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Feature Point based Highway Curl Road Recognition

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***Abstract*—This paper introduces a recognition algorithm of highway curl road based on feature point. Firstly, a road model was established and traditional Hough transform was adopt to obtain linear equations of lanes in order to improve the real-time performance and robustness. The curve direction of current lanes was judged with certain criteria, and the feature points in the curvilinear section were extracted and corrected. Finally, the linear and curvilinear section was fitted to realize the ultimate two dimensional rebuilding of the current bent lanes. Experiments proved that both continuous and dashed lanes were recognized accurately with strong robustness.**

Keywords-intelligent vehicle; highway; bent lanes; feature point;curve direction

I. INTRODUCTION

The number of accidents occurring on highway curl roads is obviously higher than which occurs on the straight roads per kilometer. As a case study in Japan, the proportion of the traffic accidents occurred on the curl roads is 41.01% of those occurred on the whole highway [1]. According to China Traffic Accident Statistics Annals, the number of accidents occurred on the curves accounts for 7.84% of all accidents in 2005 in China. Therefore, to improve traffic safety is quite important today. For intelligent vehicles, the accurate recognition of road boundary is a key technology.

The method based on road model is the main method of bent lane detection at present. There are some common road models, such as quadratic curve model [2-3], parabola model [4], hyperbolic model [5], linear-parabolic model [6-7], linear-hyperbola model [8], generalized curve modal [9], spline curves model [10-11], clothoid model [12-13] and so on. But the recognition technology of bent boundary now is not mature enough in China. The main reason is that the pattern of curves recognition is complex, and the situations are various, which makes it difficult to unity those road models [14]. In addition, it also has difficulty to satisfy the requirement of real-time performance and accuracy because of the complexity of the algorithm. In this paper, however, the feature points in linear and curvilinear section are extracted accurately, and the recognition and rebuilding of the bent lanes is realized by piecewise fitting these two sections. The basis of this method above is as follows, ①the close-rang part of curves image can be considered as straightaway. ② according to the differential geometry, the considerable short curvilinear section can also be considered as straightway. On the other hand, with the ellipsis of road modal establishment and mathematic parameters solution, the method in this paper is simple, effective and high real-time, which achieves a good result. Above all, this method could be applicable for general highway curl roads, which is better than traditional detection algorithm of bent lane based on road model.

II. THE IMAGE EXTRACTION AND PREPROCESSING

The road information needed when driving is obtained by machine vision. So the CCD image sensor is installed in front of the vehicle in order to acquire visual information, and to get a serious of digital images at the same time. In this paper, color optical CCD image sensor driven by VC++ is used to obtain images, so as to realize image-preprocessing and to get binary images finally.

The method in this paper deals the obtained color image with gray, image smoothing using bilateral filtering, threshold segmentation based adaptive OSTU. Then make an AND operation between binary image after threshold segmentation and gray image after filtering, which reserves the same part and removes different parts between the original image and background during binarization. Experimental results show that the road boundary can be stood out clearly through image-preprocessing above. In addition, this pretreatment method can also have strong robustness under different illumination conditions in different weather as well as with different interferences. The image-preprocessing results are shown in Fig.1.

Original images Binary images

Figure 1. Image-preprocessing results

III. LANE DETECTION

A. Establishment of Road Model

According to CCD calibration parameters and its visual rang, as well as referring to highway construction standard,

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the conclusion gotten from massive experimental road images: the bent lanes within 40m of the vehicle's visual plane can be approximate to straightaway [15]. The curl road model is shown in Fig.2.

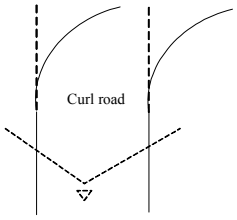


Figure 2. Curl road model

The linear equations of lanes is obtained by adopting traditional Hough transform, from which the lowest point and the highest point of the corresponding lane line are extracted. Followed that, the feature points in curvilinear section are searched and corrected according to the curve direction. Finally, the 2-D reconstruction of the current bent lanes is realized by piecewise fitting these two sections, that is to say, by connecting these points one by one. The algorithm flow is shown in Fig.3.

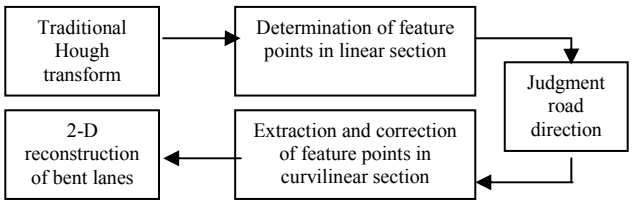


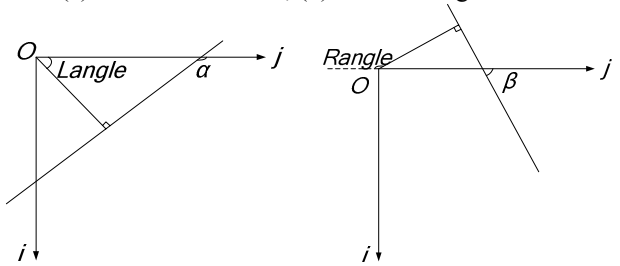
Figure 3. Algorithm flowchart

B. Traditional Hough Transform

The Approximate straightaway section of bent lanes generally locates on the under half region of road images, which could reduce the number of voted target points and the voting space of Hough transform. Therefore, it improves the real-time performance and robustness of this algorithm as a result.

The left lane detection and the right lane detection are separated in this paper so that it reduces the time of the algorithm greatly. Followed by the previous experience, the angle of left lane line *Langle* is generally less than 90, while the angle of right lane line *Rangle* is always between 90 and 180. Aiming at reduce search time, according to massive experiment conclusions, *Langle* is set from 40 to 70 at length, and *Rangle* is set from 110 to 160, jumping up and down at 5 each one.

Now, the gradient of left lane line is set as k_l, while that of right lane line is set as k_r. It's shown in Fig.4, among which (a) shown as left lane, (b) shown as right lane.



(a) Left lane (b) Right lane

Figure 4. The lane line model

The results of each gradient as follows,

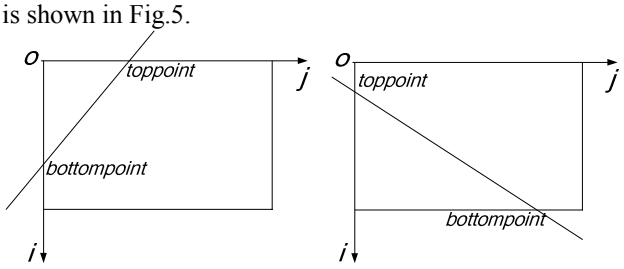
$$k_l = \tan\alpha = \frac{\sin\alpha}{\cos\alpha} = \frac{\sin(90^\circ + Langle)}{\cos(90^\circ + Langle)} = -\frac{\cos(Langle)}{\sin(Langle)} \quad (1)$$

$$k_r = \tan\beta = \frac{\sin\beta}{\cos\beta} = \frac{\sin(Rangle - 90^\circ)}{\cos(Rangle - 90^\circ)} = -\frac{\cos(Rangle)}{\sin(Rangle)} \quad (2)$$

The images after the operation of Sobel are processed through traditional Hough Transform above, from which should get the peak point in the parameter plane. Thus the linear equations of the left lane and the right lane are obtained separately.

C. Determination of Feature Points in Linear Section

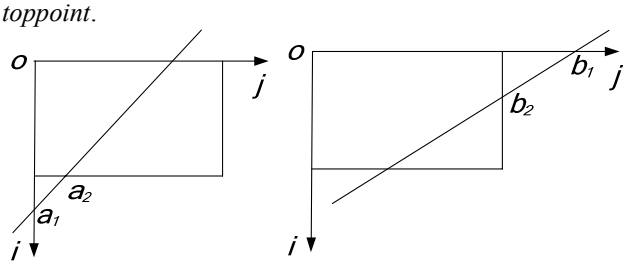
The lowest point *bottompoint* and the highest point *toppoint* of the lane line in the road image are obtained according to linear equations of corresponding lane, which are called feature points of linear section. As to the left lane, the abscissa of *bottomponit* is generally 0 and 0 also serve as the ordinate of *toppoint*. While for the right lane, the height of image Height is always as the ordinate of *bottomponit* as well as the abscissa of *toppoint* is 0, which is shown in Fig.5.



(a) Left lane (b) Right lane

Figure 5. Determination of the feature points in linear section

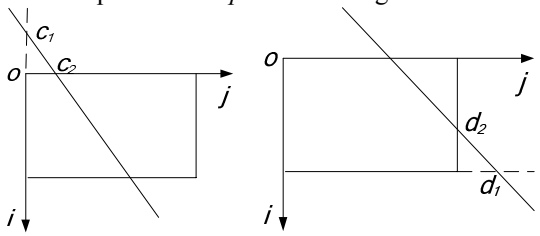
But in this paper, the overflow of the feature points is considered seriously. This situation about the left lane is shown in Fig.6. Among them, (a) is shown the overflow of the lowest point *bottompoint*, under this circumstances *bottompoint* should be a_1 in theory, but the ordinate of a_1 is beyond the maximum height of image, so the intersection point a_2 of this lane line and the maximum height is determined as *bottompoint*. (b) is shown the overflow of the highest point *toppoint*, in this case b_1 should be theoretical *toppoint*, but the abscissa of b_1 goes beyond the maximum width of image, so intersection point b_2 of this lane line and the maximum width of image is set as *toppoint*.



(a) The lowest point (b) The highest point

Figure 6. Overflow of the feature points of the left lane

The overflow of the feature points in right lane is shown as Fig.7. (a) shows the overflow of the highest point *toppoint*, (b) is shown the overflow of the lowest point *bottompoint*. Simultaneously, in this case c_2 is set as the highest point *toppoint* of the right lane, while determine d_2 as the lowest point *bottompoint* of the right lane.



(a) The highest point (b) The lowest point

Figure 7. Overflow of the feature points of the right lane

After obtaining the linear equations of two lanes, the intersection point *meetpoint* of the left lane and the right lane is extracted.

D. Determination of curve direction

(1) Extracting the preliminary inflection points of two bent lanes: With setting the linear section between the lowest point *bottompoint* and the intersection point *meetpoint* as pre-search region, the target pixel point is obtained from bottom to top with progressive scanning. Search is stopped when satisfying the given criterion. The point gotten now is seemed as the intersection point of linear and curvilinear section, which could be considered as the preliminary inflection point *temppoint* of current bent lane. In this paper, the search should be stopped when the first black pixel point is obtained and the white pixel points gotten are more than given number. If the inflection point of any a bent lane cannot be extracted according the above stopping criterion, the ordinate of the inflection point of this bent lane should be equaled to that of another bent lane, so the inflection point *temppoint* of current lane can also be determined preliminarily.

(2) Correcting and Determing the final inflection points: The preliminary inflection points need to be corrected in order to guarantee accurate location. The method of correction shows as follows: firstly obtaining higher point of these two inflection points in the road image, then setting the linear section between this point gotten above and another inflection point *temppoint* as the adjusted area, then the final inflection point of each lane is obtained from top to bottom with progressive scanning respectively. Stop search when getting the first white pixel point, this pixel point obtained now is the final inflection point *temppoint* of corresponding bent lane.

(3) Judging the curve direction: With setting the area between *temppoint* of each lane and *meetpoint* of two linear equations as search region, progressive scan the pixel points from bottom to top respectively. On each line in the image, firstly finding the pixel point on linear section, then from this point scan 5 columns towards both left side and right side one by one. Then statistical of white pixel points on both sides is gotten respectively. Among them, as to the left lane, the number of the white pixel points on the left side and the right side is set as *Numll* and *Numlr* respectively, likewise, which on the left side and the right side is set as *Numrl* and *Numrr* for the right lane.

The criterion is set as follows

$$\begin{cases} Numrr > Numll \ \&\& \ Numll < N, right \\ Numll > Numrr \ \&\& \ Numrr < N, left \\ others, straight \end{cases} \tag{3}$$

where N is constant, and is set to 10 in this paper.

The flowchart about solving the direction of bent lanes is shown in Fig.8.

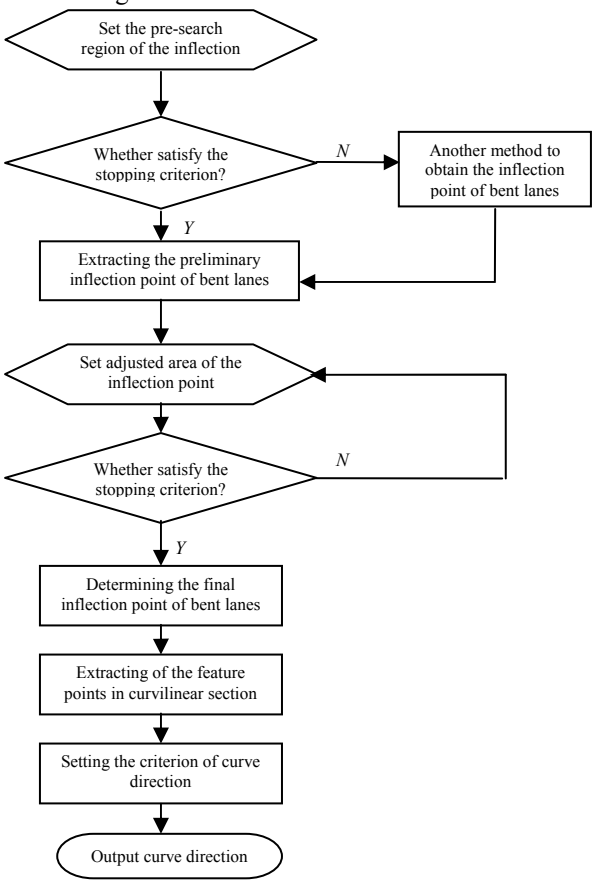


Figure 8. Flowchart about solving the direction of bent lanes

E. Determination of Feature Points in Curvilinear Section

The direction of the bent lanes is determined already, on the premise of which, the stopping criterion is set to set to extracted the feature points in curvilinear section. The criterion is shown: from the point on the linear equation of current lane, scan N columns towards curve direction, and stop search when getting the first white pixel point. N is a supposed constant. Taking the left bent lane for example, with setting the area between the inflection point *temppoint* and the intersection point *meetpoint* of two linear equations as search region, progressive scan the pixel points from bottom to top. On each line in the image, firstly to find the pixel point in linear section, then from this point scan 10 columns towards the left side in turn. Stop search when obtaining the white pixel point, this point gotten now is the feature point in curvilinear section on this row. The feature points in curvilinear section of the right bent lane can be obtained by using the similar method.

F. 2-D Reconstruction of Bent Lanes

Road modal establishment and mathematic parameters solution are left out in this part as distinct from traditional method based on road modal. In this paper, firstly store the feature points in curvilinear section of both lanes in the iterators called *Lpoints* and *Rpoints* respectively. The address of the first data in the iterator is gotten so that the inflection point *temppoint* of corresponding bent lane could be obtained. Then connect the adjacent points in the curvilinear section, and obtain a relatively smooth curve according to differential geometry, because of considerably short distance between any two points. The linear section can be obtained by connecting the lowest point *bottompoint* and the inflection point *temppoint* of corresponding bent lane. Above all, the recognition of bent lanes based on feature point extraction could realize 2-D reconstruction of bent lanes accurately as well as achieve good effect of real- time processing. Finally, the word "left" and "right" are input into the road image to stand for left bent lane and right bent lane respectively.

IV. Experiment Results

Massive images in different road conditions are already experimented based on the recognition algorithm above, from which the accurate identification rate is about 89.63%, and experimental results prove the effectiveness of this algorithm. The recognition results of different shape roads are shown in Fig.9, the left is original image and right stands the final result. In the images, the red line segments stand for 2-D reconstruction of bent lanes, and the direction of bent lanes is shown through the blue words. From the images followed, this method not only has high accuracy in continuous bent lanes recognition, but also performs strong robustness in dashed lane detection.

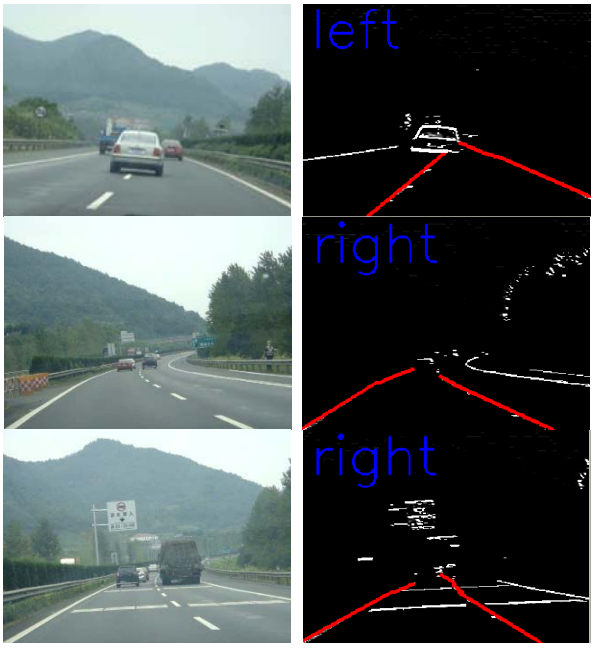


Figure 9. Recognition results under real circumstances

V. Conclusion

Experimental results prove that the algorithm introduced in this paper can recognize bent lanes accurately and judge curve direction correctly, and its computational complexity is within applied rang of regulation. But this method can only recognize the current lanes where the vehicle locates in. On one hand, for the sake of traffic safety during lane change, the method above should be improved to realize the detection and reconstruction for multi-lane lane. On the other hand, the curvature radius of current bent lanes need to be calculated in order to realize bent lane departure warning, from which the angle of steering wheel and critical safety speed in the curves could be determined based on automobile theory. As a result, it could better improve automobile safety when driving, and that will be the key point as next research in the future.

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