Lane Detection of Curving Road for Structural High-way with Straight-curve Model on Vision

Huifeng Wang, Yunfei Wang, Xiangmo Zhao, Guiping Wang, He Huang, Jiajia Zhang

***Abstract*—Curve is the traffic accident-prone area in the traffic system of the structural road. How to effectively detect the lane-line and timely give the traffic information ahead for drivers is a difficult point for the assisted safe driving. The traditional lane detection technology is not very applicable in the curved road conditions. Thus, a curve detection algorithm which is based on straight-curve model is proposed in this paper and this method has good applicability for most curve road conditions. First, the method divides the road image into the region of interest and the road background region by analyzing the basic characteristics of the road image. The region of interest is further divided into the straight region and the curve region. At the same time, the straight-curve mathematical model is established. The mathematical equation of the straight model is obtained by using the improved Hough transform. The polynomial curve model is established according to the continuity of the road lane-line and the tangent relationship between the straight model and the curve model. Then, the parameters of the curve model equation are solved by the curve fitting method. Finally, the detection and identification of the straight and the curve are realized respectively and the road lane-line is reconstructed. Experiments show that this method can accurately identify the curve lane-line, provide effective traffic information, make early warning and it also has a certain universality .**

***Index Terms*—Structural Road, Curve, Region-of -interest, Multinomial model, Lane detection.**

I. INTRODUCTION

With the rapid growth of the highway transportation system, the number of car ownership has risen year after year which is result in serious traffic conditions [1]. In particular, the incidence of curve accidents and the seriousness of accidents remain high. When the car is turning, there will be a blind zone of sight which is accompanied by increased centrifugal force. The turning radius will decrease and the lateral sliding will occur easily, which is caused collision accidents [2]. In Japan, the traffic accident rate on the curved sections of the road exceeded 41.01% of the total accident rate [3], while the number of traffic accidents on the curved road in China accounted for 7.84% of the total accident. Judging from the severity of the accident, the fatal accidents of the curve occupies 16.3% of all fatal accidents [4]. Other statistics show that the main reasons of accidents in the curved areas are the over-speeding of the turning vehicles during turning, irregularly overtaking lane change and lane occupancy [5].

During driving, many accidents occurred due to driver's inattentiveness or unfamiliarity with the road ahead, especially at the curved road which is the place of the high incidence of accidents [6]. Therefore, if it is possible to detect and recognize the road ahead before the advent of curved road conditions, warn the driver in advance, slowdown and avoid evasion in advance, many unnecessary accidents can be avoided and the safety of life and property can be guaranteed.

II. RELATED WORKS

The lane detection technology has great significant influence for improving the vehicle's active safe driving and assisting driving. At present, there are three types of approaches used for lane detection: the feature-based methods, the model-based methods and the method which is based on other related technologies.

The feature based methods are usually applied to localize the lanes in the road images by extracting low-level features. The basic features such as color [7], width [8], edge [9,10], texture [11,12,13,14] and the gradient change [15,16] are used to extract the lane-line from the road area. The literature [7] used the color clustering method for lane-line detection. The method converts the original RGB image into the Lab color space, then uses the clustering algorithm to extract the lane-line in the Lab color space. The literature [8] used the width feature information of lane-line and combined the morphological filtering to detect the lane line. The literature [17] used the gradient information of lane edge to detect the lane-line. The method combined the adaptive Canny edge detection to maximize the edge information of the lane-line, it can effectively reduce the impact of noise edges and adapt to a variety of harsh road conditions. But it’s not good for many different lighting situations. The literature [18] used the illumination invariance to extract white and yellow alternate lane-lines, and then realized the detection of lane-line by using clustering algorithm in the alternate lane-lines. The method has a good detection effect for night or the light changes. However, for the case that the lane-line is worn, blurred or submerged by the shadow, the effect of detection is not good.

The feature based methods are not need to establish the geometric model of the lane-line and it can adapt to multiple shapes of lane-line detection. But the method is vulnerable to external factors and make it lack of good robustness [19].

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The model based methods first use suitable geometrical model to describe the lane-line, and then obtain the parameters of the geometrical model by many methods, such as Random Sample Consensus (RANSAC) [20] ,Least Square Method [21], Hough Transform [22,23,24] to fit the corresponding lane-lines. The common lane-line models include linear model [25], parabolic model [26], hyperbola model [27] and so on. The literature [28] extracted the short line in the road image to approximate the lane-line, it produced better results but it is unable to adapt the case when the lane-line is the curve. The literature [27] used the hyperbola model to describe the lane-line. The parameters of hyperbola model are solved by extracting the edge information of the lane-line in the road image and then the fitting of the lane-line is realized. This method makes full use of the characteristic of the model, so it has a good detection effect for the cases that the lane-line is worn, blurred or submerged by the shadow. The literature [23] extracted line by using Hough Transform and then the lane-line is fitted. This method can realize the fitting for straight or curved, solid or dashed lane-lines. Due to its region of interest was divided into two parts, the fitting result is not good for the lane-line with high degree of bending.

The model based methods are based on the specific geometric model, and parameters are determined by analyzing the target information in the road image. It has good robustness for the lane-line is worn, blurred and interfered. So the select of the model and the solution of parameters is the key for the problem [29].

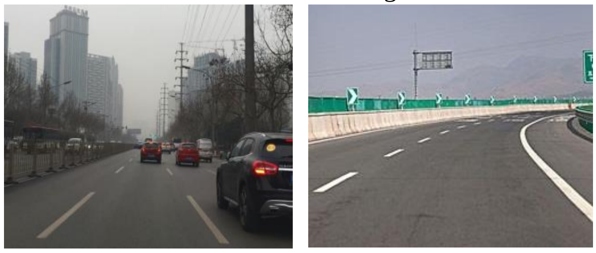
For more complex lane detection, it can be better solved with other related technologies. The literature [30] proposed a layered lane detection algorithm by classifying lane type of lane-lines and then the corresponding lane detection algorithms are used. The literature [31] proposed the method that convolutional neural network(CNN) combined with RANSAC algorithm to detect the lane-line. The method is a new thought for lane detection field and it successfully eliminate the interference lines, and also it has better performance compared with RANSAC algorithm. The literature [32] introduced the lane-line detection algorithm which is based on fully convolutional neural network(FCN).This method doesn't use time-domain information to detect the lane-line and it doesn't have the universal applicability. Due to these methods, which is based on other related technologies, are uncertain, the main method of the lane detection is the model based method and the feature based method.

However, the traditional lane detection technology is not very applicable in the curved road conditions. Thus, a curve detection algorithm which is based on straight-curve model is proposed. This method can accurately identify the curve lane, provide effective traffic information and make early warning.

III. ROAD REGION DIVISION AND MODEL

A. *Straight region and curve region division*

The layout and construction of structured roads have strict industry standards. Plane linear design usually includes: linear, circular curvilinear and gentle curves, or single-circle curves or combined curves, etc. [33]. Road basic linear structure is shown in Fig. 1.



(a) Straight (b) Curve

Fig. 1. Structured road basic linear structure

When the line is a straight line, the road lane is a straight road as shown in Fig. 1 (a). When the line is a curve, the road lane can't be only described by a straight line model as shown in Fig. 1 (b). Curve linear design is mainly according to the balance of force when the vehicle is driving on a circular curve, while based on the taking full account of the driving safety, the driving control's convenience, the fuel consumption and tire wear's economy, the comfort level and other factors to determine the circular curve radius [34]. The limit minimum radius is the curve design standard in plane linear design, as shown in Fig. 2. During the running of the vehicle and according to its corresponding driving speed, the design of the limit minimum turning radius must leave a certain margin according to the safety of turning about the vehicle.

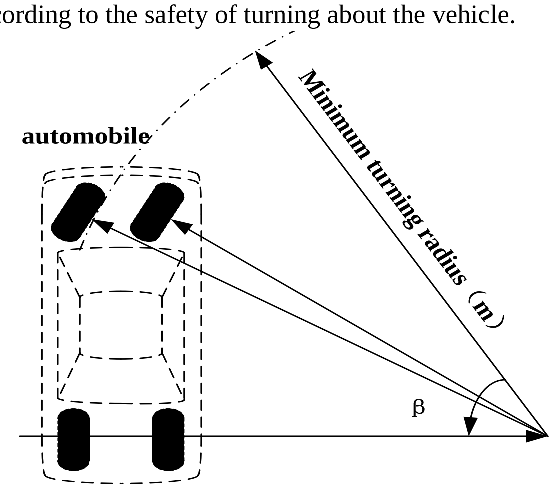


Fig. 2. Limit turning radius of vehicle

During the driving process, the vehicle's limit turning radius will increase as the vehicle's speed increases [35]. When the speed reaches $120km/h$, the vehicle's limit turning radius is 650m and the general minimum radius reaches 1000m.

As shown in Fig. 3, we assumes that the road curve radius R is 650m, and the length of arc AB is 60m (the camera shooting distance is 35m-45m in the near field due to the angle of camera installation and the arc length is assumed to be 60m according to the parameter surplus hypothesis), and the circle's central angle which is corresponded to the arc length is φ, AC is the tangent of arc AB, A is the tangent point and C is the intersection of the OB's extension and tangent.

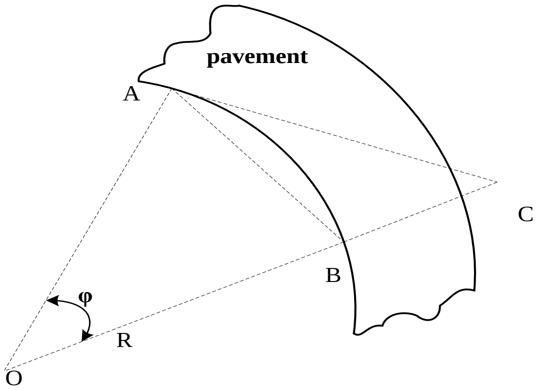


Fig. 3. Road diagram with certain curvature

According to the description of the literature [36], in the near field of view region, the angle φ is smaller, and the error is smaller when the arc length is approximated by the tangent line AC or the chord AB. While φ is larger (that is, including 300m of the far field of view region):

$$\frac{360^{\circ}}{2\pi R}=\frac{\varphi}{300} \tag{1}$$

Solve the intersection angle φ is:

$$\varphi=\frac{300\cdot 360}{2\pi R}=\frac{300\cdot 360}{2\pi\cdot 650}=26.44^{\circ} \tag{2}$$

Thus

$$\left|AC\right|=R\cdot\tan\varphi=323.23 \tag{3}$$

$$\left|AB\right|=\sqrt{2\cdot R^{2}-2\cdot\cos\varphi}=297.298 \tag{4}$$

If the road radius of curvature is 650m, as the length of the tangent segment AC and chord AB is used to replace the length of the arc AB, the deviations are:

$$\frac{\left|\left|AC\right|-300\right|}{300}=\frac{\left|323.23-300\right|}{300}\cdot 100\%=7.74\% \tag{5}$$

$$\frac{\left|\left|AB\right|-300\right|}{300}\cdot 100\%=\frac{\left|297.28-300\right|}{300}=1\% \tag{6}$$

From equations (5) and (6), it can be seen that when the radius is 650m,the error can’t be negligible when treat the sign line AB with a certain curvature as a straight line .Thus, in the road image sequence, the lane line which is in the near field of view can be approximated as a straight line while the lane which is in the far field of view can be seen as a curve and the road image can make the straight-curve highway division , as shown in Fig. 4.

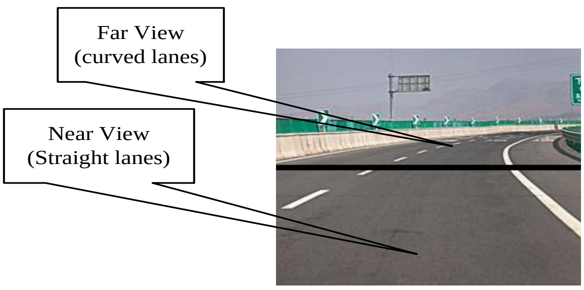


Fig. 4. Straight-curve highway division in imaging

B. *The road curve model of the far field of view*

According to the projective geometry theorem, the point on the object plane is projected by the central projection onto the image plane to obtain an image point. The image point is the intersection of the connection line between object plane and the projection center. The transformation from the object plane point to the image point is a projective transformation, as shown in Fig. 5. Set the general expression of the plane circle is:

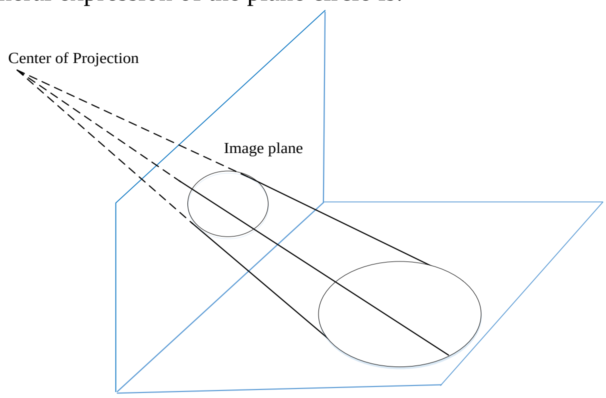


Fig. 5. The projective model

$$x^{2}+y^{2}-2ax-2by+(a^{2}+b^{2}-R^{2})=0 \tag{7}$$

Where (a,b) is the center of the circle, R is the radius, and it was written in matrix form:

$$x^{T}Px=0 \tag{8}$$

Among them, $x=(x,y,1)^{T}$ is the odd coordinate of the point on the plane.

$$P=\begin{bmatrix} 1 & 0 & -a \\ 0 & 1 & -b \\ -a & -b & a^{2}+b^{2}-R^{2} \end{bmatrix}$$

According to the rule that quadratic curve through the projective transformation, the curve is still quadratic in the image coordinate system, and the expression is:

$$x'^{T}\left[\lambda H^{-T}PH^{-1}\right]x'=0 \tag{9}$$

Then there are:

$$P'=\lambda H^{-T}PH^{-1},\quad \lambda x'=Hx$$

H is the projective transformation rule. Thus

$$P'=\begin{bmatrix} a^{2}-R^{2} & ab & a \\ ab & b^{2}-R^{2} & b \\ a & b & 1 \end{bmatrix}$$

Therefore, the far field of view curve can be approximated by the general elliptic polynomial curve.

$$Ax^{2}+Bxy+Cy^{2}+Dx+Ey+F=0 \tag{10}$$

Where $A=a^{2}-R^{2}$; $B=ab/2$; $C=b^{2}-R^{2}$; $D=-a/2$; $E=b/2$; $F=1$

C. *The straight-curve model of the road*

According to the characteristics of the structural road [37]: (1) the structural road has flatness. (2) the lane- line of the structural road is continuous with solid line or continuous with dotted line(that is, the straight lane line and the curved lane-line are smooth and continuous).Since the straight lane-line and the curved lane-line are connected and tangent, a straight-curve model of the linear structure can be established:

$$\begin{cases} y_0(x_m^+) = y_1(x_m^-) \\ y_0'(x_m^+) = y_1'(x_m^-) \end{cases} \tag{11}$$

$y_0(x)$ represents the straight line equation of the right lane-line and $y_1(x)$ represents the curve equation of the right lane-line. x_m indicates the position of the abscissa which is the straight region and the curve region's tangent point, as shown in Fig. 6.

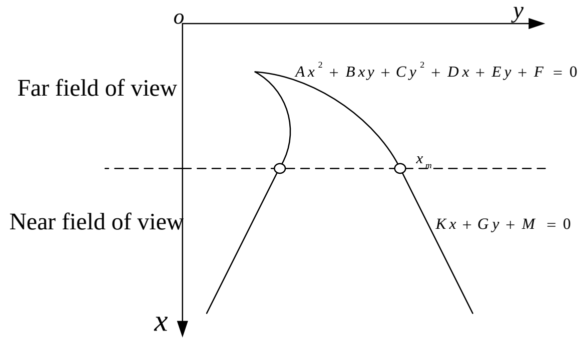
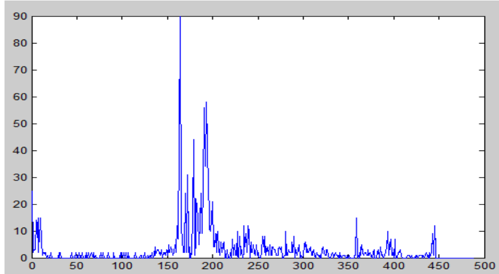


Fig. 6. Highway mathematical model

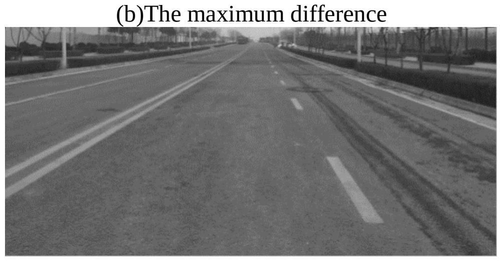
D. *The division of the ROI*

The distribution pattern of the road image scenes generally can include the environmental region of the image background and the main lane region of the road [38]. Here, the horizontal line is set by finding the abrupt change of the road image's pixel, thereby obtaining the ROI region. To simplify the calculation, firstly, the image is grayed and binarized [39]. The binarized values of each line of the image are accumulated in turn from the top. Then, the difference values of pixels' accumulation about each adjacent two rows is obtained by subtracting the current row's calculation from the previous row's calculation. Finally, perform extreme search on the difference values and find the maximum difference values, that is, find the mutational position of image pixel value, namely, find the horizontal line position and you can get the ROI region we want, as shown in Fig. 7.

(a)Binarized image



(b)The maximum difference



(c) The region of interest extraction

Fig. 7. Regional division of ROI

IV. THE SOLUTION OF STRAIGHT-CURVE MODEL

A. *The straight model resolving*

According to the lane image's feature analysis of ROI, it can be found that the lane which is near the field of view is approximated a straight lane and the lane which is far from the field of view is approximated a curved lane under the image [40]. Based on this, a mathematical model of far and near lane-lines is established. Linear mathematical model of the lane-line is established in the lane which is near the field of view. The equation is $y = k_0 x + b_0$ .Two unknown parameters k_0 and b_0 need to be solved. The Hough Transform [41, 42] has a good recognition rate for the application of straight line detection and the general representation is described by the parametric equation [43]:

$$\rho = x\cos\theta + y\sin\theta \tag{12}$$

In this case, the traditional Hough straight line detection is proved. Generally speaking, the lane-line is located in the both sides of the vehicle's driving direction(that is, the vertical direction of the camera plane).We divide the Hough transform detection[44,45] into two parts, one part is $\theta \in (-90^\circ \sim 0^\circ)$ and the other part is $\theta \in (0^\circ \sim +90^\circ)$. Namely, in the image space, it is detected that the lane-line which the intersection angle is $(-90^\circ \sim 0^\circ)$ and $(0^\circ \sim +90^\circ)$ respectively can improve the accuracy of the lane-line recognition. The straight slopes of the left and right lane-lines are obtained through the Hough transformation and make it connected with the linear model equations. $k = -1/\tan\theta$ and $b = \rho/\sin\theta$ can be obtained and the parameters of the linear model equation can be obtained.

B. *The curve model resolving*

Curve model is available for the lane-line curve when the view field is far and the quadratic curve model is established by analyzing and comparing the model's advantages and disadvantages of circular, hyperbolic [46], generalized curve [47], convoluted curve [48] etc. As we proved in section B of III, the curve model is:

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \quad (13)$$

Where (x, y) is the image space coordinate, A, B, C, D, E, F are the parameters of the quadratic curve, of which five are free parameters. It can be obtained from equation (11):

$$\begin{cases} Ax_{\mathrm{m}}{}^2 + Bx_m y_m + Cy_m{}^2 + Dx_m + Ey_m + F \\ = Kx_m + Gy_m + M \\ 2Ax_m + By_m + D = K \end{cases} \quad (14)$$

Among them, x_m represents the abscissa position of the tangent point between the straight line region and the curve region in the lane-line model and y_m represents the position of its ordinate. Thus:

$$\begin{aligned} &\frac{K - By_{\mathrm{m}} - D}{2x_m} x^2 + Bxy \\ &+ \frac{y^2}{y_m{}^2}(Kx_m + G\mathrm{y}_{\mathrm{m}} + M - \frac{K - By_m - D}{2} x_m) \\ &- \frac{y^2}{y_m{}^2}(Bx_m y_m + Dx_m + Ey_m + F) \\ &+ Dx + Ey + F = 0 \end{aligned} \quad (15)$$

The Hough transform is used to detect the straight line and obtain the model of the near-field lane-line. That is, the parameters of $Kx_m + Gy_m + M = 0$ are all known. Two of the parameters A and C of the quadratic curve are obtained by equation (15), and there are five free parameters in the quadratic curve. Thus, three of the four parameters B, D, E, and F are determined, and the complete mathematical model of the curve can be obtained.

Assuming that the edge points of the lane-line are detected as (x_i, y_i), for i = 1,...,n, then these data are used to fit the curve mathematical model (15) and obtain n equations:

$$\begin{aligned} &\frac{K - By_{\mathrm{m}} - D}{2x_m} x_{\mathrm{i}}{}^2 + Bx_i y_i \\ &+ \frac{y_i{}^2}{y_m{}^2}(Kx_m + G\mathrm{y}_{\mathrm{m}} + M - \frac{K - By_m - D}{2} x_m) \\ &- \frac{y_i{}^2}{y_m{}^2}(Bx_m y_m + Dx_m + Ey_m + F) \\ &+ Dx_i + Ey_i + F = 0 \end{aligned} \quad (16)$$

for i = 1,2,...,n

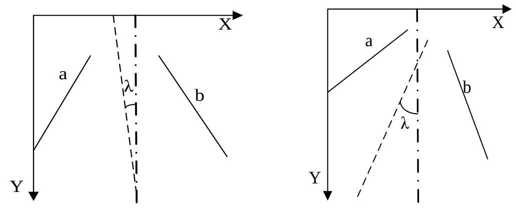
Obviously, the effect of using n equations is better than the effect of using three equations. Therefore, the method of least squares curve fitting [49] is adopted in this paper. The principle is to minimize the error between the real value and the fitting value satisfying the data point. Based on this, the curve model equation parameters can be obtained.

V. DRIVING DEVIATION WARNING AND CURVE MODEL SWITCHING

When the car is driving normally in the straight road, the tracking for the lane-line is only using the straight model and at this time, only the driving deviation early warning of the straight road is performed. While the vehicle enters the curve, the application of straight-curve model is required. At the same time, the early warning of the driving deviation and the curve are performed.

A. The driving deviation early warning model

The deviation of the early warning for the driving vehicle is judged according to the near-lane straight road region. The evaluation of the car driving direction [50] as shown in Fig. 8.



(a) (b)

(a)The driving direction of the normal threshold

(b)The driving direction of beyond threshold

Fig. 8. Orienting evaluate

In the calculation of the driving vehicle's deviated angle, we propose a more practical and effective method, that is, make use of the relationship of the triangle's middle line and vertical line, as shown in Fig. 9.

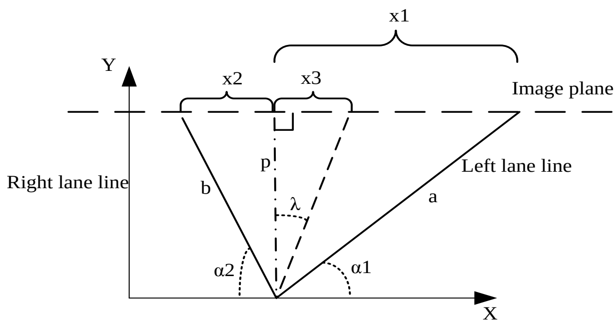


Fig. 9. Lane-lines, vertical, and the triangle

The solid lines *a* and *b* indicates lane-lines and the dotted line indicates the lane's center line. The large-dotted line which is perpendicular with the coordinate axis is the vertical line (that is, the direction of the driving car). The camera is usually installed on the front of the windshield of the car to obtain the vertical line of the image [51]. The parameter equation of the Hough transform can be converted to:

$$y = -\frac{1}{\tan\theta} x + \frac{1}{\sin\theta}\rho \quad (17)$$

The above equation is compared with the image space equation $y = k_0 x + b_0$ to obtain $k_0 = -1/\tan\theta$, $b_0 = \rho/\sin\theta$ The relational expression and the image space's slope (the intersection angle with the horizontal direction is α) and the parameter space's θ can be obtained:

$$\tan\alpha = -\frac{1}{\tan\theta} \quad (18)$$

We reversed the image coordinate system into the coordinate system which is accustomed to us, as shown in Figure 9. The following expressions can be obtained:

$$\tan\alpha_1 = \frac{p}{x_1} \quad , \quad \tan\alpha_2 = \frac{p}{x_2} \quad ,$$
$$x_3 = \left| x_1 - \frac{x_1 + x_2}{2} \right| = \frac{|x_1 - x_2|}{2} \ , \tan\lambda = \frac{x_3}{p} \tag{19}$$

And it can be derived:

$$\tan\lambda = \frac{|\tan\alpha_1 - \tan\alpha_2|}{2\tan\alpha_1 \tan\alpha_2} \tag{20}$$

That is:

$$\tan\lambda = \frac{|\tan\theta_1 - \tan\theta_2|}{2} \tag{21}$$

The intersection angle λ of the lane-line's middle line and the driving vehicle's direction can be obtained.

By solving the inverse tangent function to obtain the intersection angle λ of the vertical line and the middle line of the lane, that is the driving vehicle's deviated angle.

B. The switch of straight-curve model

Before the vehicle enters the curve, it is required to perform the early warning of bending and the early warning of the curve, as shown in Figure 6. The residual error between the detected straight line equation and the actual point of the second lane-line is solved.

$$E = \sum_{i=1}^{m} [y_i - f(x_i)]^2 \tag{22}$$

When the residual error value is greater than a certain threshold, it is switched to the straight-curve model $E > E_{th}$ .The vanishing point of the curve and the vanishing point of the straight are used to comprehensively estimate the bending direction and the degree of bending, and the early warning is performed.

VI. THE CURVE RECOGNITION AND EARLY WARNING

C. The curve image segmentation based on regional ROI

According to the analysis of the image information and the relationship of the image coordinate system and the world coordinate system, the two equidistant parallel lines in the real world must intersect at one point in the image space [52]. Combined with the characteristics of the road image, it is found that there exists a significant difference between the gray value of the middle lane region and the environmental gray values on both sides of the lane. While the vanishing point of the curve is located in the lane-line's upper edge of the image region of interest, as shown in Fig. 10.

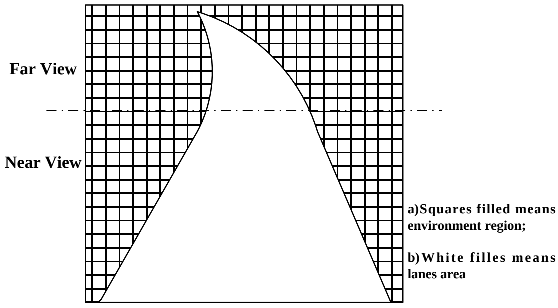
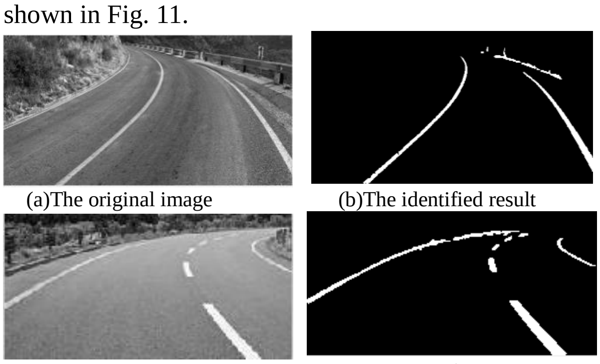


Fig. 10. Lane and environment on both sides

Since the lane-lines are mostly straight lines, the Hough transform is used to detect the longer straight line in the image and it can obtain the slope of the general direction in which the lane-line ROI region is located [53]. In order to avoid the problem that only one side orientation is detected during the straight line detection process, it can be divided into left and right lane-lines for respectively processing. After obtaining the block where the ROI region of the lane-line is located, the rectangle small ROI region is constructed [54]. Along the block, the OTSU threshold segmentation processing is performed respectively for the grayscale image, and then the processing result is spliced to obtain the better lane-line segmentation image [55], as shown in Fig. 11.



(a)The original image (b)The identified result

(c)The original image (d)The identified result

Fig. 11. Regional ROI segmentation image

D. Determine the bending direction

Rebuild the straight and the curve of the road lanes separately, as shown in Fig. 12. The left and right straight lanes are extended so that they can intersect at one point. The bending direction of the curve can be determined by recognizing the relative position of the straight intersection and the curve's vanishing point.

Determination of the curve's bending direction is divided into four steps: (1) Hough transformation detects the parameters of straight line and obtains the linear equation, (2) calculating the intersection's position of the left and right straight line lanes, (3) determining the relative position of the curve's vanishing point and the intersection point of straight line and the bending direction of the curve is predicted preliminarily. The left side of the straight line intersection point is the leftward bending direction and the right side of the straight line intersection point is the rightward bending direction, (4) counting the numbers of characteristic pixels on the left and right lane-lines between the intersection point and the inflection point in image, and comparing the results to determine the bending direction of the lane-line.

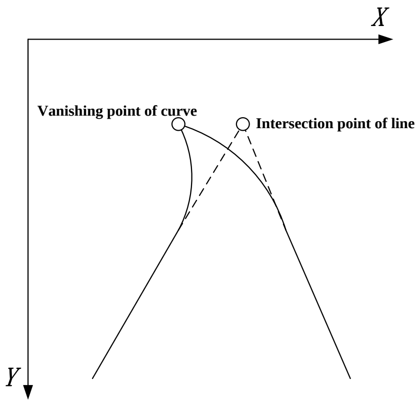


Fig. 12. Line intersection point and curve intersection point

From section B of Ш, we have obtained the left and right straight lane-line equation:

$$\begin{cases} y_0 = k_0 x + b_0 \\ y_1 = k_1 x + b_1 \end{cases} \tag{23}$$

y_0 represents the linear equation of the left lane and y_1 represents the linear equation of the right lane. The two straight lines' intersection point (x_z, y_z) can be obtained by solving equation group (11). Then calculate the horizontal relative displacement $\mathrm{d} = x_w - x_z$ of the curve's vanishing point and the straight line's intersection point. The threshold T is set to determine the relationship of the displacement d and the threshold T, and the bending direction of the curve is predicted preliminarily: it indicated that the curve is bending right when $\mathrm{d} > \mathrm{T}$, it indicated that the curve is straight when $\mathrm{d} = \mathrm{T}$, it indicated that the curve is bending left when $\mathrm{d} < \mathrm{T}$. According to the bending direction which is predicted preliminarily, the bending direction of the curve is finally determined by the formula (24).

$$\begin{cases} l_1 > r_2 \ \&\& r_2 < N & \textit{Left Curve} \\ r_2 > l_1 \ \&\& l_1 < N & \textit{Left Curve} \\ \textit{Other} & \textit{Straight Line} \end{cases} \tag{24}$$

In the above formula, l_1 is the numbers of white pixels between the left lane-line inflection point and the straight line intersection point, and r_2 is the numbers of white pixel points between the right lane- line inflection point and the straight line intersection point, and N is a threshold constant.

VII. EXPERIMENTAL RESULTS

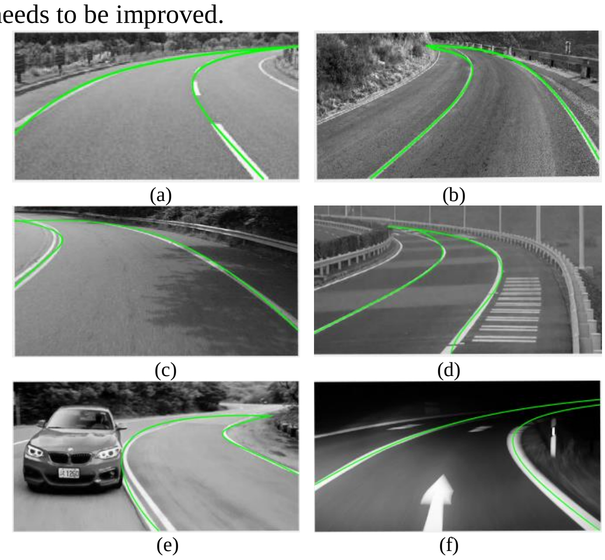
A CCD camera (WAT902H2, high-sensitivity) in the actual road conditions is used to collect a large number of road curve images. The specific experimental devices are shown in the Fig.13. The Matlab R2016a platform is adopted to identify the lane-line by analyzing and processing the data of the road image, dividing the region of interest and dividing the straight and the curve. Finally, the intersection angle of the lane-line and the driving car's direction is calculated and the direction of driving vehicle and the bending direction of the front curve are determined.

(a) (b)

Fig. 13. Experimental scene

A. Experiments 1: Straight-curve model lane-line detection

A large number of road curve images in different conditions are collected with our platform and processed by the proposed model. The video collection's site is in Xi'an city and its neighboring counties. The recognition results of various road conditions are shown in Fig.14. The Fig.14(a) and Fig.14(b) are the recognition results of the left and right curve in the normal road condition, Fig.14(c) is the recognition result that the lane-line with shadow, Fig.14(d) is the recognition result that the lane-line with other interference, Fig.14(e) is the recognition result that the lane-line with occlusion, Fig.14(f) is the recognition result of the road condition in the night, Fig.14(g) is the recognition result of the slope road condition, Fig.14(h) is the recognition result of the road condition in the foggy day, Fig.14(i) is the recognition result of the road condition inside the tunnel, and Fig.14(j) is the recognition result of the road condition in the rainy and foggy day. For the recognition results of the above various road conditions, we can see that if the slope is large, the recognition result will be slightly deviated, but it doesn't affect the identification of the overall lane-line in Fig. 14(g). Relatively speaking, the lane-line recognition result is better when the slope is small. For the road condition of the foggy day, as shown in Fig. 14(h) and Fig. 14(j).The recognition result is slightly worse, and only the lane-line in the near field of view can be accurately identified, and the recognition in the far field of view may be deviated. Therefore, the lane-line identification method in this case needs to be improved.



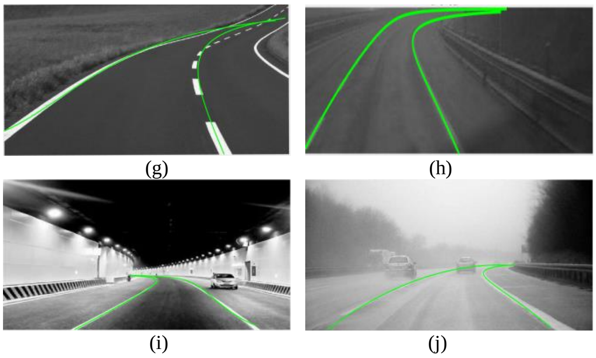


Fig. 14. Curve lane recognition

B. *Experiments 2: Curve prediction based on straight-curve model*

According to the method of section VI.B, the recognition results of the lane-line bending direction as shown in Fig. 15. The green line in the image is the preliminary lane-line reconstruction result, the red line is the extension line of the straight line in the near view region, and the red text on the left side of the image represents the bending result.

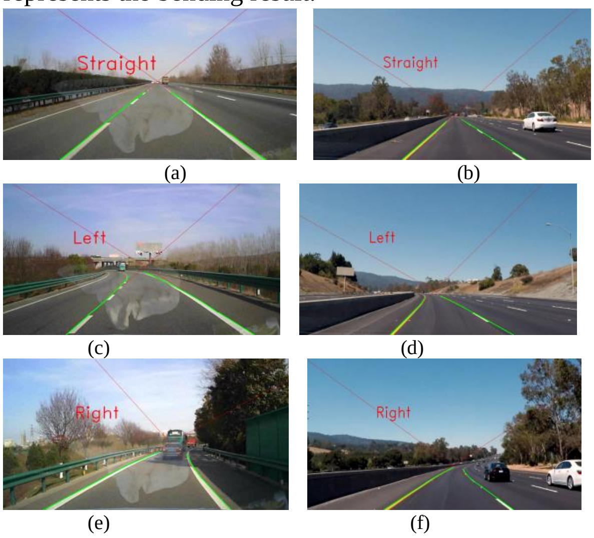


Fig. 15. Bending direction recognition

C. *Experiments 3: Lane deviated angle warning*

According to the proposed model in section **V.**A, the driving car's deviated angle λ is calculated in the straight model of the near field, and the bending direction of the curve is determined, as shown in Table 1.

TABLE I

EXPERIMENTAL DATA OF THE LANE-LINE DETECTION

NO	the deviated angle of the lane-line detection（λ/°）	The error rate（%）	the bending direction
1	3.0592	+5.20	left
2	5.1482	+1.036	left
3	9.2576	+2.86	right
4	11.8468	-2.05	left
5	17.5664	+0.37	right
6	20.7734	-0.83	right
7	24.3654	+1.52	right
8	30.2938	+0.98	left

D. *Experiments 4: Comparison of algorithms performance*

The comparison results of curve recognition algorithms between this paper and the literature [56] , [57] are shown in Table 2. It can be seen from Table 2 that the proposed algorithm can slightly better than the two algorithms in the time and accuracy aspect.

TABLE II

PERFORMANCE COMPARISON OF ALGORITHMS

Algorithm	Time (ms)	Accuracy(%)
This paper's algorithm	60~80	92~93
Literature[56]'s algorithm	70~80	92~93
Literature[57]'s algorithm	<100	93~94

VIII. CONCLUSION

This paper proposed the lane-line's detection algorithm which is based on the straight-curve model by establishing the model of the straight and curve and analyzing the characteristics of the road image. It can better solve the accurate detection of lane-lines and it has great significance in practical applications. The experimental results show that the algorithm can accurately identify the road lane-line and give the deviated information of vehicle and the direction of the curve. It has great significance to improve the active safety driving and assisted driving of the vehicle which is in the curved road conditions.

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