A Method of Lane Edge Detection Based on Canny Algorithm

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***Abstract*—Lane detection is one important process in the vision-based vehicle assist system. The results of lane edge detection play an important role in feature-based lane detection. The complicated conditions of road make the correct edge detection of lane markings become very challenging. In order to get an ideal edge of lane markings in road image, a method of lane edge detection based on Canny algorithm is proposed. Firstly according to the importance in lane markings recognition, the road image is divided into three regions. Only the regions with useful information are processed. Then by the features of gray distribution and lane markings width, some noises are removed from the image. Using the shape features of lane markings, the lane edges are detected based on Canny algorithm. Finally by use of the Hough transform theory, lane detection is achieved. Experimental results show that the proposed method is effective.**

Keywords—Canny algorithm; lane edge detection; binarization; Sobel operator; Hough transform

I. Introduction

Lane detection is an important prerequisite for the vision-based vehicle assist system. It can be used for intelligent autonomous and smart vehicle applications, such as the lane departure warning system, vehicle navigation, and forward collision avoidance. The complicated conditions of road make the correct identification of lane markings become very challenging. The main problems that must be faced in the detection of lane markings are: 1) the presence of shadows, producing artifacts onto the road surface, and thus altering its texture, and 2) the presence of other vehicles on the path, partly occluding the visibility of the road [1].

At present, there have been many approaches proposed for solving the above problems in lane detection [2] [3] [4]. In general, these methods can be grouped into two categories: feature-based recognition method and model-based recognition method. Feature-based recognition methods are usually implemented using different edge detection techniques. The results of lane edge detection have an important influence on feature-based lane detection. John Canny gives an edge detection algorithm in 1986 [5]. The Canny algorithm is known as an optimal edge detection method for good detection, good localization and only one response to a single edge.

In this paper, a method of lane edge detection based on Canny algorithm is designed. The method is given by combining using the characteristics of road image. The paper is organized as follows: Section II gives a short overview of the road image characteristics such as the partition, the binary description, the sub blocks image and the edge; Section III presents how to realize lane edge detection, and gives the procedure of lane edge detection; Section IV introduces the method of lane detection based on Hough transform; Section V presents the experimental results, and section VI summarizes this work.

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II. Characteristics of Road Image

The lane markings are considered to be targets in lane detection. For the targets detection, the targets region has the following characteristics:

- The targets region is always located at the lower part of the road image.
- The gray value of targets is always higher than background area.
- For a small block image, if there are the targets, the gray mean and gray variance of the block image should meet certain conditions.
- The edge of targets is the most important information for the lane detection.

A. Partition

According to the importance of lane detection, in this paper we divide the road image into region 1, region 2, and region 3. The road partition can be illustrated as Fig. 1. The height of sub region 1 is related to the mounting angle of the camera. The sub region 1 usually accounts for 2/5 of the entire image. This region is mainly the sky area, and it does not contain useful information. Only sub region 2 and sub region 3 have useful information.

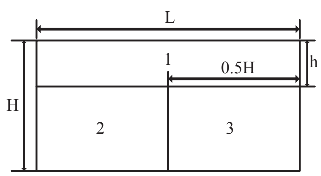

Fig. 1. Illustration of road partition

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B. Binary Description

For lane detection, the useful information is included in the binary description of the road image. In order to detect lane markings, the corresponding binary image should be obtained. It is necessary to judge whether each pixel should belong to the foreground area (lane markings) or the background area. Binary image not only greatly reduces the amount of storage, but also allows the later identification to be less disturbed.

The binarization algorithm, also known as the threshold algorithm, aims to find a suitable threshold. The studied area is divided into the two parts of foreground and background, and finally the binary image is obtained. At present, there are many methods of binarization. But no method that is universally applicable to any object. Binarization method must be based on the object to be handled. According to the choice of threshold, the methods of binarization can be divided into global threshold method, local threshold method and dynamic threshold method. The dynamic threshold method is an adaptive binarization method in which threshold selection depends not only on the gray value of the pixel and the gray value of the pixels around it, but also on its position.

C. Sub Block Image

If an image is divided into many sub blocks, the gray mean and gray variance of each sub block can be calculated according to formula (1) and formula (2). $g(i,j)$ is the gray value of the i-th row and the j-th column pixel in the (k,l) sub block. M is the number of row and N is the number of column.

$$AveG(k,l)=\frac{\sum_{i=0}^{H-1}\sum_{j=0}^{W-1}g(i,j)}{H\times W},\quad k=1,2,\cdots,M;l=1,2,\cdots,N \tag{1}$$

$$Var(k,l)=\frac{\sum_{i=0}^{H-1}\sum_{j=0}^{W-1}\left[g(i,j)-AveG(k,l)\right]^2}{H\times W},\quad k=1,2,\cdots,M;l=1,2,\cdots,N \tag{2}$$

D. Edge

Edge is the place where the gray value of a pixel in an image changes very sharply. That is, we usually say that signal changes singularly. In mathematics, the gray value of derivative can be used to represent the change of gray value. Gradient is the two-dimensional equivalent form of the first-order derivative. The magnitude of gradient represents the intensity of the edge, and the direction of gradient is perpendicular to the edge. For a continuous function $f(x,y)$, the gradient can be represented as a vector at the position (x,y).The vector can be shown as formula (3). The magnitude of this vector (also often referred as the gradient) can be shown as formula (4), and the direction angle of this vector can be shown as formula (5) [6].

$$\nabla f(x,y)=\left[G_x \quad G_y\right]=\left[\frac{\partial f}{\partial x} \quad \frac{\partial f}{\partial y}\right]^T \tag{3}$$

$$mag(\nabla f)=\left[G_x^2+G_y^2\right]^{1/2} \tag{4}$$

$$\phi(x,y)=\arctan(\frac{G_y}{G_x}) \tag{5}$$

Edge detection is a very important aspect of image segmentation and analysis. The gradient-based edge detection methods include a first order derivative and second order derivative which detects change or discontinuity in neighboring pixel intensity. The conventional edge detection methods are the most commonly used in image processing. In practice temple convolution is used to calculate the magnitude. One template is used for G_x and the other template is used for G_y, so a gradient operator is composed of two templates. According to the size of the template and the value of the elements in it, many different operators are proposed. General edge detecting operators include Sobel operator, Prewitt operator and Robert operator [6].

In 1986, an edge detection algorithm was given by John Canny in [5]. The Canny edge detector is known as the three performance criteria for edge detection [5]:

- Good detection. There should be a low probability of failing to mark real edge points, and low probability of falsely marking nonedge points. Since both these probabilities are monotonically decreasing functions of the output signal-to-noise ratio, this criterion corresponds to maximizing signal-to-noise ratio.
- Good localization. The points marked as edge points by the operator should be as close as possible to the center of the true edge.
- Only one response to a single edge. This is implicitly captured in the first criterion since when there are two responses to the same edge, one of them must be considered false. However, the mathematical form of the first criterion did not capture the multiple response requirement and it had to be made explicit.

An optimal edge detection algorithm can be obtained by combining the above criteria of Canny. The Canny algorithm is mainly composed of six parts [5]:

- The original image is processed into gray image. Using the format of RGB image as an example, the gray conversion formula can be expressed as formula (6).

$$g(x,y)=0.299R+0.587G+0.114B \tag{6}$$

- Original data is convoluted with the Gaussian smoothing template. Compared to the original image, the resulting image is slightly blurred.
- G_x and G_y can be calculated by template. Gradient magnitude is computed by formula (4) and gradient direction angle is computed by formula (5).
- The pixels corresponding to local gradient non-maximum are determined. These pixels are suppressed

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by a higher threshold, and those are considered as false edge.

- By a lower threshold, the starting pixels of boundary are searched, and new edge pixels are collected according to the searched pixels. Finally the entire image edge is closed.
- According to the edge of the found pixels, the edge of image is tracked.

III. Lane Edge Detection

In Lane detection, we are only interested in the edge of lane markings. The lane markings have such features: those widths are small and there are no horizontal and vertical way lane markings. By the above features we can remove the edges that do not belong to the targets. Removing these noise points has a direct effect on the speed and accuracy of the next lane detection.

A. The Realization Method of Lane Edge Detection

Based on Canny algorithm, a method of lane edge detection is given by using the features of road sub region image, sub block image and image edge. The method is illustrated as follows:

(1) The road image is divided into different regions according to the Fig. 1. Only region 2 and region 3 are processed separately.

(2) In road image, the lane markings always have higher gray value. So the edge points with lower gray value should be considered as noise. The noise can be removed by gray threshold. The gray threshold can be obtained by dynamic threshold method. By the gray threshold, the pixels in the sub region image can be classed as foreground and background.

(3) In road image, the width of targets is small. So the bigger foreground region should be considered as noise. The sub region image can be divided into many sub blocks. The size of sub blocks is determined by the image width of real lane markings and the size of road image. The image size of real lane markings can be obtained by experiment. By the variance threshold, each sub block image can be judged into foreground and background.

(4) For the pixels in background, the G_x , G_y , gradient magnitude and gradient direction angle are set to 0. For the pixels in foreground, the G_x , G_y , gradient magnitude and gradient direction angle are calculated by Sobel operator.

(5) There are no the horizontal and vertical lane markings in road image. If the gradient direction of a pixel is horizontal or vertical, the pixel should be considered as noise. In this paper, we consider the gradient angle in the range of [0,20], [70,110], [160,200], [250,290] and [340,360] as noise. If gradient direction angle of a pixel is in above range, the G_x , G_y , gradient magnitude and gradient direction angle of the pixel are all set to 0. For the other pixels whose gradient direction angle is not in above range, the gradient non-maximum is determined in local, and the corresponding pixels are suppressed by a higher threshold.

(6) By a lower threshold, the starting pixels of boundary are searched, and new edge pixels are collected according to the searched pixels. Finally the entire image edge is closed.

(7) According to the found edge pixels, the edge of image is tracked.

B. The Procedure of Lane Edge Detection

Image plane coordinate system is established as Fig. 2. We take the upper left corner of an image as the coordinate origin, the horizontal direction as the x axis, and the vertical direction as the y axis.

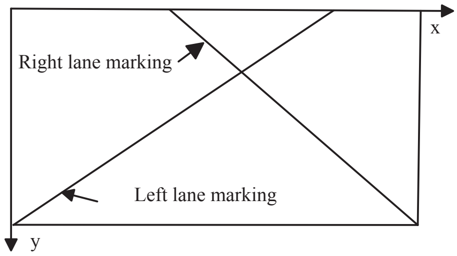

Fig. 2. Image planar coordinate system

According to the image partition of Fig. 1, the sub region 2 and sub region 3 are processed separately. The procedure of lane edge detection can be shown as:

Step 1:

(1) Calculate the histogram of the image A, denoted as $H\left[256\right]$.

(2) According to $H\left[256\right]$, the maximum gray value $f_{\max}$ and the minimum gray value $f_{\min}$ can be obtained. The initial threshold nT is $\frac{f_{\max}+f_{\min}}{2}$. Let $i=f_{\min}$, $C=0$ and $S=0$.

(3) According to formulas (7), (8) and (9), the $dL[i]$ can be obtained. Let $i=i+1$. If $i \le f_{\max}$, the (3) of step 1 is repeated. The value of $dL[i]$ is the gray mean of the pixels whose gray levels are less than or equal to i. Similarly, the value of $dH[i]$ can be calculated. The value of $dH[i]$ is the gray mean of the pixels whose gray levels are greater than i.

$$C = C + H[i] \tag{7}$$

$$S = S + H[i] \times i \tag{8}$$

$$dL[i] = \frac{S}{C} \tag{9}$$

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(4) Let $nOldT = nT$. The new threshold nT is $\frac{dL[i]+dH[i]}{2}$. If $nOldT \neq nT$, the (4) of step 1 is repeated.

(5) For each pixel in the image A, if the gray value of a pixel is less than nT, the gray value is set to 0.

Step 2:

(1) The sub region image is divided into small blocks. For each block image, the gray mean $AveG(k,l)$ is calculated according to formula (1) and variance $Var(k,l)$ is calculated according to formula (2).

(2) If $AveG(k,l) < T_1$ and $Var(k,l) < T_2$, there are no targets in the sub block image. The value of each pixel in the block image is set to 0.

Step3:

(1) For each pixel in the image, if the gray value of a pixel is not equal to 0, Sobel operator is used to calculate the G_x, G_y, gradient magnitude and gradient direction angle.

(2) For each pixel in the image, if the gradient direction angle of a pixel is in the range of [0,20], [70,110], [160,200], [250,290] and [340,360], the G_x, G_y, gradient magnitude and gradient direction angle of the pixel are all set to 0.

(3) Based on the histogram of gradient magnitude, the higher threshold *pnThdHigh* of the gradient magnitude image is determined. Let *dRationNum is* the number of pixels whose gradient is less than *pnThdHigh. Let pnNum* is the total number of pixels in the gradient magnitude image. Let *dRatioHigh* be the ratio of *dRationNum* and *pnNum*. Let *dRationLow* be the ratio of *pnThdHigh* and *pnThdLow.* The lower threhold *pnThdLow* equals $pnThdHigh \times dRationLow$.

(4) The pixels corresponding to local gradient non-maximum are suppressed by *pnThdHigh*.

(5) By *pnThdLow*, the starting pixels of boundary are searched, and new pixels are collected according to the searched pixels. Finally the entire image edge is closed.

(6) According to the edge of the found pixels, the edge of image is tracked.

IV. LANE DETECTION

In this paper, the lane detection is based on the assumption that the lane markings are linear, and the road is flat. The right lane markings are modeled as formulas (10), and the left lane markings are modeled as formulas (11).

$$x = k_r \times y + b_r \tag{10}$$

$$x = k_l \times y + b_l \tag{11}$$

The linear lane detection is the basis in lane markings identification. So far, many methods have been proposed for solving the linear detection. As a classical method for linear detection, Hough transform is often used to detect linear lane markings. Hough transform is a method of connecting edge pixels to form a closed boundary by using the image global feature. It is easy to get the boundary curve and connect the discontinuous edge pixel points under the condition of knowing the shape of the region. J. ILLINGWORTH and J. KITTLER present a comprehensive review of the Hough transform, HT, in image processing and computer vision [7]. Based on Hough transform, many new methods are introduced to detect line segments in an image [8] [9].

In this paper, we detect linear lane based on the Hough transform. The sub region 2 and sub region 3 are processed separately. The plane coordinates are represented by polar coordinates, and the line equation can be expressed as:

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

The collinear points in the image can be detected by use of the Hough transform. The detection task can be completed by the simple cumulative statistics in the parameter space.

V. EXPERIMENTAL RESULTS

The above method presented in this paper is verified. The test platform is a mini-van, and a vehicle CCD is installed in the center of the front windshield of the van. The vehicle camera has captured nearly 500 road images under different road environment and illumination condition. The lane edge detection and lane identification are carried out on these images. The image size is 368×296. Some experimental results are shown as Fig. 3 and Fig. 4. Fig. 3 shows some experimental results of the lane edge detection. The original road image and the edge detection effect are presented in the Fig. 3. Road noise is mainly on the road signs (such as "large cars", "small cars", etc.), zebra and a variety of traffic participants. In Fig. 3, we can see that most of noise is effectively removed. Fig. 4 shows some experimental results of the lane detection based on Hough transform. The red line is the lane markings detected. The experimental results show that the illustrated method of lane edge detection is effective.

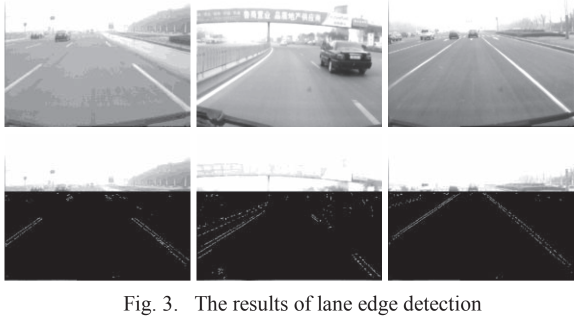

Fig. 3. The results of lane edge detection

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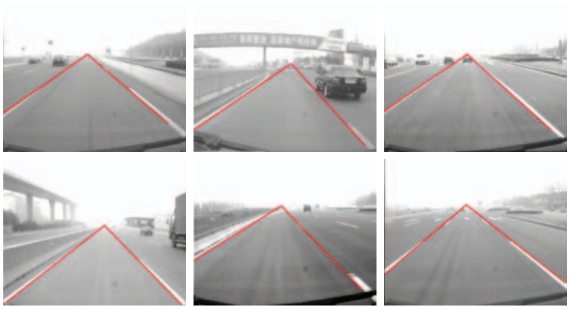

Fig. 4. The results of lane detection

VI. Conclusion

In this paper, we have briefly discussed a method of lane edge detection based on Canny Algorithm. We analyze the characteristics of the road image. The road image can be divided into sub region 1, sub region 2 and sub region 3. The binary image can give the useful information to lane detection. Edge is an important feature to lane detection, and Canny algorithm is known as an optimal edge detection method. Combining using the above features, the realization method of lane edge detection is given. Then the implementation steps of lane edge detection are given. We detect linear lane based on the Hough transform. Finally the method described is experimentally verified. The experimental results show that the illustrated method of lane edge detection is effective. In the near future the method of lane tracking will be researched.

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