namely, 3.91 meters. The absolute error corresponding to standard lane of 3.75 is 0.16m. The relative error is 4.27 %. Simulation experiment results show that current two-dimensional lane line can be well reconstructed by the coordinate anti-perspective transformation.

Through the former camera calibration and two-dimensional reconstruction of the lane lines, four parameters can be calculated: distance from the automobile to the left lane line ΔD_L, the distance from the automobile to the right lane line ΔD_R, the actual slope and vehicle practical yaw angle [11].

We set parameters as follows: D_{car} is 1.4 m long, pixel of f is 2680, and set the camera with the car running in the same direction and no yaw angle and prone and angle. Road image 3 and image 4 is shown in the Fig. 17 to Fig. 18. The identification results of road image 1-4 on the road are shown in Table 1.

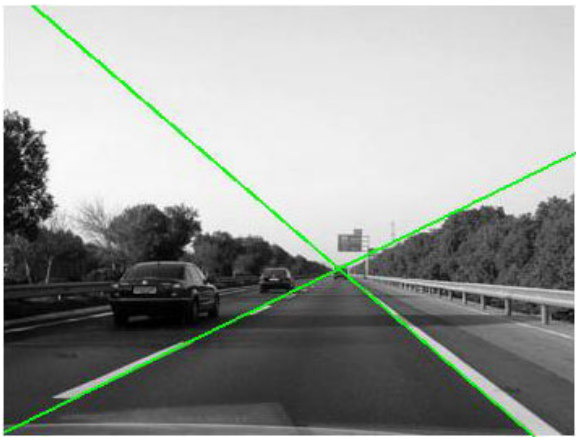

Fig. 17. Road image 3.

These parameters can provide useful information to automobile deviation preventing systems and automobile navigation systems. When , the left side of the automobile travels over the lane line, thereby left side lane deviation is generated, when , the right side of the automobile travels over the lane line, thereby right side lane deviation is generated. When one of the two accidents happens, the navigation system can give the driver warning. At the same time, deviation angle of automobile driving and the slope

of driving road can be provided, thereby drivers can take them as reference to keep the automobile in right driving direction, thereby it plays a supporting role in navigation [12].

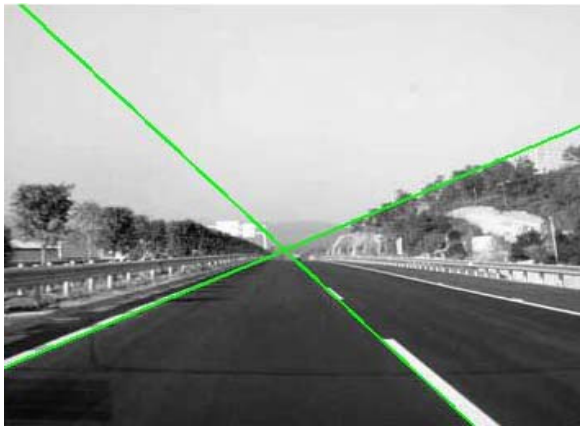

Fig. 18. Road image 4.

Table 1. Lane parameters which are identified

Road image	$\Delta\alpha$	$\Delta\beta$	D_L	D_R	ΔD_L	ΔD_R
1	5.51	4.31	-2.68	1.06	-1.98	0.36
2	4.87	4.30	-1.80	2.11	-1.10	1.41
3	2.85	2.44	-2.38	1.35	-1.68	0.65
4	2.49	2.44	-2.57	1.17	-1.87	0.47

7. Conclusions

From the practical application of intelligent vehicle, the image segmentation process is required to have better robustness, real-time performance and practicality. Most of external images caught by intelligent vehicles have noise, Hough transformation provides a method for obtaining continuous object contours, the transformation utilizes voting principle to guarantee the robustness of the segmentation process and improves the computing speed on the algorithm, and enables image segmentation to be possible.

The practical application of intelligent vehicle is considered, the image segmentation process is requested to have better robustness, real-time and practicality. Hough transform provides a method of obtaining continuous object outline. It ensures the robustness of the segmentation process from the algorithm. The inverted perspective principle of the camera is used to realize two-dimensional reconstruction of the lane lines to reach lane identification purposes, and it has important application significance to further develop intelligent vehicle technology.

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