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Research on detection of lane based on machine vision

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Abstract: To prevent a vehicle from departing the lane in assistant or automatic steering, real-time vision-based detection of lane is studied. The system architecture, detecting principle and lane model are described. Then the detecting algorithm of the lane image is discussed in detail. In this algorithm, several proper sub-windows in one image are first selected as the processing regions. To every sub-window, by means of such steps as appropriate pre-processing, edge detection and Hough transform, etc., the lane description features are extracted. Experimental results reveal that this detection method is of good real-time, high recognition reliability and strong robustness, etc., which can provide the decision-making foundation for the following automatic or assistant steering to some extent.

Key words: vision sensor; lane edge; image processing; detection

Many traffic incidents are caused by drivers' subjective factors, including drowsiness, inattentiveness or over-aggressiveness. 60% of intersection crashes and 30% of head-on collisions could have been avoided if drivers' reactions had been a half a second quicker. Also, 90% of automobile incidents are from drivers' errors[1]. Therefore, it is necessary to study assisted or automatic steering, which can also remarkably improve the traffic efficiency. In fact, they have been major parts in many relevant researches such as intelligent transportation system (ITS), advanced vehicle control system (AVCS) and intelligent vehicle highway system (IVHS) in many countries[2-5].

Compared with other sensors, automatic or assisted steering based on machine vision is characterized by huge information, low cost, high similarity to human steering decision-making and no damage to the road, etc. It has been one of the hotareas in ITS research in recent years. Since automatic or assisted steering is performed in complex and varying natural environments, performances such as real time and recognition reliability are key points of vision sensor. According to these, real-time lane detection based on machine vision, which can provide decision-making foundation for subsequent path tracking or lane keeping, is studied in this paper.

1 System Configuration and Lane Model

1.1 System architecture

A lane detection system is composed of a monocular CCD camera, image acquisition card, computer, screen, and experiment vehicle, as shown in Fig.1. When the vehicle is driven in the lane, every successive frame image of the lane is captured by the image acquisition card and then is processed by proper real-time algorithm to detect the lane information. Through this experimental system, we can put forward the detection algorithm and verify whether it is appropriate.

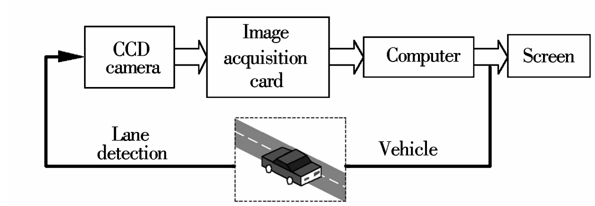

Fig.1 System architecture

1.2 Camera placement

In most cases, a human driver makes steering decisions according to things occurring in front of his vehicle within a certain distance, which is called the driver's preview behavior. And this distance is dependent on the vehicle's speed. For example, it is about 5 m at a low vehicle speed while it can reach 20 m and 40 m at medium speed and high speed, respectively[6]. So it is important to properly place the camera on the vehicle. The shooting range should be wide enough to get lane information fully but it should not be excessively wide for fear that unnecessary extra information needs to be processed.

According to the above, the monocular camera is installed on the longitudinal symmetry plane of the vehicle and its optical axis and horizontal line lie at an angle of α which is adjustable (see Fig.2). The angle α can be determined by the preview range L_0 in terms of the camera projection principle, and their relation is as

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$$\alpha \leqslant \frac{\pi}{2} - \delta_2 - \arctan\left[\frac{-\frac{L_0}{h}\tan(\delta_1+\delta_2)}{2\tan(\delta_1+\delta_2)} + \frac{\sqrt{\frac{L_0^2-4h^2}{h^2}\tan^2(\delta_1+\delta_2)+\frac{4L_0}{h}\tan(\delta_1+\delta_2)}}{2\tan(\delta_1+\delta_2)}\right] \quad (1)$$

where h is the distance between the camera and ground, δ_1 and δ_2 are the perspective angles of the camera, which can be ascertained by the relative parameters of the camera.

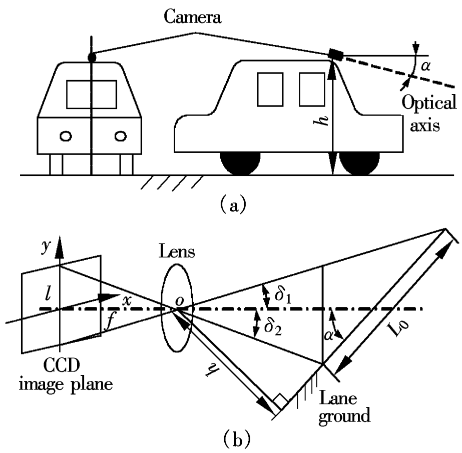


Fig.2 Placement of the camera and determination of the angle α

1.3 Lane model

Generally, for every lane in a highway, there are two marking lines, i.e., the left marking line and the right one. Furthermore, they may be continuous or discontinuous. And usually they can be described by second-order polynomial equations. In the image coordination system (see Fig. 3), all the lane descriptions including the left lane marking line, the right one and the middle one can be described by the following expression:

$$x = ay^2 + by + c \quad (2)$$

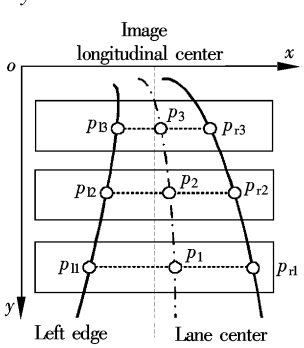


Fig.3 Lane model

2 Real-Time Detection of Lane

As mentioned above, automatic or assisted steering is performed in a complex and varying natural environment, so its precondition must be reliably to get lane information in real time, which becomes the key point of the vision sensor in this case. In this paper, an image processing algorithm is proposed (as shown in Fig.4) and has been verified in lane detection experiments. In terms of some pre-knowledge, every frame image captured by the image acquisition card is separated into several proper sub-windows which replace the whole image as the processing regions. Obviously, this can improve the system's real-time performance and prevent the objects around the lane from disturbing lane recognition. Besides, it is also helpful to the subsequent Hough transform. It is noted that the size and number of sub-windows should be appropriate. On one hand, every sub-window size should be appropriate which can ensure that both the left marking line and the right one of the lane can be detected and be approximately straight lines. On the other hand, the number of sub-windows can be ascertained according to the practical demand (Three sub-windows are shown in Fig. 3). Too many sub-windows are bound to influence the processing velocity while too few windows may lead to an inexact description of lane. In our experiments, the CCD camera is installed in the longitudinal symmetry plane of the vehicle, so the vehicle center is consistent with the image longitudinal central line. Then the relative position of the vehicle and the lane can be easily determined.

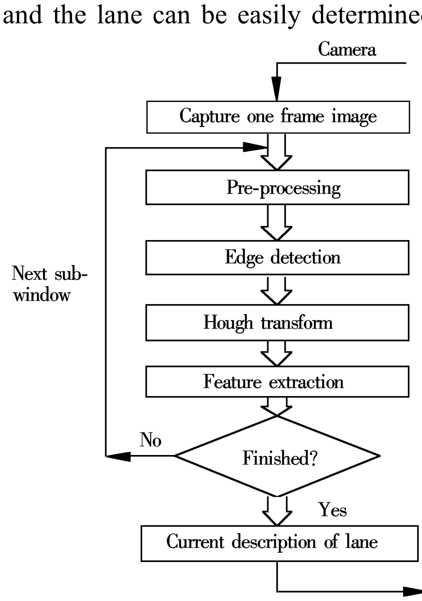


Fig.4 Flowchart of image processing algorithm

2.1 Image pre-processing

The image pre-processing here is the gray-scale transformation processing. Because the lane detection is performed in natural circumstances, the change in weather or illumination may make great influence on the image, which always leads to poor contrast. For example, inadequate illumination can make the whole image seem very dark while excessive illumination may yield the opposite result. In other words, the gray scale of the image is always limited to a very narrow scope, which is not beneficial to the extraction of lane features. In this case, by means of the gray-scale transformation, the gray scale is enlarged and the contrast is enhanced, which will be very helpful to the subsequent edge detection. The gray-scale transformation formula adopted is

$$g' = \begin{cases} 0 & g \leqslant g_{\min} \\ \dfrac{255(g - g_{\min})}{g_{\max} - g_{\min}} & g \in (g_{\min} \ \ g_{\max}] \\ 255 & g > g_{\max} \end{cases} \qquad (3)$$

where g, g' are gray values of one point in the image before and after gray-scale transformation, respectively; $g_{\max}$, $g_{\min}$ are maximum and minimum gray values of a primitive image, respectively, which are dynamically computed by the current gray histogram.

2.2 Edge detection

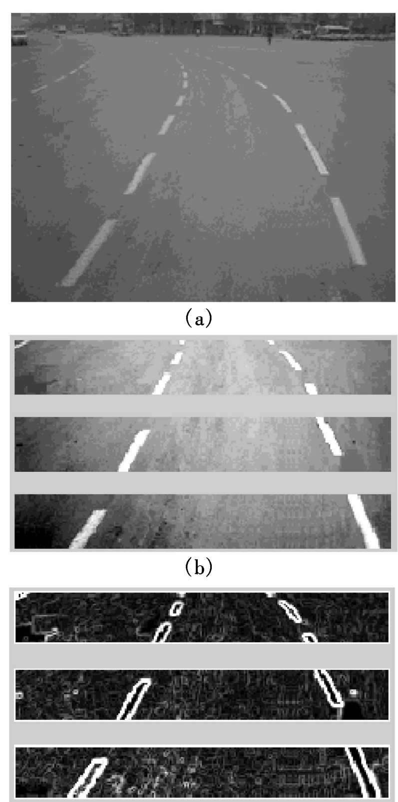
As to the pre-processed lane image, the edge is one of its primitive features. Hence, some image segmentation methods such as edge detection algorithms can be used to extract these edge features. Among these edge detection algorithms, Prewitt operator is a quick and practical one. In this operator, every point in the image will be computed by the appropriate convolution operators, which can not only extract edge points but also resist the noise disturbance notably. The following is the concrete Prewitt operator used in this paper:

$$\left.\begin{aligned} \Delta_x f(x, y) &= [f(x+1, y-1) + f(x+1, y) + f(x+1, y+1)] - \\ &\quad [f(x-1, y-1) + f(x-1, y) + f(x-1, y+1)] \\ \Delta_y f(x, y) &= [f(x-1, y+1) + f(x, y+1) + f(x+1, y+1)] - \\ &\quad [f(x-1, y-1) + f(x, y-1) + f(x+1, y-1)] \\ G[f(x, y)] &= |\Delta_x f(x, y)| + |\Delta_y f(x, y)| \end{aligned}\right\} \qquad (4)$$

2.3 Hough transform and parameter extraction

Hough transform (HT) can transform all the points on the specific curve or line into one peak point in the transformed space. Therefore, by the means of searching for this peak point, the problem of detecting the curve or line can be solved. This method is especially reliable and robust in the case of a region border being disturbed by the noise or partially covered by other objects[7,8].

As to Eq.(2), through HT, coefficients a, b and c can be ascertained in 3-D transformed space. However, this direct method is performed in 3-D space, which may cause so much computing-load to the program that the real-time performance cannot be ensured. In practice, we divide the image into several sub-windows. In every sub-window, the lane left or right marking line is regarded as a "thick" straight line. After edge detection, every "thick" line has several boundaries (see Fig. 5 (c)), two of which are approximately parallel along the lane direction and have more pixels than others not along the lane direction. Therefore, a group of larger peak value points, i.e., two points, which represent the lane direction, would be formed in a small region in the transformed space after HT. According to the parameter magnitude in the transformed space, one peak value point, which corresponds to the lane marking line inner boundary or the outer one, can be extracted and then can act as the description point of this lane marking line. Since both the direction and



(a)

(b)

(c)

Fig. 5 Image processing. (a) One frame primitive image; (b) Gray-scale transform; (c) Lane detection and HT intercept of the left and right lane marking lines in one sub-window are very different, two groups of larger peak value points, whose distance is great in the transformed space, can be gotten after HT. Subsequently, these two groups of peak value points can be easily extracted in terms of the parameter scope. One group of peak value points represents the left lane marking line while the other denotes the right lane marking line. It is noted that as to the left and right lane marking lines, the inner boundary or the outer one should be simultaneously selected as their corresponding description.

In addition, we should ascertain a rough parameter region in advance of the HT according to the relative position of the lane marking lines in the image and then execute HT, which can help to improve the real time and accuracy.

2.4 Lane description

According to the linear equations of the left and right lane marking lines acquired in section 2.3, we can acquire some feature points (for example, endpoints or midpoints) in every sub-window. In terms of the least-square method, the lane description equation, i.e., Eq.(2), can be acquired by properly fitting or interpolating (through these feature points). For instance, if we adopt three sub-windows (see Fig. 3), three groups of midpoints $p_{li}(x_{li}, y_{li})$ and $p_{ri}(x_{ri}, y_{ri})$ ($i = 1, 2, 3$) corresponding to the left and right lane marking lines in three sub-windows respectively, can be obtained. Subsequently, three points $p_i(x_i, y_i)$ on the lane "center line", which is only a virtual one convenient for the following steering decision-making, can be attained. Finally, all the coefficients a, b, c in Eq.(2) of the center lane line can be solved by the following formula:

$$\begin{Bmatrix} a \\ b \\ c \end{Bmatrix} = \begin{bmatrix} y_1^2 & y_1 & 1 \\ y_2^2 & y_2 & 1 \\ y_3^2 & y_3 & 1 \end{bmatrix}^{-1} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} \tag{5}$$

where $x_i = \dfrac{x_{li} + x_{ri}}{2}$, $y_i = y_{li} = y_{ri}$, $i = 1, 2, 3$.

3 Lane Detection Experiment

Based on the method proposed above, the detection program of lane marking line is developed in the C ++ Builder 6.0 compiling environment. Afterwards, a series of experiments were carried out in many weather conditions including sunny, cloudy and even rainy days to test the practical effect of this method. And, the detected lane comprised straight and curving segments, which were sometimes discontinuous. Experimental results reveal that this method can effectively detect the lane that may be continuous, discontinuous, obscure and even shadowed. Besides, such performances as good real time, strong robustness and noise resistance can also be ensured. The overall time consumption is less than 150 ms from capturing one frame image to extracting the present lane description (three sub-windows). As an example, Fig.5 shows the processing of one frame image captured in the experiment.

4 Conclusion

The lane detection method proposed in this paper features quick processing speed and high recognition reliability, which can provide the decision-making foundation for the following automatic or assisted steering. Furthermore, this method is also applicable to other real-time image-processing cases such as automatic reading of mechanical instruments in some dangerous industrial environments and untouched size measurements of regular parts.

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基于机器视觉的车道标志线检测研究

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摘要: 针对车辆辅助驾驶或自主驾驶中的车道保持问题, 研究了基于视觉的车道标志线实时检测方法. 介绍了系统组成、工作原理和车道模型, 并着重讨论了车道图像的检测算法. 其主要思想是在图像上选取几个合适的处理区域, 通过对每个处理区域进行适当的预处理、边缘检测和霍夫变换等过程来提取车道描述特征. 试验结果表明, 该方法具有实时性好、识别可靠性高等特点, 在一定程度上能为后续的辅助驾驶或自主驾驶提供决策依据.

关键词: 视觉传感器; 车道标志线; 图像处理; 检测

中图分类号: U46